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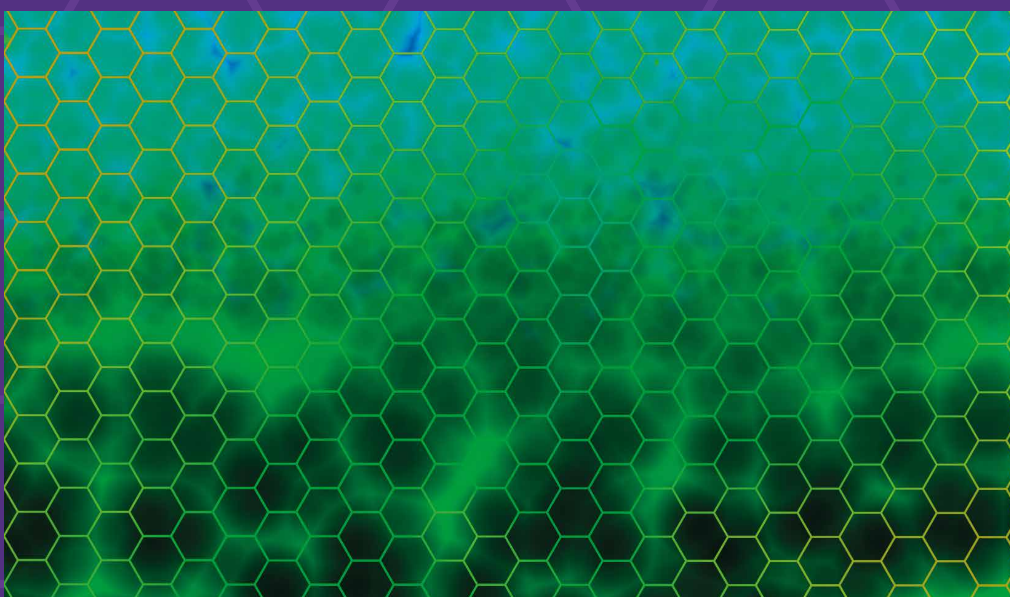

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Waste Management and the Environment VIII

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Preface

This Volume contains a selected number of revised papers presented at the International Conference on Waste Management, which was held in Valencia, Spain, organised by the Wessex Institute of Technology.

The contributions provide up to date information on the current situation in Waste Management.

The ever-increasing amount and complexity of discarded domestic and industrial waste require the search for novel solutions, which require better practices and safer procedures.

This creates the need for more research on current disposal methods, trying to avoid the mistakes made in the past, when short-term solutions led to long-term implications in terms of human health and environmental damage.

Current research and development in waste management focuses on the approach, which has been called 4Rs, comprising reduction, re-use, recycling and recovery of waste.

The papers in this volume focus on the solution to these problems and their implementation in modern society. Such solutions will require collaboration between the public, government and private sectors, with an increasing degree of involvement by all stakeholders.

The Editors
Valencia, 2016

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Contents

Companies' efforts towards reduction, reuse, recycling and recovery (4Rs) of e-waste
B. Krumay & R. Brandtweiner 1

Unrecognised informal solid waste recycling in an emerging African megacity: a study of Johannesburg, South Africa
S. Q. Dlamini & D. Simatele 13

Recycled construction and demolition waste in mining rehabilitation
F. J. Fernández-Naranjo, E. Alberruche, V. Rodríguez, J. C. Arranz & L. Vadillo 27

The necessity of recovering soluble phosphorus from sewage sludge ashes before use in concrete based on concrete setting and workability
N. M. Sigvardsen & L. M. Ottosen 37

Waste management in major events and the relevance of environmental certification
L. Alves, L. Freire & E. Vazquez 49

Resource efficiency: progress and challenges of 3Rs technologies and policies
A. Khajuria 57

Recycling, waste management and urban vegetable gardens
A. Sgobbo 61

Analysis and improvement possibilities of waste management at Kuwait Oil Company (KOC)
Y. Al Qallaf, S. Al-Kandari, K. Yousef, S. Al Mutairi & H. Fouzy 73

A new procedure for recovering heavy metals in industrial wastewater
S. Heuss-Aßbichler, M. John & A. L. Huber 85

Can palm oil waste be a solution to fossil fuel scarcity and environmental sustainability? A Malaysian case study provides the answer
Y. K. Choy 97

Analysis used for the installation of an IFMSW processing center for cement plants in the state of Hidalgo, Mexico
J. E. Sánchez, J. A. Araiza & M. N. Rojas-Valencia 109

Discussion about citizens' cooperation in a new waste separation rule through a social experiment on the collection of separated food waste in Toyohashi City, Japan
T. Okayama 123

Developing the service value: a case study of waste management in offshore petroleum logistics
P. Engelseth 135

How we transform industrial organic waste into vermicompost and champion environmental sustainability
M. Quintern, M. Morley, B. Seaton & R. Hamilton 147

The possibilities and challenges of using industrial rest products on mine waste management in the Arctic
J. Lu, F. Yuan, A. Barabadi, A. H. S. Garmabaki & F. Zhang 161

A Fourier series model for forecasting solid waste generation in the Kumasi metropolis of Ghana
D. Asante-Darko, E. S. Adabor & S. K. Amponsah 173

Sustainable waste management: the example of the informal settlement "Las Fincas" on Cozumel Island, Mexico
T. L. Steenbeck, O. Frausto Martinez, M. Schirmer, C. Koch & S. Giese 187

Development of a sustainable MSW landfill as an intrinsic part of a low-priced, integrated waste management facility
I. Madon 195

E-waste in Mexico: a case study of Tepic, Nayarit
C. E. Saldaña, S. Messina, Y. Rodriguez-Lascano, M. García & H. Ulloa 205

Refinery waste: the spent hydroprocessing catalyst and its recycling options
M. Marafi & M. S. Rana 219

Waste minimization practices at the National University of Costa Rica
J. Mora, J. Sibaja, J. Rodríguez & C. Salas 231

Proposed management and exemption of radioactive waste in nuclear medicine facilities according to the recommendations of the ICRP Publication 103
A. S. Carmo, A. X. da Silva, E. A. Vianello & E. M. L. de Macêdo 243

The impact of health services' waste to public health and to the environment
H. M. P. Ramos, V. R. N. Cruvinel & D. Galato 255

Experimental study on the compression properties of degraded municipal solid waste
Z. Zhang, D. Wu, L. Yan, Z. Ding, Y. Wang & S. Lei 265

Pretreatment of MSW for co-digestion in waste water treatment plants
M. Meirer, W. Müller & A. Bockreis 277

The use of low temperature thermal desorption technology in the treatment of drill cuttings
O. U. Nwosu, C. O. Nwoko & C. O. Chigbo 289

The characterization of brewing waste and feasibility of its use for the production of porous ceramics
N. Quaranta, M. Caligaris, G. Pelozo, M. Unsen & A. Cristóbal 299

Effects of the aeration on the fluid dynamic behaviour of a multi-zone activated sludge system
F. Sánchez, A. S. Kaiser, A. Viedma & A. Gómez 311

Cluster formation of potential assessment for swine manure treatment and biogas generation in an experimental watershed in Rio Grande do Sul, Brazil
V. Schneider, N. Zanoni & S. Carra 323

An assessment of crop residue characteristics and factors militating against efficient management in the Ikara local government area of Kaduna state, Nigeria
E. I. Aruya, R. O. Yusuf & Y. O. Yusuf...333

A review of the current digestate distribution models: storage and transport
P. Vilanova Plana & B. Noche 345

Short-term and long-term studies of the co-treatment of landfill leachate and municipal wastewater
Q. Yuan, H. Jia & M. Poveda 359

Wastewater treatment and reuse in Alicante (Spain)
A. Arahuetes...371

Removal of sulphates from acid mine drainage using desilicated fly ash slag
F. Ntuli, T. Falayi & U. Thwanane..383

Evaluation of the influence of method preparation in properties of heterogeneous ion exchange membranes
N. C. Martins, L. B. Rodrigues, F. T. do Nascimento, G. M. da Silveira, J. F. Corte, M. V. Flach, M. A. S. Rodrigues, F. Celso, V. D. Jahno & R. M. de Martins..391

Understanding recycling behavior: a study of motivational factors behind waste recycling
K. Johansson..401

Author index...415

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Companies' efforts towards reduction, reuse, recycling and recovery (4Rs) of e-waste

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Abstract

The e-waste pile is constantly increasing, 41.8 million tons e-waste was generated in 2014 and prognosis shows there will be further increases. On one hand, technological reasons for discarding electronic devices, such as life cycles of products is an explanation for e-waste. However, non-technological reasons like lifestyle-indicated rebuying or psychological obsolescence lead in addition to more and more replacement of electronic devices – especially mobile devices – before they have reached their end-of-life. Furthermore, products that are designed with short life spans with the intention of generating frequent repurchases (planned obsolescence) are supplementary drivers for the increase of the e-waste pile. Since companies nowadays depend highly on the usage of computers, they of course contribute to the e-waste generated by private users. In this paper, however, we specifically focus on companies' approach towards reducing, reusing, recycling and recovery (4Rs) of e-waste. Based on interviews with managers, responsible for companies' e-waste handling, we identify different approaches towards these 4Rs. As a result, we see that companies' approaches towards reduction of e-waste are mainly targeting towards prolonging the life spans of computers, driven by costs evolving from replacement. Reuse, however, is an issue which is shifted to partners and experts outside the companies. The same is true for recycling and refurbishment. We identified different categories of ICT products, which are replaced more likely before reaching end-of-life, in particular smartphones. Concerning peripheral ICT hardware (printers, projectors), other triggers, e.g. energy efficiency of newer devices or new technologies, dominate the reasons for replacement. Based on the so-gained insights, we depict the results in a matrix of the current approaches towards 4Rs of e-waste in business.
Keywords: e-waste, 4Rs, reduce, reuse, recycling, recovery, life span.

1 Introduction

Electronic waste or e-waste is one of the scourges of humanity. Living without electronic devices seems to be impossible in the developed world – with severe consequences. At the end-of-life, electronic devices add up to a huge pile of e-waste. However, the computerization and further increase of mobile devices as well as the integration of computer hardware into non-computer products (e.g. cars) to realize connectedness between different components constantly multiplies the amount of e-waste. In addition, short life cycles, lifestyle-connected rebuys and the fast development of new technologies speed up this trend. The frightening impacts on the environment and society are the depletion of rare metals, pollution of the environment and poisoning of people living close to e-waste landfills, to name just a few. Although the e-waste topic has found attention in research and public authorities, this consideration mainly focuses on the environmental, economic and social impacts in countries – often developing countries – where the electronic devices are dismantled [1–3]. To date, only a few studies have investigated how organizations handle this issue. The focus so far was on the responsibility of producers [4–6], however, organizations using computers also have a responsibility. Consequently, our research serves as a starting point to understand how organizations tackle the e-waste problem. We rely on concepts, stemming from the corporate social responsibility (CSR) and business ethics research community and focus on the awareness of organizations for their responsibility towards e-waste. We conducted interviews, revealing organizations' approaches towards reduction, reuse, recycling and recovery of e-waste. Our main question therefore is: how do companies adopt their responsibility for the e-waste they generate. The rest of the paper is structured as follows: first, we give a brief introduction into the state of the field, second we explain our methodological approach, followed by results of our studies. Finally, we discuss the results and show their contribution to research, society and business. We finish this paper with a sound conclusion, limitations and further research possibilities.

2 State of the field

All over the world, the so-called Information Society [1] depends on computers, providing the highly valuable resource of information, but at a high price: the necessary hardware is produced mainly in low-income countries where environmental protection is often not an issue [2, 3]. Furthermore, computers require scarce and precious resources (e.g. gold and tantalum), mined under miserable working conditions [2, 4]. While using computers, the energy used generates greenhouse gas emissions [5]. Besides production and usage, the disposal in the form of e-waste shows even more impacts that are negative. The far-reaching consequences of e-waste can be found in at least two dimensions: time [6] and space [7]. In terms of time, disposed e-waste may produce hazardous substances, leaking into the soil, which returns into the food chain via polluted ground water, finally poisoning nutrition over time [8–11]. The spatial problem refers to the fact that computers having reached their end-of-life are shipped to developing countries, masqueraded as donations to avoid disposal costs [7, 12–14]. Once in the country, the computers are destroyed and cannibalized: rare and precious materials are excavated, the rest is disposed or burned, leading to heavy pollution of the air [7, 11, 15]. In addition, the excavation takes place without preventive measures, being suspect to causing cancer and low life expectancy [8, 15, 16]. Although regulations and voluntary initiatives are in place, they are often evaded [17]. Unfortunately, the amount of electronic waste (e-waste) is further increasing. According to a report published by the European Commission in 2005, 9 million tons of e-waste have been generated and 12 million tons are forecasted for the year 2020 [13]. When talking about electronic waste (e-waste) or waste evolving from electrical and electronic equipment (WEEE) every pieces of hardware used in private households and business, from washing machines, TV sets to computers is part of it [7]. The EU e-waste guideline 2012/12/EU [18], for example, names ten different categories, but excludes large-scale electronic plants. However, in the business context the term e-waste especially refers to ICT products respectively goods including microchips, whereas WEEE is more general and includes white goods, too. However, these borders become blurry, since microchips are integrated for communication with each other into non-ICT products (e.g. cars, refrigerators).

In general, devices become e-waste when they are discarded [7] due to technological, business or other reasons. Technological and business reasons for discarding ICT products include replacement by better and faster technologies, deterioration, or incompatibility with new software requirements, to name just a few [19–21]. Furthermore, products which are designed with a short life-span and the intention to convince consumers to frequent repurchases (planned obsolescence) [22] lead to discarding. For example, the life span of a central processing unit (CPU), used in every computer, decreased from six to four years between 1997 and 2005 [13]. Other reasons to discard devices are lifestyle indicated rebuy or psychological obsolescence [20, 23]. This is the felt need of users to replace a device due to non-technical reasons. Smartphones, especially, are replaced long before they reached their technological end-of-life [24]. When an electronic product is discarded due to not fitting the needs anymore, it can be reused as is by other users with other needs and does not become e-waste [7]. However, when the technological end-of-life has been reached, recycling, recovery, refurbishment and disposal are possibilities to handle the devices [11, 25, 26]. Possibilities of recycling, refurbishment and recovery, however, depend on how the devices are built, as some designs do not allow reassembling, making them inefficient or even dangerous [7, 10, 11, 27]. Thus, green or eco-design of ICT products – designing devices in a modular, environmentally friendly way – is a precondition for achieving e-waste reduction [10]. The 4Rs – reduction, reuse, recycling, and recovery – are not new in the field of waste management, but, e-waste studies targeting towards the 4Rs can rarely be found [28].

3 Methodological approach

To examine how companies tackle e-waste, we conducted open qualitative interviews to explore relevant issues from the interviewee’s perspective [37, 38].

To identify characteristics and explore patterns we used thematic analysis. With this approach, one is able to evaluate the manifest content of statements. This requires condensing the interview information via a structured summary and making the interviews comparable without neglecting their specificities [39]. We conducted semi-structured topical interviews with managers responsible for e-waste in January 2015. Based on literature we designed an interview guideline with pre-defined topics. Thus, we were able to embrace the whole subject area in accordance with the research question [40]. The pre-defined topics include (a) e-waste (what is it, how much is allocated at your company, how long are the life cycles of devices, does green design influence buying decision?), (b) end-of-life handling (what is happening to the devices at the end of life?), and (c) responsibility for e-waste (who is/should be responsible for e-waste?). Moreover, the interviewers encouraged the interviewees to further explain their thoughts by keeping the interview open [37]. The interviews were audio-recorded, transcribed and analysed. All interviews were conducted in the native language of the interviewees and interviewers. We used the software Atlas.ti for coding and analysis. Two researchers were involved in the coding process. The coding process was led by the topics of the interview guidelines. In the course of the analysis, we developed categories from the interviews.

Interviews were conducted on the phone and face-to-face. The interview length was between 22 and 47 minutes. Concerning their position in the company, one interviewee is technical manager, responsible for all technical equipment (I1), the second is a chief information officer (CIO) and chief financial officer (CFO) and the third one is a CIO. All interviewees have been in the companies for several years and in the current position for at least five years. The companies are operating in different industries and are of different size. Table 1 summarizes the characteristics of interviewees and the interview situation.

Table 1: Details of interviews and interviewees.

	I1	I2	I3
Duration (min.)	35	47	22
Type	Phone	Face-to-face	Phone
Position	Technical Manager	CIO and CFO	CIO
In the company since	2003	2005	2005
In this position	2008	2010	2005
Industry	Media	Pharmaceutical	IT Services
Employees (approx.)	400	110	25

4 Results

The results developed from the interviews revealed important issues concerning e-waste handling. Interviewees showed a very clear understanding what e-waste is: from their point of view, it is waste evolving from the end-of-life of computers (servers, personal computers, mobile devices) and peripheral components (printers, monitors, input devices, network equipment). They explicitly excluded other technical equipment used in the production (I2) and household machines (I1, I2, I3) used in the office (e.g. coffee machines, refrigerators, microwave ovens). The life span of ICT products in terms of usage in the company ranges from two years for mobile devices, four years for network equipment, and about five years or more for other devices. The interviewees reported that most employees have their own personal computers or laptops, some employees have mobile devices (i.e. smartphones, tablets). Concerning servers, the companies are very different. Whereas in I1 it has been reported that they operate about 100–120 servers in house and outside the company, in I2 it was reported that they hardly have 10 servers in house, since they started to virtualize them. Finally, I3 stated that they have three servers for their own administration, but run up to 200 servers for their customers, which they also purchase and maintain, depending on the contracts.

4.1 Discarding of devices

Concerning ICT products, different groups, like small mobile devices (e.g. mobile and smart phones, tablets), personal computers (including notebooks and fixed PCs) and servers have been identified. Some peripheral devices (i.e. monitors, input devices) are experienced as computer-attached devices, whereas others (i.e. printers, projectors) are seen as shared devices. In addition, network equipment (e.g. routers, hubs, WIFI access points) has been mentioned. The interviewees clearly differentiated between devices with short (e.g. smart phones) and long (e.g. servers) life spans. Furthermore, interviewees expressed various reasons for discarding devices. Technological reasons include that the device is obviously broken (Broken), does not work appropriately without any detectable reason (Not working approp.), newer technology is available (New technology), or new software requires high-performance hardware (New requirements) and existing hardware has to be replaced by "current but approved technology" (I2). Especially when devices do not work appropriately without any detectable reason, interviews experienced it as planned obsolescence. However, interviewees expressed the necessity to differentiate between unusable (broken) and usable devices, which are "suitable for private use but do not fit the business requirements we have" (I2). One interviewee (I1) reported that they rent printers; hence, the rental company is responsible for maintenance, repair and disposal.

Business reasons for discarding are end of maintenance of devices (End of maintenance), the expectation that new devices are more efficient (Efficiency), or having reached re-investment cycles (Investment cycle). It has been stated that hardware life cycles in the company depend not only on technology, but also on investment cycles to avoid "hardware investment peaks" (I2). Other reasons are users felt the need to have new devices (user-driven) or organizational issues (organizational) such as restructuration of the company (a) e.g. after a merger or (b) when companies move to new offices. Terms in brackets refer to the codes used in Table 2, which shows detailed information.

Based on the interviews, we identified some reasons for discarding devices to be common (C), occur sometimes (S) or hardly (H). Common reasons for discarding devices are marked grey in the table. Especially small mobile devices are often not replaced due to technological or business reasons, but based on users feeling the need to replace the device. Servers, personal computers, network equipment and computer attached devices are mainly discarded due to technological reasons, whereas printers and projectors are commonly replaced due to business reasons.

Table 2: Device types, life span and reasons for discarding.

		Technological				Business			Other	
Device type	Life span (avg. years)	Broken	Not working approp.	New technology	New requirements	Efficiency	End of maintenance	Investment cycles	User-driven	Organizational
Small mobile devices	2	S	H	H	H	H	H	H	C	-
Personal computers	5	S	H	H	C	H	H	S	H	a
Servers	5	S	S	C	C	S	H	S	H	b
Network equipment	4	S	H	C	C	H	H	H	H	b
Computer-attached devices	5	C	S	S	H	S	H	H	S	a
Shared devices	5	H	H	S	H	C	C	S	H	b

4.2 Reduction, reuse, recycling and recovery of e-waste

In the interviews, we identified different approaches to reduce, reuse, recycle and recover e-waste. In general, the interviewees clearly differentiated between reuse and reduction, although reuse clearly also reduces e-waste. By contrast, interviewees did not differentiate between recycling and recovery of e-waste.

Concerning reduction, the most prominent approach in all interviews was to prolong life span of devices, achieved by buying reliable and repairable devices as well as by appropriate and regular maintenance. In addition, some organizational measures, such as replacement policies or buying standardized hardware have been mentioned. To prolong life span within the company, one interviewee (I2) mentioned that personal computers are shifted between employees when they become unusable for one task (e.g. requiring high performance), but are still suitable for other tasks.

Processes at the end-of-life of devices described in the interviews are quite similar. In general, devices having reached end-of-life from the company's point of view (unusable for business) are prepared for discard – removing all data stored on the device – and collected at a specific storage. Next steps depend on the devices' state – is it reusable or unusable. Concepts for reusable devices include selling devices or using as spare. Mobile devices especially are sold with the help of intermediaries on the market, since "mobile devices are of value, it is waste that brings money" (I1). In addition, two interviewees mentioned that the company had sold usable devices – not only mobile devices – to their employees on an "internal flea market" (I2). Other reusable devices are stored as a whole or disassembled in parts, which can be reused as spare parts for devices of the same type.

Concerning unusable devices which have no market value, companies rely on waste specialists. The specialists take over the responsibility for all devices collected from the company and identify the state of the device. The specialists decide which devices can be recycled or recovered and which have to be disposed of. All three interviewees expressed the need to know what happens to the devices. They emphasized their responsibility to select an appropriate partner company, who is "reliable, trustworthy and provides a high level of transparency" (I2). Shared devices are somehow different, since they – especially printers – are often not owned by the companies and take back by the sellers has been guaranteed in contracts, leading to refurbishment of the products.

Table 3: 4Rs and device types.

	Reduce				Reuse				Recycle, Recover, Dispose	
	Maintenance	Internal reuse	Repairable devices	Standardization	Sell on the market	Sell to employees	Use devices as spare	Use parts as spare	Take back	Transfer to specialists
Small mobile devices	–	–	–	–	X	X	–	–	–	X
Personal computers	–	X	X	X	–	X	X	X	X	X
Servers	X	–	X	X	–	–	X	X	X	X
Network equipment	X	–	X	X	–	–	X	–	X	X
Computer-attached devices	–	X	–	–	–	X	–	–	X	X
Shared devices	X	–	X	–	–	–	–	–	X	X

5 Discussion

With this study we want to explore how companies handle e-waste. To clarify the issue, it is first necessary to understand how companies define e-waste, which reasons exist to discard devices and which measures are in place to reduce, reuse, recycle and recover e-waste. In general, we identified that companies define e-waste rather similarly as waste evolving from the end-of-life of computer devices.

However, companies discard computers due to different reasons already before the devices have reached their end of life, depending on the device type and technological, business and other considerations. Approaches to reduce, reuse, recycle and recover e-waste are rather similar in the companies in our sample, but different again for different device types. Based on the interviews, we gained first insights into this topic and want to discuss the results from different points of view.

As we have seen, different device types are handled differently concerning reasons for discarding and handling. Small mobile devices (i.e. mobile phones, smart phones, tablets) are very specific as they have a relatively short life span (2 years) and are used one per employee. Moreover, discarding is primarily triggered by user demands. In addition, efforts to reduce e-waste or prolong their life span do not apply for small mobile devices. Considerations to buy more standardized, reliable or repairable mobile devices seem to be missing in the context of mobile devices. This may be due to the fact that mobile devices are lifestyle products and most prone to psychological obsolescence [20, 23], as already discussed in other studies [24, 29]. This is in line with e-waste numbers: almost 15% of e-waste created in 2014 were mobile devices [30]. Only reuse due to the market value seems to tackle this issue, however, this market value exists because they are discarded before reaching their end-of-life. Another very specific device type are shared devices, as the business reasons are commonly triggering discarding. This may be due to the fact that they are not critical for the business, can easily be replaced and do not contribute to companies' value creation. In addition, companies do not own but rent them and thus maintenance contracts are steering the replacement. However, they are very specific in two aspects: first, efficiency plays an important role for shared devices, since the interviewees have directly addressed the energy efficiency of printers. Second, the possibility that suppliers take back devices for refurbishment has exclusively been mentioned for printers. We conclude that companies shift their responsibility for e-waste for shared devices to the suppliers. Finally, devices such as personal computers (including notebooks), servers, computer-attached devices and network equipment share characteristics. First, the life span is about 4–5 years; second, technological reasons are triggering discarding and third, reduction and reuse efforts influence those most. We conclude that companies focus on those devices since they bring the most value for the company or at least keep the business up and running. As stated above, computers are a precondition for companies' competitiveness in the information society [1].

When looking at the companies' efforts to apply the 4Rs, we see that companies adopt responsibility for reducing e-waste, whereas the other Rs are mainly outside the companies' scope. Reduce e-waste is connected to buying decisions and attributes of the devices, including quality, standardization and possibilities to repair the device. All three target towards prolongation of life span, supported by appropriate maintenance whereas quality has to do with trust in the supplier and standardization targets towards the possibility to use 'old' systems as spare parts. Concerning repairability, in contrast to everything said above. This also occurs in the context of smartphones, maybe because issues on smartphone modularity and repairability have been in the media lately. Interestingly, green design has not been reported as an influencing factor for buying decisions. Although one interviewee (I1) stated that this is not an issue, because buying decisions are influenced by many other factors (e.g. price, compatibility, security and future proof devices), interviewee two (I2) mentioned the lack of labelling to be able to integrate green design into this decision. Interviewee three (I3) even expressed the need to have regulations or benefits, supporting companies in their efforts to reduce e-waste. Although energy efficiency labels are well known, they influence purchase decisions only when “hardware offerings are similar in all other points” (I2). Although companies are aware of Life Cycle Analysis (LCA) of products, they have never considered an LCA as the basis for a purchase criterion. Whereas reduction is directly connected to internal measures before or during the life span of computers in the company, reuse, recycling and recovery are clearly located beyond the scope of the companies and their e-waste management. Efforts to reuse, buy, sell devices or use them as spare parts show that they feel implicitly responsible for them [31]. Outside the companies, partners specialised in recycling and recovery or intermediaries, selling usable devices on the market, take over this responsibility. Companies utilize all possibilities before disposal of devices to reduce e-waste, but some decisions are shifted to partner companies. Interestingly, all interviewees connected the term e-waste to issues being published in the media. The main aim is to avoid that their devices “pop up in one of these illegal landfills” (I2) to not run into problems like loss of reputation [32, 33]. Consequently, the interviewees underlined their efforts for selecting the right partner with high standards and transparent processes.

Based on the above stated discussion, our work contributes to the current discussion in different ways. Firstly, we provide a basic understanding on how e-waste is seen in companies and integrate it into the current research on e-waste [13, 34]. Our research is a first step for clarifying approaches towards reduction, reuse, recycling and recovery of e-waste. This also contributes to the current sustainability discussion, which has slowly found its way into research disciplines beyond business ethics [35]. Secondly, with our research we contribute to practice since we provide first insights into companies’ approach to e-waste handling. By describing a general process and identifying reasons for discarding ICT, this research may serve as a rough guide for business. In addition, we show concepts inside and outside the companies, which may foster as an example for other companies.

6 Conclusions, limitations and further research

In this research, we provide insights into e-waste handling of a rather small sample of companies. The companies are located in very different industries, are of different sizes and produce different amounts of e-waste. However, their e-waste approaches, processes, reasons for discarding ICT devices and life spans of hardware are surprisingly similar. It becomes observable that all three companies adopt responsibility for e-waste, but with some constraints and restrictions. The differentiation between device types, the concepts for usable and valuable devices as well as finding that the reduction of e-waste is more located in the company, whereas the other Rs being shifted to partners are new and will hopefully start a discussion. Obviously, this research has some limitations. Firstly, the interviews are not representative; not for companies nor for the industry. Secondly, the interviews are strongly influenced by the experience the interviewees have. Thirdly, all companies in the sample are located in the same country and therefor share the same external conditions. Based on these limitations, our future research direction is clear: extending the basis by conducting additional interviews to be able to develop a deeper understanding on e-waste handling in companies.

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Unrecognised informal solid waste recycling in an emerging African megacity: a study of Johannesburg, South Africa

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Abstract

Informal solid waste recycling has increasingly become part of the urban landscape in many South African cities and towns. In the city of Johannesburg, for example, informal solid waste pickers are now playing an important role in the recycling of different types of waste. There is evidence in literature which suggests that these activities have both economic and environmental benefits contributing towards employment creation and environmental sustainability. Despite the role that the informal sector contributes to waste management and socioeconomic development, as well as environmental sustainability, the urban development and planning policy in South Africa have not embraced and integrated these activities in the policy framework. Drawing from a field-based study, conducted in selected parts of the city of Johannesburg, and using methods inspired by the traditional of participatory research, this paper explores the institutional framework within which informal solid waste management can be pursued. The paper is specifically interested in identifying and discussing contemporary challenges, mechanisms, systems and processes that may contribute towards the sustained neglect of the informal sector in the urban solid waste management and planning policy.
Keywords: informal solid waste collection, solid waste management, solid waste recycling, Johannesburg, South Africa.

1 Introduction

The informal solid waste recycling has emerged as a livelihood strategy of the low-income urban residents who have found themselves vulnerable and squeezed on the side-lines of the process of industrialisation. Unable to cope with the pressure of a capitalist system which is based on individualism and that of higher market demand and competitiveness, most of the urban poor residents of the developing world have resolved to informally operate in the sector of waste recycling for their survival. SAIRR [1] and supported by the World Bank survey, for example, makes reference to higher demographic pressure observed in the cities of the developing world which has created a situation that the urban authorities cannot be able to meet the needs and aspirations of their residents in terms of employment. The disadvantaged and marginalised group of people in society have to adapt to the pressure of the capitalist system and have to come up with their own means of survival among which include informal solid waste recycling in cities.

In South Africa, for example, two-thirds of the population lives in urban areas (SAIRR [1]). This situation is apparently the result of the rural exodus phenomenon through which people migrate from the rural areas to the towns and cities in search of job opportunities and the so-called ‘good life’. It can also be argued that the demographic pressure has created an enormous pressure upon the local municipal authorities who have proved to be unable to provide adequate and equitable solid waste management service to the various segments of the population dwelling in their respective jurisdictions (Kubanza and Simatele [2]). Karani and Jewasikiewtz [3] regarded South Africa as a model for African economic development. In the meantime, they have seen urban poverty as the most serious problem facing the post-apartheid government. Thus many individuals and households in South African cities have increasingly started adopting multiple and diverse strategies to cope with the challenge of poverty by using the informal sector as a solution to the challenge. Informal waste recycling has helped many poor urban dwellers to earn income and make a living (Sentime [4] and Samson [5]). Sentime [4] reports that an estimated total number of 48% of the urban residents in the city of Johannesburg are now in the industry of informal solid waste recycling which has become the main source of their income generation and livelihood strategy.

In the light of the aforementioned, it appears that most studies focused on solid waste management and informal waste recycling in an urban context, few of these studies have examined and analysed the importance of incorporating informal solid waste pickers in urban development and planning policy. Furthermore, informal solid waste management has been documented as an activity that is not fully recognised in the urban policy planning and development strategies in the countries of the Sub-Saharan Africa in general and South Africa in particular. However, including waste pickers in urban development and planning policy should form the basis that could enable changes in the promotion of green jobs and environmental sustainability in an urban context. In view of these observations, the purpose of this paper is to investigate the barriers that hinder the integration of the informal waste sector in an inclusive waste management system and mechanism. The paper also proposes an approach for a sustainable solution to informal waste management in the city of Johannesburg.

2 Solid waste management in Sub-Saharan African countries

Many cities of the Sub-Saharan African countries experience high rate of population growth stemmed from the process of migration, urbanisation, industrialisation and modernisation (Simelane and Mohee [6]). Increase in population has an impact on solid waste production in cities, which further shaped the existing solid waste management systems and cause challenges to the already desperate urban authorities. A study carried out in the East African region illustrates the financial dilemma concerning to the management of solid waste (Liyala [7]). In Uganda, Tanzania and Kenya, for instance, the problems associated with waste management is categorised as: fiscal (lack of funding), socio-cultural (lack of awareness, education and attitude) and technical (capacity, wrong equipment, inadequate equipment) (Henry *et al.* [8]). Most of the urban residents in the cities of the Sub-Saharan Africa perceive waste as a problem that affects human health and environmental well-being, and that solid waste management should be the responsibility of government. Tukahirwa and Lukooya [9] are of the view that improving funding and developing technical capacity should form the basis and mechanisms that could address the waste management challenges faced by the urban managers in the cities of Sub-Saharan Africa. This situation also requires the involvement of stakeholders at all levels and in all sectors to have a consensus and create an integrated and sustainable approach to solid waste management.

The collection, transportation, disposal and treatment of waste have proved to be a challenge faced by the municipal authorities of the developing world (Gumbo and Simelane [10]). Of greatest concern is both the lack and high cost of modern technology that efficiently and effectively converts waste to energy. Some of the projects that have already been implemented on the African cities, for example, suffer with critical shortages of experienced and well-trained personnel (El-Khattam *et al.* [11]). It must also be noticed that most of African countries lack appropriate policies and legislations that could support investment in waste recycling. Where these policies and legislations exist, they have proved to be inconsistent in their application. For example, in the eThekwini municipality in South Africa: the appropriate technologies, particularly the engines to convert the gas to electricity, have proved to be expensive. This situation has created a scenario by which the municipality has to borrow money from international sources (Chimuka and Ogola [12]). It would therefore not be an exaggeration to argue that the failure in waste management lies in the fact that African countries lack the know-how and appropriate technology susceptible to handle the increasing quantities of waste generated in the cities (Mudhoo *et al.* [13]). This situation is the result of the weak economies and poor financial management and administrative capacity that are often observed in the cities of the developing world (Muniafu and Otiato [14]), which consequently affects the ability of the local authorities to enforce environmental legislation and policies.

Despite the many strides South Africa has made in the management of its municipal solid waste, but there still some challenges to overcome. In addition to the solid waste management challenges, Chimuka and Ogola [12] are of the view that in some cases, the lack of skilled staff and funds, apathy at managerial level, corruption and mismanagement in municipalities are all contributing against the creation of a sustainable approach to urban solid waste management. Furthermore, increased in population in cities together with rural-urban migration have further worsened and complicated the problem of solid waste management. The rural-urban migration has resulted in the expansion of informal settlement in urban areas and this is the case for Johannesburg too, where informal settlements have proved to be expanding exponentially (Samson [5]). Some of the challenges are readily appreciated when looking at the entire current urban municipal solid waste management system, and comparing it with that of other countries. What it boils down to is that it is not enough simply to have good legislation and to spend time thinking of appropriate technologies and/or methods to manage municipal solid waste. The other factors are also important, such as careful planning awareness by the local municipalities on the entire topic of urban municipal solid waste management practices. In order for these practices to be properly implemented and become successful, the role of communities also needs to be taken into consideration.

3 Methodology

The data on which this paper is based was collected in the city of Johannesburg during the month of September to November 2015. Because of the nature of the study, it was purposely decided to select seventy-three (73) waste pickers who were willing to participate in the study. The remaining participants were selected through snowballing sampling method: 3 directors from buy-back centres were selected and included in the survey (Maningi scrap metals, Far-point recycling and Remade recycling), key informants from (Environment and Infrastructure Services Department, Department of Agriculture and Rural Development (Waste Management), Pikitup, Geza Jozi and Bathopele co-operative). Figure 1 portrays the spatial location of buy-back centres in Johannesburg City and Suburban.

Participant research observations and the snowballing sampling method were conducted during the investigation. This technique of data collection was particularly important because some of the research buy-back centres sites do not experience a constant presence of the waste pickers on a regular basis. Thus, using key informants, research participants who work in the municipality and organisations were identified and visited. In addition, ground-truthing exercises, semi-structured interviews, participant observations, and key informants were used as the main data collection instruments. The questions that were asked solicited for information on the barriers to an inclusive waste management system, most recycled materials, challenges encountered by waste pickers and contributions of street waste pickers on solid waste management. Other questions sought to obtain information on the possible ways or an approach for a sustainable solution to informal waste recycling in the city of Johannesburg.

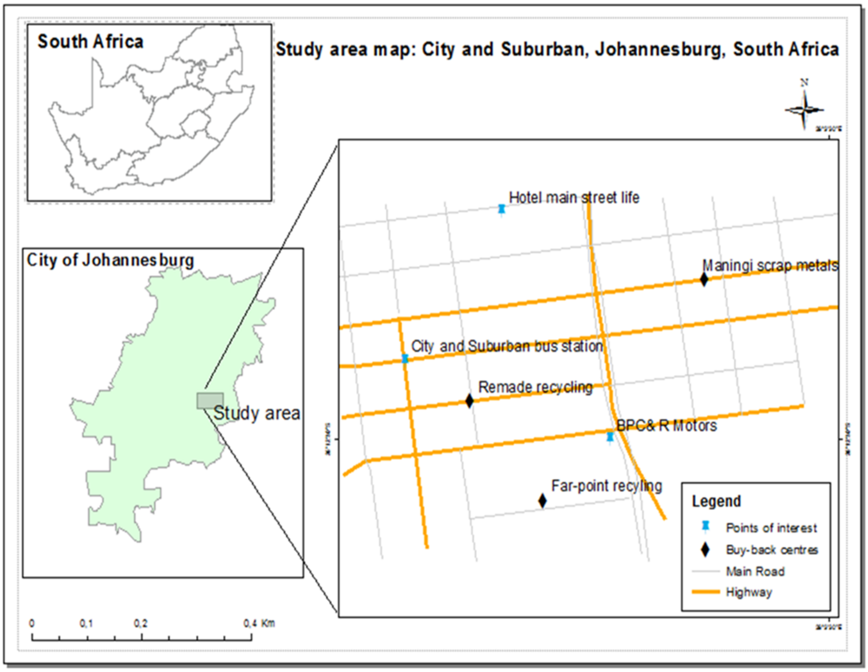

Figure 1: Johannesburg City and Suburban, South Africa.

4 Results

Four factors were identified as barriers to an inclusive solid waste management in the city of Johannesburg: First, there is lack of cooperation between waste pickers and municipal authorities. It was mentioned by a research participant from the city of Johannesburg that there is lack of coordination between waste pickers and the authorities in charge of waste management. The lack of effective coordination and management systems has led to conditions that are harsh on waste pickers. He added that:

> "*It is very difficult to get funds, resources or to break through the municipal channels. What we try to do now is to ask for trolleys in companies. Meanwhile, we are not organised yet companies want us to first register with the city of Johannesburg.*"

This observation suggests that municipal waste authorities are not informed about informal waste recycling. They do not have an idea of the real issues that waste pickers come across on the ground. Through direct involvement with waste pickers, municipalities can better understand the real issues pertaining informal waste recycling.

Specific push factors (unemployment and orphanage) force individuals to migrate from rural areas to the city of Johannesburg. Most waste pickers are attracted by pull factors (job opportunities and better living standards) which they believe will make life easier once off from the rural areas to the city of Johannesburg (Figure 2). Key informants, director's and waste pickers highlighted that informal waste recycling is mainly exacerbated by unemployment. Informal waste recycling then tends to be an alternative source of employment and a source of livelihood.

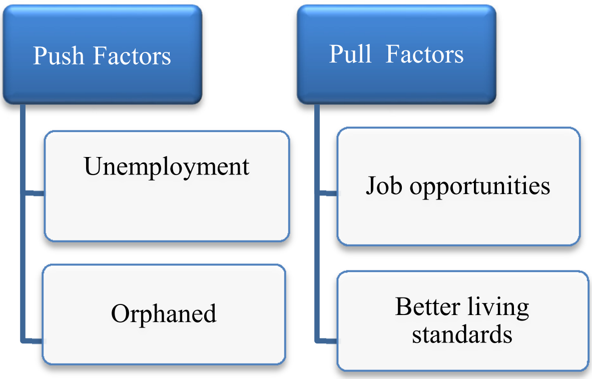

Figure 2: Push and pull factors.

Although informal waste recycling in the city of Johannesburg is not in any-way different from that obtained in other sub-Saharan African cities, its uniqueness lies in the fact that it has been exacerbated, not only by poverty and unemployment but by increased level of institutional failures. Sentime [15] stated that the legislative framework does not recognise informal waste recycling in South Africa. Necessary regulatory framework governing informal waste recycling is not yet set-up to solve the problem of increasing solid waste generation in the city of Johannesburg.

The discussions with key informants provided that there is a lack of existing institutional framework in the city of Johannesburg through which the interests of vulnerable solid waste pickers would be protected and enhanced. This is truly because in the city of Johannesburg, there is lack of transparency among institutions and inadequate accountability in the entire waste management system. In line with the above observations, research participants acknowledged that municipal authority are not working fairly with them, they only make promises which results into low government willingness to implement proper waste management strategies, infrastructure and regulations. Thus the solid waste management challenge in South Africa and the city of Johannesburg in general, has not been a result of political instability and lack of resources, but has been largely embedded in structural challenges such as the absence of an institutional and policy framework as well as unending corruption among institutions combined together with lack of effective coordination and management systems in the various waste management sectors.

However, in the face of institutional and policy challenges in solid waste management, the informal sector, through activities such as informal waste recycling is increasingly playing a critical role in the management of waste in the city of Johannesburg. Figure 3, for example, is an illustration of how informal waste recycling has become part of the urban landscape and form of employment.

Figure 3: Street pickers in the city of Johannesburg.

The majority of the solid waste pickers are poor and less privileged urban dwellers that make a living from collecting and recycling solid wastes. Table 1 for example, shows the demographic aspects of the research participants in the city of Johannesburg.

Table 1: Demographic characteristics of research participants.

Variable	**Category**	**No of respondents**	**%**
Gender	Male	69	95
	Female	4	5
Age Range	15-25	13	18
	26-35	44	60
	36-45	11	15
	46-55	4	6
	56-65	1	1
Total		**73**	**100**

Information presented in table 1 revealed that the majority of street waste pickers are men representing 95% of them and that a recent phenomenon has been the presence of women involved in this industry and they represent 5%. A further scrutiny of table 1 reveals that 60% of all waste pickers were aged between 26 and 35; 18% were aged between 15 and 25 and 15% were between 36 and 45 years. These figures suggest that informal waste recycling in the city of Johannesburg is an activity mainly dominated by young people.

Second, repressive policy and social acceptance: another difficulty towards the recognition of waste pickers is repressive policy and social acceptance. Waste pickers stated that society and authorities view their activities as backwards and a social problem that needs to be removed. The obvious challenge is that of neglect, with cases of removal of collection makeshifts and stored recyclable waste by metro police. Another research participant, for example commented that:

> *"Every day, taxi drivers beat us and call us names, saying we are blocking the road. They hit us on purpose, others they ran over our trolleys. I decide not to entertain them because at the end of the day we are all trying to make ends meet. It is true others understand us but most of them insult us."*

Because of their lack of recognition, waste pickers have never featured as significant role players in the waste management system since they are unwelcome strangers. This research revealed therefore, that the most outstanding social problems that waste pickers face is harassment more especially by Johannesburg Metro Police, taxi drivers and urban residents (Table 2). It is presented in the table that 37% of respondents interviewed mentioned that harassment is a social problem that they encounter in the city of Johannesburg. Almost 29% of the research participants revealed that they experience a problem with mistreatment by drivers on the roads and heavy traffic. Furthermore, it is also revealed that 22% of the respondents mentioned that they have a problem with the smell from dustbins as they do not have proper protective equipment to use when claiming recyclable materials. They mentioned that since waste is not separated at source, they have to first take out recyclable waste from the dustbins.

Table 2: Social challenges encountered by waste pickers.

Challenges/ Problems	**Frequency**	**No. of respondents**	**%**
Physical injury	IIIII III	9	12
Sickness	IIIII IIIII IIIII I	16	22
Harassment	IIIII IIIII IIIII IIIII IIIII II	27	37
Heavy traffic	IIIII IIIII IIIII IIIII I	21	29
Total		**73**	**100**

According to Simatele and Etambakonga [16] the negative behaviour towards waste pickers could be argued as being motivated by a lack of knowledge on the part of urban managers in terms of the contribution of informal solid waste recycling to the entire solid waste management system. Therefore, a positive change in the public's perception on informal waste recycling is an important step to secure a healthy working environment for waste pickers. In view of the above sentiments, it would not be an exaggeration to argue that in the city of Johannesburg, the major limitation to social acceptance of the informal waste sector is that they have not been integrated into an inclusive waste management system.

Moreover, most street waste pickers complained that there is no separation at source, and therefore papers, plastics, bottles and other wastes are not separated. Also due to the non-existence of resource recovery programmes, residents do not see the need to separate and recycle their waste. Municipalities need to understand that a more effective way to reduce waste is to deal with it at source through recycling. Supporting this assertion, Simelane and Mohee [6] are of the view that waste separation at source strongly depends on the level of education of citizens, government commitment and financial incentives and proper infrastructure. Appropriate education of citizens and awareness can change public and waste picker's perceptions in the city of Johannesburg. Bottom up inclusive activities such as workshops, community meetings, radio, print and television programmes and awareness campaigns, are an effective tool to disseminate information and enhance the participation of various sectors of the population.

Third, illegal migrants and lack of valid citizenship documents: another drawbacks mentioned by directors and key informants is that it is hard for authorities to recognise informal waste pickers who reclaim recyclable waste in the city of Johannesburg because most waste pickers are originally not from South Africa. Key informants mentioned that:

> *"We have approximately 40% of waste pickers who are not from South Africa. Again those who are South Africans do not have citizenship documents.*"

Likewise, interviews conducted with waste pickers pointed out that many of the waste pickers do not have identity cards or at least passports. Key informants therefore, pointed out that they can only consider waste pickers who are originally from South Africa, of which a majority of them are not South Africans. Another official revealed that most waste pickers are crime bearing individuals hence they do not have identity documents. He mentioned that "*So even if government can try to recognise waste pickers, it will not help because the system will pick up individuals who once committed crime."*

Fourth, lack of supporting evidence: Authorities pointed out that amongst challenges, waste pickers do not have a database. They see them in the streets of Johannesburg but their activities are not documented and organised. Key informants mentioned that:

"*In this essence, government cannot give opportunities to individuals*." Officials further mentioned that *"It is thus very hard to help people without knowing their contributions in waste management. In general, we do not know their numbers, their working networks, and their working stations."*

Literature states that given the lack of data on waste activities, and indeed the difficulty in measuring many important aspects, makes it difficult to tackle some important players in waste management. From this angle, it can be argued that without commitment and dedication by municipal authorities on informal waste recycling; waste pickers activities will have no database.

5 Discussion

A database of waste pickers can be developed and updated on regular basis in the city of Johannesburg. The registration process can be undertaken through the assistance of waste committees and buy-back centres. Through this process, the municipal department can be able to gather information on waste pickers operating within the city. This information can give the department an indication of where reclamation activity influx is at and the role that waste pickers play in the waste management value chain. This process can develop a platform of communication where the city authorities can engage on waste management challenges with waste pickers through their committees and association. Environmental departments can also work with the Department of Economic Development and other NGOs to assist waste pickers to form cooperatives and collaboration. Cooperatives can assist in sustaining the project and improve the lives of the waste pickers by creating opportunities for waste pickers to actively participate in formal waste management activities.

Thus figure 4 presents a model of institutional arrangement for informal solid waste pickers' inclusion and recognition in urban solid waste management planning policy and developmental strategies. This model explicates how the urban authorities can enable and register the waste pickers operation in urban

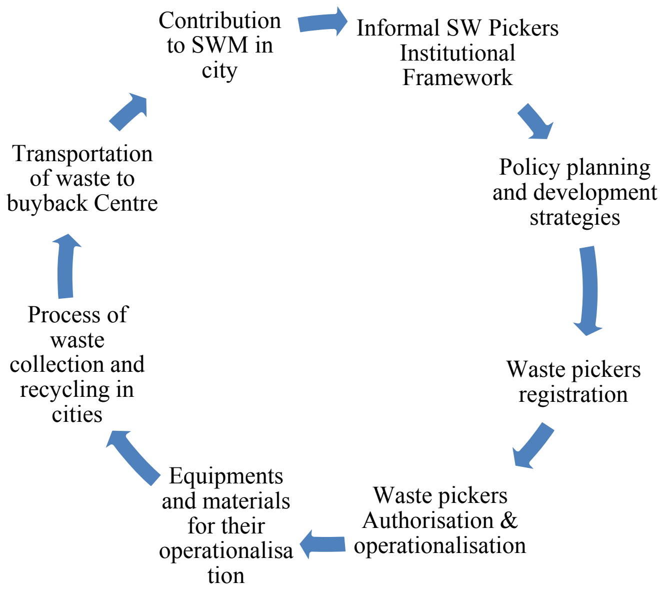

Figure 4: Institutional arrangement for informal solid waste picker's recognition.

development. These waste pickers, once, formally registered and authorised to operate, they have to be provided with materials and equipment susceptible to execute their tasks by collecting recyclable wastes in the cities and transport them to buy-back centres. This operation, not only help the waste pickers earn an income but also it contributes to urban environmental solid waste management and sustainability.

In view of the above observations, the municipal waste department can conduct a needs analysis workshop. The workshop can be used as a platform to understand issues that waste pickers encounter and for the city to be able to prioritize their needs. The workshop can be for the relevant stakeholders to identify the role that they can play and commit themselves to the empowerment of waste pickers. The stakeholders can include: Industries, National/ Provincial Departments and City of Johannesburg departments.

Personal Protective Equipment (PPEs) and trolley for waste pickers can be procured by the Department of Environmental Affairs, Pikitup, Department of Environment and Infrastructure Services, Department of Economic Development and buy-back centres. Protective clothing can consist of reflector vests which are visibly to motorist during the day and night, as waste pickers use roads. Sustainable boots which can be comfortable in their everyday walking distance. Protective clothing can include dust masks and gloves; this can protect them when they are reclaiming not to inhale dangerous or hazardous substances which might be found in the waste that is being reclaimed.

Training can be conducted in collaboration with the afore-mentioned environmental departments. The training can focus on business skills, recycling and the city of Johannesburg by-law requirements and compliance. The training can give an opportunity to the waste pickers to understand their work and how does it fits in the waste management value chain of the city of Johannesburg. When the project is rolled out, the city can further retrain waste pickers in order to reskill them if there are new developments in the recycling industry. A pilot project can be launched in the city of Johannesburg and thereafter be rolled out to other parts of the city.

6 Conclusion

The main objective of this paper was to investigate the barriers that hinder the integration of the informal waste sector in an inclusive waste management system. The paper also proposed an approach for a sustainable solution to informal waste management in the city of Johannesburg. It has been suggested and argued in this paper that informal waste recycling in the city of Johannesburg is an activity dominated by men, and in some cases women. It has been revealed that, waste pickers are vulnerable more especially to harassment by metro police, urban residents and motorist. However, it has been argued that government need to acknowledge and recognise waste pickers activities in the urban policy planning and development strategies in South Africa. This situation owes much to the barriers to inclusive waste management: lack of cooperation, social acceptance, lack of valid citizenship documents and lack of supporting evidence. In view of this observation, municipalities can empower waste pickers through an institutional arrangement for informal waste sector inclusion and recognition in urban waste management planning policy and development. Urban authorities can conduct workshops where they can register, train, discuss issues and provide protective equipment for waste pickers through cooperatives. Integration of waste pickers will therefore ensure increased community commitment and participation, both in terms of waste recycling and management.

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Recycled construction and demolition waste in mining rehabilitation

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Abstract

Currently, the main destination for non-valuable recycled construction and demolition waste (CDW) consists of its disposal in landfills. Because of the high volume of non-valuable recycled CDW generated, and due to the disposal it is usually developed in low-controlled or even non-controlled conditions, this kind of management may derive in safety and environmental issues. Therefore, it is necessary to find an alternative management system that allows, firstly, the recovery of this kind of waste and, secondly, enables the rehabilitation of areas affected by mining activities.

The Geological Survey of Spain (IGME) is carrying out a management commission for the Ministry of Agriculture, Food and Environment which aims to produce a methodological guideline for the rehabilitation of mining pits and quarries with non-valuable recycled CDW in open-pit facilities.

The main target is the implementation of the basic legislation applicable on this matter (Royal Decree 1481/2001; Royal Decree 105/2008; Royal Decree 975/2009; Law 22/2011), with the ultimate objective of reaching a framework that allows the mining rehabilitation with non-valuable recycled CDW in safety and healthy conditions for population and environment.

The abovementioned guideline will be based on the physicochemical characterization of waste, the environmental constraints, and the rehabilitation objectives.

Keywords: recycled aggregates, CDW, mining, mining areas, inert waste, concrete, ceramics, environmental rehabilitation, waste management, leachability.

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1 Introduction

Construction and demolition waste (CDW) represents more than 20% of the total generated waste in Spain during 2012 (data from Eurostat, 2012) surpassed only in percentage by industrial waste.

Furthermore, Spain was the sixth European Union country with the greater production of CDW, with around 26 million tonnes during this period (data from Eurostat, 2012). This high quantity of CDW represents a major environmental issue. The recovery of this kind of waste is essential to reduce its negative impact on the environment and human health, and to ensure a rational use of natural resources.

According to the Waste Framework Directive and the Government Waste Management Framework Plan (2016–2022), 70% (by weight) of non-hazardous CDW, excluding excavation waste, should be subjected to some sort of recovery operation (re-use, recycling, backfilling operation using waste to substitute other materials, etc.) by 2020. Although the level of recovery of CDW in Spain has been significantly increased in recent years according to the Spanish Federation of CDW Management Companies (data from FERD, 2015), the recovery ratio was about 38% in 2013, far below the objective established by the European Union (EU). The remainder of CDW production (non-valuable recycled CDW) was disposed of in inert landfills (26%) or dumped in unsupervised landfills (36%). In recent years, the declining demand for recycled CDW due to the crisis in the construction sector has contributed to strengthening this situation.

Royal Decree 975/2009, about management of extractive industries waste and protection and rehabilitation of areas affected by mining activities, contemplates the possibility of filling mining pits with inert waste of non-mining origin. In addition, for landscaping purposes, Royal Decree 105/2008, (which regulates the production and management of CDW in Spain), considers the use of inert CDW in the restoration of degraded areas or in refurbishment works as a recovery operation.

In this context, the Ministry of Agriculture, Food and Environment orders the elaboration of a management commission to the Geological Survey of Spain (IGME) which aims to produce a methodological guideline for the rehabilitation mining pits with non-valuable recycled CDW. Additionally, this use could be a new path to increase the percentage of recovery of CDW in our country, in order to reach the recovery ratio established by the European Union for 2020.

2 Potential use of non-valuable recycled CDW in mining rehabilitation

There are no official statistics at a national level about the use of CDW in mining rehabilitation. Anyway it is possible, as the first approach to the issue, to estimate the potential of recovery of the non-valuable recycled CDW that is feasible to use for mining rehabilitation purposes. To do this, the minimum annual volume of mining pits generated as well as the annual volume of CDW intended to landfill operations have been determined.

The year 2012 has been selected because it is the most recent year with available data for both subjects: mining and waste.

Based on the National Mining Statistics (http://www.minetur.gob.es/ENERGIA/MINERIA/ESTADISTICA/Paginas/Consulta.aspx), it was possible to obtain the total mass of mining minerals extracted in 2012. Only those mine sites considered to have favourable conditions for the rehabilitation with non-valuable recycled CDW (evaporitic lithologies, sedimentary minerals, fine-grained rocks, etc.) were selected.

Furthermore, the density of these minerals was determined through searching in several web sites. The simply division of the total mass produced and the density gives, as result, the total volume of mineral extracted (table 1).

It is necessary to consider that volumetric data obtained are referred to a minimum mining void, due to it being probable that the holes generated during the extractive operations are higher (the non-productive material are also removed and occasionally remains stored in mining heaps or tailings dams).

Table 1: Estimated minimum pit volume generated due to mining activities in 2012.

	Annual production (kg)	**Density[a] (kg/m^3)**	**Volume (m^3)**
REFRACTORY CLAY	78,000,000	1,362	57,269
BENTONITE	97,000,000	593	163,575
KAOLIN	247,000,000	2,510	98,406
POTASSIUM CHLORIDE	632,000,000	1,996	316,633
GLAUBERITE	1,050,000,000	2,785	377,020
SEPIOLITE	622,000,000	2,000	311,000
THENARDITE	175,000,000	2,690	65,056
CLAY	8,289,000,000	2,638	3,142,749
MARLSTONE	5,581,000,000	2,243	2,488,185
GYPSUM	6,360,000,000	2,550	2,494,118

[a]www.csgnetwork.com/specificgravmettable.html
www.engineeringtoolbox.com
webmineral.com
www.edumine.com/xtoolkit/tables/sgtables.htm
rocscience.com/help/rocfall/webhelp/baggage/Rock_Density_Table.htm

This way, the estimated total (minimum) pit volume generated due to mining activities was 9 514 011 m^3.

In addition, data about the use of non-hazardous CDW, excluding excavated soils were obtained from the Spanish National Institute of Statistics (data from INE, 2012). The volume of non-hazardous CDW, based on the treatment received, was calculated (table 2) applying a conservative density value of 2.3 t/m^3 (http://www.cedexmateriales.vsf.es/view/archivos/residuos/447.pdf).

The results obtained show that the volume of non-valuables recycled CDW is similar to the volume generated by mining activities in 2012. These data permitted to assess the estimated increase in the percentage of CDW recovery that the use of non-valuable recycled CDW in mining rehabilitation would imply. According to

Table 2: Data related to CDW management (extracted from the INE databases for the year 2012).

Non-hazardous CDW (excluding excavated soils)	Recovery	Backfilling Operations	Disposal	Total
Weight	18,705,743 t	4,328,999 t	4,292,972 t	27,327,714 t
Volume	8,132,932 m^3	1,882,173 m^3	1,866,510 m^3	11,881,615 m^3

INE data, if CDW disposed in landfills (4,292,972 t) had been destined to rehabilitate mining pits, the quantity of non-hazardous CDW used in backfilling operations (table 3) would be double. These actions are recognised as recovery operations by the Waste Framework Directive and the Royal Decree 105/2008.

Therefore, the use of non-valuable recycled CDW in mining rehabilitation would help to achieve the minimum recycling target of 70% (by weight) for CDW by 2020 and would reduce the environmental impact in areas affected by mining activities.

Table 3: Potential of RCD recovery when mining rehabilitation activities are included.

	Recovery	Backfilling operations	CDW recovery
Current recovery non-hazardous CDW*	18,705,743 t	4,328,999 t	23,034,742 t
Potential recovery non-hazardous CDW*	18,705,743 t	8,621,971	27,327,714 t

*Excluding excavated soils

Calculating a better estimation of the increase of the CDW recovery percentage due to the use on mining rehabilitation works is not an objective of this document. Moreover, INE data may not reflect the current situation of the CDW management in Spain, when compared with data provided by the Spanish Federation of CDW Management Companies. Despite these limitations, is important to highlight the great potential of the use of non-valuable recycled CDW in mining rehabilitation activities.

3 Applicable legislation

The legislative framework for the use of CDW in the rehabilitation of lands degraded by mining activities is very complex. It includes regulations regarding: waste management, specific legislation for CDW management, mining sites rehabilitation and landfills. Furthermore, European, national, regional, and even municipal (for minor works and house repairs) legislation are applicable. In table 4 the applicable national legislation is summarized.

Table 4: Summary of the applicable Spanish legislation.

CDW and waste management legislation	
Law 22/2011	About waste and contaminated soils.
R.D. 105/2008	About regulation of CDW production and management.
R.D. 1481/2001	About regulation of waste removal through disposal in landfills.
Tech. Development of R.D. 1481/2001	About waste landfill facilities.
Order AAA/661/2013	Amendment of R.D. 1481/2001.
Mining and mines restoration legislation	
Law 22/1973	About mines.
R.D. 975/2009	About management of extractive industries waste and protection and rehabilitation of areas affected by mining activities.
R.D. 777/2012	Amendment of R.D. 975/2009.
Correction of errors in R.D. 777/2012	Corrections in R.D. 777/2012.

Some interest considerations resulted from the legal framework are pointed out below. Pursuant to Royal Decree 105/2008, to be mining restoration by using CDW considered as a recovery operation, it must comply with these items: a) the competent regional environmental authority must previously declare the environmental restoration plan as a recovery operation; b) the operation must be carried out by a waste manager authorized by the regional administration; c) the operation results in the substitution of the natural resources needed for this restoration.

Moreover, the Royal Decree 975/2009 allows the use of inert non-valuable recycled CDW whenever both backfilling and rehabilitation of the pit comply with all requirements established in the Royal Decree 1481/2001, which regulates the disposal of waste in landfills. Therefore, the conditions imposed to inert waste landfills are applicable in this case. The rule establishes that inert waste landfills must be fitted with a natural geological barrier characterized by having, at least, one-meter thick and a permeability of 10^{-7} m/s. If the natural terrain does not comply with these parameters, it must be necessary to install an artificially established geological barrier, requiring a mineral layer of 0.5 meters thick, thus ensuring the waterproofing of the mining pit. In addition, the construction of an efficient drainage system is mandatory. However, due to its inert character, the rule allows the regional environmental authority, when the risk is considered as acceptable, to decide not to require the installation of a geological barrier and/or a drainage system.

4 Characterization of CDW for mining restoration

Most of the recycling plants are equipped with two separate recycled aggregate production lines: concrete line and ceramic line (figure 1).

Ceramic waste usually come from building demolitions or domiciliary maintenance minor works. It is not unusual that this kind of waste arrives at the recycling plant without selective separation at the source.

Waste of a lower quality than recycled aggregate and size from 0 to 20 mm or 0 to 40 mm, are produced in both production lines, during the pre-sieved (previously to grinding and classification) phase. This kind of waste does not have commercial opportunities (GERD [1]). About 50% of CDW entering the recycling plants are ceramic waste. These non-valuable recycled CDW are disposed in inert landfills or stockpiled in recycling plants. This project focuses on non-valuable recycled CDW. Inert nature is the main precondition for using this kind of material in mining rehabilitation.

In order to characterize and determine their inert nature, essays and criteria set out in the Order AAA/661/2013 were applied to CDW samples. A total of 10 samples of non-valuable recycled CDW were obtained from 7 recycling plants in the Autonomous Community of Madrid. Samples were separated in three groups according to the origin of the CDW: CDW from concrete residues, CDW from ceramic residues and CDW from mixtures of concrete and ceramic residues.

Non-valuable recycled CDW (concrete line) Non-valuable recycled CDW (ceramic line)

Figure 1: Non-valuable recycled CDW from both concrete and ceramic lines.

Leachability of CDW samples was assessed by carrying out the leaching test UNE-EN 12457-4:2003 "*Characterization of waste. Leaching. Compliance test for leaching of granular waste materials and sludge. Part 4: one stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction)*". As, Ba, Cd, total Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se and Zn, chloride, fluoride, sulphate, phenol index, dissolved organic carbon (DOC) and total dissolved solids (TDS) contents were determined and compared with the limits set by the Order AAA/661/2013. The results of the leaching tests and the limit values are shown in table 5. Non-compliances with the limit values are highlighted.

Furthermore, the total content of TOC (total organic carbon), BTEX (benzene, toluene, ethylbenzene and xylenes), PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls) and mineral oils (C10-C40) were determined. The results of the analyses and the limit values are shown in table 6. Non-compliances with the Order AAA/661/2013 are highlighted.

Table 5: Results of the leaching tests. Comparison with limits set by the Order AAA/661/2013. Non-compliances with the limit values are highlighted in bold print.

LEACHING TEST UNE-EN 12457-4 Order AAA/661/2013		**NON-VALUABLE RECYCLED CDW**		
		CONCRETE (mg/kg)		**MIXTURE (mg/kg)**
Parameter	**Limit value mg/kg dry matter**	**1**	**2**	**10**
As	**0.5**	0.028	0.063	0.197
Ba	**20**	0.725	0.0429	0.402
Cd	**0.04**	<0.02	<0.02	<0.02
Total Cr	**0.5**	0.067	0.0571	0.0848
Cu	**2**	0.12	0.0517	0.0575
Hg	**0.01**	<0.05	<0.05	<0.05
Mo	**0.5**	0.043	0.0334	0.0255
Ni	**0.4**	0.058	<0.05	0.119
Pb	**0.5**	<0.02	<0.02	<0.02
Sb	**0.06**	0.023	0.0125	0.0311
Se	**0.1**	<0.05	<0.05	0.0547
Zn	**4**	0.14	0.182	0.263
Chloride	**800**	50	1	2
Fluoride	**10**	<5	<5	<5
Sulphate	**1000**	**8840**	280	**13696**

LEACHING TEST UNE-EN 12457-4 Order AAA/661/2013		**NON-VALUABLE RECYCLED CDW**						
		CERAMIC (mg/kg)						
Parameter	**Limit value mg/kg dry matter**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
As	**0.5**	0.091	0.035	0.0793	0.1	0.103	0.183	0.042
Ba	**20**	0.403	0.504	0.449	0.442	0.112	0.198	0.45
Cd	**0.04**	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Cr	**0.5**	0.043	0.244	0.0393	0.064	0.054	0.0417	0.04
Cu	**2**	0.039	0.146	0.0447	0.19	0.05	0.873	0.05
Hg	**0.01**	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mo	**0.5**	0.112	0.0695	0.0265	0.022	0.023	0.0241	0.039
Ni	**0.4**	<0.05	0.234	<0.05	<0.05	0.072	0.063	0.176
Pb	**0.5**	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sb	**0.06**	0.029	**0.0632**	0.0176	0.019	0.008	0.0167	0.015
Se	**0.1**	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zn	**4**	0.425	0.249	0.712	0.269	0.264	0.644	0.721
Chloride	**800**	140	90	1	31	1	1	4
Fluoride	**10**	<5	<5	<5	<5	<5	<5	<5
Sulphate	**1000**	**18700**	**15100**	**6079**	**7520**	**2796**	**1169**	**13793**

Table 6: Total organic parameters contents. Comparison with limits set by the Order AAA/661/2013. Non-compliances with the limit values are highlighted in bold print.

Order AAA/661/2013		**NON-VALUABLE RECYCLED CDW**		
		CONCRETE (mg/kg)		**MIXTURE (mg/kg)**
Parameter	**Limit value mg/kg dry matter**	**1**	**2**	**10**
TOC	**30000**	6300	n.a.	5676
BTEX	**6**	< 0.05	< 0.05	< 0.05
PCB	**1**	< 0.025	< 0.025	< 0.025
Min. oil	**500**	< 40	93	145.4
PAH	**55**	< 0.05	< 0.279	< 0.08

n.a.: Result not available.

Order AAA/661/2013		**NON-VALUABLE RECYCLED CDW**						
		CERAMIC (mg/kg)						
Parameter	**Limit value mg/kg dry matter**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TOC	**30000**	-	3700	5100	n.a.	n.a.	7272	8145
BTEX	**6**	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
PCB	**1**	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
Min. oil	**500**	**648.3**	< 40	< 40	99.9	41.7	64.8	243.2
PAH	**55**	17.4	1.32	0.38	0.381	0.259	< 0.08	< 0.08

n.a.: Result not available.

5 Results and conclusions

Based on the results of the leaching tests, and their comparison with the limits values set by the Order AAA/661/2013, it can be concluded that the non-valuable recycled CDW cannot be considered as inert waste, mainly due to the high contents of sulphates. There are also punctual nonconformities with regard to Sb and mineral oil contents. Therefore, the sulphate content appears to be a limiting factor.

This fact implies that, in conformity with the Royal Decree 1481/2001, it would be necessary to establish a geological barrier previously to the operations of rehabilitation with non-valuable recycled CDW. Additionally, it could preclude the use of this kind of waste in the rehabilitation of mining pits according to the Royal Decree 975/2009.

It should be noted that in mining areas whose geochemical background is rich in sulphates, the environmental impact due to sulphates is limited. In these mining areas, it is possible to renounce the installation of a geological barrier with the specifications established in Royal Decree 1481/2001. Flores *et al.* [2] suggest that, it would not be necessary to establish constrains regarding sulphates contents when non-valuable recycled CDW are destined for its disposal in mining pits located in massive gypsiferous terrains.

The sulphate content will depend on the origin of the waste and the lithological features of the aggregates or construction materials employed, according to the geological and mineral existing resources in each region (Romero [3]). The non-valuable recycled CDW samples obtained in the recycling plants located in the southeast of Madrid (gypsiferous terrains) show the highest sulphate contents (samples 3, 4, 9, and 10), while the lowest sulphate concentrations are recorded in the samples from the plants located in the north of the region (samples 7 and 8) with granitic substrate type.

Therefore, based on the results, it is not possible to predict categorically if the sulphate content of a particular non-valuable recycling CDW sample will exceed the limit values established for inert waste. In any case, the number of samples analysed is still low, and it is considered necessary to take at least 30 samples from different CDW management companies from different regions with diverse regional geochemical background.

There are many examples of restoration with CDW in gravel pits and quarries located in the proximities of large cities (Rubio *et al.* [4]). Excavation soils were employed in many of the cases.

Some specialists are in favour of the use of non-valuable recycle CDW in mining rehabilitation due to its low cost and because the use of these waste allow to perform a landscape restoration under (geotechnically) safe conditions, promoting revegetation and landscape integration. In addition, the recovery of non-valuable recycled CWD, also allows reducing the need for new landfills (Flores *et al.* [2]).

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The necessity of recovering soluble phosphorus from sewage sludge ashes before use in concrete based on concrete setting and workability

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Abstract

By replacing cement with alternative ashes, such as sewage sludge ashes (SSA) from mono-incineration plants, it is possible to reduce CO_2-emmision from the production of cement. SSA contains a large amount of phosphate which can be extracted before addition in concrete. The Danish Standard DS/EN 450-1 states an upper limit for total phosphorus in concrete, but it does not account for the solubility. The aim of this study is to determine an upper limit for soluble phosphorus in concrete, thus minimizing the formation of calcium phosphate to an acceptable level. The analysis will be based on the setting and workability. When adding soluble phosphorus salts to a mortar the setting process is extended with no pronounced difference between different soluble phosphorus salts. It is therefore assumed, that the soluble phosphorus (SP) influences the concrete setting. A logarithmic relationship between the increased addition of SP and the initial setting time is seen. By comparison with the limit for an initial setting time established in DS/EN 450-1 it is possible to establish a limit for SP of 0.54 wt% cement. When studying the workability an objective limit for SP of 0.16 wt% cement can be established. SSA from the Danish mono-incineration plant at Spildevandscenter Avedøre is examined. At a pH-value of 13 it is possible to replace 55% and 16% of the cement, based on the set limits, with SSA from Spildevandscenter Avedøre, before it is necessary to extract SP from SSA before adding to the concrete mixture. Former studies have shown a replacement of up to 20% of the cement with SSA is feasible regarding compressive strength, and therefore it is necessary to consider the limit for SP of 0.16% wt% cement.

Keywords: soluble phosphorus, sewage sludge ash, concrete setting, concrete workability, setting time, pH dependent solubility of phosphorus.

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1 Introduction

Production of cement is 4.8% of the global CO_2-emission (Olivier *et al.* [1]). In order to lower the overall CO_2-emmison, decreased use of cement might be an option with high impact. A solution can be to replace a part of the cement in concrete with an alternative puzzolanic material, such as SSA from mono-incineration plants. SSA typically contains a high concentration of phosphorus, 5–10% per unit weight (Ottosen *et al.* [2]). Phosphorus is an essential element for all life and is not substitutable in the food industry. If the mining of phosphorus isn't reduced or other ways of extracting phosphorus from alternative sources isn't found, the world will be out of phosphorus in 50–100 years (Smil [3]). A solution could be to extract phosphorus from SSA from treatment plants before addition in concrete, and thereby contributing to the decreasing of the vital phosphate reserves. Different techniques are under development for recovery of phosphorus from SSA. The techniques can be grouped in two: thermochemical treatment or chemical extraction, and the methods are reviewed in Donatello and Cheeseman [4].

If SSA is used in the concrete industry as a substitute to cement, it is necessary to study the impact of phosphorus from a concrete technical standpoint. DS/EN 450-1 [5] has set an upper limit for the contents of phosphorus in concrete on 5% per unit weight, which most of the types of SAA already exceeds. This standard does not take the solubility of the phosphorus in the SSA into account, and thus the formation of calcium phosphorus. By studying the influence of the isolated phosphorus on the concrete setting and workability of fresh concrete it is possible to argue for limit for soluble phosphorus in concrete, and thereby encourage extraction of the phosphorus from SSA before using it in concrete mixes. Assessing the influence of water soluble phosphorus on concrete setting is the aim of the present work.

1.1 Hydration of the aluminates

One of the most important aluminates on the concrete setting process is C_3A (molecular formula: $3CaO{\cdot}Al_2O_3$). The reaction of C_3A with water is immediate. Crystalline hydrates are quickly formed and unless the hydration of C_3A is slowed down, the concrete cannot be used for most construction applications. To prevent this reaction gypsum is added, and therefore the retardation of C_3A by gypsum is one of the important processes in the structural development of concrete (Mehta and Monteiro [6]).

The retardation of C_3A proceeds in two steps; first the formation of ettringite (1) flowed by the formation of monosulfate (2).

$$3CaO{\cdot}Al_2O_3 + 3(CaSO_4{\cdot}2H_2O) + 26H_2O \rightarrow 3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O \quad (1)$$

$$\begin{gathered} 2(3CaO{\cdot}Al_2O_3) + 3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O + 4H_2O \rightarrow \\ 3(3CaO{\cdot}Al_2O_3{\cdot}CaSO_4{\cdot}12H_2O) \end{gathered} \quad (2)$$

A normal setting extends over 2–4 hours after the addition of water, where the paste becomes less workable between 1-2 hours and begins to solidify within 2–3 hours. This is the case for a well-balanced addition of C_3A and gypsum (Mehta and Monteiro [6]).

1.1.1 False set

If the reactivity of C_3A is low and the availability of sulphate is high this combination will lead to a rapid formation of large crystals of gypsum with a corresponding loss of consistency. If the mortar contains an adequately low reactivity of C_3A and an adequately high availability of sulphate false set occurs, as early as 10 min after the addition of water to the mixture (Mehta and Monteiro [6]).

2 Materials and methods

2.1 Soluble phosphorus salts

Three types of phosphorus salts with a high solubility were chosen for this study, listed in table 1.

Table 1: Soluble phosphorous salts (Merck Millipore [7]).

	Solubility in water [g/l]	Molar mass [g/mol]
Di-sodium hydrogen phosphate dodecahydrate (DSP)		
$Na_2HPO_4{\cdot}12H_2O$	218	358.14
Tri-sodium phosphate dodecahyrate (TSP)		
$Na_3PO_4{\cdot}12H_2O$	285	380.18
Potassium di-hydrogen phosphate (KDP)		
KH_2PO_4	222	136.08

The salts are dissolved in dematerialized water before the water is mixed with Basis Cement and sea sand into mortar as described in section ‘2.2 Mortar mixtures’. When testing the influence of phosphorous on mortar it is assumed that all phosphorus in the salts is soluble.

2.2 Mortar mixtures

All mortar mixtures follow the recipe from DS/EN 196-1 [8], except for different kinds or amounts of salts dissolved in dematerialized water before mixture. For the mortar, Basis Cement from Aalborg Portland is used and the sea sand is dried before addition to the mortar. All mixtures are listed in table 2.

The mixing of mortar is conducted cf. DS/EN 196-1 [8].

Table 2: Overview of mixtures.

Mixture	Basis Cement [g]	Demineralized water [g]	0–4mm sea sand [g]	Phosphorus compound [g]
REF	450.0	225.0	1350.0	0.0
DSP (0.73g SP)	450.0	225.0	1350.0	8.41
KDP (0.73g SP)	450.0	225.0	1350.0	3.19
TSP (0.73g SP)	450.0	225.0	1350.0	8.92
KDP (0.18g SP)	450.0	225.0	1350.0	0.80
KDP (0.36g SP)	450.0	225.0	1350.0	1.60
KDP (1.8g SP)	450.0	225.0	1350.0	7.91
KDP (2.5g SP)	450.0	225.0	1350.0	11.05
KDP (4.36g SP)	450.0	225.0	1350.0	19.17
KDP (6.54g SP)	450.0	225.0	1350.0	28.75

2.3 Concrete setting and workability

Concrete setting refers to the solidification of the plastic cement paste (Mehta and Monteiro [6]) and is analyzed based on initial and final setting time. Initial and final setting time was measured with a Vicatronic, cf. DS/EN 196-3 [9].

The initial setting time represents the time where the fresh concrete becomes unworkable and concrete placement, compaction and finishing operators becomes difficult beyond this stage (Mehta and Monteiro [6]). Initial setting time is defined as the first time measurement where the needle of the Vicatronic penetrates the specimen up to 0.5mm from the bottom of the specimen (DS/EN 196-3 [9]).

Final setting time represents the time where solidification is complete and after which strength begins to develop (Mehta and Monteiro [6]). Final setting time is defined as the first time measurement where the needle of the Vicatronic sinks 6±3mm into the mortar sample (DS/EN 196-3 [9]).

Workability is assessed objectively by comparing the reference mixture with a mortar mixture added salts in a wet condition and the surface of the set specimens after setting.

2.4 SSA for the experimental work and pH dependent solubility of phosphorus

The SP concentration in alkaline solutions was evaluated for an SSA from the Danish mono-incineration plant at Spildevandscenter Avedøre. The sludge incinerated at the plant originated from municipal wastewater treatment. Iron was used in the waste water facility to precipitate phosphorus, and the sewage sludge was incinerated in a fluidized bed combustor about 806°C.

Extraction of phosphorus from SSA is determined by examination of SSA in alkali solutions; 0.01M NaOH, 0.05M NaOH, 0.1M NaOH, 0.5M NaOH and

1.0M NaOH. The pH-values of the solutions are measured and the concentrations of phosphorus in the solutions are measured by ICP. The SSA is crushed before conducting the experiment, since former studies have shown that crushing the ashes before adding to a mortar mixture gives a more puzzolanic effect in the same range as cement (Donatello *et al.* [10]).

3 Results and discussion

3.1 Soluble phosphorus salts in fresh mortar

To be able to determine whether it is the SP or another component in the soluble phosphorus salt which influences the initial and final setting time, mixtures with 0.73g SP were tested with DSP, KDP and TSP. Furthermore KDP has the highest solubility in water, and is therefore used to test for a limit for phosphate in mortar based on setting and workability. Prior this study Wittendorff [11] has measured the initial and final setting time of a mixture with an addition of 2.7g ADP corresponding to 0.73g SP, and this result will be included in this paper.

Figure 1 shows the setting process of a reference specimen, three specimens added the three chosen salts corresponding to 0.73g SP and ADP corresponding to 0.73g SP conducted by Wittendorff [11].

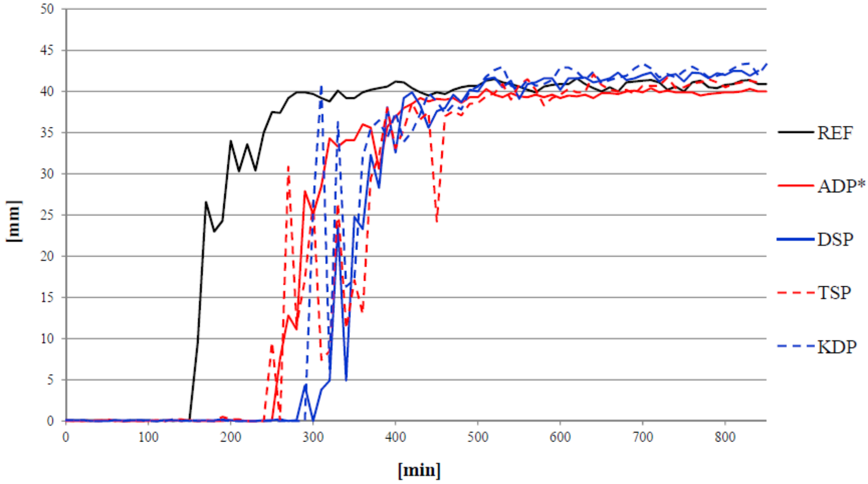

Figure 1: Setting process for specimens added 0.73g SP (*from Wittendorff [11]).

For all specimens added 0.73g SP is seen a retardation of both initial and finial sets and the course is more uneven compared to the reference sample. All figures containing salts sets later than the reference specimen.

Table 3 shows the initial and finial setting time for the specimens added the four types of salts and their respective deviation from the reference specimen.

Table 3: Setting time for specimens added 0.73g phosphorus (*from Wittendorff [11]).

	Initial setting time [min]	Deviation from REF [%]	Final setting time [min]	Initial to final setting time [min]	Deviation from REF [%]
REF	160	–	410	250	–
ADP*	260	63	540	280	12
DSP	330	106	670	340	36
TSP	250	56	560	310	24
KDP	300	88	600	300	20

The initial and final setting time for the reference specimen corresponds well with normal-setting given by Mehta and Monteiro [6].

DS/EN 450-1 [5] is used as a basis for determination of a limit of SP in mortar. DS/EN 450-1 [5] is a standard for fly ash, but since none has been drafted for SSA yet DS/EN 450-1 [5] is used instead. DS/EN 450-1 [5] establishes requirements for initial setting time, when fly ash is added to the mixture, that must not exceed 2.25 times the initial setting time for the reference sample. The addition of soluble phosphorus salts prolongs the initial setting time, but all measurements comply with the limit for initial setting time according to DS/EN 450-1 [5]. The measured time from initial to final setting time is likewise prolonged though not as severe. These results was expected, as phosphoric acids and their salts mixed with mortar results in retardation of initial and final set among other things (Kurdowski [12]).

Cement contains elements like calcium oxides (~63%), which is a phosphorus binding element (Egemose *et al.* [13]). Based on the obtained results, and know theory, the following hypothesis can be drawn up. By adding SP to the mortar mixture, SP reacts with the calcium in C_3A and gypsum, forming calcium phosphates and releasing sulfate in the mortar. This causes a prolonging of the structural development and thus the setting time. Furthermore crystallization of gypsum needles starts to form in the pores which cause loss of consistency and finally flash set.

3.2 Limit for soluble phosphorus in fresh mortar cf. requirements from DS/EN 450-1 [5]

From figure 2 it is seen that the more SP is added, the longer it takes for the specimen to reach initial and final setting time, except for the highest concentration, where the setting is much faster. This is supported by table 4.

From table 4, the initial setting time is seen to be delayed the more SP is present, till a fairly large amount of SP is present. Moreover, it is seen that the initial setting does not comply with the limit for initial stetting time according to DS/EN 450-1 [5] for the addition of 4.36g and 6.54g SP, which is below the saturated limit.

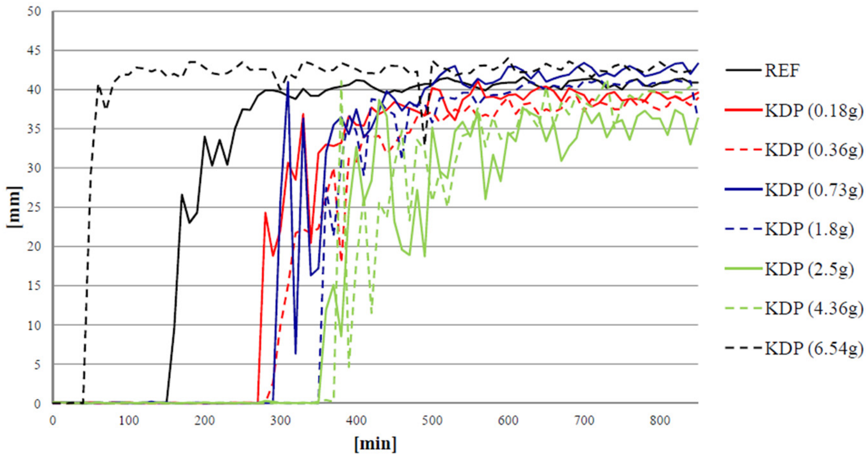

Figure 2: Setting process for specimens added different amounts of SP.

Table 4: Stetting time for specimens added KDP equivalent to 0.18g, 0.36g, 0.73g, 1.80g, 2.50g, 4.36g and 6.54g SP.

	Initial setting time [min]	**Deviation from REF [%]**	**Final setting time [min]**	**Deviation from REF [%]**	**Initial to final setting time [min]**
REF	160	–	410	–	250
0.18g SP	280	75	500	22	220
0.36g SP	300	87.5	550	34.1	250
0.73g SP	300	87.5	600	46.3	300
1.80g SP	360	125	610	48.8	250
2.50g SP	360	125	620	51.2	260
4.36g SP	380	137.5	690	68.3	310
6.54g SP	50	-68.75	190	-53.6	140

When adding larger and larger amounts of SP to the mortar more and more SP reacts with the calcium prolonging the structural development and setting time and more and more crystallized gypsum is formed. When adding a fairly large amount of KDP (6.54g) the mortar performs a false set, hence the short initial and final setting time.

Figure 3 shows the correlation between the initial setting time and the added amount of SP to the specimens, with the exception of the specimen added 6.54g SP. By using a logarithmic trend line a limit of 2.45g SP is read for an initial setting time 2.25 times the initial setting time of the reference specimen cf. DS/EN 450-1 [5]. This corresponds to a limit for SP of 0.54 wt% cement. From figure 3 it is seen that the limit of 2.25 times the initial setting time of the reference specimen already is reached with 1.8g SP. It is therefore possible to establish an interval of [1.8g; 2.45g] SP until further studies has shown a more clear trend line, which further may account for the specimen with no or very small amounts of SP. Calculations in this work will proceed with the limit for SP of 0.54 wt% cement.

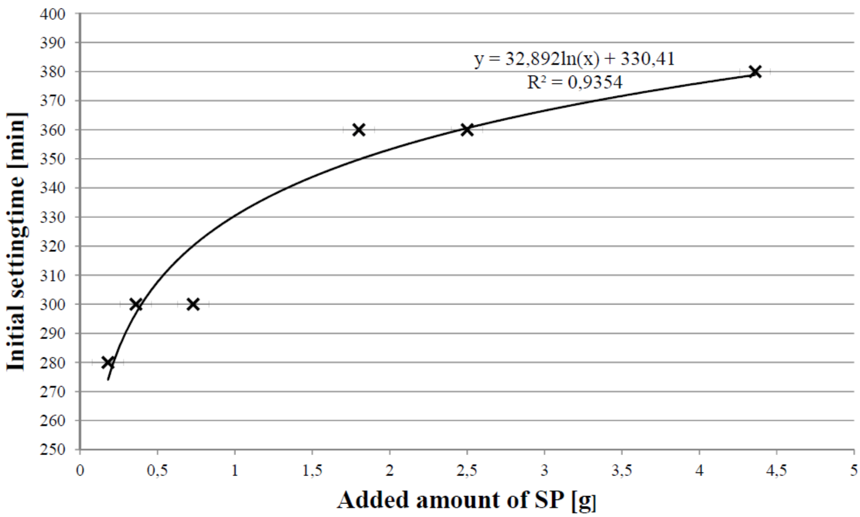

Figure 3: Correlation between initial setting time and added amount of SP.

3.3 Limit for soluble phosphorus in fresh mortar cf. workability

When mixing the fresh mortar with different amount of SP the consistency and thus the workability changes remarkably. Figure 4 shows a set specimen added 1.8g SP. It is clearly seen how the specimen contains large holes and has an uneven surface, which makes the specimen extremely porous and gives the specimen a poor compressive strength. The fresh mortar was dry and had a poor workability. The more SP is added the more this condition worsened.

This again supports the hypothesis of the crystallization of gypsum in the mortar when calcium and phosphate reacts and sulfate is released, leading to the poor consistency of the mortar. When adding 6.54g SP the mortar becomes completely unworkable.

On the basis of an objective comparisons between the reference specimen and the specimens added SP, a limit with respect to the workability can be determined to 0.73g SP, corresponding to SP of 0.16 wt% cement.

Figure 4: Set specimen added 1.8g SP.

3.4 The pH dependence of phosphate desorption in comparison to the established limits

For comparing the established limits of SP in mortar with the addition of SSA to mortar, it is necessary to amount of SP in SSA at alkaline pH-values. Figure 5 shows desorption of phosphorus from the experimental SSA. The total concentration of phosphorus in the experimental SSA was 97g/kg (Wittendorff [11]).

From figure 5 it is seen that the solubility of the phosphate in the experimental SSA is highly dependent on the pH-value to which it is exposed. This is in accordance to previous findings by Stark *et al.* [14].

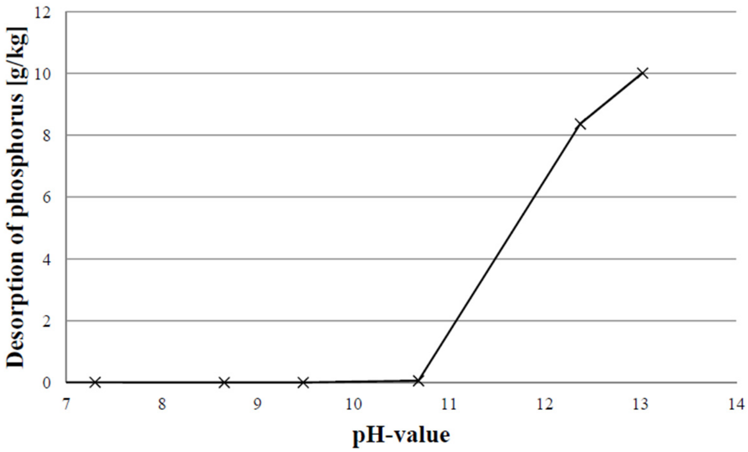

Figure 5: Correlation between desorption of phosphorus and pH-value.

Table 5 shows how much cement can be replaced the experimental SSA in relation to the establish limits for SP of 0.54 and 0.16 wt% cement (the conditions found in section '3.2 Limit for soluble phosphorus in fresh mortar cf. requirements from DS/EN 450-1 [5]' and '3.3 Limit for soluble phosphorus in fresh mortar cf. workability'). The cement replacement is calculated on basis of the receipt described in section '2.2 Mortar mixtures' and formulae (3) and (4).

$$\text{Limit for SP [g]} = \frac{\text{Calculated limit [g]}}{\text{Amount of SP at the given pH−value [g/kg]}} \cdot 1000 \qquad (3)$$

$$\text{Cement replacement [\%]} = \frac{\text{Limit for SP[g]}}{\text{Amout of Basis Cement added [g]}} \cdot 100 \qquad (4)$$

Table 5: Replacement of cement with SSA (*no restrictions with regards to SP).

Solution	pH-value	Limit of SP of 0.54% [g]	Cement replacement [%]	Limit of SP of 0.16% [g]	Cement replacement [%]
Demineralized Water	7.3	352000	100*	105000	100*
0.01M NaOH	8.7	0	0	0	0
0.05M NaOH	9.5	0	0	0	0
0.1M NaOH	10.9	43800	100*	13100	100*
0.5M NaOH	12.4	293	65.1	87.2	19.4
1.0M NaOH	13.0	245	54.4	72.9	16.2

Depending on the concentration of Na^+, K^+ and OH^- the pH value of cement ranges from 12.5 to 13.5 (Mehta and Monteiro [6]), and therefore the results for solution with 1.0M NaOH are most interesting.

For the actual SSA with a phosphorus concentration of 97g/kg it is possible to replace 54.4% and 16.2% before the established limits for SP of 0.54 and 0.16 wt% cement respectively is exceed. It is thus necessary to extract SP from the SSA. If the phosphate concentration for SSA is lowered to 50g/kg which is required by DS/EN 450-1 [5], it would be possible to replace approximate the double amount of cement.

A replacement of up to 20% of the cement with SSA has proven feasible regarding compressive strength in former studies (Ottosen *et al.* [15]), and this makes the limit for SP of 0.16% wt% cement interesting.

4 Conclusion

When adding soluble phosphorus salts to a mortar the initial and final setting time is retarded, regardless the salt tested. When adding different amounts of dissolved phosphorus to the mortar the initial and final setting time is retarded with increasing addition, until a certain amount where the mortar performs a false set.

A limit for SP of 0.54 wt% cement can be establish based on the measurements of initial and final setting time in conjunction with DS/EN 450-1 [5] and a limit for SP of 0.16 wt% cement can be established based on objective assessment of the workability of the fresh mortar.

SP in the SSA is depending on the pH value the SSA is subjected to. The SP has a high desorption at pH 13.0, which is the range within the pH of cement lays. When comprising the established limits with the desorption of SP it is seen that a 55% and 16% cement replacement respectively can be conducted before it is necessary to extract SP from the SSA.

Former studies have shown that up to a 20% cement replacement is feasible regarding compressive strength, and therefore it is necessary to take the established limit for SP of 0.16 wt% cement into consideration, and consider the necessity of extracting SP before adding SSA to a mortar or concrete mixture.

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Waste management in major events and the relevance of environmental certification

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Abstract

The generation of solid waste is a major environmental problem faced by most urban centers in the world. The management, correct disposal and reuse, in the most appropriate and planned manner are daily challenges. Major events produce a huge amount of waste in a short time. The Rock in Rio event, originally Brazilian, had some editions in Europe and returned to Rio de Janeiro in 2011. This exchange has improved the event: it became environmentally committed, by adopting the label 100R. The event is publicly committed to properly allocate as much of its waste as possible, and to contribute to social inclusion through a collectors' cooperative. This article aims to evaluate the tools used and the efficiency of the methodology adopted in the Rock in Rio event, seeking to define the most appropriate way to manage waste on events without affecting the dynamics of cities and, in addition, promote social inclusion and valuation of waste.
Keywords: solid waste, events, management, environmental certification.

1 Introduction

1.1 Background and pertinent Brazilian legislation

The rising population, along with rapid urbanization and industrialization, directly affects the amount of urban solid waste generated (Minghua *et al*. [1]). A common Brazilian accounts for approximately 378 kg of waste per year, according to the Brazilian Association of Public Cleaning Companies and Special Residues

(ABRELPE [1, 2]). The generation of solid waste is an important byproduct of socio-economic activities. The definition of solid waste varies among countries, generally including waste generated from industrial sector, commercial, domestic, institutional and municipal services (Srivastava *et al*. [3]).

In Brazil, laws aimed at environmental conservation began to be voted on 1981, with the creation of the National Environmental Policy law (Eigenheer [4]). The National Environmental Council (CONAMA), affiliated to the Brazilian Environmental and Natural Renewable Resources Institute (IBAMA), is also responsible for a number of resolutions that aimed to regulate the issue of solid waste.

Although the Brazilian environmental legislation is recognized as one of the most complete in the world since its creation, it is accompanied by a lack of supervision that affects the way it is met. Municipalities, usually responsible for managing urban solid waste in developing countries, are facing a challenge in providing an effective and dynamic system to the society. They usually fail to attain due to a lack of appropriate data collection system, lack of technical expertise and insufficient financial resources (Guerrero *et al*. [5]).

Environmental certifications are an alternative to the lack of commitment of the institutions regarding on solid waste standards. Many companies resort to this alternative, whereas getting the certification implies complying with the legislation, gaining benefits and promoting an integrated solid waste management system aiming to maintain balance of social, environmental, health, institutional, technical, financial and legal issues in order to provide sustainability to the system (Van de Klundert and Anschütz [6]). As an example, the Rock in Rio event in Brazil decided to adopt the same environmental label, the “100R”, as previously acquired on the editions held in Lisbon and in Madrid.

Regardless of the country, solid waste must have a correct destination, implying on a series of laws and regulations to control this activity. The Brazilian standard #12305/2010, that established the National Policy of Solid Waste in Brazil, sought to bring together the best practices around the world. Thus, it is possible to identify some differences between the presented laws (Brazilian Federal Law [7]).

The importance of the environmental issue has increased in business and in daily life, as observed by the great proliferation of products and services that claim to be environmentally friendly, or meet some specific certification requirements.

Despite the great proliferation of certifications and the importance it has taken on environmental marketing companies, events certification was still a relatively unexplored niche by 2012, when only the 100R label was employed. On June 2012, the standard ISO20121 began to be applied, establishing Sustainability Management Systems for Events, created by major organizers of world events, such as members of the sustainability team of the organizing committee of the Olympic games in London (ISO20121 [8]).

“*Sociedade Ponto Verde*” (Green Point Society) is the Portuguese version of the pioneering *Der Gruner Punkt*, non-profit organization designed to give a proper destination to packages in Germany. In addition to providing services such as the German version, the Portuguese unit developed different projects, such as the label 100R (Portugal Law [9]).

The ultimate goal of 100R is to distinguish companies/organizations that are concerned by environmental issues and take ambitious steps to contribute to a better world. Despite the fact that these measures may result in some economies (for example, cost of landfilling), the major benefit is the public recognition of organizations.

2 Objective

This research aims to evaluate the relevance of environmental certification on the issue of solid waste management, in the specific field of major events, based on the Rock in Rio 2011 case and the label 100R.

From this example, the application of an international environmental award can be evaluated at all stages of the waste management process in the operating stage of large events. From the results it is possible to analyze the promotion of environmental sustainability in the generation of waste and the implementation of this control as a permanent urban policy.

3 Methodology

This research presents the music festival Rock in Rio, as a case study, to assess the implementation of environmental certification for large events, in order to promote environmental sustainability through waste management and legal compliance with applicable law.

By the description of the case study, the management model is evaluated, analyzing the relevance for the compliance of some standards at a major event and associate those with positive effects such as: valuation of waste for recycling, social inclusion, reduction of costs and environmental marketing.

4 Case study: the Rock in Rio event

Rock in Rio (RiR) is a music event that began in Rio de Janeiro in 1985, and had other issues in the city in 1991, 2001 and 2011. During the last interval, the event occurred in two European cities, Lisbon and Madrid, where the issue of sustainability and recycling of solid waste was addressed.

With the return to Brazil, the event, held on a space named Rock City, was willing to follow environmental and social precepts that have adopted in Europe. Among them, stands out the environmental label 100R.

At first, four companies were linked to waste management within the RiR 2011 event space: Municipal Urban Cleaning Company, two (2) private cleaning companies and the Cooperative of separators

In terms of equipment for waste collection, the organization of RiR 2011 bought 520 (five hundred twenty) containers of 240 liters of orange color, which after the event were donated to the Municipal Cleaning Company, to use in the collection of waste of pacified communities of the city of Rio de Janeiro.

In addition to the 520 (five hundred and twenty) containers, four (4) metal boxes of 5 m^3 of volume were placed for the collection of waste. The Municipal Cleaning Company provided two (2) more boxes of 5m^3 and a compactor box of 10 m^3. Despite the availability of the compactor box, it could not be used due to lack of a skilled operator.

4.1 Waste on the Rock City

To facilitate separation, four (4) categories of waste were defined for the event (1 – Organic, 2 – Non-recyclable waste, 3 – Recyclable waste and 4 – Waste from sweeping) and the process of disposition of each of them was defined, allowing them to be easily identified and consequently routed to their proper temporary destination.

A portion of the recycled waste was separated by the cooperative before leaving the site. All of the waste, both already separated and still mixed, went to weigh in a waste industry and then, when appropriate, followed to its destination to be recycle.

According to the Municipal Cleaning Company, the average waste production in the first weekend of the event was 50 tons per day, were 10 to 12 tons were organic waste, resulting in the daily average of 38-40 tons of waste sent for sorting (RiR Report [10, 11]). According to the recycling cooperative, the amount of recyclable waste removed during the event was approximately 69.0 tons, as described in Table 1 (RiR Report [10, 11]).

Table 1: Recyclable waste.

Date (2011)	Weight (kg)				
	Box card	Plastic	Paper	Aluminium cans	Total/day
Sept 23	4,500	1,500	1,700	640	8,340
Sept 24	4,000	1,200	2,000	950	8,150
Sept 25	4,700	1,500	1,700	1,000	8,900
Sept 29	6,000	2,000	2,100	950	11,050
Sept 30	6,400	2,300	1,900	940	11,540
Oct 01	6,500	1,900	1,200	1,000	10,600
Oct 02	6,800	1,900	1,500	840	11,040
Sub-Total	38,900	12,300	12,100	6,320	
Total/event					69,620

All material collected was separated and packaged before being marketed. Organic waste were sent directly to the composting industry, where it goes through several steps before being transformed into an organic compound that can be used as fertilizer for crops. For Rock in Rio waste, the compound was sent to use in a reforestation project of forestry units in the city of Rio de Janeiro. Of all organic waste that was sent to the composting plant, it was possible to use 85% for organic fertilizer production (Table 2) (RiR Report [10, 11]).

Table 2: Composting waste.

Date (2011)	Weight (kg)			
	Organic compound	Evaporated	Landfill	Total
Sept 23	6,300	5,600	2,100	14,000
Sept 24	4,500	4,000	1,500	10,000
Sept 25	5,000	4,400	1,700	11,100
Sept 29	3,600	3,200	1,200	8,000
Sept 30	5,400	4,800	1,800	12,000
Oct 01	3,200	2,800	1,100	7,100
Oct 02	5,400	4,800	1,800	12,000
Oct 03	1,900	1,700	600	4,200
Total	35,300	31,300	11,800	78,400
Percentage used				85%

All waste considered potentially recyclable was sent to a waste industry, where it was sorted out by the recycling cooperative. The deadline was October 18 to access and triage these residues. The daily total of this waste can be observed in 0 (RiR Report [10, 11]).

Table 3: Waste sent for triage in the waste industry.

Date (2011)	**Weight (kg)**	**Date (2011)**	**Weight (kg)**
Sept 23	12,000	Sept 29	20,000
Sept 24	30,000	Sept 30	22,000
Sept 25	19,000	Oct 01	24,000
Sept 26	1,300	Oct 02	29,000
Sept 27	1,000	Oct 03	9,100
Sept 28	2,100	**Total**	**169,500**

Only on the first weekend of the event, the waste industry was filled with 60 tons of waste suitable for recycling. The last day of the event was October 02. From Oct 05 the cooperative began to withdraw waste from the industry to route and separation. Only four (4) withdrawn were made: on days 05, 06, 10 and 14 of

October. According to the organization the waste was extremely contaminated which does not justify the separation, because it would endanger the health of their workers. Thus, only 14,600 kg of residues were removed from storage, and only 10,220 kg were recycled (the difference was discarded as waste). The totals are presented in Table 4 (RiR Report [10, 11]).

Table 4: Recyclable residues from the waste industry.

Date (2011)	Removed (kg)	Discarded (kg)
Oct 05	3,200	960
Oct 06	3,900	1,170
Oct 10	3,600	1,080
Oct 14	3,900	1,170
Sub-Totals	14,600	4,380
Total weight	10,220	

In addition to the recyclable and non-recyclable waste, with the help of a partnership signed with a cooking oil recycling cooperative, Rock in Rio was able to devote 100% of the oil produced at the event. This oil was used in the project "Recycled Oil, Fisherman benefited" on the city of *Arraial do Cabo*. The collected oil is processed into biodiesel and used to benefit 750 (seven hundred and fifty) fishermen (RiR Report [10, 11]). The amount of collected oil was not very big, as only four (4) establishments used the product. For these establishments, the cooperative provided fifty (50) gallons buckets, which were collected according as they were used (RiR Report [10, 11]). The amount of oil collected during the event is shown in Table 5 (RiR Report, 2011 [10, 11]). Considering the cooking oil density of approximately 0.918 g/cm³, the amount of oil recycled at Rock in Rio was about 1110.8 kg (RiR Report [10, 11]).

Table 5: Total of oil residues from the event.

Establishment	Volume (l)
Fried pastry	50
Arabic food	420
French fries	560
Barbecue	180
Total	1,210

According to the data collected of waste produced during the event, Figure 1 shows the quantity of waste at this stage and the percentage of each type to the total (RiR Report [10, 11]).

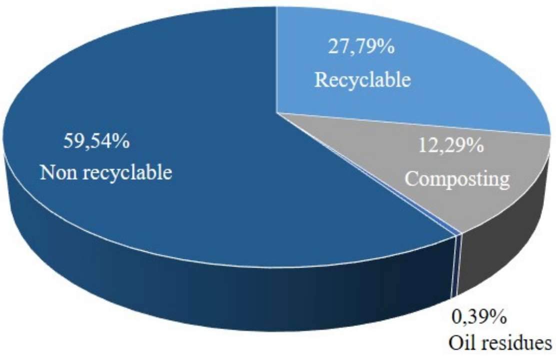

Figure 1: Total residues produced on the event.

5 Final considerations

The evolution of the Brazilian legislation and the current situation of solid waste management in the country was detailed in order to contextualize the situation at the time of the event (Rock in Rio 2011), and how it is included in the national context.

This study aimed to discuss and evaluate the Rock in Rio festival in various aspect, such as environmental certification for solid waste, flow of collection and disposal of waste, companies and partnerships developed to implement the project, difficulties faced and reuse and recycling of materials. Despite the adverse situations presented, Rock in Rio Brazil 2011 had a satisfactory result comparing to the previous edition in Portugal.

Rock in Rio was the first event in Brazil to try the environmental certification 100R. This leads to major changes in the organization of events in the country and certainly have a very positive impact on the environmental issue.

Although, as expected, some difficulties were encountered. Dependence on a consumer market for recyclable waste, the lack of contamination control that could guarantee the complete sorting of waste and the lack of previous agreements with buyers for the reused materials.

For future editions, it is important to ensure a way to engage the establishments' participation on separating the waste as it is created. This could be guaranteed through contractual determinations that establish some penalty if the guidelines are not followed. The public encouragement to participate is also essential, so publicity and awareness are essential, both before as well as during the event.

Adopting an environmental certification was important for the organization of the event in committing to properly allocate the waste. It is important to notice that the label 100R does not have targets and indicators to assess whether the event efforts were enough, making it just a commitment of the event. Thus, even if the event achieves a negative result, it can encounter this certification. To obtain the label 100R, some actions directed to the correct management, the use of human resources as collectors and the ability to send the waste for recycling have to be met, besides paying the membership fee. Such deficiency on indicators would also be observed if the event decided commit to the ISO20121 Certification.

Despite the difficulties, the initiative and originality make the Rock in Rio event an innovator when it comes to environmental issues in Brazil, and demonstrates a real concern with minimizing the impact caused.

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Resource efficiency: progress and challenges of 3Rs technologies and policies

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Abstract

Resource efficiency and waste management lacks a holistic approach which cover the whole chain of product life cycle and its management. The quantities of waste generation increases in close relation to economic growth, however, the Reduce-Reuse-Recycle (3Rs) technologies and policies are introduced through the strategic planning and management. The effective waste management is an efficient method which include both to increase resource efficiency and to replace fossil fuels with renewable energy sources. Sustainable production and consumption from the extraction-material use-disposal, could be directly linked with waste management. Addressing the problems and solutions of waste management system from 'waste' to 'resource', 'waste and resource management' and 'circular economy' all reflect the significant impact of decoupling between economy and waste management. Resource recovery and recycling activities generate revenue from the recovered and recyclable materials, compost and energy. The main objective of this study is to analyse the waste treatment strategies with the combination of progress and challenges of 3Rs technologies and policies towards resource efficiency. This paper also identifies the positive contribution of waste and resource management through financing and provide better and improved environmentally sound waste management system.

Keywords: resource efficiency, sustainable, waste, resource, resource recovery, circular economy.

1 Introduction

The waste hierarchy can be seen as a 'historical' first step towards a current move away from the 'end of pipe' concept of 'waste management' towards the most integrated concept of 'resource management' [1]. By improving resource

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efficiency, countries could easily tackle and understood the environmental problems, address pollution, climate change, and also helps to improve economic and social benefits, which ultimately contribute towards the promotion of green economy. Many developing countries have undergone a various and different kinds of environmental problems according to their economic growth. However, the waste management is one of the single largest budget item for many cities (World Bank, 2012). The waste handling significance the stage of consumption related problems and create serious infectious diseases in many developing countries, with both direct and indirect effects. Green economy impact significance as an importance of zero waste which is a long-term vision that ultimately envisages a thriving society that exists within natural resource use, constraints and its ability to assimilate waste, pathway moving towards a resource-efficient. The article analyses the importance and challenges of 3Rs technologies and policies towards resource efficiency.

2 Reduce, Reuse and Recycle technologies and policies

An approach to minimise resource consumption sufficient to reduce; reuse goods and materials until it can't be repaired or fixed to perform; and recycle and reprocess the materials that being discarded into new products. 3Rs fosters cooperation among waste generators, waste collectors, processors and manufacturers. Reducing the amount of waste plays a most significant role to manage waste. Recycling allows for production and consumption with reduced depletion of natural resources and energy, and can reduce the negative impact on the environmental system (air, water and soil). Developing countries are progressively working towards the application of an integrated waste management through reduce, reuse and recycle technologies and policies. Both public and private activities in waste management plays a significance role in reuse and recycling activities. 3Rs targets and indicators can be useful tool for monitoring the progress of 3Rs efforts. Recycling is market driven and must be run like an industry. The central and state governments may consider introducing the concept of Extended Producers Responsibility (EPR). Industry needs to realize the problems their packaging material creates once they are discarded by the purchaser of their products. EPR can act as a pressure tool for making big corporate houses, which generate large quantities of waste, to invest in recycling and take back their product waste. Extended Producer Responsibility (EPR) based recycling policies can be used for monitoring the recycling status of particular electronic waste. E-waste is one of the rising issues in the sub-region due to the rapid integration of the global market. The principal issues including: a) the need for national regulations, b) transboundary movement of E-wastes, c) improper processes for E-waste dismantling and recycling, and d) technological and financial consideration in the recycling and reuse of E-waste. However, there is a variety of challenges associated with indicator selection and target setting in Asia, be it diverse definitions and approaches to measuring the waste recovery rate or lack of baseline data or different approaches and interval of data, this article also analysed this based on case of recycling rate [3]. 3Rs effort to promote better waste management needs to be done in an effective manner. Social/institutional dimension—Community involvement in recycling, informal sector in waste management and voluntary programs for reusing/recycling programs; Financial/economic dimension—Incubation of recycling and reuse market, waste taxation and subsidies, and the Clean Development Mechanism (CDM); and Technological/engineering dimension—Development of new technology to reduce or recycle wastes, adaptation of existing technology to local conditions, safe and environmentally sound waste treatment technology, networking, and application of information technology.

3 Resource recovery towards resource efficiency

An approach that increasing resource efficiency, and contributing to sustainable consumption and production, millennium development goals and sustainable development goals. Sustainable waste management encourages various activities as substituting services for products, increasing material efficiency in the supply chain, redesigning products and packaging, and a range of other actions. Local governments benefit from these activities by reducing the amount of waste and need to manage and making better use of reuse materials and promote resource recovery. By implementing resource conservation and recovery practices, which involve avoiding, delaying, or decreasing the raw materials required to produce new products. Resource conservation and recovery strategies can produce significant environmental, economic, and quality of life benefits by helping local governments, public and private sector. Resource recovery involves four main approaches: (a) Reduce the quantity of waste generated through practices such as source reduction and reuse; (b) Promote initiatives that encourage reuse and waste reduction; (c) Manage waste effectively through practices such as recycling and composting to recover materials and minimize environmental impacts; and (d) Promote programs that provide financial incentives for waste reduction.

4 Path of circular economy: resource decoupling to achieve sustainable and sound environment

Transition to a circular economy, focus on 3Rs technologies and policies, requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource. Turning waste into a resource is part of ‘closing the loop’ in circular economy systems. Circular economy approaches ‘design out’ waste and typically involve innovation throughout the value chain, rather than relying solely on solutions at the end of life of a product. Resource and resource use are most important link between social, economic and environmental constraints and activities. The sustainable global economy depends on the decoupling of growth rate of resource consumption and environmental degradation. Resource decoupling means reducing the rate of use of resources per unit of economic activity. Resource decoupling leads to an increase in the efficiency with which resources are used, it can be expressed for a national economy- an economic sector or production chain, by dividing added value by resource use [4]. Circular economy integrates with the resource decoupling which helps to makes the resource and energy intensive pathway for the development strategies of environmental issues. To make the transition with more circular economy, the resource management strategies will be required that promote resource recovery and emphasis the resource use reduction in developed countries and relative decouple with the developing countries.

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Recycling, waste management and urban vegetable gardens

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Abstract

Waste management is an issue where several technical, technological but also social and cultural factors contribute to make it complex, while the concentration of waste production in big cities mainly gives it an urban and metropolitan dimension. Remarkable difficulties can be found in the scarce motivation of the citizens to actively participate in the process of trash separation and collection as well as in the dislike they feel towards the systems and facilities dedicated to waste processing. This paper reports on research in this subject carried out at the University of Naples thanks to a scientific cooperation agreement with the Dutch multinational company Còrio. The verified thesis showed the existence of a close relationship between direct and tangible motivations and the users' attitude to trash separation. The results were significantly above those expected to be obtained through coercive methods or, even worse, through the promise of an abstract general benefit. The above-mentioned research also brought the implementation of a prototype made up of a playful but at the same time educational urban vegetable garden of around 800 sq. m with a virtuous management system of organic household waste. The experiment, named Orto in Campania, showed the real effectiveness of the proposed solutions with a strong motivational value for the citizens' involvement but also the mutability of it both in well-established and in new urban areas. The success was so huge that this installation, intended as temporary, is still on course after more than five years.
Keywords: reduce, reuse, recycle and recovery (4Rs).

1 Introduction

That of waste is a question which several technical, technological but also social and cultural factors contribute to make complex, while the concentration of waste production in big cities mainly gives it an urban and metropolitan dimension. In Campania the problem of waste is strictly connected with the presence of well-established criminal organizations that have disposed industrial and dangerous waste in the area known as Terra dei Fuochi (Land of Fires), a media designation due to the heaps of waste that are frequently set to fire [1].

After the dump era, the waste management process is now made up of three standard phases: trash separation and collection, recycling of the useful parts, disposal of the remaining parts. The way in which such processes take place as well as the common difficulties we face [2] varies from system to system.

As far as household and industrial waste are concerned, the phase of trash separation and collection is generally developed through the so-called door-to-door system, according to which waste are brought to the company managing their collection process in the same place where they are produced. In more advanced areas the very users may also bring waste to some central storage points which, in Italy, are ironically defined as "environmental islands" [3]. In both cases the decisive factor of the success of this initiative can be found in the citizens' attitude to separate trash *a priori* and, therefore, as Giannini underlines [4], in the ability of public authorities to force/to motivate such attitude. Indeed the trash separation and selection system *ex post* is prohibitive, except for those countries where labour cost is lower than the expected benefit, such as for instance Africa, India and the South-American countries, where manual recycling of e-waste is frequently carried out, as described by Cumo *et al.* [5].

Even the disposal of those waste that cannot be directly re-used shows remarkable difficulties beyond the technical aspect in itself. Generally speaking, the process envisages the transformation into inert material through incineration as far as dry components are concerned and through digestion/oxidation as far as organic components are concerned. Such components, in fact, show combustion difficulties connected with the high content of water resulting in a higher environmental impact of the whole system [6] or in the need to adopt systems with a rotary combustion chamber which, as underlined by Williams [7], are not suitable for the processing of the remaining parts of waste.

In both cases the main difficulty faced during the implementation of such systems results in the strong opposition by the citizens, who can only see and feel huge damages for the environment, dangers for their health, inconveniences due to miasmas and general decay [8, 9]. Such an attitude is more and more emphasized in those territories where the waste management carried out by criminal organizations for decades has deeply threatened the citizens' confidence in local institutions [10].

We recently had a research opportunity on this subject at the shopping district owned by Còrio, a Dutch multinational company working in the field of retail real estate, within a scientific cooperation agreement entered into with the Department of Architecture of the University of Naples "Federico II": this brought to the implementation of a prototype made up of a playful but, at the same time, educational urban vegetable garden of around 800 sq. m with a virtuous management system of organic waste.

The verified thesis showed the existence of a close relationship between direct and tangible motivations and the users' attitude to trash separation: the results were significantly above those expected to be obtained through coercive methods or, even worse, through the promise of an abstract general benefit.

Many studies were carried out on questions concerning the environmental effectiveness of the processes of re-use, reduction and recycling of urban waste. Several researches dealt with the technical aspects of recycling of those materials which can be immediately re-used (e.g. Mark E. Schlesinger at Missouri University deals with aluminium recycling [11] or the thorough close examination by Paul T. Williams [7]), of the use of incinerators and organic waste in order to obtain energy [12, 13], of the inefficiencies that still today can be noticed in the whole cycle (a subject that MacBride [14] at the New York University has recently dealt with and that in Italy can be found in the annual report issued by the ISPRA, the Advanced Institute for Environmental Protection and Research [15]), of the alternative solutions to digestion for the disposal of organic components (e.g. the growing interest towards vermicomposting shown by Quintern [16] as well as by Soobhany *et al.* [17]). On the contrary, the contributions dealing with the attitude towards trash separation from the point of view of the citizens and with the results that may be obtained through suitable urban politics are quite limited. Among the main contributions an interesting study carried out in Portugal [18], parts of the research by Blackman [19] and the studies at the University of Naples on the implementation of advanced solutions of a multiscale system integration in urban areas are noteworthy [20].

2 Case study: the vegetable garden "Orto in Campania"

The Parco Commerciale Campania (Campania shopping district), the biggest retail structure of Southern Italy, was developed according to the typical scheme of similar settlements within the same region, as a result of the adaptation to the local law [21] of the French traditional model which became popular in Europe [22, 23]. Around the central mall, structured on a two-level building of more than 40,000 sq. m per level with a big central gallery, you can find other single-theme malls connected one another by an external promenade. The whole district is structured so to lead the user from a mall to the other remaining wide enough in order to meet the functional separation requirements necessary not to exceed the strict dimensional limits imposed by the related rule. The peculiarity of the whole structure may be found in the progressive growth of its attraction abilities, also thanks to the settlement in the neighbourhood of La Reggia, the biggest Factory Outlet Village of Central and Southern Italy, and of the international goldsmith's art centre Tarì. This, together with the shortage of playgrounds and leisure services in the densely populated neighbouring towns [24], makes the presence of people exceed 20.000 units in rush days and hours. The core of the district is represented by a wide covered area on two levels named "Piazza Campania", which, apart from being the classical food court, hosts the most important events and allows access to night entertainment activities (multiplex cinema, amusement arcades, exhibition rooms and a theatre). Right at the entrance of "Piazza Campania" you can find the area where the experimental prototype developed within the research described in this article was installed.

The shopping district management proposed the Department of Architecture a cooperation in order to implement an external place to let children play. This project should be developed in line with the retail needs of this special regional area where the applied strategy is influenced by the social context. Indeed, while in the Northern Italian regions the goal is to attract a wide audience, providing general and economic services, the need to select the audience in the Southern Italian areas makes such places for children currently evolve towards more elite forms, both from a cultural and from an economic point of view. The classical playground with simple elements such as slides, inflatable facilities and courses with recreational elements gives its seat to high-technology amusement arcades, with experiences of augmented reality that can be compared to those you can find in the best amusement parks, or is more and more equipped with educational places and rooms for reading and hosting exhibitions [25].

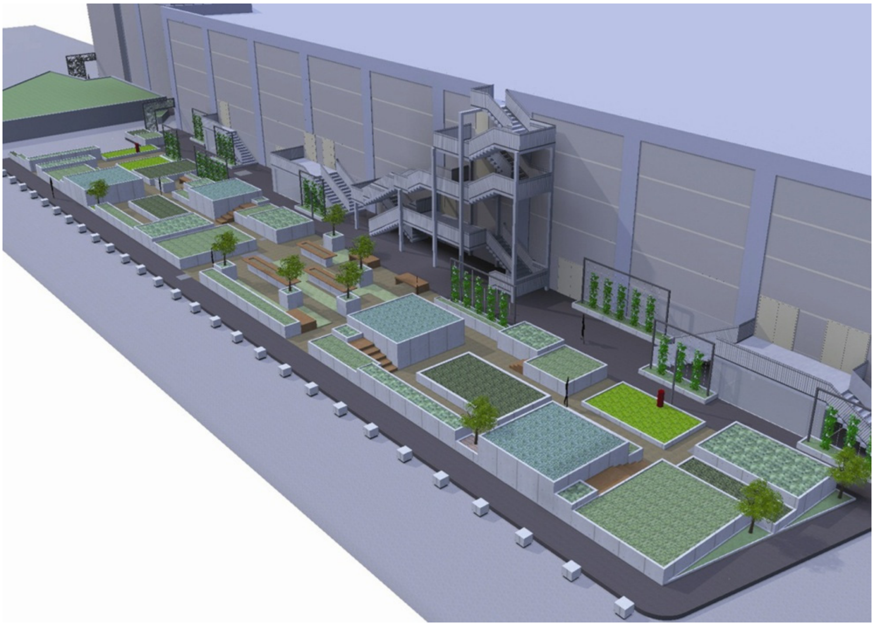

Figure 1: Rendering of the three-dimensional vegetable garden designed by the research group on the right corner of the main entrance of the shopping district owned by the Dutch multinational company Còrio.

On that occasion the district management, given the daily need of disposing considerable quantities of food waste and the scarce results of trash separation and collection, also drew the attention of the research group to the need of developing innovative solutions in this field. Indeed it was noticed that, though it was possible to carefully check the waste that were directly disposed by commercial operators, towards users and customers there was no such possibility. The containers located in the mall to host different kinds of waste were scarcely or very badly used by customers; moreover, peaks of total inefficiency could be registered in rush days. The percentage of trash separation and collection was around 70% for shop retailers, while it was less than 20% for the waste produced by customers that, however, represented the greatest part.

In order to meet the asked requirements and, at the same time, to gather effective data the research group, organized by Professors F. D. Moccia and A. Sgobbo with the cooperation of nine brilliant students of Architecture, proposed the implementation of a three-dimensional playful and educational urban vegetable garden of around 800 sq. m (figure 1), completely built with recycled rejected manufactured products, laid over the pre-existing grounds and integrated within the pedestrian circulation system as well as within the facilities of the shopping and trade centre.

Figure 2: A view of the Orto in Campania in the initial phase of the cultivation cycle of vegetables. In the centre you can see the particular of the stairs implemented with old wooden pallet banks

The structure is made up of concrete prefabricated defective basins which should have been destroyed. Such drain basins, both individually and assembled in more or less complex groups, were used to form the cultivation tanks, distributed on more levels and connected by an unsurfaced path. Old wooden banks, which are employed for pallet transportation and cannot be re-used any longer, were then used to build the stairs connecting the different paths and bringing to the elevated clear spaces raised to observe the above-mentioned tanks. Carpentry wooden axes, that had already been used and should have been disposed, form the support portal for climbing vegetables. Last but not least, old shuttering panels form the banks on which small plants are treated for educational purposes.

As far as the synergy between the vegetable garden and the cycle of waste collection and disposal is concerned, the structure is functionally connected with a modern facility producing biogas from anaerobic digestion of household organic waste; such facility has been recently built, arousing endless controversies, a few hundred meters far from the parking place of the shopping centre. Here, inside a warehouse that is always maintained in depression in order to avoid stinking emissions, the collected waste are selected, on a vibrating belt, in order to avoid any foreign remains. Before being expulse, the air inside the warehouse is completely filtered and purified. This is made with moist scrubbers using washing solutions aimed at removing odor-emitting compounds through absorption and oxidation, as well as with mist scrubbers in which the washing solution is vaporized into very fine drops that, once full of odor-emitting compounds, fall to the bottom of the filtration chamber.

The selected waste are preserved in anaerobic digestion tanks made up of aluminium-based reinforced concrete sarcophagi: these are closed by watertight pneumatic doors and they have heating pipes inside the walls. Here waste are sprinkled with small quantities of percolate (used as bio-activator) and remain at a temperature of around 55 degrees for further 14 days. In this phase biogas is formed, a gaseous fuel containing a percentage of methane, usually between 50 and 60%, used in a co-generator in order to produce power and heat [26].

The obtained composting is then transferred to another warehouse for aerobic oxidation post-treatment. Here the material slowly follows a path limited by cement embrasures and it is constantly inflated with warm air. At the end of the path the composting is totally inert and, after a further fine selection to remove any foreign waste, it is packed as agricultural fertilizer. In the case of the Campania shopping district the product is brought back to its place of origin and mixed with land to fertilize the vegetable garden.

3 Method

In order to verify the thesis we thought about connecting the functioning of the vegetable garden to the waste separation and collection made by the customers by directly involving a careful, steady group of users able to effectively condition the behaviour of the others: children. Besides, the idea of a gardening space with vegetables instead of the classical garden came out from the will to implement an area dedicated to our children in which we could also spread the message of the organic quality of the products sold by the shops in the mall. Thanks to the cooperation of Slow Food both the customers of the shopping district and the children of the neighbouring schools were playfully involved in the management of the vegetable garden and took part in guided tours allowing them to handle vegetables and even plant some of them. Moreover, both during the tours and through posters in the shopping gallery, it is explained to the customers that by throwing organic waste in the right containers causes them to be transformed into the composting used to keep the vegetable garden alive and luxuriant. The whole biogas production process, the implications of an ineffective waste management on health and environment as well as the advantages of keeping a virtuous behaviour at home are also described.

Among the indicators selected to measure the incidence of the prototype on the consumers' attitude to actively participate in the waste management process the most relevant are: the percentage of correctly disposed organic waste, with reference only to customers, compared to the total amount of produced waste; the percentage of all kinds of separated waste compared to the total amount of produced waste; the active participation in the blog concerning the vegetable garden [27], both in terms of unique visitors and of subscribed people; the percentage of wrong elements found in the organic waste brought to the neighbouring anaerobic digestion facility.

Such measurements were carried out over a period of 5 years both at daily, monthly and yearly intervals in order to have further the possibility to verify the incidence on the phenomenon during media events, moments of crisis of the regional waste collection system, etc. This also allowed one to evaluate and adequately check the fluctuations due to the novelty effect. The same measurements were used to compare the different data: with reference to the same shopping and trade centre in the previous five years; with reference to other malls in the same territory; with reference to other experiences of urban vegetable gardens.

4 Analysis of the obtained results

Once the construction was completed in April 2011, the vegetable garden undoubtedly had a great architectural impact. Moreover, both the customers' children coming to the shopping centre and the pupils of the schools visiting it were immediately attracted by the playful and educational qualities of the installation and could also have a try at intensive interaction activities ranging from the possibility to touch vegetables, to know their vital cycle, to learn their form, colours and odors beyond the distortions urban life forced them to, to the possibility to directly plant the future harvest. Some cultivation tanks were adopted by a classroom managing their needs over time, fertilizing them with composting and periodically weeding them.

The impact on the percentage of the organic waste that were correctly disposed by customers compared with the total amount of the produced organic waste, without taking into account the peak of the first opening week, began to grow more and more starting from the end of the third month. After 14 months the value of the yearly data was around 82%. The value of the monthly data reveals the close relationship with the vegetable garden cycle highlighting peaks of 93% during spring and autumn and negative records of 68% during rainy or cold months when less visitors interact with it. On a daily basis, the best results were recorded during working days when the percentage of the retained customers was higher than that of the occasional ones [28].

The compared analysis of the above-mentioned results highlights the actual existence of a motivational connection with the vegetable garden. It is above all the monthly data that exclude that a closer attitude by customers towards trash separation and collection may just come from the awareness campaigns promoted by the shopping district. Otherwise the fall in the performances registered in the period in which there is no contact with the vegetable garden would not be justified. Even the relationships detected between retained customers and daily results of trash separation and collection bring to such conclusions. In fact the Orto in Campania, rather than occasional customers, mainly affect and stimulate those users who, in time, got to know its qualities and functioning cycle.

The pattern of the data concerning the percentage of wrong materials found in the organic waste brought to the neighbouring anaerobic digestion facility has slowly enhanced. An educational need was highlighted, that is the symptom of the scarce constancy with which trash separation and collection in Campania is ordinarily carried out. At the beginning customers, though motivated, had many doubts of what organic waste actually were, often confusing them with general recyclable waste. On the contrary, when the shopping and trade centre organised information campaigns, not only the quality of trash separation and collection was better, but such a progress also tended to remain steady over time. The same happened when the towns within the 15-minute isochrone of the catchment area of the shopping district, where most of the retained customers live, started to promote awareness actions accompanying the introduction of the door-to-door trash collection system. Definitely, the citizens of Campania not only have no motivation, but they also are not adequately prepared in order to actively participate in the waste management system [29].

The data on the total percentage of trash separation and collection compared with the total amount of junk produced by customers show a pattern corresponding to that concerning the organic part only, and this also concerns all measurement intervals. On a yearly basis, after five years from the beginning of the experiment, such a percentage steadily amounts to 84%; according to the literature [30, 31] it is difficult to obtain a better value. This highlights that, where adequate motivations for a careful management of at least one waste typology are given, citizens will naturally feel pushed to take care of the whole trash separation and collection process [32].

The data concerning the participation in the blog were not so useful because the difficulties in managing it by the staff of the district did not give customers the possibility to directly intervene. The result was a scarcely updated and dynamic website visitors became soon tired of.

The compared measurements of the same indicators at other malls within the same territory allowed both to purge the gathered data from the fluctuations connected with secondary events and to evaluate the synergy effects of different initiatives. In fact, there was a limited but perceivable enhancement of the percentage of trash separation and collection in the neighbouring centres; in the same way better results were obtained by occasional customers in periods after some events with a high media impact connected with the waste cycle: the crisis of the "Terra dei Fuochi" in 2013; the sales fall in the agricultural and food sector; the exhibition of the Uffizi museum in Casal Di Principe.

Without taking into account the incidence of the initiative on the economic results obtained by the shopping district, the Orto in Campania also gave unexpected but very important results. First of all the structure, unattended and with an easy access at any time, has never undergone vandalistic actions, thus highlighting the common sense of belonging it aroused thanks to its management form, which involved the participation of everyone. Moreover, the management of the neighbouring waste anaerobic digestion site reported that some citizens, who were then identified as regular customers of the shopping district, frequently and spontaneously brought their organic household waste. Such a behaviour not only indicates the particular level of involvement the prototype could arouse, but also the overcoming of suspicion and unrest [8] citizens usually feel towards such facilities.

5 Conclusions

The experiment "Orto in Campania" showed the effectiveness of highly motivational value solutions in which everyone can take part in order to push citizens to actively participate in the process of waste separation, collection and disposal. But the best result was in the educational ability showed. Such observations highlight the mutability of the experiment in both well-established and new urban settlements in order to overcome the citizens' scarce attitude to carry out trash separation by themselves. Trash separation and collection is mainly felt as an imposition with obligations and prohibitions, accompanied by an increase in the management costs and therefore in taxation and aimed at obtaining an often abstract and not immediate benefit for the environment. At the same time the widening of urban green spaces, such as parks and gardens, is a considerable deterrent for the investment of the already scarce resources of Local Bodies towards high management and maintenance costs [33]. From here we proposed the idea according to which urban vegetable gardens and biogas production facilities, above all those implemented in CCHP systems (Combined Cooling, Heating and Power), could become new centres to be steadily proposed in order to meet the needs of green infrastructures inside urban areas [34].

A further incentive to the concrete implementation of such solution is offered by the recent technological evolution of organic waste anaerobic digestion facilities which made such installations more and more consistent with urban realities. In the most recent project model, in fact, the whole digestive structure is undergrounded and motorized, so that only the warehouse dedicated to waste receipt are visible. This is completely isolated and connected outside through depression filters making the working function of the facility consistent with the neighbouring houses [26]. The choice of the CCHP system is particularly effective for the installations to be implemented in Southern cities, where the energy consumption for cooling used during summer is higher than that for heating used during winter periods. The advantage is determined by the huge enhancement of the effectiveness of the energy production process. Indeed it is known that, in a traditional facility, only 35 ÷ 38 % of the primary energy supplied to the system is actually transformed into power, because the remaining part is dissipated into the environment. The CHP facility is able to reduce the dissipated part up to around 15–20 %. The CCHP facility introduces a further advantage: part of the recovered heating is employed in the production of refrigerated water thanks to an absorption freezing cycle [35]. In such a case the energy conservation is represented by the lower quantity of primary energy employed in the freezing cycle thus adding to the effectiveness of the co-generation system a greater effectiveness in freezing production.

A district heating-cooling system could distribute primary fluids to the inhabitants thus producing the effect of a widespread participation that, in the example of the shopping and trade centre in Campania, showed it could have remarkable positive results. Indeed citizens would become the main suppliers of organic household waste getting both direct benefits in economic terms and indirect benefits in educational terms. From the economic point of view, for instance, according to the quantity of supplied organic waste, citizens could receive some credits that may be then exchanged with the heating received from the district heating-cooling system; in educational terms it is easy to imagine that the citizens' engagement in organic waste separation would result in a general enhancement of the attitude towards the separation of all kinds of waste.

Last but not least, the integration of the biogas facility with urban vegetable gardens may have further benefits on the community. As previously highlighted, in fact, the need of green areas in the cities is opposed to the scarcity of economic resources available to Local Bodies. Parks and gardens, apart from requiring huge initial investments, imply maintenance and management costs that are often inconsistent with the actually available resources. Urban vegetable gardens, on the contrary, offer an effective alternative to the traditional model of conceiving urban green areas [36], above all if they are managed with the active participation and sponsorization of citizens, blocks of flats and schools. The experience of the shopping district Campania showed how, even in a difficult reality from a social point of view, the citizens' attitude towards the respect of green areas is, in the case of a vegetable garden, significantly higher than the attitude towards parks and gardens. Moreover, a direct management and maintenance boost constant control forms that are completely inconceivable if managed by Local Bodies.

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Analysis and improvement possibilities of waste management at Kuwait Oil Company (KOC)

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Abstract

Kuwait Oil Company (KOC), a subsidiary of Kuwait Petroleum Corporation (KPC), is involved in exploration, drilling and the production of oil and gas. The issue of waste management in KOC represents a more in-depth account of the field and covers conceptual analyses of different types of waste streams (solid, liquid, and sludge), the activity upon waste, and a holistic view of the goals of waste management. The increasing amount of waste generated, which is exacerbated by a lack of proper waste management, is of growing concern worldwide and in the main cities in developing countries due to its social, economic and environmental implications. Waste management practices are founded on the expectation that waste management is to prevent waste causing harm to human health and the environment. KOC always ensures that the generated waste be managed effectively in compliance with applicable regulations of Kuwait Environment Public Authority and KOC HSE management system (HSEMS) procedures implemented for KOC facilities. Also, KOC plays an active role in facing the adverse effects of waste through the implementation of many of the services and development new projects in the areas of collection and recycling, waste treatment and by focusing on the development of long-term waste management strategy for all over the company areas. This study was conducted to analysis and improvement possibilities on waste management at KOC. In addition, in this paper we will discuss various processes used in KOC areas indicating how waste is being managed.
Keywords: hazardous waste, non-hazardous waste, waste management, HSE management system.

1 Introduction

Kuwait Oil Company (KOC), established in 1934, is one of the largest oil exporters in the world, with its headquarters in Kuwait. The company's activities have extended to include exploration operations, onshore and offshore surveys, drilling of test wells, and developing of producing fields in addition to crude and natural gas exploration.

All over the world today, waste management and disposal remain critical issues of the day, not only because of challenging views of the best methods of managing waste, and the role of households, neighborhoods, and governments but also and more importantly on the strategies to change people's culture values and attitudes. The activities of environmentalists especially in Europe have increased both the level of awareness about the need for the safe environment and the pressure on governments to do more regarding policy. In financing public enlightenment and education, the pressure on the government is essential because "waste management and disposal involve important institutional as well as technical problems" [1].

Most of the public think that waste is cheap material to be thrown away and that it cannot be reused for useful purposes. This indicates the inattention of citizens to waste as a great resource.

According to the Kuwait Central Statistical Bureau [2], quantities of waste are increasing annually. The percentages of different types of waste in the MSW stream in Kuwait are represented in Figure 1, based on data from the Industrial Bank of Kuwait [4]. As shown in Figure 1, organic waste constitutes the largest proportion of waste, making up 50%, whereas paper and plastic come in second and third positions with 21% and 13%, respectively.

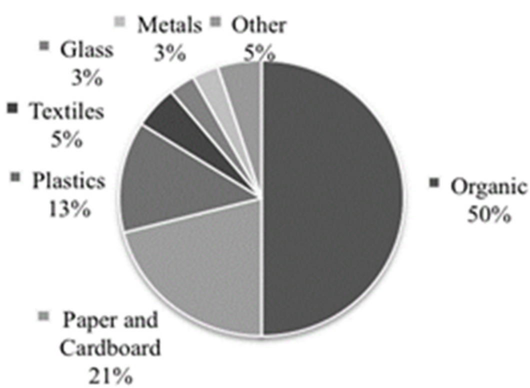

Figure 1: Composition of the MSW stream in Kuwait.

The current waste management system in Kuwait are randomly dumped into landfills without considering safety and environmental precautions from the point of collection and transportation to the last step of final cover in a landfill [2].

Waste in KOC is categorized into solids, liquids, and gases. This study discusses the waste management improvement that is classified according to its resource and material types. The general categories of waste material have also been developed. The different categories of waste are defined below:

1.1 Non-hazardous waste

Unwanted materials/substances other than the hazardous. They could be in the form of a solid, sludge, slurry and liquid. The exceptions are surplus/expired materials that are returned to the manufacturer or supplier.

1.2 Hazardous waste

Any waste (solid, sludge, slurry and liquid) which is either combustible, explosive, inflammable, corrosive, reactive or toxic; the list of known hazardous and non-hazardous waste encountered in KOC operations. KOC is always looking throughout the projects developed for waste management for new technology or service becoming available which allows for more efficient management of a particular waste stream.

KOC is well aware that waste generation from its operations is a subject of concern as there are serious consequences associated with its mismanagement, such as:

- Environment impact – soil and water contamination;
- Human health impact;
- Recycle/resale/scrap value of waste lost;
- Non-compliance with local government regulation and standards;
- Unaesthetic sight that may affect company image;
- A burden on the company for clean-up/restoration of the area.

2 Waste management philosophy at KOC

The goal of this study to highlight the KOC's waste management philosophy that focuses on reducing the waste volumes and to handle any waste that is generated in an economical and environmentally sound manner. This philosophy is supported by the KOC HSE management system in the following statements:

– Policy and strategic objectives
  Implement measures to reduce waste and minimize the consumption of materials, fuel, and energy.
– Evaluation and risk management
  A comprehensive waste management plan developed and implemented. This includes maintaining an inventory of all waste generated or stored on site. Waste that cannot be recycled or reused is disposed of in a manner that minimizes its safety and environmental impact.

2.1 KOC waste management procedures

Waste generated by KOC activities is managed in compliance with applicable HSEMS procedures:

– KOC.EV.008 – waste management procedure;
– KOC.EV.004 – management of wastewater discharge procedure.

2.2 Kuwait Environment Public Authority regulations

The management of waste is regulated by Law No. 21/1995 as amended by Law No. 16/1996 and Decision 210/2001 and amended by Law No.42 of 2014. This categorizes waste as hazardous or non-hazardous according to the Basel Protocol. For movements of waste within Kuwait, it requires that a manifest for transportation and disposal is completed, and the manifests must be supplemented according to whether the waste is hazardous or non-hazardous.

3 Waste management projects at KOC

Waste management projects have been developed at KOC to manage all types and quantities of waste generated within the company's sites. Currently KOC waste (hazardous/non-hazardous) is collected from more than various 300 distant locations, which consists of offices, operational facilities, camps, workshops, fire and booster stations drilling sites, security posts, water treatment/injection plant "South & East Kuwait (S&EK), West Kuwait (WK), North Kuwait (NK), Export & Marine Operation (E&MO), Gas operation and Ahmadi Town Hall" (shown in Figure 2).

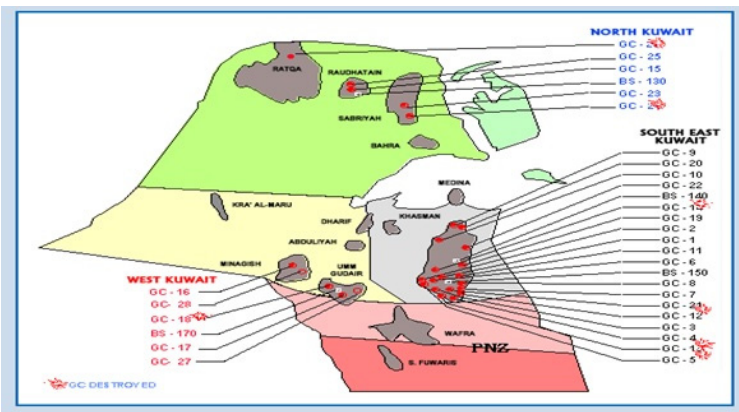

Figure 2: Waste generated from all KOC facilities.

All types of waste are collected, stored, transported, treated and disposed of in a safe and protected area in compliance with all regulations (as shown in Figure 2).

3.1 Collection

Hazardous and non-hazardous waste from all KOC facilities, installations, and operations.

3.2 Segregation

Separate and recover recyclable waste to minimize environmental impact of KOC operations.

3.3 Treatment

Recover crude oil, reduce environmental hazards.

3.4 Disposal

Transport waste to KEPA approved disposal facilities.

Figure 3: Waste management process at KOC.

The waste materials at KOC are subjected to reduction, re-use or recycling, recovery or disposal and to dispose them properly to Kuwait Environment Public Authority (KEPA)/Company approved locations.

After collection and segregation, the waste from all KOC areas is transported to the transfer stations. Transfer stations are the intermediate points between the collection of waste and transportation to recycling and disposal facilities [5]. KOC's waste is transported in vehicles fitted with a vehicle tracking system for monitoring the proper transfer to designated locations. The time required for the collection and transportation of solid waste should not exceed either the period for the waste to rot and start releasing odors or the period for fly breeding (to avoid disease transmission) [6].

KOC's strategy is to manage and document all types and quantities of waste produced or generated at the KOC areas and to route correctly and dispose of them at approved locations.

3.4.1 Waste management projects

1. Waste management within the company's operational area.
2. Environmental waste management at Ahmadi Township.
3. Turning waste to values in D&T Directorate by detoxifying OBM drill cutting waste using thermo-mechanical cutting cleaning technology.

4 Waste determination process

Before discarding a material, a waste determination process must be undertaken to decide how to dispose of it appropriately and legally. KOC is conducting an adequate determination for each waste stream and properly documenting which this decision will help all facilities stay in compliance and avoid costly errors. Appropriate determinations are the foundation of any hazardous and non-hazardous waste management program and will contribute to reducing administration and disposal costs. Everything we use goes through a life cycle (Food we eat and the goods (stuff) we use), and each stage of the life cycle has environmental impacts, including climate change. However, reducing the use of materials in every stage of the life cycle minimizes the environmental impact associated with the stuff we use (shown in Figure 4).

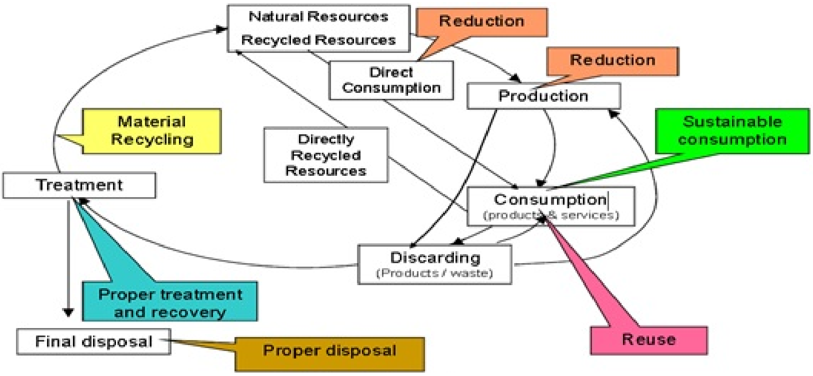

Figure 4: Waste determination process.

The waste handling option at KOC is based on the following hierarchy of preference:

4.1 Source reduction

Any action or process that causes a reduction in the generation of waste. The best and most cost effective method of dealing with waste is not to generate it in the first place. If waste must be produced, the amounts generated should be minimized.

4.2 Reuse/recycle

The process of finding alternative and beneficial uses for a material that would otherwise be considered waste. Examples include the reclamation of lubricating oils and the collection and recycling of aluminum cans and paper.

4.3 Treatment

Many hazardous waste streams can be treated to render the material less hazardous or non-hazardous. Examples of treatment include solidification, neutralization, and incineration.

4.4 Disposal

This is the last of the handling options. When this point is reached, it should mean that all reasonable efforts to use one of the other three methods have been exhausted. In many cases, disposal is the only real economically viable option. However, every effort should be made to reduce the amount of waste sent to disposal.

5 Waste information collection

The quantities of all waste generated and disposed of must be recorded to ensure that all waste arising from all KOC activities are managed and disposed of legally. This requires that there is a system to record all waste that arise and track their movements until final disposal. Two types of record keeping has been implemented in KOC:

1. KOC has developed waste data forms for non-hazardous waste (types of non-hazardous waste are shown in Table 1) and hazardous waste (types of hazardous waste are shown in Table 2) for record reference these records of waste generated for all KOC areas.

Table 1: Non-hazardous waste streams and sources.

General Waste	• Mix garbage
Paper	• Cardboard, office waste papers, magazines etc,
Plastic	• HDPE &LDPE bottles, containers, pipes, cables, packaging material etc.
Glass	• Soft drinks, lab reagents bottles
Metal	• Aluminum soft drink tins, steel pipes, metal scrap, drums, redundant flow lines etc.
Wood	• Wooden Pallets
Concrete	• Construction & demolition Waste
Tires	• Vehicle tires
Food Waste	• Food waste from offices and cafeterias

Table 2: Hazardous waste streams and sources.

Solid Hazardous Waste	• Batteries, catalysts, fluorescent, tubes, sampling bottles, oil contaminated rags, pipes, filters, oily contaminated soil, etc.
Liquid Hazardous Waste	• Expired chemicals, spent acids, used lubricants, etc.
Soil/Sludge	• Oily soil/sludge from oil spills & crude oil storage tanks, etc.

2. All waste transfer to approved recycle, and disposal locations outside KOC fence are registered through a manifest form for hazardous and non-hazardous waste.

6 Analysis of KOC's management system

The collected waste from the KOC areas are segregated into recyclable and non-recyclables (Hazardous & Non- Hazardous) waste where the segregation area is to minimize environmental impact in KOC operations.

Processing of the recyclable waste is carrying out by segregating all the recyclable materials, which all are bailed and sent to recycling companies also the food waste is mixed with organic waste using the compost machine and the composite organic waste is being used as fertilizer. Treatment of hazardous waste at KOC to convert it into non-hazardous substances or to stabilize or encapsulate the waste so that it will not migrate and present a hazard when released in environment

The treatment techniques implemented in waste management projects at KOC as the following:

- Solidification of expired chemicals;
- Soil washing for the contaminated soil;
- Bioremediation for contaminated soil.

Treatment of the oil-based mud cuttings are done using a unique thermomechanical cuttings cleaner (TCC) technology. The TCC technology is a most environment friendly soil remediation method with proven effectiveness around the globe. This technology provides indirect and controlled heating by converting friction energy to kinetic energy to remove hydrocarbons undestroyed. Thermal desorption uses a non-oxidizing process to vaporize volatiles and semi-volatiles through the application of heat because thermal desorption depends on volatilization, treatment efficiency is related to the volatility of the contaminant. Thermal desorption easily removes light hydrocarbons, aromatics, and other volatile organics, but heavier compounds such as polycyclic aromatic hydrocarbons are less easily removed. Low-temperature thermal desorption systems typically operate at 250 to 350°C and may be sufficient to treat waste with light hydrocarbons, aromatics (e.g., benzene, toluene, ethyl benzene, and xylenes), and other volatile organics, which are easily removed. Recovered hydrocarbons are reusable as base fluid for making fresh OBM, the recovered water is reused to moisturize treated drilling cuttings, and hydrate treated soils. Indirect heating is safer and minimizes the pollution compared to direct heating.

7 Results and discussion

Thus, this study was conducted to describe the analysis and improvement possibilities of waste management at KOC including the evaluation waste management process and the proper management of KOC waste.

Our research study focuses on all types of waste by using the data based on the KOC waste monitoring system according to waste classification for the years of 2014 and 2015.

Cumulative data from all KOC operational areas (WK, Gas, CSD, D&T, NK, S&E, EO&MO Ahmadi Area). All waste values are expressed in metric ton for solids and cubic meters for liquid waste streams.

In 2014, KOC generated around 20120.21 M Ton/m^3 of waste in the type of hazardous and non-hazardous, were arises from all KOC areas, where was the amount of non-hazardous waste was 14752.3M Ton/m^3 (shown in Figure 5) and the quantity of hazardous waste 5209.54 M Ton/m^3 (shown in Figure 6).

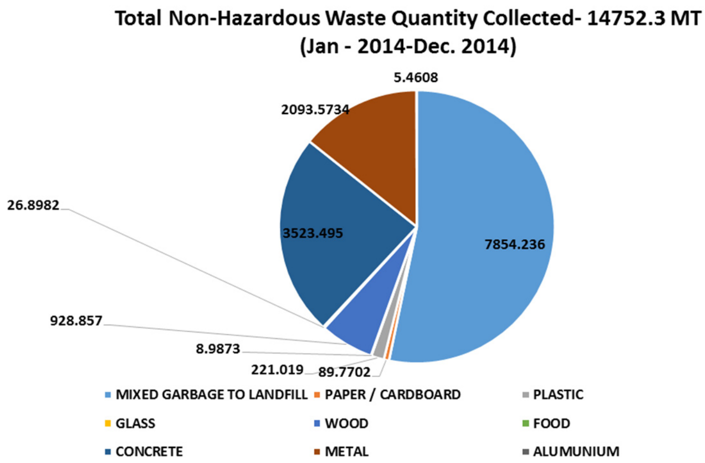

Figure 5: Amount of non-hazardous waste – 2014.

In 2014, roughly one-third of the hazardous waste was oily water, another third asbestos and another third contaminated soil. Other marginal sources of hazardous waste include domestic and sewage sludge, cleaning waste, drilling cutting, and a small portion of general waste.

Oil contaminated soil and oily sludge generated as a result of company activities are treated within KOC operational areas. Bioremediation and soil washing treatment processes are used for the treatment.

The recovered oil from the treatment is recycled back to crude oil recovery plants, and the treated soil is re-used within the company's operational areas for various backfilling purposes such as backfilling abandoned Gatch pits, trenches, etc.

Sewage management: sewage, which is generated from all KOC facilities. Currently, three (3) STPs with 300 m^3/day design capacity each is installed and being operated, which treat all the sewage generated within the company's operational areas after that the treated water is reused for various irrigation purposes.

Figure 6: Amount of hazardous waste – 2014.

In 2015 KOC generated around 30400.4 M Ton/m^3 of waste in the type of hazardous and non-hazardous, arising from all KOC areas, where the amount of non-hazardous waste was 13894.76 M Ton/m^3 (shown in Figure 7), and the quantity of hazardous waste 16437.2 M Ton/m^3 (shown in Figure 8).

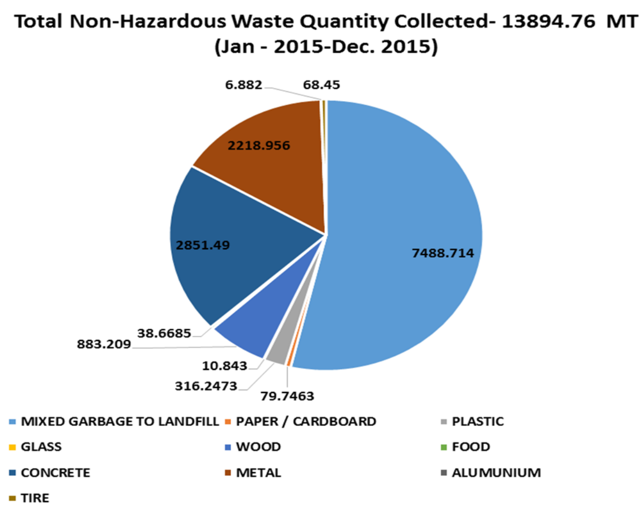

Figure 7: Amount of non-hazardous waste – 2015.

In 2014/15, roughly, 57% of the hazardous waste was soil contaminated, another half 32% domestic and sewage sludge. Other marginal sources of hazardous waste include asbestos, cleaning waste, drilling cutting, and a small portion of general waste.

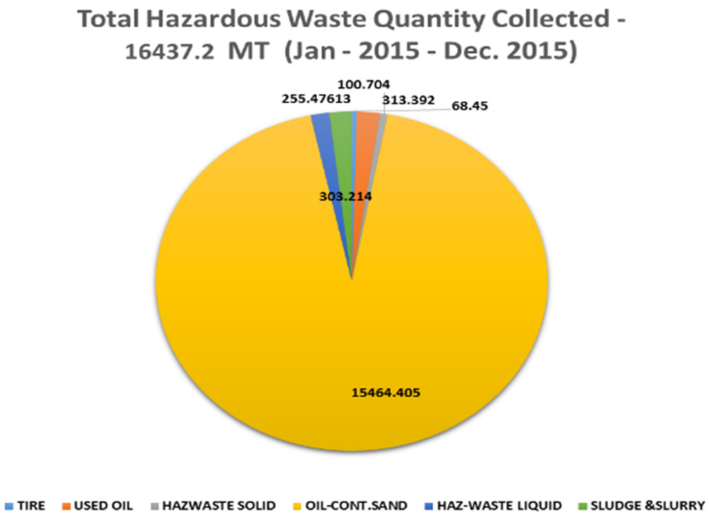

Figure 8: Amount of hazardous waste – 2015.

8 Conclusion

The effect that waste has on our natural environment and ultimately on the quality of our life has been made public in worldwide discussions. The problems related to waste have many scopes. In economically challenged communities, the scope and magnitude of the problem may often exceed the capacity that local authorities have to effectively resolve issues of waste collection and disposal, in addition to other difficult city managerial tasks.

The results obtained from the analysis of the waste management in KOC show a growing and dynamic entity with issues of development, and environmental hazards in particular in water and soil contamination

KOC has achieved some positive results in the form of recycling surplus material through salvage vendors and encouraging recycling of office paper waste and the contaminated soil is treated and recover crude oil to reduce environmental hazards and further use the treated soil for backfilling.

This study examines the waste management system in KOC. This study revealed that 57% of the hazardous waste was soil contaminated, another half 32% domestic and sewage sludge. Other marginal sources of hazardous waste include asbestos, cleaning waste, drilling cutting, and a small portion of unspecified waste.

KOC reached initiatives in waste management and also has been making every effort to maximize the opportunities of waste reduction, reuse, recycling of waste and material recovery, such as:

– To prevent waste generation, where possible;
– To encourage minimizing waste generation by implementing waste minimization techniques, such as:
    - improved operating practices;
    - proper chemical and material storage;

- purchasing and inventory control;
- spill and leak prevention.

– To promote awareness among the company employees on a number of waste management issues and encourage moving towards zero waste approach.
– To ensure proper segregation of recyclables (i.e., paper, plastic, glass, metal, food waste etc.) within hazardous/non-hazardous waste and send it for recycling.
– To compost food waste, which is used as soil conditioner and fertilizer in landscaping and horticulture purposes.
– To send scrap metal to KOC metal scrap yard, where scrap is sold to metal recycling company.
– To reuse empty metal drums where possible, or else sent to KOC metal scrap yard
– To recover oil to maximum extend from oily waste (oil contaminated, oily sludge soils) and send it back to oil recovering system within KOC.
– To provide necessary awareness on waste management to schoolchildren and community.
– To participate in waste management conferences to share knowledge with experts to improve and develop waste management and developing strategy for KOC.

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A new procedure for recovering heavy metals in industrial wastewater

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Abstract

The usual way to treat heavy metal containing industrial wastewater leads to large amounts of hydroxide sludge. In general, the concentration of the non-ferrous metals in the sludge is too low for an efficient recovery of these elements and in consequence, these secondary raw materials dissipate. New procedures were developed to treat wastewater from traces up to 25 g/l heavy metals like Cu, Ni, Zn, Mn, Pb, Sn, Pd and Ag. Using the modified ferrite process with Fe/M = 2/1 specific products free of hydroxide can be produced. The precipitates are in most cases a mixture of heavy metal ferrite, oxides or zero-valent metal. By reduction of iron ratio, it is also possible to produce doped oxides without by-products. A new treatment method is the so-called Lt-delafossite, with Fe/M = 1/1. The application of the treatment methods for five different rinsing waters from the electroplating industry showed that in each case the recovery rate is higher than 99.9%. A simplified calculation was performed for a Pd activator bath and for three rinsing water loaded with Sn and Pd, Cu or Ni. Referring to a model volume of 1000 l wastewater with weekly exchange, the loss of metal by dissipation per year sums up to approx. 1 ton, based on typical rinsing waters, showing 1.5 g/l to 3 g/l Cu or Ni or rather 15 g/l Cu. Further ecological and commercial benefit of this procedure is the drastic reduction in waste volumes. Additional costs for transport and disposal of the neutralisation sludge can be avoided.
Keywords: heavy metal, Cu, Ni, Pd, Sn, wastewater treatment, ferrite process, Lt-delafossite, recovery potential, nanoparticle.

1 Introduction

Huge amounts of industrial wastewater and effluents occur, e.g. in the electroplating industry. Generally, they are treated with lime or caustic soda in order to precipitate the heavy metals. Mostly the resulting sludge are deposited in landfills. In Germany 95% of the nonferrous metals get lost by dissipation, and only 5% of the voluminous sludge is processed to recover the heavy metals [1]. Nobel metals, e.g. Pd, are used as activators to produce reactive surfaces. The recovery of these elements out of an aqueous solution is of outermost interest.

We developed a new procedure to treat wastewater with heavy metal concentrations up to 25 g/l at temperatures < 90°C. After treatment, the purified wastewater complies the threshold values for environmental regulations. By applying our method, we are able to avoid the usual formation of hydroxide sludge. Moreover, we can recover these heavy metals as oxides or even zero-valent metals. We succeeded to treat heavy metals (Cu, Ni, Zn, Mn, Sn, Ag and Pd) in both, synthetic and real wastewaters. Below we present our concept using the example of copper and nickel containing rinsing water from electroplating industry. Additionally, we present our first results for the treatment of an activator bath to recover Pd and Sn.

2 Treatment of heavy metal containing industrial waste water

2.1 State of the art

Various techniques exist to remove heavy metals from wastewater. The most applied principles of operation are precipitation and ion exchange [2]. Both methods produce metal bearing residues (e.g. highly voluminous lime sludge, exhausted ion exchange resins, highly metal loaded deionizer regeneration wastewater), which are barely used for the recovery of metals [e.g. 1]. The lion's share of these residues is hazardous waste, representing the end of pipe treatment.

A well-known method for metal recovery is based on electrolysis. For most technical implementations of these electrowinning systems, the lower threshold for an efficient application is a minimum metal concentration of 30 mg/l and 50 mg/l respectively. Special techniques (e.g. using mesh cathode cells, fluidised or packed bed cells) provide metal recovery up to lower metal contents of 0.5 mg/l or rather 0.1mg/l [2]. However, all these techniques based on electrolysis are suffering from very high operating costs and are only applied if recovered metals can be offered competitive and profitable on the metals exchange. In combination to the previously introduced methods, oxidising and reducing reagents respectively are in use, e.g. for treatment of metal bearing effluents loaded with problematic substances, like cyanides, uranium leachates (U^{4+}) or hexavalent chromium (Cr^{6+}).

A low-tech alternative to deplete metals in wastewater is based on wetland metal mineralisation. However, the efficiency of heavy metal removal with this biogenic method is quite low compared to the above-mentioned methods [2]. Further techniques, using metal accumulation microorganisms (e.g. bacteria, algae, yeasts and fungi), are interesting alternatives but play a minor role in industrial treatment of metal containing effluents.

2.2 Model plant

To demonstrate our concept, we use a model plant from an electroplating industry with three different types of baths, comprising Pd as activator, Ni and Cu, each followed by a rinsing cascade (Figure 1).

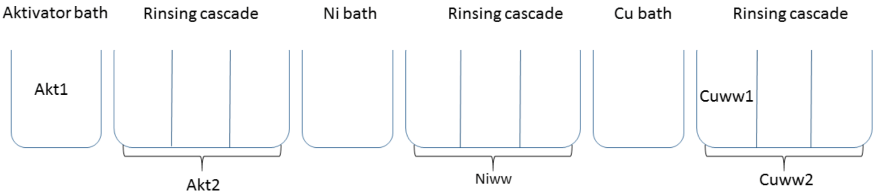

Figure 1: A model plant in electroplating industry with five different types of wastewater.

At the beginning, the surface of plastics needs a pre-treatment to enable the deposition of the chemical agent Ni on the plastics as an anti-rust layer below the next Ni, Cu and Cr layers. For example, Pd is used as an activator to form the needed catalytic sites on the surface. Sample Akt1 was collected from a Pd activator bath in the electroplating industry. Sample Akt2 is a rinsing water accrued after the Pd activator bath (Akt1). Wastewater Niww is a mixed sample collected from a multistage rinsing cascade after the Ni bath. Wastewater Cuww1 was sampled from the first rinsing tank directly after the Cu bath and Cuww2 is mixed sample collected from a multistage rinsing cascade.

The heavy metal concentrations of samples Akt1, Akt2, Niww, Cuww1 and Cuww2 are summarized in Table 1. The chemical analysis was performed by ICP-OES or AAS.

Table 1: Heavy metal concentrations [mg/l] in wastewater from electroplating industry: Akt 1 and Akt 2 are wastewater from Pd activator bath and rinsing cascade, respectively, Cuww1 is a rinsing water from the first rinsing cascade after the Cu bath whereas Niww and Cuww2 are mixed rinsing water from multistage rinsing cascades. n.d. means not determined.

Sample	Concentration [mg/l]						
	Pd	Sn	Cu	Zn	Fe	Cr	Ni
Akt1	78	2600	12	52	67	34	< 1
Akt2	7	648	3	28	4	8	< 1
Niww	n.d.	0.5.	< 0.1	< 0.1	< 0.1	< 0.5	1423
Cuww1	n.d.	n.d.	15560	13	3	6	245
Cuww2	n.d.	n.d.	3010	3	1	3	53

2.3 How large is the potential of dissipated heavy metals?

The introduction of a new environmental technology for an industrial application rarely depends alone on the ecological value of the procedure. It is generally expected that this method is economically profitable. Therefore, an assessment of the potential of this new process was conducted. Figure 1 shows a model plant for electroplating which was used as base for a simplified model calculation. Starting point for our estimation are our high recovery rates for heavy metals, ranging between 99.5% and 100% (see Section 3). The potential of the heavy metals was determined based on the main contaminants (Sn, Ni and Cu). The concentration of heavy metals in wastewater from the multistage rinsing cascades is low ≤ 3 g/l. For wastewater from the first rinsing cascade the concentration can be higher than 10 g/l. Due to the high market value, the potential of lower concentrated Pd (activator bath: 78 mg/l and rinsing water: 7 mg/l) was also calculated.

The production parameters differ extremely dependent on the individual plant sizes. For example, industrial tanks used for electroplating typically contain volumes of about 2 m^3; a typical rinsing water cascade contains capacities of 6 m^3. Typical tank volumes of small companies comprise minor sizes of about 300 l. For better comparability, applicable for both, small enterprises and industrial plants, our data are calculated for a model volume of 1000 l. The usual production conditions with a weekly exchange of water from a multistage rinsing cascade were used as basis for the estimation of the annual amount of wastewater (see Table 2).

Table 2: Recovery potential of heavy and noble metals based on 1000 l bath or rinsing water.

Sample	Metal	Concen-tration	Recovery rate	Recovery of metal[1)]	Annual recovery[2)]	Value[3,4)]
		[mg/l]	[%]	[kg/1000L]	[kg/year]	[€/1000L]
Akt 1	Pd	78	> 99.98	0.078		1378.16
Akt 1	Sn	2600	97.04 – 99.98	2.561		6.15
						[€/year]
Akt 2	Pd	7	> 99.98	0.007	0.364	6063.03
Akt 2	Sn	648	97.04 – 99.98	0.638	33.194	79.67
Niww1	Ni	1423	99.9 – 99.99	1.422	73.955	406.75
Cuww1	Cu	15560	> 99.98 – 100	15.558	809.039	2427.12
Cuww2	Cu	3010	> 99.98 – 100	3.010	156.504	469.51

1) Average values; standard deviation: > 0.2%
2) Weekly bath exchange: 52x per year
3) Scrap value on 21.04.2016 [3]: Sn 2400.00 €/t, Ni 5500.00 €/t, Cu 3000. 00 €/t
4) Market value for purchase of solid Pd on 21.04.2016 [4]: 501.00 €/oz., 1666.00/100g.

Our data clearly demonstrate that over the course of a year small amounts of non-ferrous metals in the wastewater of the three different rinsing cascades, add up to a loss in the range of 265 kg. If metal is recovered from a highly loaded rinsing water (> 10 g/l), the amount of highly concentrated heavy metals increases considerably. Based on 1000 l, the cumulative potential of Cu recovery is 809 kg (Cuww1) in comparison to 156 kg for the rinsing water (Cuww2).

2.3.1 Benefit of the recovery of heavy metals

Reflecting the resale value, the potential of recovered heavy metals from rinsing waters was determined on base of the (lowest) scrap values in order to include recycling costs (see Table 2). Following considerations are based on 1000 l waste-water treatment. The annual benefit of the simplified model plant for electroplating is in the range of 500 € (scrap value [3]) for Ni and Cu, respectively. Considering highly loaded rinsing water (15 g/l) the potential for copper recovery raises to 2500 € (scrap value). In absence of scrap values for Palladium, proceeds realized from purchase of solid Pd [4] are included in the simplified cost-benefit evaluation.

The annual potential for Pd recovered from rinsing water is approx. 33 kg or about 6000 €. The purchase value of recoverable Pd and Sn from 1000 l activator bath is about 1400 €. In total, referring to the depicted model plant with one activator bath and three types of heavy metal rinsing water systems (Pd, Ni, Cu), sums up to a loss by dissipation of approx. 260 kg of metal, representing foregone revenues in the range of about 8500 €.

2.3.2 Additional profit for companies

It is notable to point out to further enormous saving potentials. By applying our method of wastewater treatment, the actual costs incurred by transport and disposal of highly voluminous neutralisation sludge will be obsolete. The annual volume is within the range of 100 t/a and 500 t/a for smaller facilities and may exceed 10000 t/a for industrial plants. The cost structure is very inhomogeneous, due to its dependence on several parameters, e.g. volume (total amount), metal content (recycling capability/toxicity), transport distance. In Germany in 2015, costs summarised for both, transport and disposal, were in average in the range of 100 €/t to 200 €/t.

3 New methodology

3.1 Development of a new technology

The new technology presented here is based on the ferrite process published by Okuda and coworkers for the first time and several other studies using this methodology, e.g. [5, 6]. Accordingly, Fe^{2+} ions are added to the wastewater containing the heavy metals M in the ratio $Fe^{2+}/M = 2/1$. After alkalisation hydroxides precipitate and later, as a result of oxidisation of the hydroxides, heavy metal (M) is incorporated in the spinel structure (ferrite). Our investigations, however, showed clearly that e.g. Cu is only partly incorporated in the copper ferrite solid solution with magnetite [7]. But we recognised that by modification of the ferrite process two goals can be obtained: effective wastewater purification even for highly concentrated wastewater up to 20 g/l and recovery of secondary raw materials due to low voluminous residues. The recovery rates of the heavy metals are very high, generally between 99.5 and 100%. Moreover, we can design a procedure to gain the heavy metals as marketable products. Depending on type and concentration of the heavy metals in the wastewater and adjustment of the Fe/M ratio in the solution different precipitates are achieved. Reaction conditions applied during precipitation and ageing procedure control the composition of the final residues. The main interphase is green rust (GR); it represents one of the major phases in fresh precipitates.

In consequence, we developed three concepts to produce heavy metal containing nanoparticles. Option 1) high-Fe system [7] and option 2) low-Fe system [8] are based on the modified ferrite process. Option 3) comprises a new concept called LT-delafossite process [9–11]. Following case studies with possible treatment concepts for the five real wastewater are presented (see Figure 1 and Table 1).

3.2 Experimental setup

Following setup was used to perform the experiments with real wastewater from electroplating industry (Figure 2). The experiments were carried out in a 3-neck glass flask, heated by a special Al-block to guarantee homogeneous heat distribution. After a reaction temperature of 40°C or 70°C was reached, $FeSO_4 \cdot 7H_2O$ (VWR, analytical grade) was added to the solution. Then the pH was adjusted to a value between 9 and 11. The solution was continuously heated and stirred during these steps. An aliquot of the fresh sample the solution containing the precipitates was stored in a closed vessel either at room temperature

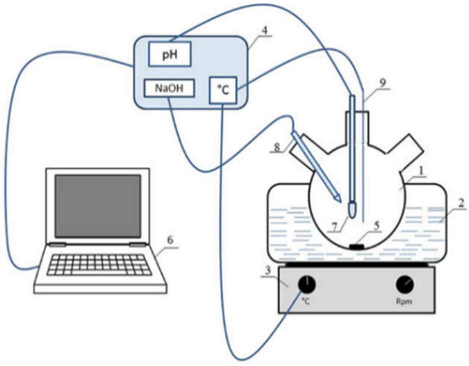

Figure 2: Experimental setup consisting of: (1) reaction vessel, (2) Al-block, (3) heating plate, (4) alkalisation unit Titrator TL 7000 (SI Analytics), (5) stirrer, (6) controlling station, (7) pH-electrode, (8) titration needle and (9) thermocouple connected to the alkalisation unit and the heating plate.

or at elevated temperature. The precipitates were filtrated and washed 3 times with high-purity water and dried at room temperature for 12–24 h.

Samples are named according to the following convention: "used wastewater"_ "Fe-content"_"reaction temperature"_"reaction pH"_"ageing time".

The extension "rt", denotes an ageing at room temperature. The abbreviation for the "Fe-content" is "m" for a medium amount of Fe added, "h" for a high amount and "vh" for a very high amount of added Fe.

3.3 Analytical methods

The concentration of heavy metal in the solution was measured by ICP-OES or AAS. Various analytical methods were used to detect the partly amorphous precipitates. Phase identification was performed by X-ray powder diffraction (XRD) with Stoe Stadi and GE Seifert XRD 3003 TT. Fourier Transform Infrared Spectroscopy (FTIR) using a Bruker Equinox 55 was performed to identify X-ray amorphous phases. Magnetic measurements were carried out, using a Variable Field Translation Balance (VFTB) by Petersen Instruments. Morphologies of precipitates were studied by scanning electron microscopy (SEM) using a GEMINI 98 manufactured by LEP (now Zeiss) and by transmission electron microscopy (TEM) using a JEOL JEM-2100F microscope.

4 Case studies

4.1 Copper loaded wastewater

4.1.1 Treatment by modified ferrite process: high-Fe and low-Fe option

The Fe/Cu ratio was varied from < 0.8/1 (low-Fe option) up to 2/1 (high-Fe option). Further parameters, which control the final composition of the solid phases, are the quantity of initial copper in the solution and ageing time. The variation of the solid phases is shown in Figure 3.

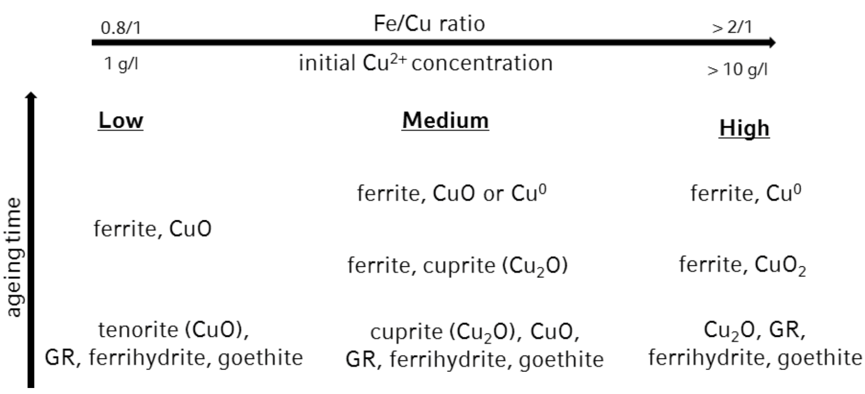

Figure 3: Scheme showing the variation of the product phases with varying initial Cu concentration, Fe/Cu ratio and ageing time.

At high Fe/Cu ratio 2/1 and high Cu concentrations in the solution (> 10 g/l) a mixture of $(Cu,Fe)Fe_2O_4$ (a solid solution of copper ferrite and magnetite) and zero valent Cu° precipitates. With ageing, the amount of Cu_2O increases at the expense of ferrite and zero valent Cu° (Figure 3). At low Cu-concentrations in the solution and medium amount of added Fe we obtained Cu_2O, CuO and ferrite. By further decreasing the added Fe content to the wastewater the amount of CuO increases. Table 3 shows that it is possible to precipitate Fe doped CuO as mono phase by the low-Fe concept.

Table 3: Phases of sample series Cuww2. Those observed with XRD are marked with X/x and phases observed with FTIR are marked with F/f. Capital letters stand for a high amount, small letters for a low amount of the appropriate phase.

Sample	Phases				
	CuO	Cu_2O	GR	$Fe_{10}O_{14}(OH)_2$	Fe_2O_3
Cuww2_0.5_f	x		f	f	f
Cuww2_0.5_24h	X	x			
Cuww2_0.25_f	X		f	f	
Cuww2_0.25_24h	X				
Cuww2_0.125_f	X			f	
Cuww2_0.125_24h	X				
Cuww2_0.06_f	X				
Cuww2_0.06_24h	X				

4.1.2 Treatment by Lt-delafossite process

Another option presents a totally new synthesis route for delafossite $CuFeO_2$ at Fe/Cu ratio 1/1 solely by precipitation and ageing at temperatures between 50°C and 90°C, called Lt-delafossite process [9, 10]. The adaptation of this process on real wastewater was successfully performed with initial copper concentration > 15 g/l, typical for the first tank of the rinsing cascade and < 5 g/l, typical for multistage rinsing systems [11]. The reached water purification rates are exclusively ≥ 99.99%. After 16 h of ageing the residues consists of pure, nano-sized delafossite without any additional phases.

4.2 Nickel loaded wastewater

Table 4 summarizes the precipitated phases of two sample series Niww. Reaction temperatures < 70°C and reaction pH values of ≥ 10.5 promote the formation of $Ni(OH)_2$. By specific adjustment of the reaction conditions of the ferrite process, we succeeded to decrease the $Ni(OH)_2$ content and to increase the ferrite component in the precipitates (see Figure 4). The achieved water purification rate for Ni is exclusively ≥ 99.9% independent of reaction temperature and pH value.

In contrast to reaction pH we observed no relation between reaction temperatures and the purification rates. The lowest Ni concentrations were detected in fresh solutions after treatment with reaction pH values of ≥ 9. Better water purification rates in comparison to fresh filtrates were achieved after treatment with reaction pH of 8 and 8.5 and ageing of the samples for at least 24 h.

In sample series Niww, with low initial Ni^{2+} concentration < 1.5 g/l, we succeeded the precipitation of ferrite as main phase at temperatures ≥ 70°C, a reaction pH value of 9.5 and ageing at elevated temperatures for 24 h. After treatment of wastewater Niww the Ni concentration dropped from 1423 mg/l to ≤ 0.24 mg/l. At optimal conditions, the Ni concentration dropped down to ≤ 0.11 mg/l. This corresponds to a recovery rate of ≥ 99.99%. It was also possible to remove the other minor elements (< 4 mg/l) completely from the solution.

The fact that both, IR-bands and reflection positions in XRD pattern, are shifted, indicates that Ni is preferentially incorporated into the ferrite structure.

Table 4: Phases of sample series niww. Phases detected by XRD are marked with X, phases analyzed by FTIR with Fm and traces with x and f.

Sample	Phases			
	Ferrite	$Ni(OH)_2$	GR	$Fe_{10}O_{14}(OH)_2$
Niww_9.5_50_f		x, f	F	F
Niww_9.5_50_24h	x, f	X, f	f	f
Niww_9.5_70_f	f	x, f	F	F
Niww_9.5_70_24h	X, F		f	f
Niww_9.5_70_7d	X, F	x, f		f
Niww_9.5_70_7d_rt	X, F	x, f	f	F
Niww_9.5_90_f	x, f	x, f	f	F
Niww_9.5_90_24h	X, F			f
Niww_10.5_70_f	x, f	f	f	F
Niww_10.5_70_24h	X, F	X, F		f

4.3 Palladium and tin loaded wastewater

The concentration of Pd in activator bath is 78 mg/l and shows 7 mg/l in rinsing water. Furthermore, minor amounts of Cu, Zn and Cr have to be treated.

Within this study 12 sample series using Pd activator bath and the corresponding rinsing wastewater were performed. The experiments were carried out at pH values of 9 and 11, temperatures of 40°C and 70°C and under adjustment of three different Fe/M ratios.

For both samples (Akt1 and Akt2), highest purification rates were achieved at a reaction pH value of 9. Afterwards the Pd concentration dropped to < 0.1 mg/l; this corresponds to a recovery rate of ≥ 99.98%. At higher reaction pH ≥ 10 the Pd concentration in the purified water increased (≈ 0.5 mg/l for sample Akt1). The purification rate for Sn was lower, ranging between 97.04% and 99.98%. The minor elements Fe, Cr and Cu we removed to ≈ 99%. Only in case of Zn in sample Akt1, the recovery rate was ≈ 55% independent of the reaction conditions.

The first mineralogical investigation of sample Akt1 showed that the main controlling parameters are temperature, ageing conditions and added Fe^{2+} content. Depending on the experimental conditions, we observed four different phase assemblages in the residues:

1) After ageing, the residues obtained by precipitation with a high Fe-content, at pH 9 and temperatures between 40 and 70°C mainly consist of jeanbandyite $FeSnO(OH)_5$ (sample Akt_h_70_9 and Akt_h_40_9). A minor amount of ferrite compound is detectable independent of reaction temperature and ageing conditions.
2) With decreasing temperature, the ferrite content in the sample markedly increases. For samples precipitated at a low temperature of 40 °C, pH value of 9 and addition of "medium" Fe contents, the residues consist of ferrite as the only crystalline phase (Akt_m_40_9).
3) Reaction temperature of 70°C and 24 h ageing time promotes the phase mixture of $FeSnO(OH)_5$, ferrite, SnO and an additional phase we cannot identify so far (Akt_m_70_9_1d).
4) After ageing the reaction products of option 3 at room temperature (Akt_m_70_9_1d_rt), the sample consists mainly of the "unknown" phase. Additionally, small contents of $FeSnO(OH)_5$ and ferrite are observable.

5 Discussion and conclusion

In this study, we presented possible treatment methods for 4 different wastewaters and 1 process water bath from electroplating industry companies. The results show that it is possible to purify effectively the wastewater in compliance with the legal requirements for environmental regulations. Moreover, it is unambiguously possible to recover heavy metals. In contrast to traditional water treatment methods of industrial effluents, the precipitate phases have only negligible amounts of metal hydroxides and therefore they have the potential for a profitable marketability. This new treatment procedure can also be used to treat highly loaded rinsing water with heavy metals > 10 g/l.

One outstanding aspect of our treatment method is the precipitation of metal oxides in the sense of product design, like nano-sized delafossite ($CuFeO_2$) or doped CuO. Under certain reaction conditions, heavy metals can also be recovered as zero-valent metals. An overview of possible product lines gives Figure 4.

A simplified model plant including one Pd containing activator bath, and three rising water cascades after Pd, Cu and Ni bath was used as base for considerations about the recovering potential of heavy metals in electroplating industry. Referring to a model volume of 1000 l wastewater, the loss of the non-ferric metals by dissipation sums up to approx. 250 kg per year. In case of 15 g/l copper, the recovery potential raises to 800 kg per year.

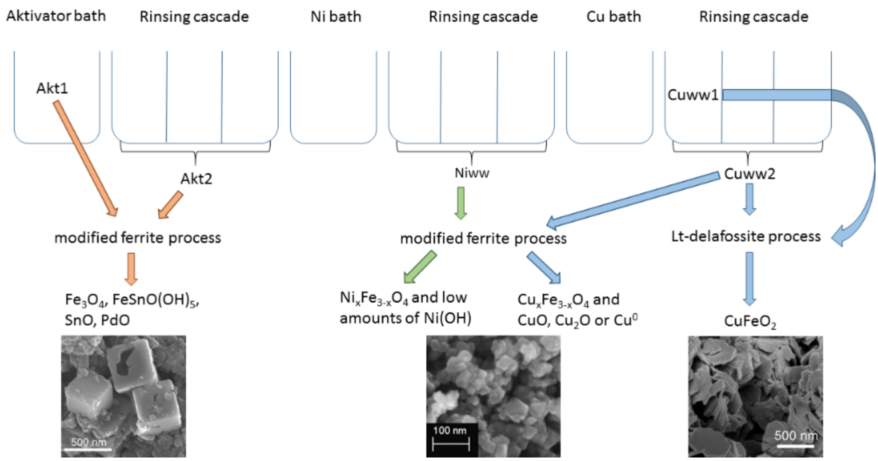

Figure 4: Overview of phase assemblages obtained after treatment of the modified ferrite process or Lt-delafossite process.

In general, all precipitates are highly suitable for recycling and reprocessing of heavy metals as secondary raw materials in a smelter. A more innovative approach is the production of nanocrystals in terms of upcycling, by synthesising valuable phases like delafossite or doped oxides with much higher value. These phases are highly demanded (raw) materials for several technical applications. Our results show that it is possible to produce them directly from the effluents.

Another ecological and commercial benefit for companies is the drastic reduction in waste volumes. Additional costs for transport and disposal of the neutralization sludge can be avoided.

Acknowledgement

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Can palm oil waste be a solution to fossil fuel scarcity and environmental sustainability? A Malaysian case study provides the answer

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Abstract

The main aim of this paper is to examine the potential of energy resources of non-fossil origin as a feasible alternative that will enhance energy security and environmental sustainability. This is examined quantitatively based on a case study in the state of Sarawak located in Malaysia. It is demonstrated that optimizing the use of palm oil waste from the palm oil industry in Sarawak for bioenergy production can be a crucial means of mitigating the pressing problems of hydrocarbon resource scarcity, waste disposal and the greenhouse effect. The conclusion is that biomass in general, and palm oil waste in particular can be a sustainable energy source to rely on in the near future especially for the emerging Asian economies.
Keywords: palm oil plantation, biomass, second law of thermodynamics, energy security, environmental sustainability.

1 Introduction

The Southeast Asian nations along with China and India are shifting the geopolitics of global energy due to their insatiable appetite for energy demand amidst robust economic growth. The quest for increasing energy resources in the region is straining traditional and depletable fossil fuel reserves such as coal, oil and natural gas. Conceivably, the finitude fossil fuels coupled with concerns over increasing carbon footprint and anthropogenic climate change have led to growing regional interest in exploring alternative energy sources.

One potential solution is to re-model the energy-mix away from fossil fuel resources to biomass energy. This is examined quantitatively based on a case study in the state of Sarawak in Malaysia. It will be demonstrated that optimizing the use of palm oil waste available in abundance in the state for bioenergy production can be a crucial means of mitigating the pressing problems of hydrocarbon resource scarcity, waste disposal and the greenhouse effect.

A theoretical scaffolding of natural resource scarcity in relation to fossil fuels is presented, with particular reference to oil. The discussion that follows highlights the fact that the search for alternative renewable energy sources in a finite natural world poses one of the biggest challenges humanity has ever faced. It concludes that biomass in general, and palm oil biomass in particular can be a sustainable energy source to rely on in the near future for the emerging Asian economies including China and Southeast Asia, and especially for Indonesia and Malaysia, as they are respectively the largest and second largest palm oil exporters in the world.

2 Fossil fuel resource scarcity: some basic concepts

Natural resource economics distinguishes between renewable and non-renewable resources. Renewable resources are resources that may be replenished indefinitely through natural biological regeneration processes and sustainable harvesting. These include for example, forest or fishery stocks. Non-renewable or exhaustible resources, however, have no natural biological regeneration abilities, at least not within a relevant human or economic time scale. Mineral deposits and fossil fuels are such examples. These resources are often found in fixed amounts, that is, they are finite and are consumed more quickly than nature can regenerate them. Since the stocks of these non-renewable resources are depletable, when they become depleted, it is an irrecoverable loss, and will be unavailable to future generations.

Non-renewable resources may be further divided into two categories: recyclable and on-recyclable. Mineral deposits, such as iron ore, can be recycled, but fossil fuels such as coal, oil and natural gas are physically non-recyclable. Once these hydrocarbon resources enter into a production chain, they will be irrevocably transformed into energy and waste. That is to say, once used, they will be gone forever. Another distinctive feature of these resources are that they are without a backstop technology. A backstop technology is a substitute technology that is not constrained by exhaustibility (Nordhaus [1]).

The irreversible nature of these fossil fuels may be explained with specific reference to oil using the second law of thermodynamics or the entropy law. Entropy is a measure of the quantity of energy not capable of conversion into work. That is to say, in any transformation of useful form of energy, for instance, usable oil to another form in a production process, it undergoes a process of entropic decay or dissipation whereby it will be destroyed and lost irreversibly (Georgescu-Roegen [2]). In other words, once used, it is gone forever. Furthermore, the entropy law imposes an absolute resource scarcity which cannot be overcome by the deployment of advance technology, exploration, or substitution (Daly [3], Georgescu-Roegen [4]). Technically speaking, fossil fuel resources are absolutely scarce thanks to the entropy law. Consequently, for a given reserve level, the amount that may be extracted will be permanently decreased as the exploitation process progresses over time.

Moreover, the amount of oil that can be extracted is also limited by geological constraints governing its formation. It may well be that the hydrocarbon resource, which is generated from the remains of prehistoric planktonic algae and bacteria (biotic material) takes millions of years to form under a precise combination of pressure, temperature and time. Consequently, the natural supply of oil cannot be physically increased over an economically relevant time horizon by resource-augmenting technological progress or industrial process. Thus, production level will begin to decline gradually and irreversibly once it reaches its peak level due to geological constraints. The peak oil production level coincides with the point at which the oil reserve has been depleted by 50 percent. Peak oil decline does not mean running out of oil, but running out of cheap pumpable oil. The period after the peak is known as depletion. Viewed from this perspective, oil is absolutely scarce because of the geological time necessary for regeneration.

This above exposition raises concerns about the continued availability of fossil fuel energy resources over space and time to support long-term growth and human socio-economic wellbeing. It further cautions us to reduce our dependence on finite hydrocarbon resources by diversifying our energy-mix based on the optimization of renewable and non-fossil energy resources. Renewable energy is defined as energy generated from continually replenished sources such as solar photovoltaic, wind power and biomass. The following subsection provides an assessment of the extent that palm oil biomass can contribute to this. This is based on a case study in Malaysia with specific reference to the state of Sarawak.

3 Biomass: the potential green wealth and the key to energy security

The use of renewable energy sources continues to grow rapidly amidst growing concern about hydrocarbon resource depletion and growing energy consumption especially in the fast developing Asian economies including China and Southeast Asia. Indeed, renewables especially biomass are increasingly becoming a mainstream energy source. Biomass is any organic matter derived from plants or animals. However, in the context of energy sources it is commonly used to refer to decomposable solid material that can be collected from biological organisms, primarily plants, on a renewable basis (Davis *et al.* [5]).

Biomass, a stored solar energy, is the fourth largest energy source after coal, oil and natural gas. It is also considered to be the most important renewable energy option (Ladanai and Vinterbäck [6]). In 2013, biomass accounted for about 19% of global final energy consumption, and biomass for energy (bioenergy) remained the major contributor to renewable energy worldwide at nine percent of all renewables in the same year (REN21 [7], Teske *et al.* [8]). The optimal use of biomass is also expected to contribute to energy security, significant reduction in greenhouse gas and mitigation of waste accumulation problems (Cigolotti [9]).

Despite this, however, biomass waste, which is available in abundance in the Asian emerging economies, remain basically unused or underutilized. This not only poses major disposal problems but also raises grave environmental concerns. It is thus argued that optimizing the use of biomass waste for energy production serves as a crucial means of mitigating fossil fuel scarcity problem while also promoting environmentally sustainable development. This will be systematically demonstrated based on a case study in the state of Sarawak in Malaysia.

4 Palm oil waste: some basic facts

Palm oil is the most important commercial agricultural crop in Malaysia. Currently, Malaysia is the second largest palm oil producer and exporter in the world after Indonesia, accounting for about roughly 32% (19.8 million tons) of global production level in 2014, with exports of 17.2 million tons in the same year (Index Mundi [10, 11]). The palm oil planted area as of 2014 was 5.39 million hectares (MPOB [12]). It may be noted that Indonesia's production level in the same year was 33 million tons, or 53.5% of global production level. It exported 22.5 million tons of palm oil in the same year. The positive annual growth rate of palm oil production also resulted in substantial production of biomass waste and residue in the palm oil industrial sector.

For the purpose of analysis, palm oil biomass comprises the following: (i) empty fruit bunches (EFB), (ii) palm kernel shells, (iii) mesocarp fibres which are derived from the palm oil production process. The palm oil industry also generates substantial amounts of liquid waste in the form of palm oil mill effluent (POME). POME is a brownish, concentrated and acidic liquid discharge. It is also a potent source of methane emission when it undergoes an anaerobic process, contributing to regional warming. If it is put to sustainable use, its high organic content provides one of the most promising sources of renewable energy in the form of biogas (methane) for bioenergy generation (Chin *et al*. [13]).

It is thus clear from the above that optimizing the use of biomass from the palm oil industry in Malaysia has great potential to contributing towards greening its energy-mix system, which is heavily dependent on the use of fossil fuels, and towards increasing security in the power generation sector. It may be of passing interest to note that in 2012, natural gas and coal contributed 46% and 41% respectively to the electricity generation mix in the country (Energy Commission [14]). It would also result in the reduction of waste product disposal from the mill. This will be discussed based on a case study in the state of Sarawak.

5 Greening the palm oil industry in Sarawak: the bioenergy potential

Sarawak is the largest state in Malaysia with an area of 124,450 square kilometres. The palm oil industry is one of the most important sectors underpinning the Sarawak's robust economic growth. It has expanded rapidly from about 54,790 hectares (ha) to about 1.26 million ha in 2014, and is expected to cover two million ha by 2020 (MPOB [15]). The rapid expansion of the palm oil industry in the state offers a promising opportunity for greening its environment and reducing its dependence on fossil fuel for power generation.

The amount of solid waste generated from each tonne of fresh fruit bunch (FFB) processed as shown in Table 1 contains energy which can be recovered by combustion in a boiler while POME produced may be captured for its energy-containing biogas, methane, for bioenergy generation.

Table 1: Solid and liquid waste produced per tonne of fresh fruit bunch (FFB) processed.

Biomass waste	**kg**
Empty fruit bunches	220
Palm nut shell	55
Mesocarp fibre	130
Palm oil mill effluent (POME)	650

Source: Sarawak Energy [16].

Based on the above, it is possible to compute the energy potential for palm oil waste in Sarawak (Table 2).

Table 2: Energy potential analysis of major palm oil solid waste in Sarawak.

Column		**1**	**2**	**3**	**4**	**5**	**6**	
	Moisture content (MC) (%)	**Fraction of FBB (%)**	**Net calorific value (MJ/tonne)**	**Steam energy (MJ/tonne of FFB)**	**Mill steam use (MJ/tonne FFB)**	**Turbine efficiency (%)**	**MJ/tonne FFB**	**Electricity /tonne FFB (kWh)**
Empty fruit bunches (EFB)	**60**	**23**	**5,300**	**1036**	**324**	**30**	**214**	**59**
Palm nut shell	**37**	**13**	**11,100**	**1227**	**384**	**30**	**253**	**70**
Mesocarp fibre	**12**	**6**	**17,300**	**882**	**276**	**30**	**182**	**51**
Solid waste total			**33,700**	**3145**	**984**		**649**	**180**

Note:

(a) All parameters in columns 1 and 2 are based on the information from UNFCCC (Kunak Bio-Energy Project 2921), p. 46. UNFCCC [17], EFB, palm nut shell and mesocarp fibre is around 23%, 13% and 8% by weight at its post-processing moisture content of 60%, 37% and 12% respectively. It should be noted that different moisture content results in different energy values. Prior to being used as boiler feed, EFB, for example, is typically air dried to reduce its moisture content or a screw press is used to remove oil and excess moisture to improve fuel property. The lost moisture weight means the usable fuel is only 23% of FFB by weight.

(b) Steam production in column 3 follows UNFCCC (Kunak Bio-Energy Project 2921) UNFCCC [17], at 85% boiler efficiency. To illustrate, steam energy is derived at column 1*column 2*85% (e.g. [EFB]: 23%*5,300 MJ/tone*85%=1036MJ/tonne FFB). Efficiency at 85% means the boiler is capable of converting 85% of the potential heat energy in biomass to hot steam, with 15% of the energy being lost.

(c) Steam diversion in column 4 is based on 25 out of 80 tonnes per hour of high pressure steam (31.3%) (e.g. 1036 MJ/tonne of FBB * 31.3% = 324 MJ/tonne of FBB) (McNish *et al*. [18]).
(d) Steam turbine efficiency in column 5 is assumed to be 30%, that is, it is capable of converting 30% of the heat energy in steam to electric energy (McNish *et al*. [18]).
(e) Energy output (MJ/tonne FFB) in column 5 is calculated based on steam energy (MJ/tonne of FFB) - Mill steam use (MJ/tonne FFB) X Turbine efficiency (30%) (e.g. 1036 MJ/tonne of FBB-324 MJ/tonne of FBB * 30% = 214MJ/tonne FFB while kWh is based on online conversion table.

Following the above, it is possible to estimate the energy potential of the palm oil industry in Sarawak (as shown in Table 3).

Table 3: Energy potential of the palm oil industry in Sarawak, Malaysia.

Basic information		Residual materials produced per tonne of fresh fruit bunch (FFB) processed		Total amount of residue materials produced in 2014	Electricity /tonne FFB (kWh)	Energy potential (kWh)	Fossil-fuel saving potential (tonne of oil equivalent
		Waste category	tonne				
Total planted area (2014)	1,263,391ha	Empty fruit bunches (EFB)	0.22	4,483,269	59	264,512,889	22,744
FFB yield per tonne per ha per year (2014)	16.13 per tonne/ha/yr	Palm nut shell	0.06	1,222,710	70	85,589,687	7,359
Total FFB yield (2014)	20,378,497 tonnes	Mesocarp fiber	0.13	2,649,205	51	135,109,434	11,617
		Palm oil mill effluent (POME)	0.65	13,246,023	26	344,396,596	29,613
Grand-total				21,601,207		829,608,606	71,333

Source of data: Leong [19], Malaysian Palm Oil Board [12].

It is increasingly clear from the above that the palm oil industry in Sarawak can be an important source of alternative energy that not only contributes to enhancing energy security by reducing its dependence on fossil fuel for electricity generation but also helps to promote environmentally sound waste and pollution control systems. It is also clear from Table 3 that optimizing the energetic use of palm oil waste allows Sarawak to generate more than 829,000 kWh (about 71,000 toe), and at the same time helps to mitigate its waste disposal problem. More importantly, given that every tonne of treated POME releases an average of 5.5 kilogram (kg) of methane (Yacob *et al*. [20], Madaki and Lau [21]), recapturing the biogas for energy generation serves as an important means of reducing greenhouse gas emission by 72,853 tonnes per year. Here, it is relevant to note that methane is 25 times more powerful than carbon dioxide as a global warming gas.

Extrapolating the Sarawak's case study to Malaysia as a whole, with a total palm oil cultivated area of more than 5 million ha with an average FB yield at 17.3 per tonne per year (MPOB [12], the amount of energy generated is about 3.7 million kWh or 323,000 toe and greenhouse aversion impact amounting to approximately 333,500 tonnes of methane or 8.3 million tonne of CO_2 equivalents (see Table 4).

Table 4: Energy potential analysis of major palm oil solid waste and POME in Malaysia.

Basic information		Residual materials produced per tonne of fresh fruit bunch (FFB)		Total amount of residue materials produced in 2014 (tonne)	Electricity /tonne FFB (kWh)	Energy potential (kWh)	Fossil-fuel saving potential (tonne of oil equivalent, toe)
		Waste category	tonne				
Total planted area (2014)	5,392,235 ha	Empty fruit bunches (EFB)	0.22	20,522,847	59	1,210,847,945	104,114
FFB yield per tonne per ha per year (2014)	17.3 per tonne/ha/yr	Palm nut shell	0.055	5,130,712	70	359,149,814	30,881
Total FFB yield (2014) (ton	93,285,666	Mesocarp fibre	0.13	12,127,137	51	618,483,966	53,180
		Palm oil mill effluent (POME)	0.65	60,635,683	26	1,576,527,755	135,556
Grand-total				98,416,378		3,765,009,480	323,731

Applying the Malaysian case study to the Indonesian palm oil industry, the environmental benefits accrued are even more impressive (Table 5).

Table 5: Energy potential analysis of major palm oil solid waste and POME in Indonesia.

Basic information		Residual materials		Total amount of residue materials produced in 2014 (tonne)	Electricity /tonne FFB (kWh)	Energy potential (kWh)	Fossil-fuel saving potential (tonne of oil equivalent, toe)
		Waste category	tonne				
Total planted area (2014)	8,000,000 ha	Empty fruit bunches (EFB)	0.22	39,600,000	59	2,336,400,000	200,894
FFB yield per tonne per ha per year	22.5 per tonne/ha/yr	Palm nut shell	0.055	9,900,000	70	693,000,000	59,587
Total FFB yield (2014) (tonnes)	180,000,000	Mesocarp fibre	0.13	23,400,000	51	1,193,400,000	102,613
		Palm oil mill effluent (POME)	0.65	117,000,000	26	3,042,000,000	261,564
Grand-total				189,900,000		7,264,800,000	624,658

Note: FFB yield per tonne per ha per year is based on the average of FFB yields of 23.5 $t\,ha^{-1}$ in Sumatra and FFB yields of 21.5 $t\,ha^{-1}$ year in Kalimantan (Harsono *et al.* [22]).

As demonstrated clearly in Table 5, the amount of energy Indonesia may recover from palm oil waste is approximately 7.3 million kWh or 624,000 toe, and the amount of greenhouse gas aversion is about 643,000 tonne of methane or 16 million tonnes of CO_2 equivalents. Assuming that Malaysia and Indonesia adopt zero-emission measures in the palm oil industries by optimizing the full use of palm oil waste, this can serve as a potential, albeit not exclusive, solution to fossil fuel scarcity and environmental sustainability as shown in Table 6.

Table 6: Environmental and energetic benefits of palm oil waste in Malaysia and Indonesia combined.

	Malaysia	Indonesia	Total	Remarks
Energy potential (kWh)	3,765,009,480	7,264,800,000	11,029,809,480	promoting energy security
Fossil-fuel saving potential (tonne of oil equivalent, toe)	323,731	624,658	948,389	mitigating fossil fuel depletion problem
Palm oil mill effluent (POME) (tonnes)	60,635,683	117,000,000	177,635,683	mitigating waste disposal problem
Major solid waste (tonnes)	37,780,695	72,900,000	110,680,695	mitigating waste disposal problem
Methane emission (tonnes)	333,496	643,500	976,996	mitigating greenhouse gas emission problem
Methane emission (CO2 equivalent) (tonnes)	8,337,406	16,087,500	24,424,906	mitigating greenhouse gas emission problem

6 Palm oil waste, resource scarcity and environmental sustainability: the implications

Undoubtedly, fossil fuel resources, especially oil, will continue to dominate the global energy mix. Oil is the major hydrocarbon resource that poses an ultimate constraint to sustaining long-term economic growth and human progress. This is because there is no immediate viable substitute for oil as a dominant energy source in terms of its intrinsic qualities of extractability, transportability, versatility and cost (Singhania *et al*. [23]). Close to 40 percent (or 152 quadrillion BTUs) of the global energy consumption is based on oil and no other fuel source holds as much energy as oil. For instance, it holds 1.3 to 2.45 times more economic value per kilocalorie than coal (Hanson [24]). It may be noted in passing that 1 quadrillion BTUs (British thermal units) is equivalent to about 180 million barrels of oil or 500,000 barrels per day for one year.

Oil is also useful in other ways. It is an essential input in many of the production chains or economic activities but its long-run supply capacity is fixed and finite. Thus continued exploitation necessarily leads to depletion once it reaches its peak production level. Examples of global oil fields which have reached their peak oil production levels include the Lower 48 States and East Texas oil fields in the United States, and the major North Sea oil fields in the United Kingdom and Norway (Zittel [25], Mearns [26], EIA [27], British Petroleum [28]).

To sum up, the long-term availability of oil is dictated by the entropic law of decay and dissipation, geological constraints, and the peak oil phenomenon as elucidated above. This will prove to be the ultimate resource constraint to long-term economic growth and human wellbeing amidst surging energy demand in the emerging Asian economies especially China, India and Southeast Asia (IEA [29]).

The above exposition is sufficiently indicative to fortify the search for alternative sources of energy, not as a substitute for oil but as a buffer against the continued and unabated stress of rapid and irreversible oil depletion caused by increased population and the fervent pursuit of economic growth and high consumerism especially in the Asian fast developing countries including China and India, and Southeast Asia.

The Malaysian case study highlights the fact that harnessing the energy potential of biomass waste offers a critical mitigating solution against ultimate fossil fuel resource constraint. It also serves as an environmentally benign energy option to reduce waste disposal problems which at the same time reduces greenhouse gas emission. Implicitly, viewed from the Asian perspective, it is without question that optimizing the use of the mostly unutilized biomass in the Asian emerging economies including China and Southeast Asia offers one of the most strategic means to address the fossil fuel-induced socio-economic quagmire.

Implicitly, given that globally about one billion tonnes of biomass from different sources is produced annually (Agamuthu [30]), optimizing the use of this huge amount of fossil fuel-saving waste is undoubtedly environmentally sustainable. Take the case of China which annually generates about 650 million tonnes of agricultural residue, straw and forest waste, 50 percent of which can be utilized for bio-energy production. However, a large portion of these resources is still largely unused or burned in the field, causing severe environmental problems (BE Sustainable [31]). A more serious observation is that only about five percent of the total biomass potential is being collected on a systematic basis despite the fact that if all the usable biomass waste was optimized for its energy potential, it would create 1.2 billion tonnes of coal equivalents (tce) or 0.84 billion tonnes of oil equivalent (toe) (Klimowicz [32]).

Similarly, Southeast Asia also has a huge biomass potential from various biological sources including rice husk, wood residue, bagasse and palm oil waste. For example, rice mills in the region generate about 38 million tonnes of rice husk and 30 million cubic meters of woody biomass annually. This mostly untapped biomass may be used for power and heat generation. Also, the sugar mills in Thailand, Indonesia, the Philippines and Vietnam generate roughly 34 million tonnes of bagasse every year which can also be utilized to generate electricity.

Conceivably, with the future of the global economy hinging on the continued availability of the finite and depletable fossil fuel resources, adopting the environmentally benign "waste to energy" strategy offers an inexorable solution to mitigate the entropic hydrocarbon resource depletion problem. Optimizing the sustainable use of biomass waste also serves to protect the sink capacity of our biosphere from the cumulative environmental impacts of the ever increasing volume of waste disposal.

7 Concluding remarks

The entropy law imposes a long-run absolute scarcity on the availability of the exhaustible fossil fuel resources, in particular oil and natural gas, which the deployment of advanced resource extraction technologies, the introduction of backstop technology, resource substitution, and exploration cannot reverse. Given the finiteness of these resources as well as the limited capacity of our terrestrial biosphere to absorb greenhouse gases, this paper demonstrates that harnessing the energy potential from biomass such as palm oil mill waste can play an important role in enhancing energy security, at the same time mitigating the imminent threat of hydrocarbon resource depletion, and waste disposal and management problems. Increasingly, the present case study has far reaching implications for the greening process of rising biomass waste streams across the globe especially in the fast developing Asian economies.

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Analysis used for the installation of an IFMSW processing center for cement plants in the state of Hidalgo, Mexico

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Abstract

In the last few years, municipal solid waste has become a very important issue in many countries, especially Mexico. Waste has evolved during the last decades as regards both volume and composition, mainly because of population growth, changes in consumption habits and an inefficient management by the local environmental authorities and society itself, leading to negative impacts on several environment areas such as underground and surface waters, air and soil. In order to prevent environmental contamination, it is necessary to install a waste management infrastructure that fulfills standard requirements. This document discloses the analysis conducted to select sites that fulfill standard technical and environmental requirements based on a multi-criteria evaluation of the geographic information systems for installing a processing center for the inorganic fraction of municipal solid waste in the state of Hidalgo. Currently, there are few centers of this type in Mexico and most of them do not comply with these requirements leading thus to inefficiencies.
Keywords: waste management infrastructure, multi-criteria evaluation, geographic information systems, inorganic fraction of waste, state of Hidalgo.

1 Introduction

In Mexico, over 102, 000 tons of Municipal Solid Waste (MSW) are generated daily, 2% of it being generated in the state of Hidalgo (equivalent to 1,870 t/day), mainly from housing, parks, gardens and public buildings INECC [1]. The MSW management infrastructure in the state is traditional and waste is disposed of in open dumping sites. Most of the times, the recovery of useful materials is made by very low income people working in unhygienic conditions. Moreover, waste is very often incinerated because of the lack of municipal sanitation services. This situation places the state of Hidalgo in an unfavorable position in the handling and use of MSW compared to the other states of the Mexican Republic (Sánchez [2]).

The main obstacle for an appropriate management of MSW relates to the infrastructure required for handling waste that, depending on their physical and chemical characteristics, may potentially be recovered. There is thus a need to build an appropriate infrastructure for the various activities of the waste management chain including collection centers, selection plants, processing centers and final disposal sites.

In parallel with management and harnessing of waste, concrete is the second most consumed material in the world after water and its main component is cement. The cement manufacturing process requires intensive use of fuels. In Mexico, since 2011, the cement company CEMEX has been conducting research on an alternative source of fuel, in order to save energy and lower gas emissions to the atmosphere. This alternative source of fuel is the Inorganic Fraction of Municipal Solid Waste (IFMSW). In order to tap this energy, it is necessary to separate the waste (especially the waste having a high calorific power), or any fuel material derived from MSW, in an IFMSW, submit them to a thermal treatment, especially co-processing, which is of great interest to the cement companies.

In this context, this work analyzes the installation of an IFMSW processing center in the state of Hidalgo to mitigate the negative environmental impacts caused by the disposal of waste in landfills or open dumping sites and to permit the recycling and use of the inorganic fraction as a source of alternative fuel through co-processing.

2 Waste regulations and management in the state of Hidalgo

2.1 Regulations

Mexican environmental regulations govern the location, building, operation and closure of MSW final disposal sites as well as the sites where Waste requiring Special Handling (WSH) and dangerous waste is confined. At state level, only the state of Mexico has a standard containing the requirements and specifications for the installation, operation and maintenance of the infrastructure for the collection, transfer, selection and use of MSW. In the specific case of the state of Hidalgo, there is no robust legislation regulating the installation and operation of MSW processing centers or selection plants.

This work includes standardized environmental criteria, a compilation and analysis of most of the current restrictions in the Mexican regulations (laws, standards, rules and criteria) as regards the building of infrastructure related to the selection and processing (energetic valorization) of MSW; as well as technical criteria, restrictions as regards topography (land slopes), access and transportation roads and origin of the waste.

The following Mexican standards were considered to establish the location of the IFMSW processing center: Mexican official norm for the building and operation of final disposal sites (NOM-083 [3]); the manual related to the installation of transfer stations (Sánchez *et al.* [4]); the manual of technical criteria for the location, operation and closure of environmental infrastructure for collecting, transferring, separating and treating Municipal Solid Waste and Waste requiring Special Handling (SEMARNAT [5]); the technical standard related to the requirements and specifications for installing and operating collection, transfer, separation and treatment centers for MSW and WSH in the state of Mexico (NTEA-010 [6]); and the environmental standard establishing the criteria and technical specifications under which the separation, classification, selective collection and storage of waste in Mexico City must be conducted in order to promote its use and prevent its generation (NADF-024 [7]).

2.2 Current situation in the management of the RSU

Solid waste management in the state of Hidalgo faces many difficulties, such as inappropriate separation, limited environmental culture, social resistance to the building of infrastructure for handling and using MSW and lack of economic resources for installing said infrastructure. The state is formed by 84 municipalities with 4,596 settlements and a population of 2,826, 650 inhabitants. Figure 1 shows the projection of MSW generation for the year 2,045, based on data from the year 2015 (estimates calculated by the arithmetic method) in the municipalities of Hidalgo having over 45, 000 inhabitants (INEGI BII [8]). Mineral de Reforma and Pachuca are the municipalities that will be generating most waste in 2,045.

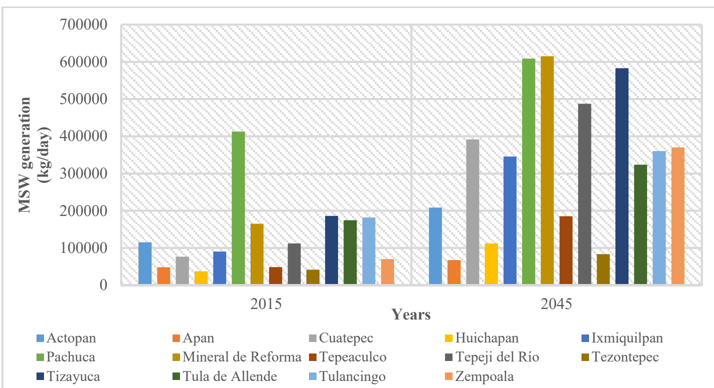

Figure 1: Projection of waste generation in the municipalities of Hidalgo.

The average percentage composition of the waste generated in Hidalgo is as follows: organic waste (food and garden waste): 34%; recoverable waste (cardboard, tetra-pak, metals, paper, plastic, glass, PET, PEAD, amongst others): 30%; non-recoverable waste (basically various materials such as plastics, rubber, sanitary paper, diapers, cardboard and textiles): 36% (PEPGIR [9]).

2.2.1 Infrastructure of management and harnessing of MSW

Most of the waste handling sites and cement plants are located in the southeast of the state of Hidalgo. This was the first criterion taken into account to delimitate the study area to propose the optimal location of an IFMSW processing center.

3 Energetic valorization of the solid waste as alternative fuels

Mostly, alternative fuels are agricultural waste or by-products of industrial, domestic, agricultural and forestry processes, including used tires and oils, IFMSW, processed biomass such as rice and coffee husks, sewage sludge, amongst others. Alternative fuels generate several benefits for the environment, such as the reduction of the use of non-renewable conventional fossil fuels, the provision of an ordered, final and ecologically responsible solution to waste disposal that leads to the prevention of landfills saturation, the reduction of the emission of greenhouse gases to the atmosphere and, above all, its use as energy source.

IFMSW is obtained selecting waste that cannot be recycled because they are contaminated or too small. Said waste include glass, PET, aluminum, paper, cardboard, etc. as well as hospital waste and waste requiring special handling that cannot be further treated such as diapers, batteries, syringes, metals, among others. This selection process leads to the obtainment of two mixtures of organic waste: one having a faster degradation speed and another having a slower degradation speed, known as IFMSW. It is separated, compacted and wrapped to be then used as alternative fuel in cement kilns. Because the amount of the ash generated by the combustion of the IFMSW is minimal, it is possible to incorporate it into cement manufacturing process. It is noteworthy to mention that the composition of the oxides of the ash that is compatible with the composition of the clinker, which closes the co-processing cycle and does not affect the quality of the properties of the raw material of the cement.

3.1 Co-processing in cement kilns

Cement manufacturing is an energy-intensive process because of the high temperatures it requires.

The energy consumption depends in part on the raw materials used, but mainly on the technology and the feeding system employed, wet feeding systems requiring the evaporation of the water introduced with the raw materials. Under these circumstances, fuel consumption in the clinker rotary kiln ranges from 700 to 1,300 kcal/kg of clinker (from 3,000 to 5,500 MJ/t), which is equivalent to 100 to 185 kg of coke per ton of cement. Traditionally, this energy has been supplied by various fossil fuels such as oil, coke, coal, fuel oil and natural gas (Cedano [10]).

The difference between co-processing and conventional incineration is that, in the case of co-processing, both the energy and the minerals present in the waste is used. This is because the high temperatures (approximately 2,000°C) and a residence time greater than 5 seconds generate a self-cleaning process of the gases in an alkaline atmosphere, so that the ashes can be integrated to the cement manufacturing process. On the other hand, waste incineration produces ashes that have to be further treated, and generates polluting gases that are emitted to the atmosphere because of an inappropriate process control (Rojas-Valencia and Marín [11]).

Before using alternative fuels, it is necessary to process them in order to limit their contents of given elements such as organic matters, chlorine, heavy metals, among others. This is done to ensure that they will not negatively impact the process itself, or the quality of the final product, or the environment. Moreover, an energetic valorization as well as a strict quality validation must be performed.

3.2 MSW calorific value

Waste is an important source of energy the calorific value of which can be used through thermal processes such as incineration and co-processing or through the use of biogas from landfills and anaerobic digesters.

An important factor for the generation of energy from MSW treatment is the energetic content or calorific value that indicates the quantity of heat that a body may emit to determine whether the waste is suitable for producing energy or will only consume a greater amount of energy and make the process less profitable.

Because of this, thermal treatments must always be accompanied by MSW pre-treatment or processing in order to obtain the waste fraction of interest. The objective of this material conditioning is to use the higher percentage of waste that comply with the treatment requirements. The calorific value may vary depending on the waste. However, it is not only the calorific value which is relevant but also the mineral content (ash) of the waste. Through combustion, a MSW volume reduction comprised between 85 and 90% is obtained (Choy *et al.* [12]). Most MSW can be used as a fuel option in kilns because although their minimum calorific value is 10.70 MJ/kg, which is lower than commonly used fuels, their calorific value vs volume ratio must be taken into account. Table 1 shows a comparison of the most representative calorific values, of both commonly used fossil fuels and waste according to Rojas-Valencia and Marín [11].

Table 1: Calorific values of MSW vs. fossil fuels.

Commonly used fossil fuel	**Calorific value (MJ/kg)**	**Collected waste**	**Calorific value (MJ/kg)**
Coke	33.49	Mixed plastics	32.70
Natural gas	48	Cardboard	26.20
Fuel oil	44	Textiles	18.30
Coal	29	Mixed paper	15.70
Lignite	20	MSW	10.70
		Mixed food	4.20

The calorific value of the combined MSW is 6 to 14 MJ/kg. The total energy content of waste is exploited more efficiently through thermal processes. During combustion, energy is obtained directly from biomass sources (waste paper, wood, natural textile material and food) and fossil coal (tires, plastics and synthetic textile materials) (Queiroz *et al.* [13]).

The quantification of the calorific value has been performed on several samples from IFMSW bales arriving at CEMEX plant in Huichapan, Hidalgo. The quarter method was used to obtain 1.0 g of IFMSW compound sample and analyze its calorific value.

Five samples were taken from various bales in July and September. The results obtained are shown in Table 2. Variable calorific values are obtained because of the different types of waste that the selected sample may contain and the various climatological conditions. The average value was 18.26 MJ/kg.

Table 2: Results of the analysis of the calorific value performed on samples from IFMSW bales.

Date of obtainment of the sample	Calorific value (cal/g)	Calorific value (MJ/kg)
03-July-15	4,300	18.00
06-July-15	4,104	17.18
10-July-15	4,316	18.07
18-September-15	4,850	20.31
21-September-15	4,232	17.72

3.3 Processing systems to generate IFMSW bales

The processing systems have been designed to be located in strategic places taking into account environmental, social and economic aspects. Mobile or fixed plants may be available. Mobile plants are installed for a given period of time at the origin of the materials to be used as alternative fuels, carrying out the sanitation of a specific site, one at a time. The fixed processing systems allow practical improvements in the MSW management leading to a better use of the waste in different areas, such as recycling and alternative fuels in cement kilns.

Figure 2 shows a model of the proposed infrastructure for the IFMSW processing center (fixed) to process the MSW generated in the state of Hidalgo. First, the waste is transported from different disposal sites or towns through garbage trucks. Then, they are deposited in a reception pit and placed in a hopper to be transported and processed through two selection lines to various reduction, separation and compaction equipment. Processing starts with a pre-grinding to break bags, then the waste go through trommeles that separate the fermentable organic materials from non-fermentable materials, known as the inorganic fraction that is in turn submitted to a manual selection to separate the recyclable materials (PET, cardboard, glass, metal, leather, paper, wood, etc.) that are compacted to be transported to recycling companies or collection centers. The ferrous waste that may still be in the selection line are separated from the remaining (rejected) inorganic fraction through magnetic separators. Finally, the rejected IFMSW are compacted and wrapped in stretch plastic film to form bales that optimize their handling and transportation to the cement plants.

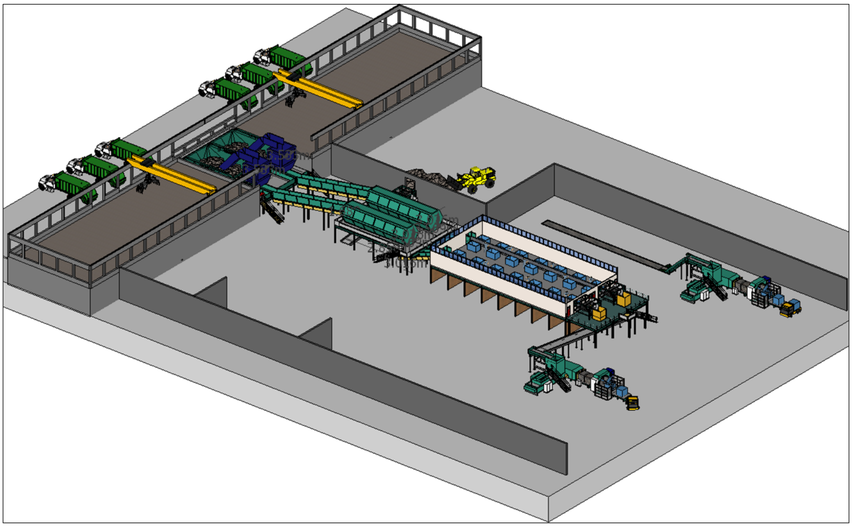

Figure 2: Model of the infrastructure of the IFMSW processing center (fixed).

The capacity of the IFMSW processing center in 20 years based on the projection and composition of the waste generated in Hidalgo is 2,474 t/day and its infrastructure would require a total surface of about two hectares. The plant will process 120 t/h and operate two selection lines, 20 working hours per day divided in 2 shifts. The estimated total cost of the installation and commissioning of each one of the lines is $62, 388, 558.00 MXN. The cost estimate was jointly established with the company MASIAS RECYLING from Spain.

4 Evaluation and selection of the optimal site for installation of the IFMSW processing center

In various zones of Mexico, infrastructure for the MSW management is available. However, in most of the cases, the plants operate in inappropriate conditions, generating health risks and damages to the environment. This is due to the lack of an appropriate legal and technical framework in the states of the republic and in other cases their functioning is inefficient because a determination of the optimal location in environmental, technical and economic terms was not performed.

Geographic Information Systems (GIS) are important supporting tools to generate maps, environmental and land use planning. These tools are important because besides permitting to manipulate environmental and technical variables, they incorporate GIS-based procedures with georeferenced information, and the decision making is reinforced by the opinion and validation of experts in the development and application of the information through various techniques (Olivas *et al.* [14]).

In Mexico, as well as in other parts of the World, there exist previous experiences in which procedures have been used with GIS tools to locate the places considered for building transfer stations (Araiza [15]) and centers for waste recovery (Roé *et al.* [16]). However, they have not been used for locating the optimal sites for the installation of an IFMSW processing center.

4.1 Multi-criteria evaluation to determine the most suitable areas for the location of the IFMSW processing center

For the evaluation of the location criteria, various methods are available, not only to identify potential areas for MSW management but also for the location of other type of infrastructures such as hydroelectric stations, ports, highways, among others. One of the most commonly applied methods is the Multi-Criteria Evaluation (MCE) that uses GIS for its implementation (Herrera [17]). MCE refers to a group of decision-making operations, taking into account simultaneously several criteria or conditioners. The proposed method facilitates suitability grading and differential weighting of the criteria in the final decision. MCE in a GIS environment implies the use of geographic data and the manipulation of the information according to defined decision rules. Moreover, indicators linked to environmental and technical criteria must be taken into account (De Pietri *et al.* [18]).

The study area is the south of the state of Hidalgo (see Figure 4). The main waste handling sites and cement plants were previously located and georeferenced. It was found that all of them were in the southern part of the state and the study area was defined based on this information.

4.1.1 Approach and development of the MCE in the GIS environment

The approach consisted in the application of one of the most studied MCE techniques, denominated "Hierarchical Analysis Process" (HAP) to determine a group of suitable preliminary areas where the IFMSW Processing Center could be located. This technique was chosen mainly because it permits to identify the parts forming the system as well as their links, acknowledging the weight of each one of the parts and proposing a rational solution.

Satty, the creator of the technique, indicates that HAP consists of dividing a complex problem or situation into its parts or variables, performing a hierarchical order arrangement to assign numerical values to each part according to subjective judgments based on the relative importance of each part or variable, so as to synthesize them to determine the ones of greater priority (Satty [19]).

The hierarchical scheme usually consists of three basic levels: main objective, decision criteria (usually accompanied with specific criteria), and solution alternatives. Its mathematical formula is given in equation (1).

$$\boldsymbol{R_i = \sum_k w_k r_{ik}} \tag{1}$$

wherein "W_k" is the priority (weight) vector associated to each element "k" of the criteria hierarchical structure. The sum "W_k" is equal to 1 and "r_{ik}" is the priority vector obtained upon comparing the alternatives with each criteria.

Before applying an MCE technique to a SIG environment, it is important to establish the criteria that will impact the reception capacity of the territory (Gómez and Barredo [20]). The location criteria (general criteria) used in this work were divided into three parts: environmental, socioeconomic and technical criteria. In turn, the so called general criteria were divided into specific criteria and organized according to two aspects: “factor and constraints”, the “factors” being the variables that must have more than two categories or levels, while the “constraints” may have a maximum of only two levels.

4.1.2 Criteria weighting and standardization

To perform the general and specific criteria weighting (Wgc and Wsc), the pair comparison developed by Saaty [19] was modified. The relative importance scale with values ranging from 1 to 9 was not directly used, but was substituted by the percentage scale. Table 3 shows the example of the environmental criteria, in which is shown how these values are.

For the standardization of the levels (SL) of the specific criteria, a simple weighting of values from 1 to 3 was applied to the factors and from 0 and 1 to the restraints; wherein the smallest value indicates the least favorable condition, while the highest value indicates the most favorable condition.

Table 3: Weighting and standardization of environmental criteria.

Wgc	Specific criteria	Wsc	Description		SL
0.35	*Water bodies and streams*[1]	0.25	The surface water bodies and streams and, above all, the ones of continuous flow must be at least 500 m away from the location of any MSW handling infrastructure.	> 1000 m	3
				500–1000 m	2
				< 500 m	1
	Water extraction wells[1]	0.25	The exploitation of underground water for supplying residential areas, industries, watering systems, drinking water for cattle, both in operation as well as abandoned must be at least 500 m away from the possible location of any MSW handling infrastructure.	> 1000 m	3
				500–1000 m	2
				< 500 m	1
	Soil types[1]	0.25	The permeability of a soil determines the contamination level that can be caused by a MSW handling infrastructure through leachates and other liquid waste. Sites with sedimentary soils having sand-clay characteristics will be preferred because of their low permeability.	Slow permeability	3
				Moderate permeability	2
				Rapid permeability	1
	PNAs and others[1]	0.25	The MSW handling infrastructure must not be located in protected natural areas, and other areas of relevance. The cartography published by CONANP [21] was used to generate this layer.	Outside zones	1
				Inside zones	0

[1]*Criterion based on NOM-083[3].*

Figure 3 shows the maps on which the MCE was developed. The final map was obtained through the sum of the various maps of each one of the criteria (general and specific) showing the study zone classified in four levels, based on the degree of suitability for the installation of the IFMSW processing center.

Areas classified as low suitability (5,465 km^2) predominate, mainly in the southeast and northeast of the territory, while 4,086 km^2 correspond to medium suitability areas because they are very close to zones having surface water bodies and crops.

An area of 3,122 km^2 of the study zone is highly suitable. It is mainly concentrated in a radio of 20 to 30 km to the north and northeast of the limit of the capital of the state (Pachuca, Hidalgo). Other small areas having the same level of suitability exist, but further analysis is necessary to determine feasibility.

Special attention must be given to the region which has not been shaded (restricted level) in the northern part of the study area, which was immediately rejected by the MCE technique because it corresponds to natural relevant zones and other smaller zones where considerable urban areas are located.

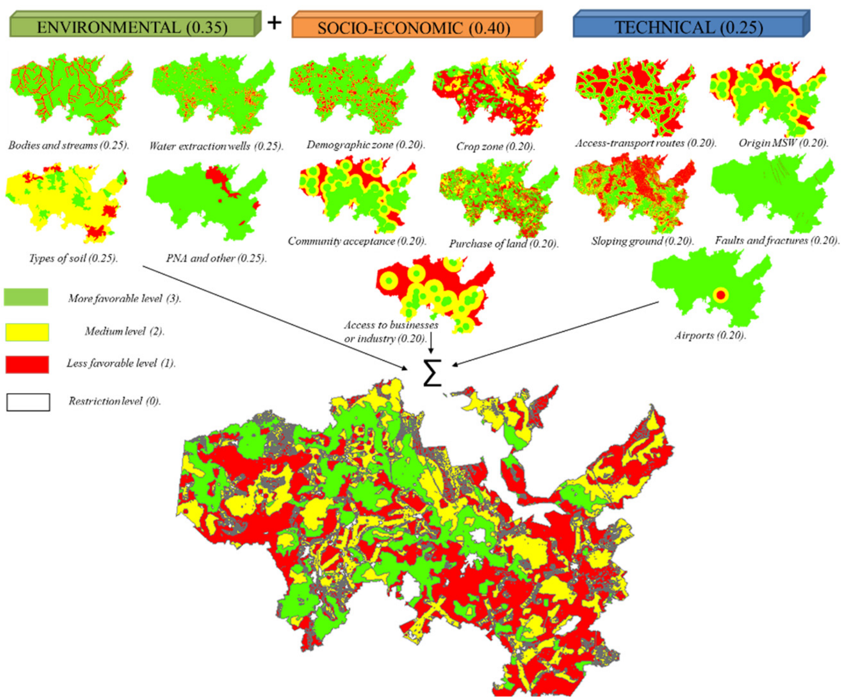

Figure 3: Thematic maps and MCE final development.

4.2 Selection of the optimal site for the installation of the IFMSW processing center through an origin-destination analysis

MSW transportation is one of the most important aspects that has to be taken into account to analyze the economic feasibility and management optimization (collection, transfer, treatment and final disposal) of any study zone considered for locating MSW management infrastructure. Thus, it is necessary to carry out an origin-destination analysis to determine the optimal transportation route.

The objective of transportation planning is the optimal use of the road infrastructure and transportation means, and population mobility has to be factored in. It is important to consider the changes that may occur because of modifications in transportation systems. The socioeconomic characteristics of a region are valuable information to establish scenarios regarding the transportation system. These aspects are interrelated and thus changes in the characteristics of one of them automatically generate changes in the other.

4.2.1 Determination of the optimal location sites

In order to develop an origin-destination analysis, the georeferencing of the cement plants and the main MSW disposal sites (municipal and state landfills) currently operating in Hidalgo was performed by a GPS. Then, 21 preliminary optimal location points were found based on areas with a highly favorable suitability determined by the MCE and using the SIG software, ArcGis 10.2.2. Out of these 21 points, five were discarded because the long distance from the road network implied a greater investment cost to access the IFMSW processing center.

Once the 16 optimal points, the MSW handling sites and the cement plants were located, the analysis was divided in two phases. The first phase consisted of measuring each one of the distances in order to determine the shortest route from the MSW handling sites (origin) to the optimal location points (destination). The second phase was performed from the optimal location points (origin) to the cement plants (destination). Finally, the distances were multiplied by the waste transportation cost (freight), for both bulk waste transportation and processed waste transportation (IFMSW bales). The main difference with regard to waste transportation is the fact that compacted waste (IFMSW bales) permits to transport more material than bulk waste, and thus it is expected that the cost per kilogram of compacted waste will be lower.

Figure 4 shows the location of one of the three optimal points for the installation of the IFMSW processing center that were determined through the origin-destination analysis. The first point is located outside Pachuca, in the eastern region, the second one is located in the western region, also outside Pachuca and the third point is located about 14 km north of Huichapan, in the western area of the state of Hidalgo.

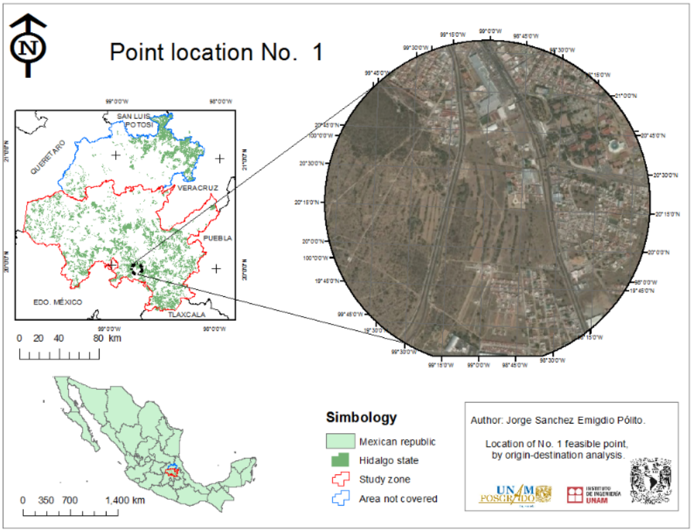

Figure 4: Location of the number one optimal point.

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Discussion about citizens' cooperation in a new waste separation rule through a social experiment on the collection of separated food waste in Toyohashi City, Japan

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Abstract

In recent years, especially since the Japan earthquake 2011, recycling and utilization of organic waste attracts attention in Japan. For example, the Ministry of Agriculture, Forestry and Fisheries (MAFF) announced "the biomass industrial town plan" to encourage local biomass industries and the reinforcement of the self-sustaining local energy supply system. In 2012, the Ministry of Economy, Trade and Industry (METI) carried out an Act on Special Measures concerning Procurement of Renewable Electric Energy by Operators of Electric Utilities and began the Feed In Tariff (FIT) that power companies have to buy the generated electricity by renewable energy for 20 years at a fixed price.

In response to such a national request, Toyohashi University of Technology, Nagoya University (later, changed to Taisho University) and Aichi Prefectural Government started an experiment to utilize biogas by methane fermentation of sewage sludge and food waste at the Toyogawa sewage disposal plant in Aichi Prefecture, in October 2011. In the experiment, biogas was used to generate electricity, and the carbon dioxide included in biogas was applied for photosynthesis to accelerate culture of vegetables and seaweed.

In this project, Tomoko Okayama (the author) of Taisho University was in charge of investigating the collection of food waste which became the raw materials for the biogas. From May to July 2014, I carried out a social experiment that approximately 400 households nearby the Toyogawa sewage plant separated food waste at the source, and the food waste was collected to the sewage plant to be anaerobic digested. I will mainly report on this social experiment and analyze

the amount of collected food waste, finally have a discussion on citizens' cooperation to separation of food waste from combustible waste at the social experiment, and provide information that will contribute to real policy making in the city of Toyohashi.

Keywords: food waste, municipal solid waste, separation of waste, social experiment, citizens' cooperation.

1 Introduction

1.1 Policies on biomass resource usage in Japan

In 2002, the Japanese cabinet approved the Biomass Nippon Strategy. Municipalities nationwide announced plans to utilize the biomass within their areas and sought the implementation of those plans. With widespread coordination among those involved in the regions, a comprehensive usage system was built, forming an efficient process from the creation of biomass to its use. The goal was to utilize biomass in a stable and appropriate way, and the plans created by municipalities and the like were referred to as "biomass town plans." By the time the biomass-town-concept announcements concluded in 2010, a total of 318 municipalities had announced plans for such towns. Additionally, the term "biomass" used here refers to organic waste (waste paper, livestock waste, food waste, wood from construction work, sawmill remnants, sewage sludge), unused biomass (rice straw, straw, chaff, timber from forest thinning), and resource crops (sugar cane, corn).

The Basic Act for Promoting the Use of Biomass was enacted in 2009, and the Basic Plan for Promoting the Use of Biomass was formulated in 2010. Furthermore, a biomass commercialization strategy was crafted at the Biomass Use Promotion Conference held by seven ministries, including the Ministry of Agriculture and the Ministry of Forestry and Fisheries (MAFF) in September 2012. Recruitment for the publicizing of the Biomass Industrial Community Plan began in 2013, and 16 municipalities have made announcements regarding the plan so far. Additionally, amendments for the Food Recycling Law were submitted in 2014, and it was decided that further advances would be made in the reduction of food waste. The use of biomass should be promoted because it is a carbon-neutral energy source and, within the category of biomass, the reuse and recycling of organic waste, which does not compete with food, deserves the most promotion.

In 2012, the Ministry of Economy, Trade and Industry (METI) carried out Act on Special Measures Concerning Procurement of Renewable Electric Energy by Operators of Electric Utilities and has begun the Feed In Tariff (FIT) that power companies had to buy the generated electricity by renewable energy for 20 years at a fixed price.

According to those laws, acts and plans, it is clearly understood that Japanese government regards food waste recycling especially heat recovery and generation by biogas as important policy.

1.2 Organic waste recycling policy: goals and issues

By weight, food waste (kitchen waste) is the most common component of municipal waste. In particular, food waste makes up a larger proportion of municipal waste in Asia than it does in Europe and North America. Further, because food waste is over 80% water, it is not suitable for disposal by incineration. Accordingly, rather than disposing of food waste as combustible waste through incineration, it is separated out and goes through methane fermentation, producing biogas. This is an efficient method of waste disposal in Asian cities, for biogas businesses that deal with biogas-based electricity generation and heat utilization.

One issue for the biogas industry is the fact that it requires citizens to separate food waste and to cooperate with policies in order to operate. Furthermore, in order to obtain the largest amount of energy, policies that attempt to obtain the maximum amount of cooperation from citizens are necessary. Although it depends on policy goals, aiming to maximize the food waste collected is not always necessary for running a biogas business that disposes of waste. However, if "waste to energy" is the policy goal, the government must build a structure in which as much food waste as possible is steadily collected as an energy resource.

Specific policy examples and issues are introduced below. Starting in 2017, Toyohashi City in Aichi Prefecture Japan, which has a population of approximately 380 thousand people, will begin separately collecting food waste, which is municipal solid waste, from residences and businesses (supermarkets, restaurants, and so on). There will also be a PFI (Private Finance Initiative) business in which Toyohashi City's Nakajima Sewage Treatment Plant takes the 59 tons/day of food waste and 53 tons/day of sewage sludge collected, puts it through the methane fermentation process and generates biogas-based electricity, then carbonizes the digested sludge and sells it off. Accordingly, all citizens and businesses, such as supermarkets, will be required to separate out the food waste they generate, rather than include it with combustible waste as in the past.

For the citizens of Toyohashi, this means adopting new rules for municipal waste while for PFI businesses, it means generating electricity as part of their business in addition to waste treatment. Because the amount of biogas and electricity generated is proportional to the amount of food waste collected, PFI businesses are likely to request that the city collect as much food waste as possible. Meanwhile, Toyohashi City will commission the treatment of a daily maximum of 59 tons of food waste to PFI businesses, and it is also policy target of Toyohashi City.

2 Social experiment: separation and collection of food waste

2.1 Estimates of food waste collection amount and separation cooperation rate in Toyohashi City

For food waste generated by businesses, the available amount of food waste produced by businesses like supermarkets within Toyohashi City is estimated to be 4,700 ton/year (Aichi Prefecture Biomass Utilization Review Meeting Report, 2011), while the daily amount is estimated to be 12.8 tons. Thus, if 85% of the available amount is collected, 10.6 ton/day (metric tons per day) can be collected.

Because the average amount of food waste per capita per day is 234g/day (The current state of the trash and match in the city, Toyohashi city, 2014) and the population of Toyohashi city is 378,890 (December, 2014), the available amount of food waste generated by households is estimated to be 88.7ton/day. Thus, if 62% of the available amount is collected, 55ton/day can be collected.

Overall, an 85% cooperation rate from businesses and about 60% cooperation rate from citizens is expected in Toyohashi City. However, population of Toyohashi City is now the most and at a time when the housewives is shrinking because of the falling birth rate and the aging population, the collection target is also maximum and it is regarded that the collection amount of food waste in Toyohashi City's PFI project will be decreasing.

2.2 Overview of a social experiment for food waste collection planning

Seeing trends like those above in the national policy and Toyohashi City policy, Toyohashi University of Technology and Taisho University (author) carried out a research project called the "Toyogawa Biomass Park Project" from 2011 to 2015. The project was conducted as follows (see Figure 1). At the Toyogawa Sewage Disposal Center where is in Toyohashi City, which treats sewage from the four cities of Toyohashi, Toyokawa, Gamagori, and Shinshiro in Aichi Prefecture, sewage sludge and food waste went through methane fermentation (co-digestion). Energy was generated from the obtained biogas and the CO_2 produced was used for accelerated culture at vegetable greenhouse and seaweed greenhouse.

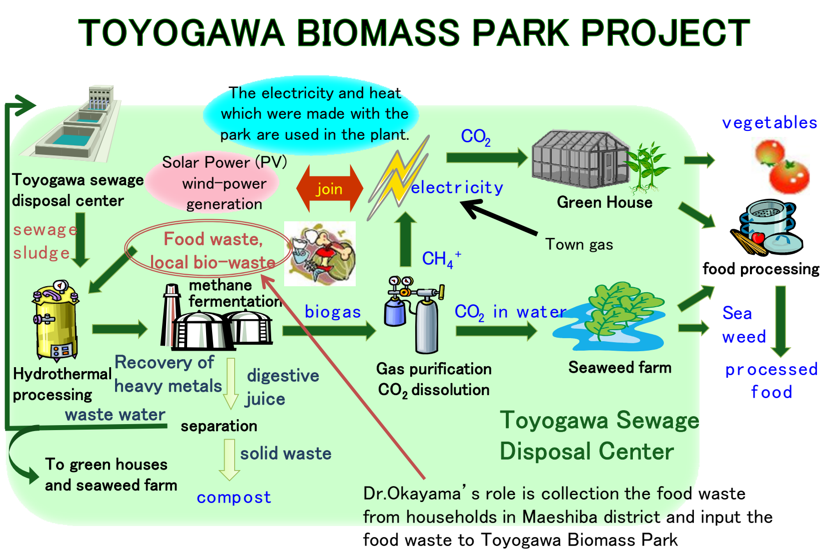

Figure 1: Research project overview and author responsibilities.

The author's role in this project was to collect the food waste from households in Maechiba district that is Maeshiba elementary and secondly school ward, and input of the food waste to Toyogawa Biomass Park. So, the author was formulating and implementing the new separation rules, namely, to collect food waste separately and to recycle the food waste. This activity was a social experiment in which, unlike normal government plans, not only the government but also others like citizens and businesses, come together to formulate food waste separation plans; then implement those plans. One goal of this social experiment was to promote effective use and recovery of heat energy related to food waste that is currently being incinerated. The second goal was to create "social capital" related to the building of a Sound Material-cycle society, in other word 3R Society. (This is nearly the same as the concept of regional environmental governance capacity in Japan's annual environmental white paper, defined as the condition in which regional stakeholders are seen to be participating and cooperating in order to solve environmental issues.) To achieve these goals, the environmental burden of the waste treatment flow would be minimized using methods such as reducing the amount of intermediate disposal (such as incineration), and to establish evidence for the adoption of waste management systems that maximize environmental efficiency. The research was to involve the area project target: the Maeshiba Community, which is made up of five neighborhood (resident) associations in Toyohashi City.

In the two-month period from May to July 2014, collection according to the new waste separation-model for household-generated food waste was implemented in the Maeshiba Community, which is the community to be the nearest to the Toyogawa Sewage Disposal Center. The collected food waste was brought into the experimental facility of the Toyogawa Biomass Park for this project, and submitted to test sampling to investigate how much biogas and electricity could actually be obtained from this food waste.

Herein, the results of this social experiment are reported, and a discussion provided about the participation rate for food waste separation, in particular. In addition, suggestions are offered for the PFI work to be started in 2017 by Toyohashi City, regarding expected separated food waste collection amounts and other issues related to separate collection of food waste implemented by Toyohashi City.

3 Methods of social experiment

The social experiment proceeded as follows. The Maeshiba Community Committee for Implementing a Social Experiment on the Separated Collection of Biomass and Food Waste (referred to as the Citizens' Committee below) was formed on 22 March 2013, and has taken the approach of making all decisions at those talks. This is a so-called citizen-participation meeting or multi-stakeholder meeting, which supports the approach of building consensus through discussions between stakeholders. The members of the Citizens' Committee include chairpersons and vice chairpersons from each resident associations, relevant businesses in the area (general waste treatment businesses, recycling businesses, and others), citizens and citizen groups in the area, the relevant local governments (Toyohashi City and Aichi Prefecture), and researchers (the author and others). The Citizens' Committee has held meetings every month since its founding.

Several social surveys were carried out by the Citizens' Committee during planning and implementation of the collection of separated food waste. First, the "Survey on Municipal Waste Separation" was given to residents of the Higashi-Mikawa area (see Figures 2 and 3), east part of Aichi prefecture in Japan in March 2013 as a web questionnaire. Based on these results, it was proposed to the Citizens' Committee that food waste and other combustible waste be put out separately on combustible garbage collection days, and that Bio-dedicated bags be used for collection as the dedicated bags. Through discussion during several meetings of the Citizens' Committee, the following steps were planned. During the separated food-waste collection period (Tuesdays and Fridays from 13 May to 4 July: 16 collections) each household would receive 16 (10 L) dedicated biodegradable plastic bags. Only food waste would be put in the dedicated bags. These bags would be placed in dedicated boxes set up at specific collection stations. Other details were also discussed.

Figure 2: Location of Aichi Prefecture in Japan.

The Citizens' Committee spent the first year after its founding determining how food waste should be separately collected as described above, and then recruited participants in the area in question. Upon selecting the method for collection of separated food wastes, the research team attended neighborhood association meetings to explain the aims of the project and to ask for understanding. A questionnaire survey was done in the summer of 2013, to understand how each neighborhood felt about participating in this social experiment. Ultimately, the cooperation of 385 households was obtained. In March 2014, a survey of these

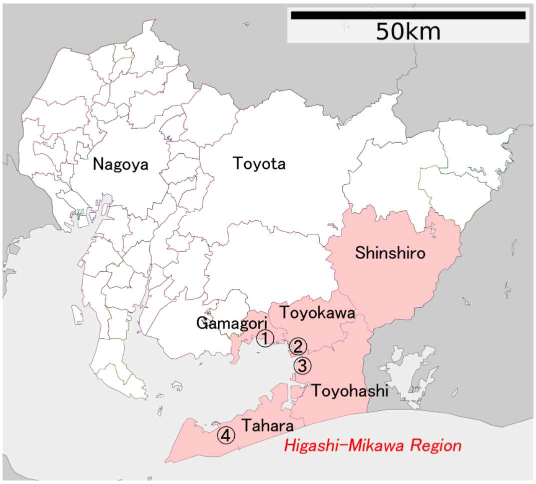

Figure 3: Sewage treatment plants locations in the Higashi-Mikawa region.

385 households was conducted prior to the social experiment. After this, the dedicated food-waste bags and a "Food Waste Separation Manual" summarizing separation and collection methods were created, and then distributed to the 385 households through the resident association presidents in April 2014, immediately before the social experiment began. Upon completion of the social experiment, a retrospective survey of the 385 households was conducted from July 2014. These results revealed citizen awareness and opinions about separation of food waste.

In addition, detailed combustible waste composition surveys of the area were conducted in the summer and winter of the year before the social experiment (2013), and detailed combustible waste and separated food waste composition surveys were conducted in 2014 while the social experiment was in progress. These results showed quantitatively the proportion of separated food waste and how the composition of general waste changed due to separation of food waste.

4 Results of the social experiment

Figure 4 shows changes in the amount of food-waste collected during the separated food-waste collection period. The average amount per collection was 296.6 kg. As the researchers had planned to put 100 kg of food waste per day into the experimental verification unit, it can be said that each collection was more than adequate. There was approximately 1 kg of misplaced materials (such as plastic bags) mixed into the approximately 300 kg from the first collection, and a trend of increasing amounts of misplaced material was observed as more collections were done. Furthermore, for reasons that are unclear, the amounts collected declined steadily until the end of the experiment.

The collected food waste was subjected to hydrothermal treatment and, while gradually increasing the mixing ratio with sewage sludge (hydrothermally treated sludge + raw sludge), the input amount was planned such that on Day 30, the ratio

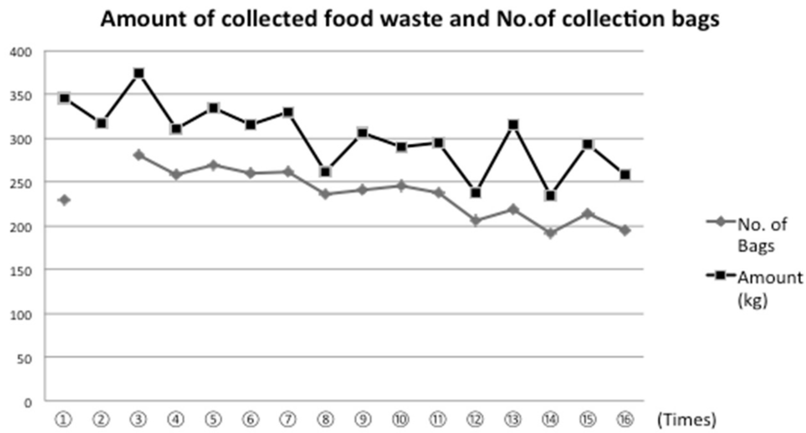

Figure 4: Changes in the amount of food waste collected during the social experiment.

of raw sludge to hydrothermally treated sludge to food waste, would be 1:1:1 inside the methane fermentation tub. As a result, 1kg of Food waste of Maeshiba community included 7g of carbon. Degradation rate is set to 80% as the premise. The methane concentration in the biogas is set to 60%, 40% is CO_2. Then methane gas of 4.48kg (about 7N m^3, 70L) can be taken from food waste of 100kg. This is equivalent to 0.07m^3 of city gas. Moreover, sewage sludge produced about half the biogas that food waste did. If 300 kg of food waste per collection were sustained, then 21 m^3 of city gas (methane) could be produced per collection, meaning that 336 m^3 of methane would have been produced from the 16 times food waste collections during the social experiment.

The questionnaire survey after the social experiment showed that satisfaction was extremely high with the methods of collecting food waste on the same day as combustible waste, collecting with dedicated plastic bags, and collecting by putting the bags in dedicated boxes. There was a small difference between the survey responses (before and after) regarding the impact of adding a fee as an incentive for separation. In the survey beforehand, 43% indicated that a difference in cost was an incentive to separate, while 41% so indicated in the survey after the experiment. Adding a fee is considered effective for improving separation rates. In addition, the percentage of people who answered that they would separate food waste if it were less expensive was 26% in the survey after the social experiment, an increase of 10%. However, the percentage of people who answered that they would always separate regardless of fees was unchanged at 43%, and this group was the largest.

The detailed waste composition survey conducted during the social experiment in 2014 showed that kitchen waste made up 45% of waste from households that do not separate food waste, while this figure was approximately 25% for households that do separate. For waste composition in which 100% of the material separated out is food waste, plant-based kitchen waste is the most common component at 80% liquid, followed by sweet at 6%, after which come rice, and bread at approximately 3% and beverages at approximately 2%. The rates of untouched food differ between households that participated in separation and households that did not separate. The percentage of food that was left without eating was 8.5% for non-separating households and 2.3% for separating households. Additionally, in interview surveys during the sampling period, it was revealed that no one-person households were participating in food waste separation.

5 Discussion

5.1 Discussion on cooperation rates with separation during the social experiment

① Neighborhood participation rate in the school district (percentage of households) 32%

Among the five resident associations in the Maeshiba Community, Nishihamacho withdrew from the experiment. Ultimately, the total number of participating households (from among the participating Maeshiba Community neighborhoods of Umeyabu, Maeshiba, Hishikino, and Maeshiba household) was 32.4% of the entire school district. The reason for the withdrawal of Nishihamacho was that the resident association president believed participating would be difficult. There are a large number of apartments and young households in Nishihamacho, and the rate of participation in the resident association is low. Meanwhile, the other four neighborhoods are older and the rates of participation in their resident associations are high. However, in the city as a whole, situations like that in Nishihamacho are actually common.

② Participation rates according to an intention survey 48%.

From July to August 2013, a survey on intent to participate in the separated food waste social experiment was provided to 810 out of 840 households. From these, 598 intention forms were received (a return rate of 74%), and of these, intent-to-participate was received from 385 households. The participation rate for all households in the four neighborhoods (distribution number) was 47.5%, while the intent-to-participate rate out of the number of intention forms was 64%.

③ Participation rate based on the number of bags collected during the social experiment 61%.

During the social experiment, an average of 236.5 bags was picked up per collection, 61.4% of the 385 bags distributed.

④ Participation rate based on the amount of food waste collected during the social experiment 55%.

If 1400 g of food waste were collected from 385 households per collection (assuming waste production of an average of 400 g/d per household, with one collection picking up 3.5 days' worth of waste), approximately 540 kg could be expected per collection. However, the actual collection amount was 296.6 kg per collection, 54.9% of the expected value.

⑤ Participation rate based on an interview survey 55%.

According to an oral survey conducted at Maeshibacho Station on 27 June 2014, out of 36 households who responded that they were participating in the separated food waste social experiment, 20 households (55%) were actually separating out the food waste they generated.

⑥ Participation rate based on the questionnaire return rate 54–58%.

The number of valid responses to the survey questionnaire returned before the experiment (conducted in March 2014) was 225, a return rate of 58%. The number of valid responses received from the retrospective questionnaire (conducted July to August 2014) was 208, a return rate of 54.0%.

⑦ Actual rate of separated food waste implementation (four neighborhoods) 28%.

As ④, ⑤, and ⑥ generally agree, the actual amount of cooperation with the social experiment is considered to be ~55% of households that agreed to participate. Although this figure was calculated as 61% in ③, if 225 households (58%, median 59.5%) actually participated, this means that, ultimately, the percentage that actually separated food waste in the four neighborhoods was 27.5%. Therefore, taking into account ① through ⑥ collectively, it should be safe to anticipate a cooperation rate for food waste separation of about 30–50% in Toyohashi City.

Furthermore, according to a report out of Kyoto [1], a model experiment on separated collection of food waste conducted in Kyoto from October to December 2008, and from April to September 2009, resulted in a median participation rate of 35.5%. This was based upon an estimate of model-experiment-participation households for the entire model area (estimated using the number of bags of food waste generated ÷ average number of bags generated). The ultimate participation rate was around 30% for Kyoto as well.

5.2 Opinions offered by Toyohashi City regarding collection of separated food waste

Toyohashi City plans to process approximately 50 ton of household-generated food waste daily (about 59 ton/day when business-generated food waste is added) during collection of separated food waste from 2017 on.

The amount of waste in Toyohashi City is more than the national average, the discharge of waste per person per day is estimated as with 234 g/day more than national average, too (Toyohashi city, 2014). So if the food waste produced per household per day were, accordingly, 612 g (average number of family was 2.615 in 2014), 44 ton/day could be reached with a 50% cooperation rate. However, if the cooperation rate were 30%, an approximate daily amount of 29 tons could be expected. If about 50% of business-generated food waste were collected, that means that 6 ton/day could be collected. When this work begins, it would be favorable to start by collecting about 30 tons of household-generated food waste and gradually increase this amount. In other words, the researchers propose a business plan in which operations start by co-digesting about 36 tons of food waste relative to the 53 ton per day of sewage sludge, gradually increasing the amount of food waste.

Because this social experiment made thorough use of regional organizations such as school ward and resident associations to design and implement a separated collection plan, rates of citizen recognition and cooperation rates in the target area were high. Even so, cooperation rates settled around 60%. In other words, citizen participation and cooperation between business, academia, and citizens alone are not enough to raise separation cooperation rates for actual PFI businesses in Toyohashi City. It is important to combine them concurrently with other political techniques, such as financial incentives to encourage waste producers to separate.

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Developing the service value: a case study of waste management in offshore petroleum logistics

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Abstract

This research concerns how waste can be perceived as a valued object from a supply chain prospective. The resource-based view of the firm supplemented by service-dominant logic in an overall frame of supply chain management is used to develop an analytic framework guiding this research. A single case study reveals how waste in petroleum logistics includes a role of waste as a traded product downstream in the supply chain. "Waste management" is discussed from a SCM perspective; an "afterlife" of the outbound product; a normal logistical flow. The flow from the supply base is reverse, but not the flow out of the supply base which also is associated with ownership and trading waste products. Waste management firms are specialised in creating logistics service through networking. In relation to petroleum logistics, waste management is a function associated with this overall logistics function in offshore petroleum production.
Keywords: petroleum logistics, waste management, resource-based view, supply chain management, networks.

1 Introduction

This case study focuses on the seemingly paradoxical topic of *value* associated with managing industrial waste in a petroleum logistics empirical setting. A number of scientific publications mention that there exists a value aspect to waste [1–12]. On the other hand, many publications also mainly focus on environmental impacts of waste management providing a view that waste management is needed mainly as a safeguarding mechanism to protect the

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environment [13–18]. In business practice a range of specialized firms incorporate waste management as a specialized business activity. These firms provide a service value associated with waste management as type of industry. This case study involves describing waste handling and management processes in an industrial network characterized by a high degree of outsourcing of waste management and operations. All firms that produce and thereby possess waste must to some degree manage and transact waste products. This case study aims to develop a supply chain management (SCM) based approach to developing customer-responsive waste flows; aligning waste management with SCM theory in general.

2 Supply chain management

SCM thinking is associated with systems dynamics theory [18]. System dynamics deals with aggregate rather than individual agents where individual action is unimportant [19]. This discerns SCM from logistics, which is more technical in nature. SCM involves studying complex networks of firms from a holistic perspective. From a normative viewpoint, SCM concerns, according to Lambert *et al.* [20] developing the level of integration. It concerns creating an understanding of how different supply chain actors work together to coordinate predominately logistical flows. Halldórsson *et al.* [21] describe SCM as a collection of conglomerate theories that are more or less well fit with each other including transaction cost analysis, the resource based view of the firm, principle-agent theory and network theory. “Logistics” implies production (transformation) associated in physical distribution, which waste is characterized as, with transport, inventory and goods handling. Logistics provides utility in the form of time, place and form features of goods upon delivery to a customer.

In line with Croom *et al.* [22], SCM can be described as different levels of analysis as “dyads”, “chain” or “network”. These conceptualisations are complementary. Dyads are business relationships, the immediate organizational context of interaction between two companies. Dyads are associated with relationship management and are by nature fundamentally reciprocally interdependent. In line with Emerson [23], the power-dependence in such relationships varies impacting on interaction processes. They encompass learning and innovation. Supply chains indicate a *normative* quest to integrate different firms following a linear flow of goods. SCM involves accordingly the integration of a functionally interlinked series of dyadic relationships characterised by sequential interdependencies. This is the core realm of SCM following the Lambert *et al.* [20] definition of SCM. The network, on the other hand, encompasses multiple-actor *identity* and pooling these identities; the potential to navigate trading with different business partners as well as the feature of interacting with multiple suppliers and multiple customers simultaneously.

3 The resource-based view supplemented by service-dominant logic

The resource-based view (RBV) of the firm originated with the seminal works of Werenfeldt [24] and later developments by Barney [25]. Werenfeldt [24] put forward the view that most products require the services of several resources and most resources can be used in several products. This view is rooted in Penrose's [26] original view that services yielded by resources are a function of the way in which they are used – exactly the same resource when used for different purposes or in different ways and in combination with different types or amounts of other resources provides a different service or set of services. RBV is criticized due to oversight of the dynamism, environmental contingencies, and the role of the manager [27]. Barney [28], however, states in a more recent publication that the "…resource based theory suggests that purchasing and supply chain management will often have the attributes that can enable them to be sources of sustained competitive advantage". This indicates a strategic viewpoint of RBV pertinent to SCM; it encompasses supplier relationships. Core RBV thinking implies that firms are different from each other; this invites search for complementarity. Firms, are however different in character, and this is in part determined by their nature as bundles of resources, and in part by the nature of their context; organizational, social and natural environment. The RBV is here applied to study functionally-integrated supply chains.

Service-dominant logic (S-DL) is a marketing management approach associated with strategic understanding of customer value. This merging of the RBV and S-DL is also relatively uncomplicated since the fundamental writings in RBV, essentially Penrose's [26] "Theory of the Growth of the Firm", represent a vital foundation of S-DL thinking. S-D logic contributes to RBV by developing a value-oriented network interaction approach (Lusch and Vargo [29]). Value is also relational, and thereby the analytical framework becomes more inter-organisational. In line with Mintzberg [30], meaning is generated through network interaction and not through a single company's stand-alone strategic planning created in a boardroom. RBV is in this study developed using S-DL to encompass interaction through dyads in networks. S-DL is more limited in encompassing, in line with empirical evidence brought forward by Håkansson and Persson [31], that each company must handle often a large set of dynamic business relationships. This brings us back to classification of SCM levels (Croom *et al.* [22]); all these SCM levels need to be encompassed as complementary theoretical components in developing the "SCM of waste management".

4 Industrial waste and its value in supply chains

Waste may, according to Smith [32], be defined in many ways. Is waste "resource"? The conception of "waste" is important because of strict government legislation associated with waste handling [33]. The European Council [1] defined that "Waste shall mean any substance or object in the categories, which the holder discards or is required to discard". Pongracz [8] stated that, one of the methods to define waste is by listing activities or substances that fall within the range of abovementioned defined categories. Pongracz and Pohjla [34] argued that the term waste as "a thing that its holder is to discard", meaning that the holders intend to throw this physical object away. Waste is created and perceived by supply chain actors first created then logistically handled. The notion of "discard" is a perception held by the waste creator. Waste, when leaving the waste *producer* may be disposed, reused, resold, or re-manufactured; this is conceptualised as "return flow"; waste is returned to a supply chain subject that originally produced the "waste".

According to De Brito and Dekker [15], waste management is the collection and processing of waste that has no longer any reuse potential. The management of waste is associated with a "waste hierarchy": 1) prevention, 2) re-use, 3) recycling, 4) recovery and 5) disposal [35]. The waste solutions involve different logistics and perceptions of value. From the perspective of waste producers, waste management involves specialized resources distinct from the main production of a firm. This implies also using specialized equipment and competence in handling waste. Waste management firms are accordingly bundles of resources specialized at managing and handling waste. The strategic importance of waste management companies in a network setting constitutes its identity, and this identity generates perceptions of complementarity stimulating networking including trading. In a supply chain dyad, both firms are in some manner attracted to each other, envisioning reaping benefits of perceived complementarities. Based on this perception the relationship evolves seeking a solution to the waste problem of the waste producer provided by the waste management firm. As Foss [36] states "…capabilities belonging to networks of firms clearly emerge from the interplay of firm capabilities; not the other way around." Furthermore, Hayek [37] states, it is through interaction relationships that solutions to practical problems are found since knowledge is never limited to a single mind. This implies, following Richardson [38] a view that waste management cannot be viewed in isolation from the perspective of single firm. The drawing of inter-firm boundaries and sourcing within or outside of a firm's waste operations including its logistics are accordingly an important issue in waste management. As the degree of specialization and outsourcing increases form a supply network perspective, waste management emerges as embedded in a chain of strategically managed sequentially interdependent dyadic relationships. This entails a need for SCM; to integrate the supply chain's logistics and other operations resources to improve the coordination of these activities. Waste management in a supply network context involves sourcing decisions; the exit or invite of new chain actors. As more waste management operations are outsourced, the importance of purchasing as well as networking through business relationships increases in importance [39].

Since waste is envisioned as part of a returns flow in a supply chain, in logistics, waste management is often considered a form of reverse logistics. Rogers and Tibben-Lembke [11] define reverse logistics as: "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". From this reverse logistics definition it can be argued that the purpose of reverse logistics is to recapture value and, second, disposal if the return materials do not carry any value. De Brito and Dekker [15] claim that "reverse logistics" differs from "waste management" because the last part of reverse logistics definition by Rogers and Tibben-Lembke [11] mainly concerns the efficient and effective collection and processing of waste, that is, products for which there is no longer any reuse potential. De Brito and Dekker [15] support their argument that waste is something which has limited re-use possibilities. However, Shakantu *et al.* [40] argue that there are similarities between some of the processes used by product recovery networks and waste disposal networks. Cherrett *et al.* [41] claim that the similarities between reverse logistics and waste management is most evident from a supply side perspective where used products are collected from many sources and need to be consolidated for further processing and transportation. However, Fleischmann *et al.* [42] argue that a flow of recovered products is directed towards a reuse market and waste streams eventually end at landfill sites or incineration plants after various treatment processes. This indicates that the destination of a waste flow in a predefined systems-configured supply network structure does not always entail, literally speaking, a *reverse* back-to-origin flow. De Brito and Dekker [15] argue that depending on the type of reverse process, products may not necessarily be returned to their point of origin, but to a different point for recovery. Cherrett *et al.* [41] argue, that the delivery of return materials back to disposal sites and treatment centres is a natural extension of reverse logistics. Hillegersberg *et al.* [43] and Cherrett *et al.* [41] characterize transportation is one of the main attributes of reverse logistics. This discussion evokes some confusion regarding what actually constitutes "waste" as well as its place as management practices in in a supply chain context. Is waste only what always has been and always will be waste? Or may waste be transformed into something desirable, a product? Is waste management a function or classification of type of firm?

The upstream offshore petroleum logistics operations secure platform operations through managing supplies of goods and services through on land supply bases, modelled as logistics flows in figure 1.

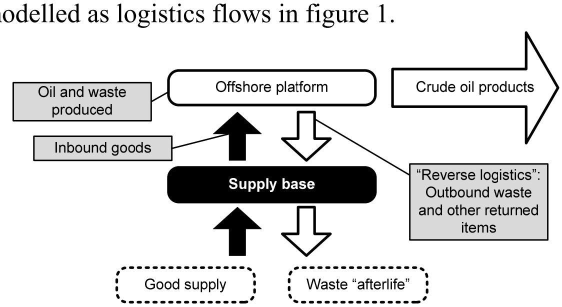

Figure 1: Petroleum logistics and waste management.

Petroleum logistics encompasses all logistics flows. Crude oil is transported directly from the platform to refineries on land, and not through the supply base. Figure 1 indicates how, “reverse logistics” may be deemed conceptually superfluous, especially since logistics associated with the “afterlife” of waste hardly can be characterised as “reverse”. The concept of *“value-in-use”* is central to S-DL and implies that “value” human perception from the perspective of the service recipient, the customer. Following S-D logic, value is not information (objective); it is perception (subjective), a form of sense making that takes place in a network of actors [29]. Value is impacted by interaction in business relationships. Since value is associated with integration and communication, the type of value created and obtained by a specific collaboration is accordingly dependent on the degree of maturity of that collaboration [44]. The combined competencies of the parties in the supply chain affect and shape the value proposition of collaborative supply networks. Mollenkopf and Closs [10] provide through a study examples of how improved reverse logistics flows including handling waste items creates increased value at different stages of a flow of goods. Waste, as “product”, is a transformable resource. While for the waste producers waste is an annoyance, a waste management company perceives waste as a *raison d’être*, a resource with product-type features. A notion of waste as resource emerges when taking a supply chain perspective.

5 Method

This was an explorative quest. A single case was studied providing detail rather than comparison. Informants came from four different companies: the supply base Vestbase, a waste management company handling waste operations called Norsk Gjenvinning, a waste management company trading waste called Maritime Waste Management, and Norske Shell, an oil as well as a waste producer. Semi-structured enabled an emergent design, interviews carried out during a period of four months. Questions were organized as follows: 1) waste as technical resource, 2) waste management practices and perceptions, 3) the logistics of waste in potentially a “reverse” flow, and 4) conceptions of value. Each interview carried an average of 10 main questions. Each main question was further extended to several sub questions. A single interview lasted long an average of 1 hour. Limitations are associated with the single case study format which allows deeper insight, but also limits generalization [45]. This form of case study permits theory building [46] and thereby theoretical generalizability [47]. It may therefore contribute by generating theoretically founded ideas to discourse both in academia as well as in business practice; a foundation for waste management innovation based on new insight.

6 Case description

The Vestbase supply base is located in Kristiansund Norway. It functions as an industrial park with harbour and terminal facilities. There are currently more than

60 firms located with rented facilities on this base. All these firms are involved in either producing or handling at least miniscule amounts of waste. The studied waste flow involves Norske Shell as waste producer at its offshore Heidrun platform. Shell has strategically chosen to outsource its waste management procedures and operations. Mainly it is the supply base that manages waste received from offshore installations and coordinates their activities with the specialized waste management firm, Norsk Gjenvinning. Another specialized waste management firm, Maritime Waste Management handles trading waste, facilitating the continuing downstream flow of waste from Vestbase. This firm is a subsidiary of Vestbase. In addition, transport firms, mainly both road and shipping play an important role in waste management. These are the four main companies considered in this case; 1) Vestbase, 2) Norske Shell, 3) Norsk Gjenvinning and 4) Maritime Waste Management. These companies are first considered in brief.

Vestbase was established based on an investigation in the early 1970s by an oil committee appointed by the Norwegian government to place Kristiansund on the map relevant for the oil business. Vestbase is 100% owned by NorSea Group AS. NorSea Group is the leading supplier of integrated logistics system and base services to the Norwegian oil and gas industry. Vestbase facilitates several production platforms, drilling rigs and subsea installations outside Krisitiansund. Large amounts of waste are produced from oil platforms. This waste is shipped to Vestbase for treatment and further processing by other companies at other locations; Vestbase carries out the logistics of receiving, and dispatching this waste.

Norsk Gjenvinning (NG) is Norway's leading environmental service provider. *Maritime Waste Management* (*MWM*), closely associated with Vestbase, offers waste management services at all bases in Norway. It controls and co-ordinates waste flows through Vestbase. At Vestbase MWM works along with Norsk Gjenvinning to handle, manage and transport of offshore waste generated by oil companies. NG mainly carries out waste operations, while WMS manages the flow of waste into and from Vestbase.

NG handles four types of waste: 1) industrial waste, 2) bulk waste, 3) metal waste, and 4) hazardous waste. All waste is transported from the platform on platform supply vessels (PSV) designed to handle a range of different cargo in tough weather conditions. The Vestbase personnel first receive and handle waste from these ships before turning them over to NG who then handles this waste. After processing by NG, waste is sent to the downstream recipients brokered by MWM. Waste implies costs for Norske Shell while for MWM and Norsk Gjenvinning, waste represents a source of revenue.

7 Analysis

The described the petroleum logistics goods flow reveals a logistical loop-formed flow that functions to support petroleum raw material production at the offshore platform. It is fair to say that the studied flows, both outbound goods and return flows, are services supporting the main petroleum production offshore. These supporting activities are substantial in importance and this is a reason to characterise this support flow as part of the main production. In any case, waste management is a vital supporting function; logistical and embedded in a network context demanding coordination following SCM principles. The first logistical part of the described waste flow is clearly reverse. While upstream, closer to the platform, waste is seemingly worthless and value emerges downstream as recipients of waste are found in the network. Two aspects of waste are indicated; 1) as service by specialist forms supporting the flow of waste, and 2) a gradually emergent value in waste itself as it is transformed into a tradeable item downstream in the supply chain. Waste ownership is an important issue. This evokes disparity of value perceptions also opens up for the view that transacting waste demands specialized competence not only in handling waste, but also in transacting it. WMS is expression of a company reaping rents based on complementarities educed through inter-firm interaction. This need for specialized competence opens up for understanding the grounds for outsourcing waste management since it involves both need for specialized waste handling resources and specialized knowledge resources to manage the waste including marketing it. Following S-D logic, waste management as supply chain function develops customer-supplier interaction to secure customer value objectives. SCM practices may support this vital dyadic interaction embedded in relatively integrated chains managing waste to and through Vestbase.

The flow of waste is a form of logistics involving transport, storage, terminal activities and handling. However, as the case also shows, as waste is transformed into a traded item two aspects of service provision merge in the described network. First specialized waste management firms provide service to waste producers aiming to move waste from the platform in accordance with government legislation governing oil production. Furthermore, waste, when processed also indicates that “manufacturing” as concept is pertinent to waste management. Managing waste at core implies a form of production; while the primary functionality of production in petroleum logistics associated with supplying petroleum products to customers. Waste production is a negatively-laden off-spin of this primary production. As a gradually tradable item, waste is rendered into goods. Maybe it should be considered as goods all along even though its flow starts as an item of discard? Waste as “goods” implies waste is valued; considering it as a resource object, a tradable product, in supply chains subject to the logistics of time, place and form transformation. This logistics is fundamentally the same as inbound logistics to the platform. The same as the goods, waste is also traded. Waste may be classified accordingly as not only goods, but products. As products the marketing aspect of waste is evoked.

Customer-supplier interaction takes accordingly two forms of exchange in the case. First is the interaction between NG and mainly their waste producing customer Norske Shell. However, NG must also simultaneously collaborate through other business relationships, such as Vestbase, shipping companies, logistics service operators and more. This implies collaboration through established structurally dynamic supply chains. Value in this scenario is rooted in the perceived network identity of the two core waste management companies, NG and MWM, very similar to identities of any logistics service provider (LSP) who never claims title to a product. Waste management companies may be classified accordingly as a specialised type of LSP. Value is associated with two prime aspects: 1) transforming waste as well as 2) network trading.

8 Conclusion

Waste management is proposed, grounded on this petroleum logistics specific context, rather than as *a form of* reverse logistics be considered a form of industry that is represented by unique supply chains. Waste management is logistically an *afterlife* version of supply chains with close resemblance of other forms of supply chains, but clearly distinct from the preceding stages of product supply. The logistics of waste management is proposed considered an empirical variation of supply chain management perspective. Waste management, as any other form of activity in a supply chain, is associated with service provision and customer value. Waste management as service provision is proposed classified as a type of LSP. "Waste management" when used to characterise firms in a network provides sourcing-related identity. Creating service value is dependent on interaction through business relations as in any other business. The waste management industry involves, however, particularities that include, potentially in part as when waste is shipped from platform to supply base, a reverse flows of "goods". Knowing waste as "resource" (as goods) creates foundation for clearer SCM initiatives.

Research in developing the *supply of waste* concerns simply goods or products. Waste has particular characteristics, just as bananas or ships. Furthermore, given the high degree of outsourcing, waste management as service, more precisely as LSPs, represent a body of literature beneficial to developing waste management. Finally, the predominant classifying of waste management as something logistically "reverse" is deemed empirical, not conceptual. Further studies aiming to refining this understanding of the logistics and supply chain management in waste management are called for. This includes manly considering waste as 1) an empirical phenomenon in SCM and logistics, as well as considering 2) waste management as logistics service provision, a way to classify firms in the network, including considerations of outsourcing.

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How we transform industrial organic waste into vermicompost and champion environmental sustainability

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Abstract

The traditional means of disposing of processing waste to landfill is receiving close scrutiny due to high capex and opex costs and negative environmental impacts. Increasingly stringent legislation means communities and industries are seeking the security of alternative solutions when planning their long-term organic waste disposal strategies. Important to these are excellence in environmental performance, ecological sustainability and to cost effectiveness. Vermicomposting technologies achieve this through the conversion of wet organic waste to a nutrient rich, safe fertiliser for sustainable land utilisation. Vermicomposting is highly cost effective for industrial and municipal organic waste streams. MyNOKE is currently vermicomposting 30,000 tonnes per year of co-decanter dewatered waste activated sludge (WAS) and dissolved air flotation (DAF) sludge from Fonterra milk processing plants in New Zealand. The sludge is blended with 50,000 tonnes of several pulp and paper mill sludge's from Oji Fibre Solutions Paper Mills for vermicomposting. The product, some 20,000 tonnes of vermicast, is land applied to dairy pasture and maize land. As a result, productivity, soil water efficiency, and nutrient uptake are increased. Plant available water holding capacity, root density, and root depth reduces the risk for nitrate nutrient leaching when applied as effluent or mineral fertiliser. The new vermicomposting operation is integrated into a Fonterra owned 1,600 ha farm. The Noke vermicomposting process developed by Quintern has grown from vermicomposting 2,000 tonnes of sludge in 2008 to 200,000 tonnes in 2015.
Keywords: vermicomposting, pulpmill solids, milk sludge, land utilisation.

1 Organic waste resources

Within the central North Island region of New Zealand, the primary economic industries are dairying and timber processing. The resultant organic 'waste' resources originating from these industries have traditionally, mostly been disposed of to landfill. More recently these valuable organic resources have been processed using proprietary vermicomposting technologies, which are presented and discussed in this paper.

1.1 Milk plants waste

Fonterra Co-operative Group Ltd. (Fonterra) operates a number of milk plants in the central North Island region of New Zealand. These processing results in the production of some 30,000 tonnes of various organic waste, which had previously only been partially land applied. Some of the organic waste sludge has been disposed of to landfill.

1.1.1 Waste activated sludge

Waste activated sludge (WAS) with a solids content of approximately 0.45% is produced at various Fonterra milk plants in the Waikato Region. The result of the activated sludge biological treatment of site waste. WAS is thickened by decanters at two sites to approximately 15% solids to reduce transportation costs and to achieve a solid, spadeable product. Typical analysis of the WAS from the two sites are given in Table 1.

1.1.2 Decanted dissolved air flotation sludge

Wastewater is introduced into continuously operated dissolved air flotation (DAF) process, where larger particles including fat and proteins are extracted through a DAF process. The particles attach to the air bubbles and float to the surface as a DAF sludge and is mechanically skimmed off. The sludge is decanted prior to transportation to the vermicomposting operation. Nutrient contents (Table 1) are significantly lower than those of the WAS. At both the Te Rapa and the Waitoa sites, DAF sludges are co-dewatered with waste activated sludge.

1.2 Pulp and paper mill organic waste

Oji Fibre Solutions Ltd. (Oji) operates four pulp and paper mills located in New Zealand's North Island. All four sites produce organic waste generally described as pulpmill solids or sludges. The fibrous pulpmill solids are blended with the Fonterra milk plant sludges. The characteristics of pulpmill solids can be highly variable depending upon the source of fibre e.g. from wood chips or recycled cardboard or paper, the particular pulp mill wastewater treatment processes used and the sludge separation technology.

Table 1: Characteristics of waste activated sludge (WAS) and anaerobic sludge from various Fonterra milk plants in Central North Island – New Zealand.

Parameter	WAS sludge decanted		Anaerobic sludge
Milk plant	Waitoa	Te Rapa	Tirau
Dry matter (%)	14.1	16	13
Carbon (%)	40	43	5.6
Nitrogen (%)	7.2	6.6	1.5
C/N ratio	5.6	6.5	3.7
pH	6.2	5.8	7.7
Phosphorus (mg/kg)	16,700	18,700	6,400
Sulphur (mg/kg)	6,900	9,000	850
Potassium (mg/kg)	8,300	9,800	1,850
Calcium (mg/kg)	10,600	13,500	56,000
Magnesium (mg/kg)	3,000	2,700	1,030
Sodium (mg/kg)	3,600	4,900	720
Boron (mg/kg)	75	54	1,45
Arsenic (mg/kg)	< 1.0	< 5	0.51
Chromium (mg/kg)	5	7	0.67
Cadmium (mg/kg)	< 0.1	< 0.3	0.03
Copper (mg/kg)	6	7	1.38
Lead (mg/kg)	1.4	0.8	0.45
Mercury (mg/kg)	< 0.1	< 0.3	< 0.002
Nickel (mg/kg)	3	< 5	1.16
Zinc (mg/kg)	71	67	53

1.2.1 Pulp and paper sludge from Kinleith Pulp and Paper Mill

Losses to the pulp and paper mill's wastewater systems from routine cleaning of the pulp and paper machine, average around 15 t/d (dry basis) of rejected fibre material. This product is referred to as 'primary solids' and is removed in the primary clarifier. The pulp and paper mill's wastewater treatment system produces approximately 12 t/d (dry basis) of secondary biological solids from the oxidation ponds which are combined with the primary solids prior to being pumped into two gravity-dewatering ponds. Table 2 gives an overview of the characteristics of the primary and secondary solids from Kinleith Pulp and Paper Mill. By blending the different solids the limits for organic certification are met and an organic certified product is produced. The process of producing the pulp and paper sludge from the Kinleith Pulp and Paper Mill is described in more detail by [1].

1.2.2 Recycled paper solids from Kinleith Pulp and Paper Mill

The recycled paper solids show similar carbon and nitrogen concentrations to the primary solids. The slightly higher metal concentrations of the recycled paper solids (Table 2) compared to the primary pulp and paper mill sludge are still well below the limits for safe land application [3].

1.2.3 Pulp and paper solids from Tasman Pulp and Paper Mill

At Tasman Mill, the primary pulp and paper solids are separated in the wastewater treatment plant clarifier by adding a polymer to coagulate the solids which are then de-watered mechanically resulting in a much dryer product than the pulp and paper solids from the sedimentation ponds at Kinleith Mill (Table 2). The pulp and paper solids are generated in a continuous flow process, which enables a consistent supply to the vermicomposting operation.

Table 2: Characteristics of pulp and paper mill sludge and recycled paper solids from various Oji Fibre Solutions' pulp and paper mills in New Zealand.

Parameter	Primary and secondary solids	Recycled paper solids	Primary solids	Limits organic certification*
Pulp and paper mill	Kinleith		Tasman	
Dry matter (%)	17.8	26.9	34.1	
Carbon (%)	37.6	37	29.7	
Nitrogen (%)	0.5	0.17	0.4	
C/N ratio	75	217	75	
pH	7.4	6.9	7.9	
Phosphorus (mg/kg)	509	153	939	
Sulphur (mg/kg)	3,200	< 5,000	1,321	
Potassium (mg/kg)	1,060	240	2,180	
Calcium (mg/kg)	24,200	58,900	114,900	
Magnesium (mg/kg)	2,440	1,900	2,120	
Sodium (mg/kg)	1,130	820	3,640	
Boron (mg/kg)	0.28	< 50	20	
Arsenic (mg/kg)	1.0	< 5	2.6	20
Chromium (mg/kg)	2.9	7	62	150
Cadmium (mg/kg)	0.1	0.2	0.26	1.0
Copper (mg/kg)	9	46	55	60
Lead (mg/kg)	1.72	15.2	5.0	250
Mercury (mg/kg)	0.04	< 0.3	< 0.11	1.0
Nickel (mg/kg)	1.3	5	6.1	60
Zinc (mg/kg)	43	77	63	300

*[2]

2 Industrial vermicomposting in New Zealand

The first laboratory scale vermicomposting trials using paper waste as a carbon source and blending agent for nutrient rich organic waste have been published by

[4]. From the 1990's scientists started using pulp and paper mill sludge also referred as pulpmill solids for vermicomposting as bulking agents [5–10]. Vermicomposting of purely pulpmill solids has not been conducted at any significant scale because the wide C/N ratio of pulpmill solids makes this product unsuitable for vermicomposting. Laboratory trials have shown that best reproduction of earthworms is achieved when the C/N ratio is adjusted to 25 with nitrogen rich waste streams [8, 11, 12]. Various industrial organic waste have been studied for the past 40 years using vermicomposting technology to produce a high quality soil conditioner or fertiliser [13]. Paper waste with a C/N ratio of up to 200 and higher were used as a carbon rich blending agent for nutrient rich waste such as biosolids, food waste [4, 14], manure [14], and other industrial waste [15]. In recent years, Quintern *et al*. have demonstrated that a sub-optimal C/N ratio in the earthworm feedstock can be successfully applied in commercial vermicomposting operations and that nitrogen sources captured from the wastewater treatment plant of a pulpmill can be used as nitrogen source for blending with primary pulpmill solids [16–18]. Vermicomposting of DAF sludge from milk processing industries in combination with pulpmill solids has first been studied and published by [19].

Industrial scale vermicomposting of sludge from Oji's pulp and paper mills and other industrial and municipal organic waste streams commenced in 2007 and currently totals 150,000 t/a [1, 16, 17, 20, 21]. In 2010 Noke Ltd. undertook feasibility studies on commercial vermicomposting of the organic waste stream from pulp and paper industries in combination with dewatered WAS and DAF sludge from Fonterra's milk plants. The aim was to produce a valued added product, vermicast, for beneficial land utilisation. In 2014 Noke Ltd established the efficacy of operating as a full-scale vermicomposting operation and a new site is being developed to receive only these products. This site commenced operating at full industrial scale in September 2015 with a capacity of 70,000 t/a.

2.1 Vermicomposting process: general

Thermophilic composting of wet organic sludge with little or no structure as well as wet pulpmill solids with a wide C/N ratio proves both difficult and economically challenging. Both organic waste require either mixing with suitable agents to provide oxygen flow or require adding nutrients, mainly nitrogen and phosphorus for rapid decomposition. Thermophilic composting requires mechanical turning thus adding complexity and costs to the process. The high temperatures achieved through the thermophilic process can create significant odour issues, which can be problematic if processed close to populated areas. Thermophilic composting achieves a volume reduction of approximately 1/3.

Vermicomposting is a mesophilic process, which uses *epigeic* compost earthworms to ferment and decompose organic matter producing a specific earthworm casting called vermicast or vermicompost [13]. Compost worms can 'operate' in moist conditions between 60 to 90% depending on the structure of the feedstock, so no pre drying is required. Vermicomposting requires no mechanical turning since the feedstock waste is applied in smaller quantities as earthworms are mixed with the feedstock through their activity. This action is described as ‘bio-turbation’ in soil science or could be described as ‘vermi-turbation’ in the process of vermicomposting. During the digestion of the organic waste a volume reduction of up to 80% can be achieved, this reduces transportation costs of the vermicast to its end users.

2.2 Vermicomposting technology used in New Zealand

The vermicomposting technology developed by Quintern Innovation Ltd. is based on the Windrow Vermicomposting System described as low-technology vermicomposting systems [22]. Windrow vermicomposting technology in general is characterised as low capital expenditure (CAPEX) and easy to manage. The drawbacks of conventional Windrow Vermicomposting Systems are a large footprint, labour-intensive, slow processing time, considerable nutrient losses, and need for separation of earthworms from vermicompost. Most of these drawbacks have been resolved by Quintern (Table 3). The key improvements have been achieved by avoiding continuous feeding practices in order to reduce labour costs and processing time. The footprint / net production ratio for vermicomposting has been significantly reduced by minimising the non-productive areas of the vermicomposting site. The Quintern Windrow Vermicomposting Technology has been developed and proven over the last decade and is successfully operating at an economic industrial scale.

2.3 Integrated vermicomposting in farm management systems

To manage the nutrient losses, such as leaching and gaseous losses from vermicomposting sites, the C/N ratio of the feedstock is carefully adjusted, which reduces the potential of enriching the underlying topsoil with nutrients and humic acids. Operating at the same location over multiple years could create a hot spot of nutrient loss into the soil ecosystem. To address this potential risk the author adopted the strategy of integrating vermicomposting into farm and forest management practices. Similar to integrating outdoor pig ranging, with extreme high nutrient accumulation in hot spots, the vermicomposting sites will rotate either on the farm [23, 24] or within the forest. After a certain time of vermicomposting on one specific site the vermicomposting windrows will be placed on a new paddock or forest block. On the former vermicomposting site the vermicast will be harvested and a so-called ‘catch crop’ with high nutrient demand, such as maize, will be planted. In forest management systems the new plantation benefits from the vermicast residues as the demand for nutrient of trees is highest in the first years of plant growth.

2.4 Vermicast

Vermicast and vermicompost are used in the literature often synonymously. In New Zealand vermicast is defined as mature pure earthworm casting whereas vermicompost may contain some material that has not been processed by compost worms [25]. There are hundreds of references characterizing

Table 3: Characteristics of the Quintern Windrow Vermicomposting Systems in comparison to conventional windrow vermicomposting systems described by [22].

	Quintern vermicomposting	Conventional vermicomposting
Benefits	Low CAPEX*	Low CAPEX*
	Easily managed	Easily managed
	Not labour intensive (mechanised)	
	Reduced footprint	
	Retention of nutrients through wider C/N ratio	
	Harvesting vermicompost without earthworm separation	
Drawbacks		Labour-intensive
		Large footprint
	6 to 12 months processing time	6 to 16 months processing time
		Loss of nutrient through leaching and volatilisation
		Impossible to harvest vermicompost without earthworm separation

*Capital expenditure.

vermicompost in relation to the degree of earthworm activity, vermicomposting technology used, and the parent waste or 'feedstock' used. Arancon and Edwards [26] provide a review of the recent findings of beneficial use of vermicast.

In comparison to commonly advised vermicomposting technology, the vermicast produced in this commercial operation has received a much larger portion of fibrous and carbon rich feedstock source as a blending agent. As a result the vermicast has a more advanced peaty structure with lower nitrogen content and therefore a slightly wider C/N ratio. This provides the MyNOKE vermicast with various advantages when applied in nutrient sensitive ecosystems, which are lacking in soil humus required for maintenance of a high nutrient and water holding capacity. Specific characteristic of the vermicast are described in Table 4.

3 Beneficial land utilisation of vermicast in New Zealand

3.1 Application of vermicast

Vermicast is applied in bulk to various crops at rates of 2.5 t/ha to pasture, 10 t/ha to kiwi-fruit orchards, and up to 20 t/ha to maize and to other crops according to the specific soil quality and nutrient demand of the crop. Screened vermicast can be applied with standard compost or manure spreaders.

Table 4: Characteristics of MyNOKE® vermicast produced from mixed Oji's pulp and paper mill sludge and waste activated sludge from Fonterra's milk processing plants in New Zealand.

Parameter	MyNOKE® vermicast	Limits organic standard*
Dry Matter (%)	49.0	
Organic matter (%)	39.6	
Carbon (%)	21	
Nitrogen (%)	1.6	
C/N ratio	13.5	
pH	7.0	
Phosphorus (mg/kg)	4,720	
Sulphur (mg/kg)	5,100	
Potassium (mg/kg)	1,055	
Calcium (mg/kg)	136,100	
Magnesium (mg/kg)	2,060	
Sodium (mg/kg)	2,180	
Boron (mg/kg)	23	
Arsenic (mg/kg)	6.2	20
Chromium (mg/kg)	23	150
Cadmium (mg/kg)	0.4	1.0
Copper (mg/kg)	39	60
Lead (mg/kg)	38	250
Mercury (mg/kg)	0.08	1
Nickel (mg/kg)	12	60
Zinc (mg/kg)	174	300

* [2]

3.2 Benefits to plant growth

Vermicast produced by compost earthworms (*Eisenia foetida*) contains humic substances described as humic acids, humates, gibberelins, auxins, 3-indole acetic acid, and various other substances. These humic substances promote plant growth in multiple ways starting with faster germination [9, 27–29], increased root development of more and longer lateral and vertical roots, increased area of root hairs and even higher root activity [30–39]. Increased root area, root growth depth, and activity leads to increased nutrient uptake and access to more available soil water during drier seasons.

Positive effects were measured in higher numbers of blossoms, flowers, and fruits, increased photosynthesis which overall leads to higher yields [36, 37, 40], and fruit harvests [41]. Recent studies have shown that vermicast has the potential to suppress plant diseases and to control pests such as insects and nematodes [42–48].

3.3 Benefits to soils

The beneficial uses of vermicompost to various crops and forests on different soils have been widely documented. Little is known about the continuous application of vermicast on intensive dairying land, especially on pasture and on intensive monoculture maize cropping systems. Intensive dairy farming is currently criticised for increased nitrate leaching and phosphate runoff. Improved topsoil functions in regards to water and nutrient retention would most likely mitigate nutrient losses, such as nitrate in the groundwater. Higher humus content and more intense root systems would improve soil function, as well as increasing nutrient uptake including nitrogen. Intensive maize cropping may lead to a reduction in soil organic matter and therefore carbon loss from these soils [49]. In a recent trial, vermicast applied at a rate of 20t/ha and at a constant nitrogen fertiliser application rate of 400 kg N/ha has increased the production of maize silage by 3 to 5 t/ha dry matter. The shoot to root (S:R) ratio for maize is 5.6 [50] and would increase the root production by 0.54 to 0.89 t/ha dry matter. In addition to the extra humus accumulation through extra root growth, carbon is applied at a rate of 2.06 t/ha.

4 Outlook

Vermicast application to soil has the potential to mitigate nitrate losses, increase soil organic matter directly as a carbon source and indirectly by increasing root production.

Vermicomposting of combined industrial and municipal organic waste offers multiple benefits on the carbon footprint for industry, the community and for the agribusiness sectors. Of significance is the reduction in greenhouse gas emissions originating from the land filling of organic waste and the avoidance of the high economic penalties associated with the design, construction and ongoing monitoring of landfills. For the farming and horticulture sectors, soil carbon would be increased and higher carbon sequestration by increasing root mass and crop yields. A reduction in mineral fertiliser application would reduce the carbon footprint and a better soil structure would reduce nitrous oxide (N_2O) emissions from pastoral soils.

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The possibilities and challenges of using industrial rest products on mine waste management in the Arctic

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Abstract

Acid Rock Drainage (ARD) generated from oxidation of sulphide-bearing mine waste is one of the main pollution problems associated with mining activities. Dry cover and water cover are normally used methods to prevent the formation of ARD. However, in the Arctic region, the harsh cold climate, the vulnerability of ecosystems and the drastic climate change make the waste management methods different from other non-Arctic regions. This paper reviewed several successful case studies of dry cover and water cover applications with industrial rest products and further discussed the possibilities and challenges of using industrial rest products to manage mine waste in the Arctic region.
Keywords: ARD, rest products, mine waste management, Arctic.

1 Introduction

The rise in prices for metals and minerals since 2003 has led to increased mineral production in several parts of the world, especially the Arctic regions. The polar mining boom is heating up as climate change makes new areas and sea routes accessible. The extraction of metals and minerals can affect the natural environment to a significant extent both while active and after operations have ceased. Large amounts of waste rock and tailings are produced during resource extraction. It is estimated that more than 90% of the extracted materials will become waste. A feasibility study in Sweden [1] demonstrated that within 10–20 years the planned mines in Norrbotten area will alone produce 100M tons of tailings per year and almost similar amount of waste rock.

Acid Rock Drainage (ARD) from oxidation of sulphide-bearing mine waste is one of the main pollution problems associated with mining activities. When the sulphide-bearing waste exposes to oxygen and water, it will start to oxidize and form ARD. As far as the oxidation process starts, it can last for hundreds or even thousands of years. ARD has low pH and high concentrations of SO_4^{2-}, heavy metals and metalloids, which may have detrimental effects on the surrounding environments [2]. The leaching of contaminants from waste deposition facilities will significantly degrade the environment, and the contaminants will further transport through the environmental medium to the ecosystem and the human beings living in the area in the long-term [3]. Therefore, such waste has to be carefully disposed to prevent or reduce the oxidation process.

In Arctic regions, the harsh cold climate, the vulnerability of ecosystems and the drastic climate change make the waste management methods different from other non-Arctic regions [4]. Slow mass and energy exchange in ecosystems of high latitudes, makes trophic chains short, and biodiversity low, which causes rapid migration of pollutants through trophic levels and results in fast and severe ecosystem damages [5]. In addition, the low calcium concentrations in the Arctic lakes make organisms more vulnerable to toxins [5], which is a limiting factor for the management of mine waste. The differences between the polar regions and the rest of the world will affect the remediation strategies and approaches to the contaminated site significantly.

ARD from oxidation of sulphide bearing mine waste has to be prevented or treated. To prevent the formation of ARD from mine waste deposition facilities, two commonly used techniques are dry cover and water cover, i.e. to put a layer of solid or water above the mine waste to prevent the infiltration of oxygen or water, and thus prevent the formation of ARD [6]. In recent years, research has been focusing on using alkaline or organic industrial rest products together with water cover or dry cover technique to mitigate the ARD problem. The use of rest products from other industries to mitigate mine waste problem is preferred technique because it can solve two waste problems at the same time. This paper reviewed several successful case studies of water cover and dry cover together with industrial rest products and discussed the possibilities and challenges of using industrial rest products to manage mine waste in the Arctic region.

2 Methodology

2.1 Dry cover

Dry covers are typically earthen, organic, or synthetic materials placed over mine waste [6]. The primary purpose of placing dry covers over reactive waste material is to minimize ARD and metal-rich leachate production and its transport [6].

Through the MEND (Mine Environment Neutral Drainage) program in Canada, a significant amount of information has been generated about the design and use of dry covers for the prevention of sulphide oxidation [7].

Dry cover has been studied extensively in laboratory, pilot and field scale at real mine sites. Dry cover system usually contains a sealing layer with low hydraulic conductivity and high water holding capacity to decrease the oxygen and water intrusion into the waste. A protective layer is applied above the sealing layer to resist root penetration, freeze/thaw effects, drying etc. When functioning as planned, dry covers can slow sulphide oxidation to an acceptable rate (Figure 1).

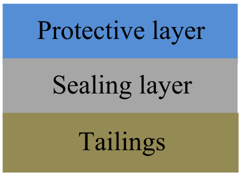

Figure 1: Schematic figure of dry cover application.

In recent years, studies have been focusing on the use of alternative materials such as industrial and municipal waste for mine waste remediation, which could solve two waste problems at the same time. The application of incineration ashes, waste from wood and paper industry and other industries, sewage sludge, steel slag and combinations of these materials for construction of sealing layers and for other applications in mine waste remediation have been investigated [8–10]. Using various types of materials as dry covers on mine waste has been successfully applied at many sites throughout the world [11, 12]. Several case studies of using industrial rest products such as sewage sludge, green liquor dregs, fly ash, paper mill sludge, steel slag to mitigate mine waste contamination have proved to be successful in laboratory or field scale [10, 13].

2.1.1 Green Liquor Dregs (GLD) from paper mills as dry cover

Green Liquor Dregs (GLD) is a residual product from sulphate paper mills. GLD has desirable properties to be used as a sealing layer in cover system and maintain its effectiveness in the long term. Table 1 lists the properties of GLD and several successful case studies in laboratory and pilot scale tests.

The long term application potential of GLD is also investigated [9, 17]. The results showed that the GLD's buffering capacity is high and can last for a long time [17]. According to the calculation from leaching experiments, a 30 cm thick GLD sealing layer with a hydraulic conductivity of 1E-08 m/s would retain its buffering capabilities for more than 200,000 years [9]. Therefore, GLD is a good cover material that can be used in large scale in the field and effective in the long-term.

Table 1: Properties of GLD and its applications.

Sealing layer	Desirable properties	Drawbacks	Application
GLD	• Low hydraulic conductivity (10^{-8} to 10^{-9} m/s) [14] • high water retention capacity [14] • small particle size [14] • high neutralization potential [14]	• Sticky property [14] • Insufficient shear strength [14]	Admixtures of GLD with till, tailings, fly ash and bark sludge [15, 16]

2.1.2 Fly ash and sludge from paper mills as dry cover

The potential to use alkaline fly ash from paper mills as a cover material on mine waste is tested in laboratory batch leaching tests and field scale and showed positive results [18]. The efficiency of using fly ash and sludge from paper mills as dry cover over mine tailings was geochemically evaluated at four ten years' old test areas at Garpenberg mine, Sweden [10]. Significant reduction in oxidation rates and leaching of elements from tailings was observed in the profiles with fly ash and sludge cover [10].

2.1.3 Sewage sludge for mine waste mitigation

The possibility to use sewage sludge from wastewater treatment for mine waste remediation is investigated in pilot and field-scale at the Kristineberg mine, northern Sweden [19]. The effectiveness of sewage sludge as a sealing layer over sulphide mine waste was evaluated. Data on tailings, leachate water and pore gas geochemistry during eight years from two experimental pilot-scale test cells revealed that the sludge was an effective barrier to oxygen influx [8]. The sulphide oxidation and ARD formation was prevented effectively. The sewage sludge can be effectively utilized as an alternative cover material both as a sealing layer and as a final vegetation substrate within the study periods.

2.1.4 Fly ash from energy production

Fly ash is produced from burning of fuels and other materials for energy production. The ash products (fly ash, fluidized bed ash) were excellent buffering materials and had great potential in improving the quality of acidic water. Petrik *et al.* [20] reported that neutralization of various sources of acid mine water with fly ash or fly ash leachate was possible.

The application of fly ash can attenuate the oxidation of mine waste. The acidity production life of a sulfide-rich mining waste is much higher than the alkalinity production life of any reactive material. The ideal treatment for ARD would suggest the use of techniques that passivate the sulfide surface, and therefore cancel its reactivity [21]. Fly ash can attenuate the oxidation process by forming Fe coatings over pyrite grains at alkaline pH that impede interaction with oxidizing agents [21]. Perez-López *et al.* [22] examined the processes controlling the oxidation attenuation of a pyritic rich sludge by the buffering capacity of a fly ash using saturated column experiment.

Fly ash can be used as a sealing layer in mine waste mitigation. Formation of hardpan in the contact zone between an alkaline substance and an acid producing waste has been described by many authors (Figure 2) [23]. A hardpan reduces the extent of wind and water erosion at the tailings surface, limiting dust dispersion [24]. Many ash materials have cementitious properties when allowed to react with moderate amount of water [25]. Mixing fly ash with mine waste may result in a reduction of permeability, thus hinder the oxidation of mine waste [26].

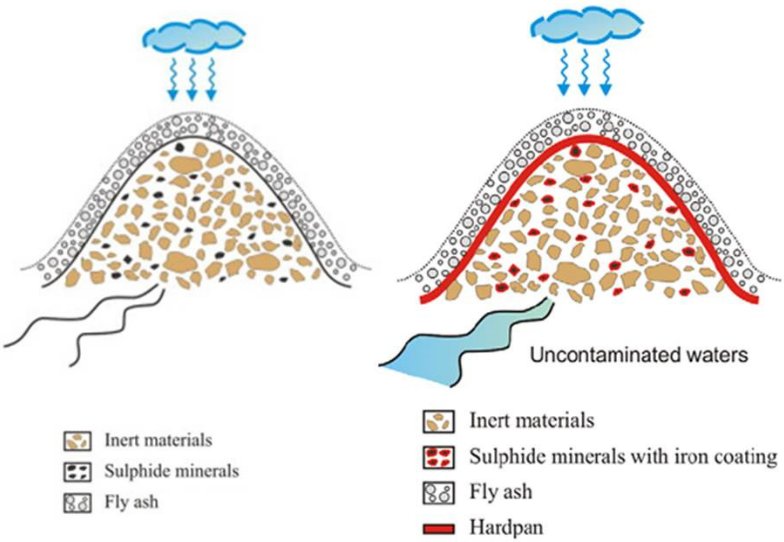

Figure 2: Formation of iron coating and hardpan after fly ash application [23].

2.2 Water cover

Concentration of dissolved oxygen in water is significantly lower than that in the atmosphere (approximately 30 times less than in the atmosphere). Disposal of acid generating materials below a water cover is one of the most effective methods for limiting ARD generation [6].

Due to increasing amounts of mine waste generated annually, and the environmental and social issues surrounding disposal on land, mining companies are seeking alternative methods of disposal. Deep-sea mine tailings placement (DSTP) is an alternative to land-based mine-waste disposal options, and is currently practiced by several mines worldwide (http://www.srsl.com/mining/deep-sea-mine-tailings-placement-dtsp).

Currently submarine tailings disposal method is only used at five countries. This method is not on the EU's best available technology list. This waste management got a lot of controversial due to its potential impact on the aquaculture and seafood export industry, and tourism around the disposing areas. The mining activity and submarine disposal of mine waste in the Arctic has long-term effects on the ecosystem in the receiving environment. The metal contamination was still detected in seaweeds and blue mussels near the former Black Angel Pb-Zn mine in Maarmorilik, West Greenland after two decades of mine closure [27]. Discernible environmental impacts was found up to 10 km from the tailings discharge point and significant biological effects on blue mussel have been detected in the recipient up to 3km from the tailings disposal point in 2015 [28]. Thus, this management method should be fully investigated before its full application.

2.2.1 Use of rest products in water cover

To reduce the environmental impact from submarine tailings deposition, a thin layer at the water-tailings interface (<1mm) known as the diffusive boundary layer is applied [29]. The application of this thin layer showed to be effective at limiting oxygen diffusion through the tailings in several case studies [30, 31]. Using rest products from other industries as an underwater cover material was investigated in several studies to reduce the negative environmental impact from underwater storage of tailings. The potential suitability of digested sewage sludge as an underwater cover for mine waste tailings, and the degradability of sludge at 20–22°C under flooded anaerobic conditions was evaluated during an incubation time of 230 days [31]. Low biodegradability and low leaching of elements from the sludge was observed [31]. The addition of organic carbon to tailings was investigated to improve the colonization of ecosystem and proved to be effective [32]. Thin-layer caps with activated carbon in Trondheim harbor, Norway were tested at in situ experimental plots and showed high efficiency in reducing the leaching of contaminates into the pore water and thus reduced bioaccumulation of contaminants in marine sediment fauna [33]. The ecosystem effects of thin-layer capping of contaminated sediments were tested in a mesocosm experiment on 9 different capping materials [34]. Thus the application of a thin layer cover above reactive mine tailings could reduce the environmental impact from under water storage of mine waste significantly.

3 Discussions

The cold climate in the Arctic region makes environmental management of mine waste different from other regions. At present relatively little research has been conducted relating to contamination issues in cold climates and the unique situations that exist in the Polar Regions. Information gaps exist in this area such as bioaccumulation in polar species, toxicity of contaminants to polar species, migration rates of contaminants through permafrost, and the development of risk assessment models [35].

In the Arctic regions, the unique environmental characteristics need to be considered when planning strategies for minimizing ARD [36]. The low temperatures slow most chemical and biological processes and freezing may restrict the migration of pollutants. However depending on the thermal properties of the ground material and local weather conditions, development of an active layer was observed in several studies in the Arctic which promote the transport of oxygen and release and spread of contaminants to the surrounding environment [36]. More work needs to be done in this area regarding contaminant barrier design, cold-climate bioremediation, and transfer of technologies from other areas etc. [35].

In addition, the environmental impacts from climate change in the Nordic region are expected to be more drastic than other regions [37]. Climate change has great impact on the process of contaminant transport and concentrating process in the environment [38]. Changes in global climate and the associated environmental changes in the Nordic region are expected to have significant consequences for contaminant pathways. Over the past 50 years, unprecedented rates of change for both temperature and precipitation have been recorded [39]. Increased temperature will affect chemical reaction kinetics. Any step along the transport and redistribution pathways is influenced by climate change because chemical reactivity, adsorption and accumulation are temperature-dependent. With increased flows there will be changes in stream power and sediment loads with the potential to alter the morphology of rivers and the transfer of sediments to lakes [40]. Climate change is expected to alter environmental distribution of contaminants and their bioaccumulation due to changes in transport, partitioning, and bioaccumulation process [41]. Therefore drastic climate change should be considered when we plan a waste management strategy in the Arctic region.

Industrial rest products have shown promising applications in other regions. Few cover applications in the Arctic have shown positive results [42, 43]. However due to the specific environmental conditions in the region such as the extremely low temperature, low precipitation, freeze-thaw cycles, drastic climate change etc., more research needs to be done to investigate the feasibility of using these rest products in mine waste remediation in the Arctic region.

4 Conclusions

Dry cover and water cover were applied above the mine waste to prevent the formation of acid rock drainage (ARD). Industrial rest products such as green liquor dregs (GLD), sewage sludge, fly ash etc. were proved to be successful as a sealing layer above tailings, which significantly reduced the formation of ARD and leaching of contaminants from the waste. Using a thin layer of industrial rest products an underwater cover above mine waste was shown to be efficient in reducing the negative environmental impact from under water storage of mine waste. This waste could potentially be applied in the Arctic region on mine waste management when adjusting the method according to the specific Arctic conditions.

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A Fourier series model for forecasting solid waste generation in the Kumasi metropolis of Ghana

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Abstract

Successful planning of a solid waste management system depends on the accuracy of prediction of solid waste generation. With a continual economic development and increase in the living standards, the demand for goods and services is increasing at an unprecedented rate, resulting in a commensurate increase in per capita waste generation. In order to facilitate informed decision making for effective solid waste management, we propose a Fourier series model to forecast solid waste generation in Kumasi, Ghana. A monthly solid waste data from 2007 to 2014 was obtained from the solid waste department of the Kumasi Metropolitan Assembly, Ghana. This was used to formulate the Fourier series model for forecasting solid waste. This approach incorporates the characteristics of the data making them more appropriate for forecasting solid waste. It was found that out of the 84 periods considered in the Fourier series model, period 42 was the best model for forecasting solid waste generation. The 1 year monthly forecast revealed that the generation of solid waste will increase as a result of the high rate of urbanization and population growth.
Keywords: solid waste, Fourier series, waste management, forecasting.

1 Introduction

Solid waste management is a global challenge and the situation is worse in urban areas of the developing countries where, in most cases, there are no data of how much solid waste is generated over a specific period of time. This calls for a means

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for anticipating the solid waste to be generated in order for the authorities to take proactive actions in managing the solid waste [16].

Successful planning of a solid waste management system depends critically on the prediction accuracy of solid waste generation. Prediction of municipal solid waste generation provides the basic data on which waste management system is planned, designed and operated thus,the waste transportation trucks required, segregation plant capacity, land requirements for compositing, capacity of landfill site are directly depend on the quantity of municipal waste [17].

Planning and design of municipal solid waste management systems require accurate prediction of solid waste generation [3]. Yet achieving the anticipated prediction accuracy with regard to the generation trends facing many fast-growing regions is quite challenging. The lack of complete historical records of solid waste quantity and quality due to insufficient budget and unavailable management capacity has, in his submission, resulted in a situation that makes the long-term system planning and/or short-term expansion programs intangible.

Thus, [2] proposed that to effectively handle these problems based on limited data samples, a new analytical approach capable of addressing socio-economic and environmental situations must be developed and applied for fulfilling the prediction analysis of solid waste generation with reasonable accuracy.

The prediction condition of generation trend in many developing countries (such as Ghana) is different from those in developed countries. The lack of sampling and analysis of waste in many developing countries due to insufficient budget and the lack of requisite management task force has resulted in a situation where the historical record of solid waste generation and composition can never be completed in the long term. This present a world of challenges when dealing with the subject of waste management let alone the issue of waste prediction, especially in the developing countries [4].

Waste management is a complex process that requires a lot of information from various sources such as factors on waste generation and waste quantity forecasts. When operations related to promotion of waste management systems are considered, it is observed that generation of waste and planning are found to be influenced by different factors including socio demographics [2]. These have led to numerous studies which sough to predict the quantity of solid waste generation worldwide, with the time series and the Fuzzy logic approach being the most common.

For instance, [1] used ARMA/ARIMA and exponential smoothing models to forecast solid waste generation in Arusha city Tanzania. The past data used were monthly amounts of solid waste collected by the city authorities from year 2008 to 2013. The results obtained from the extensive study indicated that ARIMA $(1, 1, 1)$ outperformed other potential models in terms of MAPE, MAD and RMSE measures and hence used to forecast the amount of the solid waste generation for the next years. [5] also used ARIMA time series model to explore the dynamics of solid waste generation in the Kumasi metropolitan assembly with a monthly solid waste data from 2005 to 2010.

Other studies that have applied the Time series (ARIMA) models include [12] who used the Time Series ARIMA model approach to forecast municipal solid waste generation. The works by [1, 12] suggested that ARIMA $(1, 1, 1)$ model is the best model among all parametric time series models for forecasting solid waste generation though they assumed that the solid waste generation data follows a stationary stochastic process. That is, its mean and variance do not change over time.

However, the solid wasted generation data has a non-parametric characteristics. This implies that they are seasonal or time heterogeneous. For this reason, other researchers including [4, 10, 11] used the fuzzy logic to predict the expected quantity of solid waste.

In a quest to get a model that best predicts solid waste generation, some researches have explored the applicability of other models including the Artificial neural networks [13, 16], linear programming model [6, 13–15] and the waste management system [7].

Clearly, there is no convergence in literature in terms of the method that can be best applied in the prediction of solid waste. This paper proposes forecasting solid waste generation will require that model capture the underlying characteristics of data. This includes the non-parametric characteristics, the time heterogeneous nature and the periodicity of data. Our approach, the Fourier series model accounts for these characteristics in the data set. This paper, firstly, develops a model that can best describe the quantity of solid waste generated using monthly data in the Kumasi metropolis. Secondly we evaluate the proposed model by comparing its sum of squared error (SSE) with the SSE of high performing existing approach namely the ARIMA time series. Finally, we apply our model to estimate the expected quantity of solid waste generation in the Kumasi metropolis for the year 2016.

2 Method

2.1 The Fourier series model

Fourier series is named in honor of Joseph Fourier, who made important contributions to the study of trigonometric series, after preliminary investigations by Leonhard Euler, Jean le Rond d'Alembert and Daniel Bernoulli. Fourier applied this technique to find the solution of the heat equation [15].

The founding principle behind the field of Fourier series analysis, is an infinite expansion of a periodic function in terms of sines and cosines or imaginary exponentials. It also makes use of the orthogonality relationships of the sines and the cosines.

James Walker [8] presented the Fourier series of a function as represented Equation (1).

$$f(x) = a_0 + \sum_{k=1}^{K}\left(a_k \cos\frac{2\pi k}{n}x + b_k \sin\frac{2\pi k}{n}x\right) \tag{1}$$

where $f(x)$ is a periodic function,

$$a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\cos nx\,dx, \quad n = 1, 2, 3, \ldots, \tag{2}$$

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\sin nx\,dx, \quad n = 1, 2, 3, \ldots. \tag{3}$$

For the purpose of this research the discrete decomposition of Fourier series is considered since we dealing with the monthly tonnage solid waste generated from January 2007 to December 2014. The Fourier series for continuous function is then decomposed to give us a discrete representation which is given by Equation (4).

$$Q_s^{d,s} = a_0 + \sum_{k=1}^{K}\left(a_k \cos\frac{2\pi k}{n}m + b_k \sin\frac{2\pi k}{n}m\right) \tag{4}$$

where
a_0 is the mean value of the seasonal cycle,
$m = 1, 2, 3, \ldots, 84$,
$n =$ the total number of periods,
$Q_s^{d,s} =$ the discrete values to forecast,
$K =$ the harmonic being considered,

$$a_k = \frac{2}{n}\sum_{m=1}^{n}\left(Q_m^{d,obs}\cos\frac{2\pi k}{n}m\right), \tag{5}$$

$$b_k = \frac{2}{n}\sum_{m=1}^{n}\left(Q_m^{d,obs}\sin\frac{2\pi k}{n}m\right), \tag{6}$$

$Q_m^{d,obs} =$ the discrete values observed,
$m =$ the individual data points,
$n =$ the total observed data points,
$k =$ the period being considered.

As each new harmonic (period) was added to the Fourier series, the sum of square errors were determined. The sum of square errors will be used in identifying the optimal period (k) associated with the Fourier series function. This is achieved by measuring the deviation between the prediction of the Fourier series function at each period (k) and the observed prediction.

$$SSE = \sum_{k=1}^{\infty}(Y - Y^*)^2 \tag{7}$$

where Y is the observed value and Y^* is the predicted value. This leads to the formulation in Equation (8) used in the research.

$$SSE = \sum_{k=1}^{\infty}(Q_s^{d,obs} - Q_s^{f,s})^2 \tag{8}$$

where
$Q_s^{d,obs}$ = observed solid waste generated,
$Q_s^{f,s}$ = predicted solid waste generation.

The smaller the SSE, the better the predictive ability of the Fourier series function. In the concept of series, the Fourier coefficients are unique. This Uniqueness is what differentiates one series from another (Weierstrass Approximation Theorem). In other words, what will make this Fourier series model unique to Kumasi is the unique Fourier coefficients. This means to apply Fourier series to any other location the Fourier coefficients have to be determined.

The number of periods(k) used is actually determined by the number of individual data points considered. Since we considered 84 data points for this study, our period(k) must run from 1 to 84. The essence hear is to be able to get a Fourier series model that is able to estimate all the individual data points. This model will then be referred to as a good representation and then used for forecasting based on the fact that we have 84 data points. It means we have 84 models and 84 different graphical interpretation that goes to inform the strength of the model. We present the best 4 out of the 84 possible models have been presented namely 6, 12, 42 and 84.The other models are presented as supplementary files.

3 Results and discussion

3.1 Study area and background of data

Kumasi is the capital city of the Ashanti region. Tradition is held very high in Kumasi and blends very well with modernity. There is a wide range of attractions in Kumasi. Kumasi is located in the transitional forest zone and is about 270 km north of the national capital, Accra. It is between latitude $6.35°$–$6.40°$ and longitude $1.30°$–$1.35°$, an elevation which ranges between 250 and 300 meters above sea level with an area of about 254 km^2. Kumasi features a tropical wet and dry climate, with relatively constant temperatures throughout the course of the year. Kumasi averages around 1400 mm (55 inches) of rain per year. The city is a rapidly growing one with an annual growth rate of 2.7% and a 3.5% rate of urbanization.

The population of Kumasi is about 4,780,380 as of 2010. In the year 2005, 1,000 tons of solid waste was generated each day in the city; three years later, it increased by 20% resulting in 1,200 tons a day. As at 2014, 4,000 tons of solid waste was being generated daily in the Kumasi Metropolis [9]. According to [5], KMA is not able to manage solid waste effectively due to rapid urbanization, poor financing capacity of authorities and lack of safe waste disposal sites, which is a reflection of the weak solid waste generation data of the city.

The lack of proper waste data eventually leads to the inability of the authorities to accurately forecast the quantity of waste to be generated. The cyclical mantra of planning is thus invoked: planning to predict or predicting to plan.

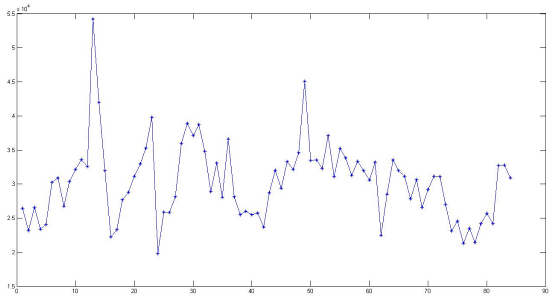

Figure 1: Time plot for solid waste for 84 months.

3.2 Model formulation

A time plot of the monthly solid waste generated in the Kumasi metropolis for the 84 months is presented in Figure 1. It can be observed from the time plot in Figure 1 that the data is periodic with its highest value being 54,203 tons occurring in January 2009. This peak value can be associated to the Christmas and new year festivities which comes along with high rate of consumptions of goods. A lowest value of 19,807 tons occurred in December of the same year.

We, firstly, model a Fourier series function that gives a very good representation of the time plot (Figure 1). This will be a model from Fourier series that best describes the trend of solid waste generation in the Kumasi municipality. This model obtained will then be used to predict the quantity of solid waste to be generated in the next two (2) years.

Fourier series in its definition is simply a sinusoidal representation of a periodic function,this optimal representation of a periodic function is found by alternating the value of k in the Fourier Series.The least sum of squared error is used to ensure a suitable k is chosen. For instance at $k = 1$, one will obtain a predictive Fourier series function made up of a_o and just two other Fourier coefficients that is a_1 and b_1.

$$f(x) = a_0 + a_1 \cos \frac{2\pi}{n} m + b_1 \sin \frac{2\pi}{n} m \tag{9}$$

When the period is increased to $k = 2$, we will realize a change in the Fourier function since this will yield an increase in the number of Fourier coefficients, thus a_0, a_1, a_2, b_1 and b_2. Hence, Equation (10):

$$f(x) = a_0 + a_1 \cos \frac{2\pi}{n} m + a_2 \cos \frac{2\pi}{n} m + b_1 \sin \frac{2\pi}{n} m + b_2 \sin \frac{2\pi}{n} m \tag{10}$$

The periods are progressively increased for every single period point under consideration from 1 through to 84 but selected periods with their corresponding time plots, thus periods 6, 12, and 42 are displayed, as a sample representation of all 84 computations, to show the gradual progression to the ideal curve.

3.2.1 Modeling Fourier series at $k = 6$

At period 6, $k = 6$, six (6) Fourier coefficients were obtained.These coefficients was used to build a predictive Fourier series function, the Fourier function obtained using $k = 6$ was used to forecast the expected waste and the least sum of square errors was also computed to enable choose the optimum point out of the 84 periods being considered.

$$\begin{aligned} Q_m^{f,s} &= 3.027 * 10^4 + (-2.1058 * 10^3)\cos\frac{2\pi}{84}m + (-1.5608 * 10^3)\cos\frac{2\pi}{84}m \\ &+ (0.4705 * 10^3)\cos\frac{2\pi}{84}m + (-2.2247 * 10^3)\cos\frac{2\pi}{84}m \\ &+ (1.7951 * 10^3)\cos\frac{2\pi}{84}m + (0.8545. * 10^3)\cos\frac{2\pi}{84}m \\ &+ (0.7631 * 10^3)\sin\frac{2\pi}{84}m + (2.1033 * 10^3)\sin\frac{2\pi}{84}m \\ &+ (0.3757 * 10^3)\sin\frac{2\pi}{84}m + (0.5193 * 10^3)\sin\frac{2\pi}{84}m \\ &+ (-1.7134 * 10^3)\sin\frac{2\pi}{84}m + (-0.3859 * 10^3)\sin\frac{2\pi}{84}m \end{aligned} \tag{11}$$

It is clear from the observation of Figure 2, that the difference between the Fourier series prediction denoted by the color red and the actual time plot of Figure 1 is huge at period 6 ($k = 6$), this huge variance is further established statistically with the least squared method where we obtained a value of $2.8968 * 10^7$. This Fourier series prediction at ($k = 6$) was rejected since the deviation between the Fourier series prediction and observed values were huge, characterize by a large SSE. Hence, we increased our period (k) from 6 to 12.

3.2.2 Modeling Fourier series at $k = 12$

At period ($k = 12$) Fourier series coefficients were obtained in addition to a_0 to construct the Fourier series predictive function as shown in Table 2. This function was used to obtained a predictive graph illustrated by Figure 3.

At point $k = 12$.

It is observed from Figure 3 that the Fourier series prediction of period 12 ($k = 12$) performed better than that of Figure 1 of ($k = 6$). The SSE between the Fourier series prediction denoted by the color red and the actual time plot of Figure 1 is not as huge as that of Figure 2. This fact was further substantiated statistically when the least sum of square error of Figure 3 was found to be $2.6746 * 10^7$, which is less than that of Figure 2. This Fourier Series prediction at ($k = 12$) was rejected since its deviation was not the smallest in all the 84 periods considered. Hence, it is increased from 12 to 42.

3.2.3 Modeling Fourier series at $k = 42$

An optimal point was finally obtained at period ($k = 42$). This period gave the smallest deviation in all the 84 periods considered,with a numerical value of

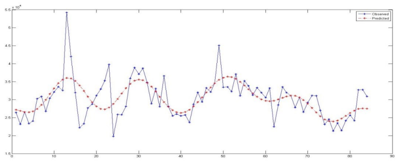

Figure 2: Fourier function prediction for period 6.

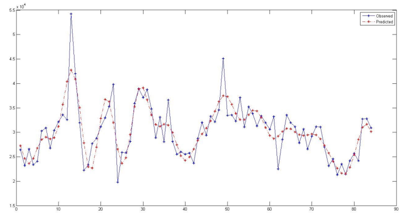

Figure 3: Fourier Function prediction for period 12.

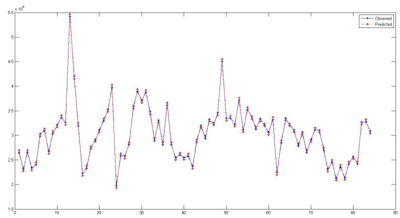

Figure 4: Fourier function prediction for period 42.

$1.8124 * 10^7$. It can be observed that the Fourier series function obtained for this period gave a perfect prediction of Figure 4. The difference between the Fourier series prediction and the time plot of Figure 1 is almost negligible. The 42 Fourier coefficients obtained for this Fourier series predictive function was then used for the construction of a 2 year monthly Predictive Fourier series model.

Table 1 below present the SSE associated with each period (k) considered. Period 42 gave the smallest SSE among the SSE presented.

Table 1: A tabular representation of the sum of squared errors for model selection.

Various iterations (at various periodic values)	Sum of squared error
6	$2.8968 *10^7$
12	$2.6746 *10^7$
42	$1.8124 *10^7$

3.2.4 The Fourier Series model for forecasting solid waste generation

In order to forecast the solid waste, an extrapolation is carried out with respect to n being the interval. Since our data points end at 84, the forecast then starts from the 85th month which represents the month of January in the year 2015.

The model for forecasting is then represented by:

$$Q_m^{f,s} = a_0 + \sum_{k=1}^{42}\left(a_k \cos\frac{2\pi k}{n}m + a_k \sin\frac{2\pi k}{n}m\right) \qquad (12)$$

where a_k and b_k are the coefficients of the model, $n = 84$ data points.

3.3 Evaluation of model

In this section the applicability, suitability and performance of the Fourier series model is verified by comparing it to a known high performing existing model the ARIMA Time series model. This ARIMA Time series has been widely used in research in forecasting including the area of solid waste generation [8]. The high performance of ARIMA time series models make them useful for evaluating the proposed model.

3.3.1 Performance indicators

The performance of the models are indicated by the SSE, the smaller the SSE the better the model. In this section, we build an Arima time series model using the same data set of solid waste generation from January 2007 to December 2014. The SSE from the ARIMA time series model and the Fourier Series Model are compared the model with smallest SSE is the best model for forecasting solid waste generation. That is the SSE gives a measure of the suitability of the model for forecasting solid waste generation. The SSE associated with each model is presented in Table 1.

3.3.2 ARIMA time series model

In reference to the time plot of Figure 1, an ARIMA model is identified. The model identification process is where the structure and order of the possible models are mainly selected. The structure and order of the models are selected from the sample using the partial autocorrelation function for the AR part and the autocorrelation function for the MA part of the observed series. However the AR and MA parts of the series are identified when the series is stationary.

For the stationarity test of the data, the unit root and the KPSS test are used and presented in Table 2.

The unit root test tests the null hypothesis that there exist a trend in the series, with a p-value of 0.01694, the null hypothesis is rejected in favour of the alternative that the data is stationary. On the other hand, the KPSS test, tests the null that the data is stationary and from the p-value of 0.1, we fail to reject the null hypothesis of stationarity. Thus, the two test results indicate the data is stationary.

Table 2: Unit root and stationarity test.

Test	Statistics	P-value	alpha-level
ADF	−3.9277	0.01694	0.05
KPSS	0.2642	0.1	0.05

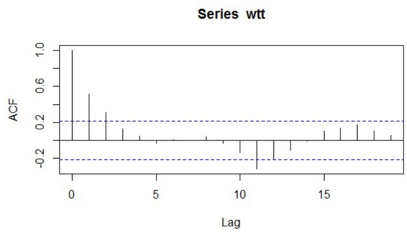

Figure 5: Autocorrelation function.

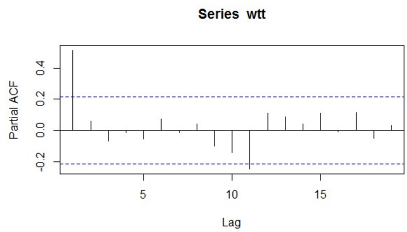

Figure 6: Partial autocorrelation function.

Augmented Dickey–Fuller Test
Dickey–Fuller = −3.9277, Lag order = 4, p-value = 0.01694 alternative hypothesis: stationary.

Next we proceed to determine the MA and AR parts from the ACF and PACF respectively presented in Figures 5 and 6.

From Figures 5 and 6 the candid models for the data will be ARIMA $(1,0,1)$ and ARIMA $(1,0,2)$. Since the PACF have spike at lag one and that of the ACF have spikes at 1, 2 and 3.

Model identifications
In order to identify the appropriate ARIMA models, the values of the AIC's from all the possible models are compared. The best ARIMA model is the one with the minimum AIC value. The ARIMA $(1,0,1)$ recorded an AIC value of 1668.78 in the first experiment. The details of the ARIMA $(1,0,1)$ are presented in Tables 4 and 5. However, the ARIMA $(1,0,2)$ model had a high AIC value of 1670.36 with other details presented in Table 6. Therefore ARIMA $(1,0,1)$ is the best ARIMA time series model for this data set.

3.3.3 Performance of model

In this section we compare the two models and use SSE to choose the best one. The actual monthly solid waste collected by the waste management division of the Kumasi metropolitan Assembly for the year 2015 was obtained. This data set is compared to the 2015 prediction of the Fourier series model and the ARIMA $(1,0,1)$ model. The SSE of both the ARIMA and Fourier series model gives the

Table 3: Coefficients ARIMA $(1, 0, 1)$.

	AR1	MA1	MA2	INTERCEPTS
	0.4559	0.0298	0.1067	30094.91
S.E	0.2815	0.2926	0.1589	1066.38

Table 4: Coefficients ARIMA $(1, 0, 2)$.

	AR1	MA1	INTERCEPTS
	0.5845	−0.0944	30079.651
S.E	0.1553	0.1841	1112.732

Table 5: Sum of squared error for Fourier series model and the ARIMA model against actual observed.

Month	Fourier series model	ARIMA model	Actual	Fourier S.E.	ARIMA S.E.
January	30066	28284	24367.7	32470167.0	15334586.0
February	28097	29030	21194.0	47650856.8	61412112.4
March	30078	29466	24584.5	30178849.9	23830975.3
April	29039	29870	22784.8	39114642.3	50201050.9
May	26621	29870	22747.7	15002452.8	50728439.3
June	28708	29957	21462.5	52497849.8	72160267.8
July	31576	30008	21685.5	97822781.4	69265837.2
August	30811	30038	21467.4	87303272.0	73458476.1
September	30457	30055	21142.0	86769187.7	79445098.6
October	26608	30065	25531.2	1159485.3	2055852.4
November	22580	30071	20736.6	3398278.16	87137408.2
December	24988	30075	17906.5	50147982	148067378.9
SSE				543515806.04	751584183.46

suitability of the two models to the given data. The smaller the SSE the better the model.

The Fourier series produces better forecast of solid waste generation since it has the minimum SSE of 543515806.04 compared with the ARIMA $(1, 0, 1)$ model which had an SSE of 751584183.46. This optimal performance by the Fourier series model is due to its ability to incorporate the periodicity and the time heterogeneous nature of the solid waste generation data set. This makes our novel approach of forecasting solid waste approach more desirable than existing forecasting approaches.

3.4 Forecast of solid waste by the Fourier model

The Fourier series can effectively be used to forecast solid waste generation. We use MATLAB code to implement our proposed model to forecast solid waste generation for the year 2016. The forecasting values are shown in Table 6.

Table 6: The expected waste of the year 2016.

Month	Year 2016
January	36000
February	21135
March	23986
April	21643
May	22021
June	25943
July	24867
August	24249
September	29421
October	34416
November	32128
December	30413

The model gives adequate information on the monthly quantity of solid waste to be expected from January 2016 to December 2016 with a peak value of 36,000 tons occurring in January 2016 and a minimum value of 21,135 tons occurring in February the same year. This informs the decisions of management in putting in adequate measures to address this pertaining issue of waste in the metropolis. Furthermore, the results presented elucidate managers on the human personnel required for the collection, the trucks for solid waste transportation and the size of land required to be used for landfills.

4 Conclusion

The Fourier series model has a smaller SSE than that of the ARIMA time series model. This makes Fourier series a more suitable model for forecasting solid waste. Thus, Fourier series has successfully been applied to the problem of forecasting solid waste generation. The periodicity and the time heterogeneous nature of the data set make the Fourier series model suitable for forecasting solid waste generation. Therefore, For data sets that are time heterogeneous and periodic,The Fourier model is more suitable for forecasting.

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Sustainable waste management: the example of the informal settlement "Las Fincas" on Cozumel Island, Mexico

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Abstract

The study is part of the long-term research project called "Indicadores de productos de Interés Sustentabilidad aplicados a regional – México-Argentina" in collaboration with the University of Quintana Roo and the University Litoral of Argentina.

The project deals with the question: "How can you create sustainable waste management for an informal settlement to improve the social and environmental problems?" The knowledge gained from the last survey in 2014/2015 indicates that there is no systematic waste management within the settlement where 1015 people currently live. An unknown part of the waste is collected and disposed of in a disposal site by the waste management company PASA (Promotora Ambiental, S.A.B. de C.V.). The other part is burnt either on private property or improperly disposed illegally outside the land by residents. This leads to social tension between residents and to environmental pollution, such as, soil and groundwater pollution.

So far there are no data of waste and recycling management of the informal settlement Las Fincas. The study attempts to investigate the situation, to find out how the waste on the island is treated and how the municipal waste of Las Fincas is composed. The total amount of waste and its composition is analyzed by means of a waste analysis. Later a disposal plan for the settlement will be developed.

The basis for the analysis of waste are the corresponding sorting work guidelines and the household waste analysis data sheets of the Thuringian State Institute for Environment and Geology. The amount of waste of selected families

is collected and analyzed in two consecutive samples. The average amount of waste per inhabitant per year is determined by the earnings projection. The results obtained are used on the one hand for the development of a sustainable waste management concept and on the other, for the economic analysis in the case of recyclable materials. In addition, the aspects of waste prevention and recycling, the use of bio-waste were considered as well.
Keyword: waste analysis, sustainable waste management, informal settlement, waste concept, environmentally influencing, bio-waste composting.

1 Introduction

The island of Cozumel is located on the eastern coast of Mexico's Yucatán Peninsula in the state of Quintana Roo (see Fig. 1). It has a maximum north-south length of 45 kilometers and a maximum east-west distance of 15 kilometers and covers an area of approximately 684.48 square kilometers. It is the third largest island of Mexico [1]. About 95,000 inhabitants currently live on the island [2]. The island's capital is San Miguel de Cozumel, where almost the entire population lives.

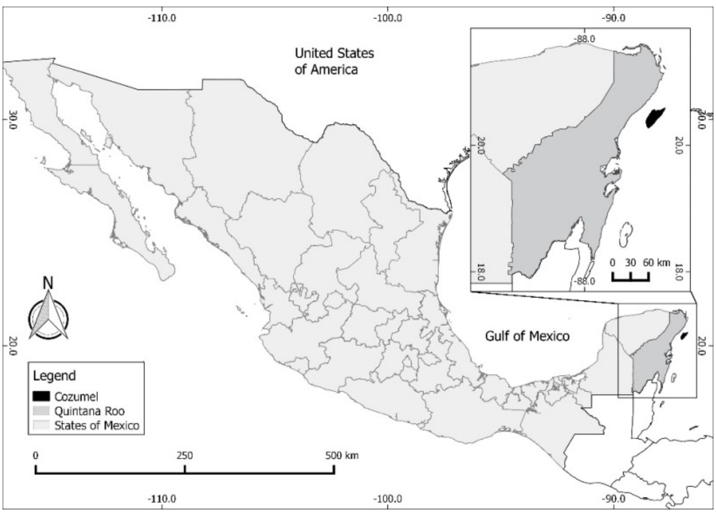

Figure 1: Geographical location of the island of Cozumel.

The Yucatán Peninsula is mainly composed of limestone. Cozumel Island is part of the Yucatec carbonate platform. Dissolution processes in the limestone lead to karstification; groundwater preferentially flows into karstic cavities and underground, the groundwater moves through karst cavities [3]. Because of the location of the island the groundwater is in contact with seawater.

The present study deals with a study area in the northwest of the island of Cozumel. This is the informal settlement Las Fincas, which is located outside the town of San Miguel de Cozumel. Due to the informal urbanization of the settlement there is no public water or power supply nor a sewerage or waste disposal system. The construction of buildings and the inhabitation of parceled land takes place in an uncontrolled manner. Streets and roads are unpaved. The aquifer has a high sensitivity to anthropogenic influences. The fact that no public supply exists, constitutes a danger to the ground water, which can easily be contaminated by waste and sewerage.

In this study a waste analysis was implemented in Las Fincas. The sorting technology has been applied according to the specifications of the waste sorting guidelines respectively household waste analysis data sheets of the Thuringian State Institute for Environment and Geology. As a result, a recommendation for action on sustainable waste disposal and waste recycling was elaborated.

2 Waste management in Cozumel and Las Fincas

The Secretary of the Environment (SEMARNAT) and the Federal Environmental Agency (PROPFEPA) of Mexico are responsible for environmental policy. The Waste Management Act of 2003 (Ley general para la prevención y gestión integral de los residuos) forms the basis and legal forms for Mexican waste and recycling management. However, the individual states have their own environmental legislation. The definition and implementation of the legal forms are regulated by the state government – except in the case of special waste (here the Federal Government is responsible). Thus, there are specific laws (leyes), regulations (reglementos) and standards (normas) for waste management in the states [4]. In the state of Quintana Roo, the Waste Act (Ley para la prevención y la gestión integral de residuos) regulates the prevention and treatment of waste.

About 100 metric tons of waste are produced daily by the total population of Cozumel [2]. This amount of waste is collected and disposed by the private waste management companies called Promotora Ambiental (PASA). Although a law for the prevention and treatment of household refuse has been in existence in Mexico since 2003, the waste of Cozumel was deposited on a wild dump until 2009. Only since 2010 has waste been deposited on a 25-hectare disposal site.

The statistics show that in Mexico only 10% of waste is collected separately [5]. The rest is placed on disposal sites. The recycling rate is about 5% [6] (in Germany it is 65%). The waste management company PASA is responsible for the collection and transportation of waste on the whole island. In Las Fincas the waste is collected three times a week. There are no data available concerning the amount of waste for Las Fincas.

3 Methods

3.1 Preparation

For the separation of waste according to the specifications of the waste sorting guidelines and household waste analysis data sheets of the Thuringian State Institute for Environment and Geology, two sieves with mesh sizes 50 mm and

10 mm were constructed. The leaflet has a mesh size (sieve cut) of 40 mm, but it was not possible to build the given mesh size in Mexico. Fractionation of waste was divided into three classes for a screening:

- Coarse waste — Waste components > 50 mm
- Medium waste — Waste components ≥ 10 mm -≤ 50 mm
- Fine waste — Waste components < 10 mm

3.2 Sampling

As part of household waste analyses, it was necessary to consider the settlement structure circumstances of each study area [7]. For this the basic data of the previous survey of 2015 played a decisive role. Las Fincas was characterized by the following features [8]:

- Informal settlement without connection to public primary care;
- Thin housing development with high proportions of green space;
- Dry and rainy weather seasons;
- No systematic waste collection by municipal waste containers;
- No fees for waste by public institutions.

Las Fincas is divided into eight municipal districts (so-called manzanas). Figure 2 shows the location of the current waste collection places. Due to lack of infrastructure, the provisional collecting garbage cans were only positioned along the main road. A sampling of the waste of the public collection system was considered not to be effective in order to determine waste amounts because the inhabitants did not dispose their total amount of waste into the collecting garbage cans, but they burnt them or stored them in the vicinity of their homes.

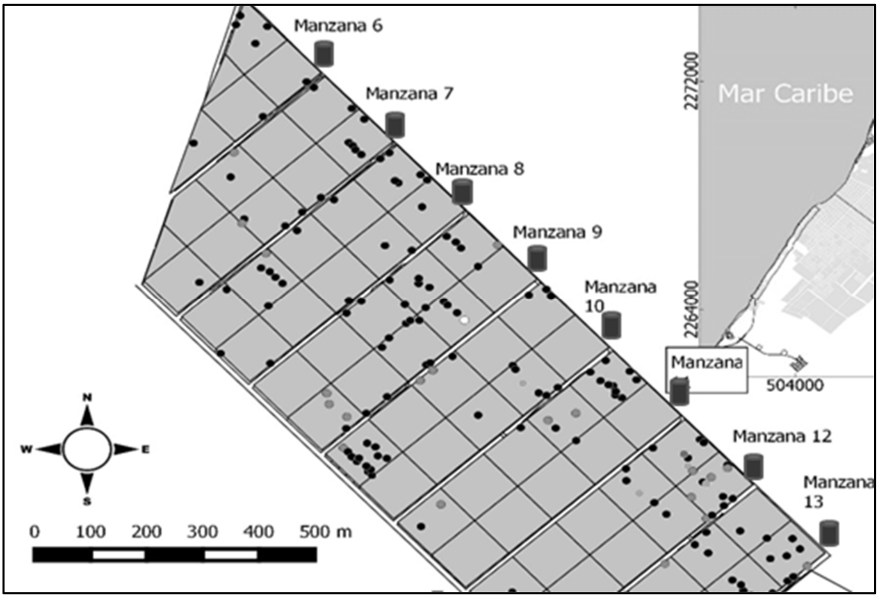

Figure 2: Current waste collection places in Las Fincas.

The actual amounts of waste could therefore only be ensured by direct detection. From eight manzanas, twenty families with a minimum capacity of three and a maximum of fourteen family members were selected. Another criterion was the permanent residence of the selected families. In these households, waste was collected as a sample for waste analysis. Garbage bags were distributed to the selected families to accommodate the total waste. Sampled households are shown in figure 3.

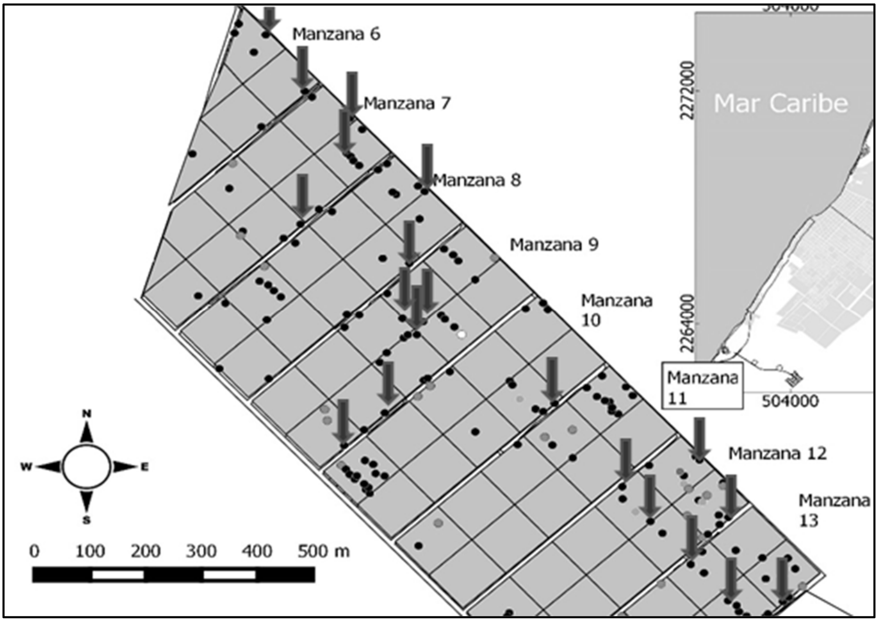

Figure 3: Location of the sampled households.

3.3 Sample size

The sample included twenty out of 274 families. This presented about 7% of the families and enabled a serious assessment with respect to the waste analysis. From a statistical rule 5% would be sufficient, that means about 14 families. The investigation period was defined for a week, so it was long enough for the sample size [7]. The amount of the continuously accumulating bio-waste was taken down on a special form which made a subsequent assignment possible. In this way it was possible to detect the average mass of waste of the respective sorting action in the aftermath and thus it was possible to calculate the specific data (kilograms per inhabitant per year), which were indispensable for an accurate settlement structure-specific extrapolation of sorting results for the whole area of Las Fincas.

3.4 Sorting work implementation

The collected samples of the households were picked up by a pick-up truck and transported to the sorting station. Before the sorting work, the containers were prepared with labels for the different waste fractions. There took place a manual sorting of the samples according to the waste garbage guidelines of the TLUG [9] into 24 fractions, which form 14 groups of substance (see Table 1). For separation of the waste the designed sieve that is described in section 3.1 was used. The amounts of waste were weighed by using a kitchen scale. The results were tabulated.

4 Results

In order to calculate the specific amount of household waste in kilograms per inhabitant per week or kilograms per inhabitant per year, it was necessary to determine the number of inhabitants who were considered in the sample. The total number of included residents was 120. The results could be used for an extrapolation. Waste amount were calculated for the whole settlement.

During the first sorting campaign (15–22 March 2016) was collected an amount of 169.50 kg). During the second sorting campaign (23–30 March 2016) was recorded an amount of 177.20 kg.

Looking at table 1 it is clearly to be seen which main substances characterize the domestic waste composition.

Table 1: Shares of household waste composition according to material groups.

Household waste composition Las Fincas		
Material group	**Waste amount per inhabitant per year [kg]**	**Proportionally [%]**
(1) Compostable materials	21.8	30
(2) Glass	13.04	18
(3) Plastics	10.02	14
(4) Paper/cardboard/carton (PCC)	7.26	10
(5) Hygiene products	3.48	5
(6) Composite packaging	2.82	4
(7) Inert material	2.61	4
(8) Other types of waste	12.63	15
(1-7) Total I	**61.03**	**85**
(1-8) Total II	**73.66**	**100**

Table 1 shows clearly that the municipal waste composition of Las Fincas is mainly dominated by a small group of substances. These are the groups of substances organic, glass, plastics, paper-cardboard-carton packaging (PCC) and inert material, which accounted an amount 85% (see table 1).

The sorting work showed an average amount of waste of about 0.21 kg per inhabitant per day. There was an average drop mass of 75 kg per person per year. Table 2 shows the average results per inhabitant (daily, weekly and yearly) and the total annual mass for Las Fincas.

Table 2: Specific volume of household waste for Las Fincas.

Specific volume of household waste per person in Las Fincas			
	kg/d	**kg/wk**	**kg/yr**
1. Sorting campaign	0.20	1.41	74.00
2. Sorting campaign	0.21	1.48	77.00

Based on the sampling data, the waste production in Las Fincas of all residents was calculated, which mount up to about 76 metric tons per year.

5 Recommended action

Compared with the average waste balance (385 kilograms per person per year) of Cozumel, the results of the study (about 74 or 77 kilograms per person per year) are lower. The cause of the higher volume of waste in the balance sheet in Cozumel over Las Fincas is because of the fact that most of the waste are from hotels and retail stores. However, not environmentally storage and disposal of waste leads to significant and adverse impact on groundwater and the soil in Las Fincas. This demonstrates the groundwater investigation of Koch *et al.* [10] from the year 2016. The public waste management in San Miguel de Cozumel passes waste to the disposal site on the island. The small amounts of waste in Las Fincas, which are predominantly recyclable, could be eliminated without damage by an organized separation and disposal. Organic waste could be recycled through composting. As part of environmental education programs, the citizens of Las Fincas could be sensitized for waste separation, waste prevention and safe disposal. A financial incentive could also be created through the sale of recyclable waste to collection. In the study, as a practical model a composter was built, which can be reconstructed with little effort.

6 Summary

The waste balance in Las Fincas revealed that the local waste amounts to only 20% compared to the amount of waste the island's capital. However, there is no effective public waste management and the principle of circular economy is not applied. This lead to the problem that there is no proper waste disposal takes place which has negative effects on groundwater and soil of the area. A perspective for the residents could be environmental education programs in order to increase and sensitize their awareness of environmentally sound and sustainable waste management. In addition, financial incentives such as the sale of recyclable waste, which presented approximately 36% of total waste generated, encourage people to separate the waste and the collection points. The composting of organic waste (30%) would reduce total waste generation considerably. Thus, only 34% would result by residual waste that must be disposed on disposal site. This corresponds to an amount of approximately 19 tons per year. As a result, the existing burden on water and soil would be significantly reduced.

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Development of a sustainable MSW landfill as an intrinsic part of a low-priced, integrated waste management facility

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Abstract

Usually, a landfill is designed to function as an independent technological unit from the inception of the facility to the post closure stage of its development. However, sustainable technologies like in-situ aeration and landfill flushing dramatically shorten the duration of aftercare period. The aftercare phase comes to an end when the actual emissions appear to be so low that the site can be abandoned with essentially no risk to environmental quality and public health. Closed sections, if rapidly stabilised, offer an opportunity for real-time land reclamation for the establishment of waste recycling and recovery activities there while the landfill is still active as well as afterwards. Environmental, logistic and other infrastructure already present at the site are very much applicable for purposes of integrated waste management, too. In this way, a landfill site is slowly transformed into an integrated waste management complex diverting more and more waste away from burial in the landfill. This process may last a decade or two. After the post-closure care period ends the operator is still actively present on-site which simplifies liability concerns. Additionally, synergistic effects can result in significant economic benefits for the owner and the operator, which can be considered as the money held in escrow for purposes of covering post-closure costs. In the case of a small pilot-scale Slovenian landfill, these costs appear to be very low because its design was focused on issues like socio-economic sustainability and rapid waste stabilization. Since waste disposal of untreated MSW is still widespread in low-income countries today, the approach could be of current interest for smaller, self dependent urban areas in developing countries.
Keywords: flushing landfill, semiaerobic landfill, low-cost landfill, integrated waste-management, land reclamation, transition period.

1 Introduction

Landfilling is universally considered to be the least sustainable method of waste management. In the industrialized countries, complex integrated waste management systems have been gradually established diverting large portions of recyclable, biodegradable and combustible municipal solid waste (MSW) fractions away from landfill. The remaining active MSW landfills tend to be large, highly engineered facilities. In some countries, only thermally or mechanically-biologically pretreated MSW can be landfilled.

On the other hand, a large part of MSW generated in developing countries continues to be deposited in numerous small, poorly managed, not fully controlled sanitary landfills or even in open dumps, threatening the local environments there.

Municipalities in developing countries are often left on their own in order to solve their local environmental problems. Great difficulties have to be overcome trying to define useful MSW management strategies due to low technical experience and low financial resources that often cover only collection and transport costs, leaving little resources for safe disposal (e.g., Diaz *et al.* [1]).

All the same, municipalities in several European countries faced similar challenges just a decade or two ago. Many succeeded in establishing intermunicipal associations for the operation of new MSW management systems complying with the new technical standards and also succeeded in receiving funding from a wide range of national and/or international bodies. Basic environmental problems were ultimately solved, but costs and fees sky-rocketed, too. Such approach can be rarely duplicated in low-income developing countries today.

However, there were also cases when municipalities decided to choose a relatively uncommon, low-cost path due to uncertainties and peculiar economical circumstances they were facing at the time. Some succeeded to realize their objective to a satisfactory degree, largely on their own. Such experiences could be informative today for local waste management developers in low-income countries who find themselves in comparable situations.

2 Recognising environmental benefits of low waste compaction: a case study

Ajdovščina and Vipava municipalities (~25,000 inhabitants, Slovenia) inherited a non-compliant dumpsite intended to be closed down in 2001 which was however accidentally located on an environmentally and logistically adequate site and still had an available capacity for additional waste. The proposed alternative solution at the time appeared to be very costly and environmentally unreasonable. Consequently, it was decided that the particular site should remain active. It eventually began to operate and develop as a pilot research facility (Madon [2]).

The related general strategic direction in regard to the development of the site approved by the two local municipal councils some fifteen years ago appeared to be quite straightforward, as delineated below:

1) Low cost managerial and technical interventions could make substantial impacts compensating for the deficiency of funds. Therefore, our own municipal company was given the responsibility to develop the system and an educated person who understands the scientific concepts and facts that underlie environmental issues was employed in order to cope with the demands.
2) The existing semi-controlled dump had to be legalized, rehabilitated and enlarged in order to be functional for the next fifteen years by introducing sustainable waste disposal practices at the site. However, it had to be done in the most economically feasible way.
3) During the same period of time, some simple, but effective and flexible system of integrated waste management had to be established at the site as well, diverting most of the collected MSW and other waste from entering the landfill.

It was already known that the particular dump was not among the worst ones which were active in the country during that time: the elementary public health provisions were already implemented by the local operator carrying out regular cover operations and most importantly, the hydrogeological setting was found to be optimal (Madon [3]). The facility was lacking some basic infrastructure in order to be called a 'sanitary landfill': leachate and gas collection systems, reception platform and a weighbridge among other deficiencies.

By monitoring the emissions from the old sanitary landfill sites and dumps in developed countries (e.g., Kjeldsen and Christ [4], Komilis and Stegman [5]) it was recognised that MSW buried in these facilities generally tends to stabilize quickly. The very same encouraging conclusions were derived by performing environmental research at this particular local dump site and in the nearby surroundings in 2001/02. Leachate oozing out of the foothills of the dump appeared to be of comparably good quality, objectionable odours were almost completely absent and methane concentrations in the landfill gas samples taken below the sanitary cover were found to be low. Atmospheric gases were found to be present in small concentrations in deeper parts of the landfill, too, penetrating laterally from the slopes. Dissolved oxygen was almost always present in the saturated zone on the bottom of the landfill in small concentrations as well.

Many coincidental factors were believed to have contributed in creating favorable environmental conditions within the interior of the buried waste: 1) The dump was formed as an above-ground, self-draining waste pile (landraise), at the time not yet capped; 2) Compaction energy input was minimal, since daily waste shipments were not spread over the slightly inclined working face areas in order to be compacted in thin layers (slices), but by applying compaction over a subhorizontal, 2.5–3 m thick layer of waste forming a lift in one incremental step utilizing a bulldozer only; 3) Marly-clayey soil was mostly used for carrying out daily (sanitary) cover operations. It was arriving continually from the many local construction sites without any cost for the operator.

The resultant waste pile appeared to be a subhorizontally stratified structure featuring imperfect alternation of up to 3 m thick, lightly compacted layers of disposed of waste and up to 0.5 m thick, almost impermeable lenses of clayey soils. Saturated hydraulic conductivity through the layers of disposed of waste was later found to exhibit values around $k_{sat} \approx 5.10^{-5}$ m/s , whereas in the vertical direction the value appeared to be smaller for one decadic order of magnitude, which was related to the particular pattern of stratification (Madon [3]).

The passive structure demonstrated some unique, environmentally and economically important features, uncommon for the ordinary, anaerobic sanitary landfills, which was interpreted as written below:

1) High permeability of loosely compacted layers of waste allowed for aqueous and gasseous products of decomposition to be quickly removed from the very microlocations where they were formed, indirectly enabling fast rates of stabilisation and mineralization processes to occur unabated in continuation. Lightly compacted layers of waste transmit fluids efficiently by themselves. In modern landfills specifically engineered gravel layers and blankets were constructed in order to facilitate leachate drainage, landfill gas collection and distribution of recirculated waters within the waste body.
2) Semiaerobic environment within the dump provided for a) less generated methane, b) faster decomposition releasing simpler, non-odorous substances into the environment, c) lower amonium concentrations within the leachate (e.g., Jokela *et al.* [6]) and d) positive reduction potential (ORP) resulting in low precipitation of hydrous ferric and manganese oxides after leachate oozed out on the surface. Advantageous characteristics of landfill aeration have been confirmed by many researchers (e.g., Matsufuji [7]).
3) Marly clay used for sanitary covers worked as a pH buffer, resulting in consistently low heavy metals concentrations in the landfill leachate.
4) Considerable air space lost due to low in-place compaction appers to be recovered promptly during the active phases due to high settlement rates. The initial density of ~300 kg/m^3 increases to ~400 kg/m^3.

It was acknowledged that all these positive environmental indicator values would be lost altogether as soon as operating techniques on the working face would eventually change in order to achieve higher in-place waste densities. However, extending a landfill's life for the long-term was not the goal the operator was seeking. According to the requirements of European legislation in effect at the time and by observing trends in some neighboring, highly developed European countries during that time it was already anticipated that small municipal landfills will be closed down gradually between 2005 and 2015 and only a few, brand new, large regional landfills would remain active in the country.

3 Concept of a low-cost, sustainable, high-permeability landfill

Design of the modern, highly engineered sanitary landfills is focused on long term isolation of disposed of waste and on minimizing specific costs of disposal by maximizing the quantity of disposed of waste per square meter of the available footprint area. Investment, operational, closure and post-closure costs appear to be high, which applies to both, dry and wet (bioreactor) landfills. Even the best liner and leachate collection systems will fail eventually. Heavily compacted waste can be stabilised only with difficulty. Therefore, this approach can not be considered to be sustainable.

An alternate conceptual approach to sustainable sanitary landfilling and facility development was applied at the research-oriented site fifteen years ago. The focus was put on providing low-cost, rapid stabilization and decontamination of the landfill already during the time the liable operator is still actively present on site (Madon [3]). The approach implicates the operator is able to demonstrate the pollution potential would be abated down to a effectively safe, negligible level soon after the last active landfill cell would be closed.

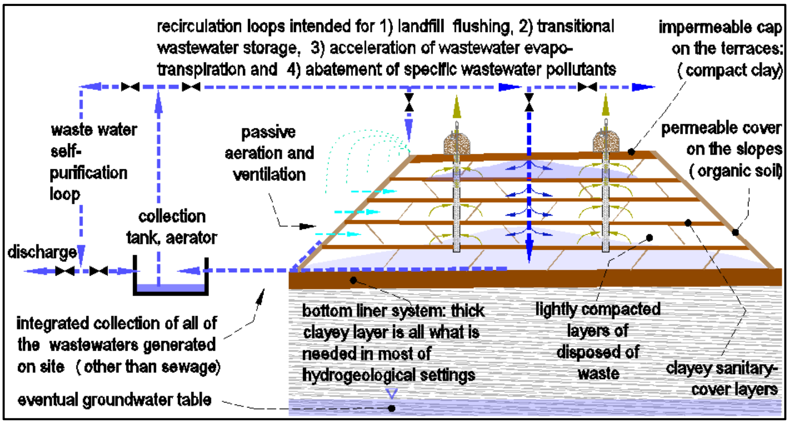

Figure 1: High-permeability landfill features.

Such-a distinct setting in turn allows for an opportunity to reclaim land of the completed landfill sections for purposes of establishing complementary waste management activities there in a real time and in a safe manner. The transformation process could pass almost unnoticed because the transition period can last for many years or even decades, depending upon the circumstances and situations encountered by the owner and/or the operator during the course of time.

Schematic of a low-cost, high-permeability landfill as was implemented on the Ajdovščina research site is depicted in Fig. 1. The most important systems are compiled below:

3.1 Multi-branched system for recirculation of wastewater

High hydraulic transmissivity and high dynamic water storage capacity are distinctive characteristics of a stratified, low-density landfill which allows for much more versatile and effective uses of recirculation technologies in comparison to conventional bioreactor landfills. Instead of focusing solely on leachate management, all of the wastewaters of comparable characteristics generated on site (polluted run-off included) are intercepted and treated together recirculating within the multi-loop system in relatively large quantities.

Recalcitrant pollutants are flushed out of the landfill by periodically flooding buried layers of waste alternately changing water injection locations. A particular horizon to be flooded is selected by sealing the choosen perforated borehole at a selected depth using an inflatable plug. In combination with an effective passive landfill aeration, in a matter of a decade, the waste body gradually transforms into a stabilized, decontaminated mass and the aftercare phase period of the actual landfill cell essentially comes to an end.

Information related to the environmental performance of the implemented recirculation systems at the pilot research site together with the related hydraulic and hydrologic data were presented elsewhere (Madon [3]).

3.2 Passive system for landfill aeration and management of landfill gases

3.2.1 Working face

Due to light waste compaction, landfill conditions are already semiaerobic during the early stages of filling a cell. Recirculation of leachate on the active working face is avoided.

3.2.2 Contour bunds

Cover on the slopes is constructed in a way to be permanently permeable for gases and waters during the operational phase, i.e., contour bunds are purposedly constructed from soils which do not contain too much clayey fractions and compaction is avoided. The related saturated hydraulic conductivity in the pilot site was found to fluctuate around the value of $k_{sat} \approx 5 \cdot 10^{-5}$ m/s, which is the same representative value as valid for lightly compacted layers of waste.

3.2.3 Final cover on the top of the landfill

Final cap on the terraces and benches is made from thick, compacted clayey soil in order to prevent any gas exchange between the interior and exterior of the landfill there. The clay layer itself is covered with organic soil or paved by gravel, respectively (depending on the final use) in order to prevent formation of dessication cracks.

3.2.4 Landfill shape

The shape of the landraise is intentionally designed in a way that the ratio between the parameters 'volume of the facility' and 'surface area of the slopes' is as low as possible ($r \leq 20 m^3/m^2$ in the pilot study case). It was found that the lateral distance from the inner parts of landfill to the the nearest slope surfaces should not exceede approximately 70 meters to prevent anaerobic zones to form in the lower central parts of the landfill, which can persist there for a few years. Therefore, the considered low-cost semiaerobic waste disposal facility appears to be suitable only for smaller capacities or for settings where prolonged, narrow-shaped landraises can be erected. Broader landfills of this type would be feasible, too, if additional measures are provided in order the air could reach the innermost parts of the facility. For example, large diameter pipes can be laid down at the bottom of the landfill conected with the vertical vents as Fukuoka method suggests (Matsufuji [7]).

3.2.5 Gas extraction wells

Vertical passive gas extraction wells of 1 m diameter were build in on ~50 m spacings to depths around 80% of the landraise height. Unsophisticated, fabricated on site coupled flare/ biofilter units were instaled over the outlets of the passive gas extraction wells on the top of the completed landfill sections (Fig. 2) in order to cope with low flows and/or low concentrations of methane. Gas oxidation unit works in a way that when the valve is manually closed, the gases are not conveyed to the burner any more but are forced to pass through a biofilter stack filled with compost instead. Similarily, on the active working faces, removable biofilter bundles were used to cover gas wells outlets to prevent direct venting (Fig. 2).

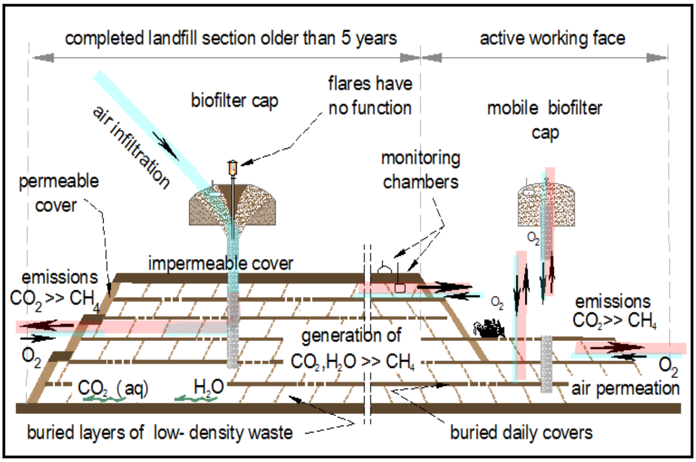

Figure 2: Passive aeration in high-permeability landfill.

3.2.6 Method description

Subhorizontal layering is a vital part of the concept of a passive, high permeability semiaerobic landfill. Landfill gases generated within the permeable waste layers are constrained to migrate horizontally through them in-between the impermeable clayey layers until reaching one of the passive gas wells or eventually reaching a permeable topsoil on the landfill slopes. Overpressure within this type of landfill is always low (generally tenths of milibars to few milibars at most) due to 1) high porosity of the landfilled waste (n > 50%), 2) fast removal of the generated gases, 3) limited methane production due to the existance of aerobic zones and 4) high solubility of CO_2.

In landfill sections and zones where the buried waste is young, landfill gases prefer to migrate upwards through the gas shafts. Consequently, air is induced into the landfill from the landfill slopes horizontally along the waste layers The driving force is a buoyancy effect (e.g., Kim [8]) caused by the moderately increased temperature within the waste body (up to 35°C). Oxygen tends to penetrate into the landfill interior also by means of diffusion, which can happen only through the permeable slope surfaces or through the biofilter stacks installed on the surface above the vertical gas wells. Permeable soil cover on the landfill slopes and biofilter stacs packed with compost are both permeated with air and function as biofilters (e.g., Stern *et al.* [9]).

Methane levels were too low to sustain continuous flaring even if the applied candle flares were equipped with wind shields. Six flare-and-biostack composite units were installed, but only one flare sustained the flame continuously for seven months and another one intermittently for three months. Landfill gases were therefore diverted to pass through the biofilter stacks.

Few years after completion of a particular landfill section the intensity of anaerobic as well as aerobic decomposition began to decrease which was manifested by the drop in landfill interior temperatures to some 20°C and in decrease of methane levels. Direction of ventilation have changed gradually, too: air was no longer entering into the waste body from the permeable slopes and landfill gases were escaping into the environment from the biofilter stacs on the top of the landfill, but the opposite became true (Fig. 2). This shift can be largely attributed to the change in density of the landfill gas mixture: CO_2 was now the gas which prevailed in the landfill atmosphere. Even during the early stages, significant quantities of CO_2 escaped into the environment from the landfill foothills, not from the vents.

3.2.7 Landfill performance monitoring gas emissions

In order to acquire gas emission rates from the biofilter stacks installed on the top of the passive gas wells as well as to assess fugitive emissions from the landfill surfaces, a static flux chamber method was applied in adition to conventional approaches. Portable flame ionization detector Photovac Microfid was the most important instrument used to fulfill the task.

It is worth noting that hydrogen sulphide was detected only once in the period of a decade and more. Year after year it was recognized that less than 10% of biodegradable carbon placed in the landfill ends up into the atmosphere as methane emissions, which is a very good result in comparison to most conventional landfills. Summary of monitoring results from 2013 considering greenhouse gasses is presented in Table 1.

3.3 Upgrading low-cost landfill site into a low-cost waste management site

Completed landfill sections pertinent to conventional, highly compacted landfills are typically of no productive use to landfill owners/operators, which is due to:

1) risks associated with possible methane gas releases, 2) the fact that space is already largely occupied for functioning and maintenance of gas collection and control systems, 3) excessive differential settlements, 4) very long aftercare period, 5) inability to manage the potential storm water pollution derived from these areas. Properly designed and operated sustainable, high-permeability landfills are practically non sensitive to these impediments.

Table 1: Emissions from the pilot site in 2013.

Emission source	Surface area [m^2]	Emiss. of CH_4 [t]	Emiss. of CO_2 [t]
Completed landfill sections			
'Methane emiss. windows' on the slopes	380	21.9	103
Other slope surfaces	26700	0	310
Terraces and benches	15800	0	15
Biofilter stacks (above gas wells)	6 × 6	0	3
Non-completed and active landfill sections			
Working face	2850	5.0	110
Uncovered working front slopes	2200	27.5	680
Gas well covered with portable biofilter	5	1	10
Other emission sources			
Area on the landfill for temporal storage of pretreated sewage sludge	2000	1	11
Composting platform and complementary areas	1600	13	260
Thinly applied pretreated sewage sludge over the completed landfill slopes	25500	0	300
Ponds, lagoons, artificial wetlands	1770	1	60
Total	5 ha	69.5	1860
Complementary data (rounded values)			
Landfilled MSW and similar waste 2007–2012 [t/year]	7.000	of this biodegr. carbon 1.100	
Received, treated and on-site utilized biodegradable waste 2007–2012 [t/year]	1.200	of this biodegr. carbon 300	
Received, stored and on site spread sewage sludge 2007–2012 [t/year]	2.000	of this biodegr. carbon 300	
Filled capacity of the completed landfill sections [t]	MSW 175.000	of this biodegr. carbon 24.000	
Already filled airspace of the active landfill section [t]	MSW 39.000	of this biodegr. carbon 4.400	

3.3.1 Pretreated sewage sludge storage, final treatment and usage

Completed landfill slopes and benches are suitable for thinly spreading the material over the surfaces at the beginning of the summer season (Madon [3]). The systems for drainage and collection of the polluted surface runoff are already designed to be an integral part of the multibranched recirculation system, therefore, from the environmental standpoint, the operations can initiate immediately after the closure of a cell. Sequential photochemical and microbial degradation of humic substances (e.g., Amador *et al.* [10]) reduces the quantity of the applied organic matter during the course of time, so the processes can be repeated for many years. Up to 200 tons per hectare (expressed in dry matter) is applied annually at the pilot facility (Fig. 4).

3.3.2 Outdoor plant for processing and sorting of waste

It is known that at sites where poor initial compaction was achieved and large amounts of precipitation were allowed to percolate into the waste, settlement was quicker and more extensive. The settlement potential has been largely consumed during the active operational phases. Additionally, at the pilot research site, after capping the landfill, a recirculation system was installed performing flushing of the landfill interior. Waste layers were intermittently flooded horizon by horizon, which has led to a fairly uniform settlement. In conventional landfills, however, significant subsidence can be observed on the capped surfaces, especially around the gas extraction wells and injection boreholes.

At the study case site, a 70-metre long plant for sorting and shredding of waste was installed in 2006/07 on the top terrace of the oldest part of the landfill just two years after final cover was applied (Figs 3 and 4). During the 2006/07 the settlements of the 20 m high landfill were on the order of 10 cm per year and diminished to 2.5 cm per year in 2013/14, while differential settlements ranged around 2 cm on 10-meter distances in 2006/07 and diminished to few millimeters over 10 meter distances in 2013/14. Geodetic levelling of bases of the uprights which support the steel frame construction was performed once per year and steel plates of proper thicknesses were laid under the base plates (Madon [2]). It can be concluded that seven years after capping of the cell differential settlements were small enough the procedure can be applied just once per three years instead of once per year.

Figure 3: Sorting plant installed on the landfill terrace.

3.3.3 Facility for storage of biodegradable municipal solid waste (BSW)

As the quantities of MSW diminish year after year, quantities of separately collected biodegradable waste fractions rise. Providing appropriate transient storage of BSW in an enclosed facility before applying further treatment is important for the environment. Terraces of high-permeability landfills are suitable locations for the instalation of such facilities. Seven years after closure of a particular landfill section the remaining potential for differential settlement appears to be easily manageable. Additionally, produced leachate can be drained directly into the waste body through a large-diameter drainage well (Fig. 4). Environment within the interior of the permeable, already stabilized landfill is very effective for treating leachate oozing out of the transiently stored BSW, mineralizing organic matter and removing nitrogen compounds (e.g. Jokela *et al.* [6]).

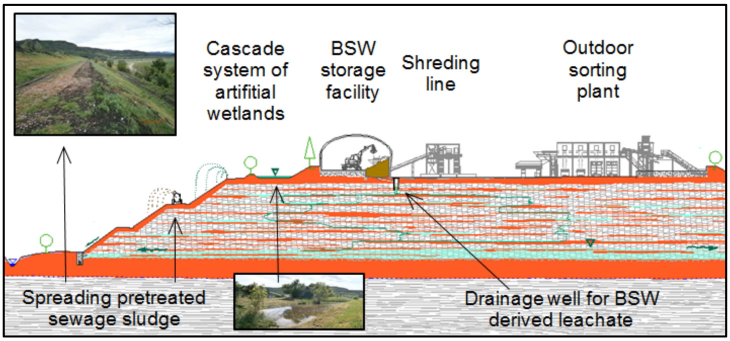

Figure 4: Real-time, low-priced uses of reclaimed land.

4 Conclusions

Sanitary landfilling has lost its relevance in developed countries. It is, however, still the most important waste management method used in many parts of the world. In low income countries, only low cost solutions seem to be viable either when coping with short term waste disposal problems or when making decisions about the long term development strategies. At the research-oriented waste management site in Ajdovščina, Slovenia, it has been demonstrated that high permeability landfill types can be developed in a way to be cost effective and environmentally friendly during the active phases and to be satisfactorily stabilized soon after closure. This approach allows for real time land reclamation of completed landfill sections for purposes of implementing complementary waste management activities there. With fairly low investment, the local waste disposal site can gradually transform into a low priced, but still sufficiently effective integrated waste management facility.

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E-waste in Mexico: a case study of Tepic, Nayarit

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Abstract

In Mexico, in the past 30 years, urban solid waste has become a serious problem of environmental pollution and a cross cutting issue. In this sense, the lifestyles of modern societies lead to primary consumer dynamics of various technologies, which include electronic equipment. Once their useful life is finished, they become waste that ends up in open dumps. Likewise, as they are mainly composed of metals, various substances harmful to health and producing toxic gas emission to soil, water, air substances, waste then generate environmental and public health problems that may be of great magnitude that deteriorate both local and regional surroundings. This research study focuses on the evaluation of an e-waste selective collection program called “Reciclatron” that has been developed at higher education, as a case study at the Autonomous University of Nayarit (UAN), Mexico. The methodology consisted of the classification of e-waste considering the stages of collection, characterization, quantification, recovery and reuse, and marketing 3064.95 kg of e-waste were collected, projected to exceed 6 tons in the next edition. This program is an opportunity to promote the culture of prevention, environmental awareness and knowledge in the treatment of waste for both the university community and society as a whole.
Keywords: e-waste, environmental pollution, Reciclatron, collection.

1 Introduction

The technological evolution induced by the highly industrialized countries has generated an extraordinary level of global consumption. Consequently, it has been given more attention and interest in the analysis of environmental problems associated with the rapid growth of urban areas in the world. The state of the environment in some cities in different countries (e.g. Pakistan, China, Nigeria, India, Costa Rica, Peru, Haiti, Nicaragua, and Mexico, among others) is an example of the physical problems associated with the process of their urban development. In this sense, urbanization is attractive because of its close relationship between population growth and living standards. However, this synergy causes a number of multifactorial problems affecting the environment; the amount and characteristics of electronic waste known as “e-waste” are a case in point [1, 2]. This occurs because the current society accelerates the frequency of replacement of electrical and electronic equipment in order to facilitate their daily activities [3].

Latin American countries adopted the technology of developed countries by ignoring the high initial investment, quality, origin and useful life. This situation helps companies to gain more consumers in a rapidly evolving market. These consumer trends trigger serious economic, social and environmental problems due to the lack of public policies aimed at sound management of e-waste. In this context, social and environmental problems caused by inadequate management of e-waste, must be addressed seriously by all countries; because, electronic waste computer equipment are the main cause of soil pollution in the world, surpassing in just ten years other pollutants that degrade the soil. Mechanisms should be implemented to prevent and mitigate the costs and impacts on the environment and the effects on human health.

Once the electronics equipment has completed its life cycle, they become waste (e-waste), and are kept opencast without any treatment. Note that monitors, keyboards, cable, circuits and drives of computers generate the large volumes of toxic waste. Furthermore, the chips of electronic equipment increase at a rate of 3 to 5% per year, three times faster than municipal waste. Recent studies on the global e-waste generation reports 41.8 million of tons in 2014 and 50.0 million of tons estimated in 2018. It is assumed that the production of current and future e-waste is at its historical maximum estimate due to growing volumes of electronic equipment in disuse [1, 4]. This highlights the multifactorial social problems related to poor management of e-waste.

The lack of mechanisms for collection and containment, and improper handling and management of toxic substances associated with e-waste harm human health and disrupt ecosystems. It is therefore essential to apply chemical physical treatments and a special provision to prevent toxic emissions to the environment. On the other hand, electronic waste contains high value metals like gold, silver, copper, and others that can be recovered and re-used in the production cycle of new technologies. This practice allows electronic waste to be a business and a source of work [5].

2 E-waste global contexts

Recent studies estimate that during this decade the developing countries produce twice as much waste as the industrialized countries [6]. Moreover, industrialized countries export e-waste to developing countries under the assumption of recycling and reuse of components. This leads to problems of a socio-environmental nature [7].

The United Nations Organization (UNO) in 2006 reported that the generation of e-waste reached 50 million tons, which can increase by 65.4 million tons in 2017.

Moreover, the United Nations Educational, Scientific and Cultural Organization (UNESCO) recognized that the problem of e-waste raises the responsibility of political actors, businessmen and society. It also notes that environmental education in schools is essential to raise awareness among students and their families to take responsibility for the waste they generate. In this sense, the media can raise consumer awareness towards integrated management of e-waste as an important part of the life cycle. Thus, UNESCO considers the problem of electronic waste as a challenge of information societies and knowledge and promotes initiatives for sustainable management [8].

In Europe most of the electrical and electronic waste is incorporated into municipal waste streams, this means that are disposed of in landfills or incinerated without any treatment. In 1998, the United States of America (US) only recycled 11% of personal computers and 26%.peripherals.

Asia discharges about 12 million tons of e-waste per year. These residues are integrated into municipal waste, as a result of new consumer habits to acquire more frequently, computers, televisions, audio equipment, and printers, among others [4].

There are agreements on the control of cross-border movements of hazardous wastes and their disposal as ruled in the Basel Convention in 1989 and the Stockholm Convention in 2001. In this context, the flow of e-waste from the US, Canada, Australia, the European Union (EU), Japan and Korea to the Asian countries of China, India and Pakistan is significant. In addition, between 60 and 75% of e-waste in the EU ends in Asia and Africa for recycling and dismantling. Meanwhile, e-waste in Pakistan is imported from the US, EU, Australia, Saudi Arabia, Kuwait, Singapore and the United Arab Emirates, among others. Similarly, Dubai and Singapore serve as centers of e-waste transfer from the EU and US [1].

Millions of tons in e-waste from developed countries are exported as alleged donations. In this sense, Mexico acts as an electronic landfill to receive electronics from the USA, which is the main waste generator worldwide [4].

3 E-waste national contexts

In Mexico, environmental pollution has led damages in people's life quality and its environment. The negative impacts on human health, water, air, and soil pollution are evident. Each region has different characteristics in the use of technologies, sale and production, legal and illegal imports and exports, different management programs for Specific Management for Waste, environmental policies and legislation, among others [3].

The annual average of e -waste generation in Mexico is 350 thousand tons from which only 10% is recycled, 40% remains stored in residential homes, offices or warehouses and 50% ends up in officials or uncontrolled landfills. The General Law for the Prevention and Management of Waste [9], lists the e-waste as waste requiring special handling and not as hazardous waste. With this in mind, this regulation delegates each state the responsibility to confine the e-waste through management plans. Furthermore, only 19 out of 32 states have a legislation on waste management. Such states are: Aguascalientes, Baja California, Chiapas, Chihuahua, Federal District, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, Michoacán, Nuevo León, Puebla, Querétaro, Quintana Roo, Sonora, Tabasco, Tamaulipas and Veracruz [10].

The Environment and Natural Resources office (SEMARNAT) through the National Institute of Ecology and Climate Change (INECC) reported that 257,000 tons of e -waste were generated in 2006, while in 2010 were 300,000 and 358,000 in 2014, which means an annually growth of 5–7% [11].

International conventions in waste matter require participation of the Federal Attorney for Environmental Protection (PROFEPA) and state laws. In this context, Mexico must regulate cross-border movements of e –waste, as well as, suitable disposal of products containing polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers. From 2010 to 2015, the PROFEPA has verified more than 598 cross-border movements of electronic waste equivalent to 3,028 tons.

In this sense, the Ministry of Environment and Natural Resources through the Official Mexican Standard NOM-161-SEMARNAT-2011 establishes criteria for classifying waste requiring special handling including electronics (section VIII, paragraph A). In addition, NOM 161 contains an appendix that mentions waste subject to a special management plan (Table 2) [12].

Although Mexican regulation for waste final disposal establishes management plans, once electronic products run their life time, they become waste and end up in landfills and controlled sites in open dumps and/or unknown disposal [11]. This practice demonstrates a high level of ignorance about the environmental damage that they cause and, moreover, the economic benefit that could lead the recovery and recycling of materials contained in the e-waste is lost.

4 E-waste and environmental pollution

It is estimated that 50% of the e-waste weight corresponds to metals. Steel, aluminum, copper, lead, mercury and precious metals are the main types. The rest of the materials (plastic and glass) are distributed in similar percentages. The most problematic compounds contained in the e-waste are heavy metals, PVC, brominated flame retardants and PCBs. In fact, the environmental impact of e-waste is mainly due to its toxic contents and their mismanagement, causing damages to the environment. It is mentioned in some studies that through an appropriate treatment between 70–90% of e-waste could be recycled or reused [4], which represents a benefit.

The role of higher education institutions must be to train professionals in sustainable human development. In response to the problem of inadequate waste management some universities in México have organized collection activities of electronic waste, including the University of Guadalajara, the University of Veracruz, the Autonomous University of Baja California and the Autonomous Metropolitan University (UAM). In the particular case of the UAM, during 2013, 2014 and 2015 were collected 95.681 kg 146.938 kg and 198.751 kg respectively, this increase in collection of e-waste is an indicator of social participation and awareness (SEDEMADF, 2016).

In this paper, we present the results on the program of selective collection of e-waste called “Reciclatron” which has been implemented in the Autonomous University of Nayarit (UAN) - Mexico with the aim of promoting in the university community and society, mechanisms to promote organized cooperation to improve the environment.

5 Case study: Tepic, Nayarit, México

The state of Nayarit is located at the central-western region of Mexico. It has an area 27,857 km^2 which corresponds to 1.4% of the country. Its territory is a strip that descends from the Sierra Madre Occidental up to the Pacific Ocean. It includes a coastline of 296 km. Latitudes are 23° 05'-20° 36'N, 103° 43'-105° 46' W. Nayarit has a population of 1,084,979 inhabitants. The city of Tepic is located at the central part of the state. Its surface represents 7.25% of the total area of Nayarit. It has a population of 382,863 inhabitants [14].

Final disposal at the city landfill in Tepic, which includes e-waste, is the controlled open landfill called the Iztete (Figure 1). The lack of controlling mechanisms and plant waste separation, treatment and recycling represents a severe problem of local pollution.

(a) (b)

Figure 1: (a) Lanfill Iztete; (b) MSW collection in Tepic, Nayarit.

6 Methodology

The program of selective collection of e-waste implemented at the Autonomous University of Nayarit, called *Reciclatrón,* has been seen as a good practice and joint collaboration among the university community in caring for the environment in the terms of management of hazardous solid waste and final destination.

The *Reciclatrón* consists of a process conformed of five stages: i) collection, ii) characterization, iii) quantification, iv) recovery and reuse, and v) the value chain in the collected e-waste. With the participation of engineering students, the event was organized successfully. The students' participation involved the design of a poster and logo (Figure 2) in order to communicate to society through university media and social networks.

The description of each stage of the process is as follows:

i) Collection. During the days and times established for the completion of *Reciclatron*, students carried out the collection and weight of electronic equipment. These students were also trained on the proper handling of e-waste and possible environmental and health risks if e-waste was handled inadequately.

ii) Then, the logistics and responsibilities of each student during the collection process were established. As an incentive for college students. This is an 80-hour workshop that is accredited by the University Office of Teaching, and, it is also recognized as an elective course.

iii) Characterization. During this stage the students' collection was classified following the official Mexican regulation: NOM-161-SEMARNAT-2011. Given this fact, a line of mechanical disassembly of the components was installed. Students manually separated components by following the rules of safety and hygiene.

iv) Quantification. After the classification and separation of the components, the separated material was weighed by following the classification presented in Table 2.

v) Recovery and reuse. The components of electronic equipment were separated. Then, they were classified into different purposes for reuse; thus, engineering students could use them in their labs or for prototyping.

vi) In addition to promoting a culture in the management and disposal of e-waste, this represents an economic and environmental benefit.

Figure 2: Logo selective collection of e-waste.

7 Results analysis

The amounts of e-waste collected in the two editions of *Reciclatrón* were treated according to the regulations of the Official Mexican Norm: NOM-161-SEMARNAT-2011.

7.1 Collection

During this stage, in the first edition 605.87 kg were collected and in the second edition was 2,459.08 kg. This trend suggests that the next edition will exceed 6,000 kg (Figure 3).

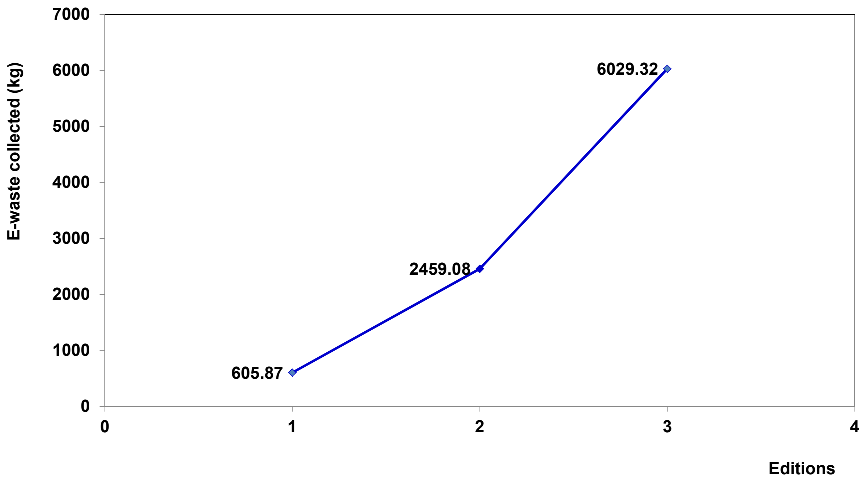

Figure 3: Total collection of e-waste per edition.

7.2 Characterization

The characterization was performed with the regulations (NOM-161-SEMARNAT-2011) on the Specific Management for Waste, which defines eight types of components of e-waste, as can be observed in Table 1.

A notable aspect was the academic benefit of the student community that participates in the process of disassembly of components. By this practice, students acquired knowledge of the design, architecture, and correlation amongst components, which could translate into the classroom to design new projects or develop innovative prototypes.

7.3 Quantification

The quantification of e-waste, was made considering the components of the eight groups defined in the legislation. In the first *Reciclatrón*, were received 605.87 kg of e-waste highlighting materials and components of the groups 1, 2, 4 and 8, with a contribution of 339.78 kg, 78.72 kg, 65.60 kg and 62.50 kg, representing a 56.08%, 13.99%, 10.83% y 10.32%, respectively (as shown in Figure 4).

Table 1: E-waste identified as classified by the NOM-161-SEMARNAT-2011.

Electronic products	Products found
1.- Personal desktop and accessories	Computers, laptops, keyboards, sources, hard drives, regulators, CD players, printed circuit boards, floppy disk drives
2.- Personal desktop and accessories	Personal desktop, chargers
3.- Cell phones	Cell phones
4.- Monitors with CRTs (including TVs)	Monitors
5.- Liquid crystal displays and plasma (including TVs)	Screens
6.- Audio players and portable video	Horns, games, modular, car stereos, VCRs, recorders, radios, discman, VHS, nintendos, DVD player, turntable, horns
7.- Electronic cables	Cables
8.- Printers, copiers and multifunctional	Printers, scanner, typewriters, copiers

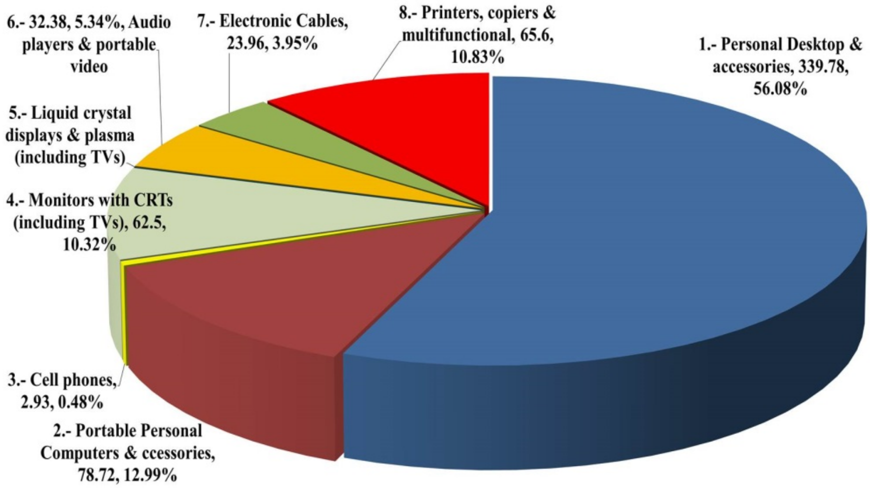

Figure 4: Quantification in kilograms and percentage of Reciclatron, first edition.

In the second edition of *Reciclatrón,* there were 2,459.08 kg of e-waste, from which the groups 1, 4, 6 and 8 contributed with 1085.20 kg, 722.30 kg, 285.25 kg and 239.37 kg, constituting the 44.13%, 29.37%, 11.60%, and 9.73%, respectively (as shown in Figure 5).

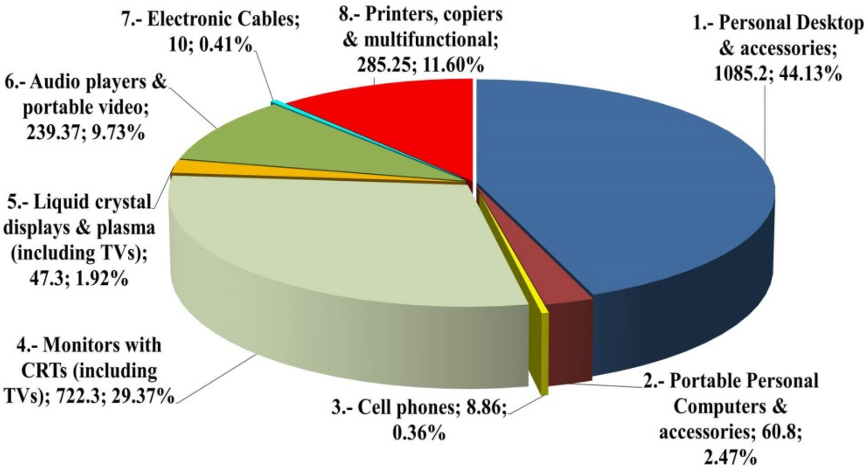

Figure 5: Quantification in kilograms and percentage of Reciclatron, second edition.

7.4 Recovery and reuse

Materials such as scrap metal, plastic, keyboards, sheet iron, cables were recovered; metals such as copper and aluminum, primarily; motherboards and hard drives from which scraps, plastic sheets and wires stand out as indicated Figure 6.

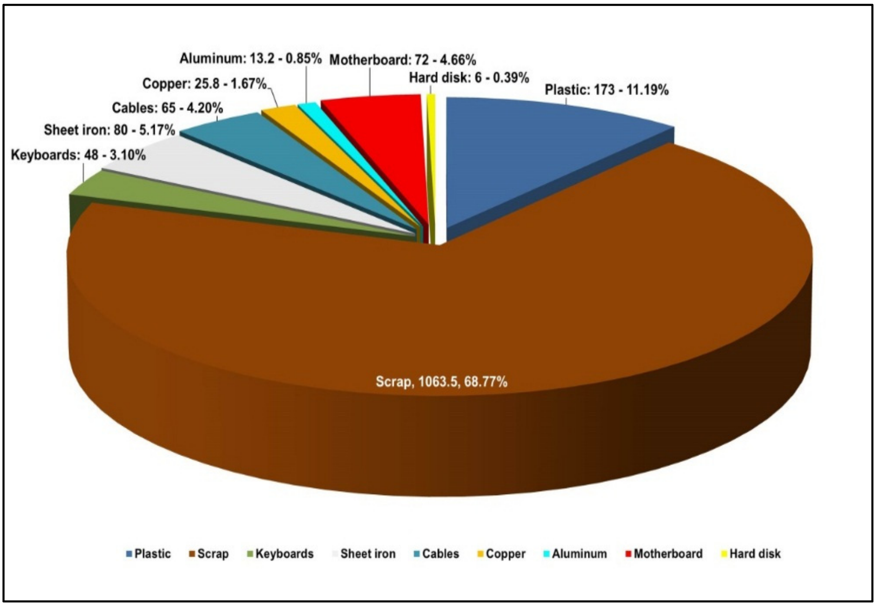

Figure 6: Type of material recovered in kilograms and percentage.

It is noteworthy that the kilograms of recoverable material obtained in the first edition were 37.98 kg raising to 1,546 kg for the second edition. This growth trend suggests that the third edition will achieve in the order of 3,124 kg recoverable for commercialization.

7.5 Commercialization

Recoverable e-waste materials were marketed considering their estimated value in the local domestic market. As it can be observed in Table 2, it shows that the greatest economic resources are obtained from motherboards, scrap copper cables.

Table 2: Component recovered and its commercial value.

Material	Quantity commercializad kilograms	Commercial value Pesos per kilograms	Total in pesos Mexican currency
Plastic	173	0.50	86.50
Scrap	1063.5	2.00	2127.00
Keyboards	48	1.00	48.00
Sheet iron	80	2.80	224.00
Cables	65	25.00	1625.00
Cooper	25.8	70.00	1806.00
Aluminum	13.2	18.50	244.20
Motherboard	72	50.00	3600.00
Hard disk	6	5.00	30.00

8 Conclusions

The *Reciclatron* is an opportunity for college students and society in Tepic as it represents the implementation of strategies to improve the environment. The collection of e-waste in the two editions summed 3.06495 tons which 6 tons expected to be collected in the next edition. The collection was done in compliance with legislation (NOM-161-SEMARNAT-2011) defining the eight types of components of e-waste classification as it is stated in the Special Waste Management. As a straightforward impact, higher education institutions in Mexico can adopt the methodology shown in this work, to help reduce the impacts of e-waste on the environment. Furthermore, this strategy plan could also provide economic and academic benefits for the parties involved. As for quantification, in the first edition there were more desktop computers than other devices. In second place, there were personal computers, printers, copiers and multifunctional devices, monitors and TVs. In the second edition desktop computers predominated as well as monitors and TVs, printers, copiers, multifunctional and play audio and video. In addition, electronic components can be recovered and reused electronic, which have a commercial value. Motherboards, copper and aluminum wires can be of significant revenue in the market. One indicator is that some of the recovered materials have been helpful in developing labs in engineering area. Such programs generate an environmental culture as a link between the society and the students, showing greater involvement and engagement for the care of ecosystems. E-waste recycling, reuse, repair and equipment upgrading are possible strategies that combined can contribute in reducing environmentally harmful materials. Nevertheless, it is commonly expensive to implement such strategies as they require high costs in investment. The management of e-waste is a global priority, therefore, the city of Tepic must develop and implement management plans aimed at electronic waste collection, characterization, quantification, recovery and reuse, as well as the commercialization of the components. Mexico represents an area of opportunity to implement a management model by state, according to the problems and needs in managing e-waste. The linked and coordinated participation of the three levels of government, federal, state and municipal is needed, together with academia, private sector and NGOs to promote in society a culture of sustainability.

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Refinery waste: the spent hydroprocessing catalyst and its recycling options

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Abstract

An industrial waste spent residue hydroprocessing catalyst, contains high levels of metals and carbon, which decreases catalytic activity and forces the refiner to replace the catalyst. The catalyst was unloaded from a KNPC refinery atmospheric residue desulfurization unit. Recycling of spent catalyst waste is at the leading edge of environmentally sound technology and sets the standards for handling the solid waste in the refinery as it is considered hazardous. Hence a concept for a recycling approach to minimize industrial spent catalyst waste has been applied for the recovery of metals (Ni, V, Mo) as a first step while supporting [$Al(OH)_3$] in a subsequent process. The recycling of a spent catalyst involves various steps such as de-oiling, drying, grinding, sieving, and decoking. In the subsequent steps, the de-coked spent catalysts were treated with acid-base reaction media to separate the various components of the spent catalyst. The metal recovery as a function of leaching agents has been investigated by using hydrometallurgical processes. A brief account has also been reported for conventional processes and recent approaches employed by using pyro-metallurgical and hydrometallurgical routes. Considering various routes of metal extractions, the EDTA containing chelation process has shown its potential in high value metal extraction of up to 99% recovery. The recovered metals and support have enabled industrial application for use as alternative raw materials for catalyst preparation.
Keywords: spent catalyst, hazardous waste, waste utilization, metal recovery.

1 Introduction

The worldwide petroleum feedstock scenario is changing toward heavier crudes, which is expected to play a crucial role in processing these crudes with more difficulties and affecting existing refining systems. The heavy oil and its residue contains more metals (Ni+V), sulfur, nitrogen and has low API gravity, which has a negative effect on various processes and decreases catalytic activity with time-on-stream (TOS). Hence, the blocking of catalyst active sites by certain elements or compounds on the surface are the main causes of catalyst deactivation [1, 2]. After deactivation, the catalysts need to unload, which is usually know as refinery spent catalyst waste. Refineries need to treat their waste streams according to the Environmental Protection Agency (EPA) in order to disseminate hazardous waste. Hence, disposal of a spent catalyst is a common problem as it falls under the category of hazardous industrial waste [2]. As a result, worldwide catalyst consumption has increased considerably and is expected to increase further [2, 3]. A refinery mainly contains four types of catalysts such as FCC, hydrotreating, hydrocracking and alkylation. The catalyst market and factors affecting the price and consumption are based on demand and fuel specifications in the specified region. Hydrotreating catalysts, which account for more than half of the hydroprocessing market, are mainly manufactured by Criterion, Albemarle, Haldor Topsøe, ART, Axens and UOP [3]. Usually recent high active hydrotreating/hydrocracking catalysts are quite expensive and their deactivation is faster than before mainly due to the heavier feedstock. Thus, refiners are now focusing seriously on regenerability of spent catalysts.

An expected catalyst market growth rate of 4.24% between 2014 and 2019 has been reported [3, 4], and is projected to generate $6,708 million by 2019. In recent years, hydrotreating catalysts have dominated the refinery catalysts market by type, which is projected to reach $2,213 million by 2019. The expected high growth rates are mainly due to the high market demand in Asia-Pacific while in Europe and North America it is fully developed and is expected to perform below average.

Considering the above said market and catalyst consumption, the region will be generating spent catalysts accordingly. Hence, the global energy trend and economic development forces refiners to increase the product profitability along with severe process conditions as well as with the expense of a lower catalyst life. Therefore, catalyst companies are merging and meeting the demand of product quality as catalyst availability. Usually, complex refineries at about 8–10 petroleum refining processes generate waste catalysts. However, the most important are listed in Figure 1.

The spent catalysts from these processes are classified by EPA as refining waste or hazardous waste [5, 6]. Although, the rule can vary depending on individual circumstances, refiners are obliged to apply for their specific operations. Residue hydroprocessing or direct upgrading processes produce most of the large amounts of spent catalysts, which contain metals like Mo, Co, Ni, V, Fe and Al in the form of metal oxides and sulfides [1]. using heavier feedstock that contains a broad range of boiling hydrocarbon fraction and carries various types of contaminants such as metals and asphaltene [7, 8]. Hence, catalyst deactivation is an inevitable phenomenon that involves both chemical and physical changes in the catalyst nature.

In the complex petroleum refinery large amounts of waste spent catalysts are being generated, which have a high content of metals and valuable alumina

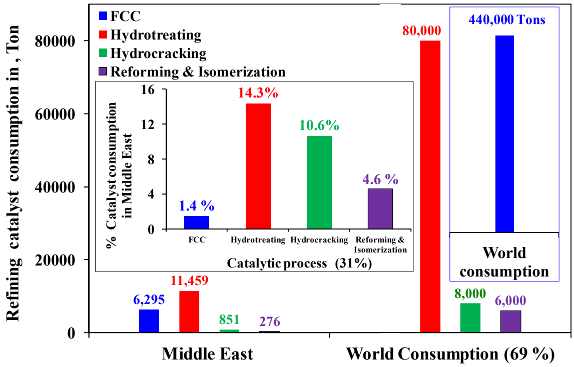

Figure 1: Worldwide catalyst consumption in petroleum refining.

support. Therefore, refineries look forward to recycling options, where recovered metals or alumina either can be re-used for catalyst preparation or can be used in the metal industries. For a small country like Kuwait, disposing in landfills is a huge concern while a considerable amount of spent catalysts is being produced (figure 1). The Middle East has a large consumption of refinery catalysts, particularly hydroprocessing. In Kuwait, catalytic hydrotreating processes are used extensively in Kuwait National Petroleum Company (KNPC); three refineries which generate large quantities (6000–7000 tons) of spent catalysts as solid waste every year. The amount of spent catalyst waste is expected to increase further in the coming years because of a fourth new refinery (Al-Zour refinery) and increasing diesel hydrotreating capacity to meet the growing demand for clean fuel with ultra-low sulfur diesel.

Therefore, recycling methodologies and eco-friendly cost-effective ways have been investigated for atmospheric residue desulfurization (ARDS) refinery spent catalysts in order to minimize spent catalyst waste and to protect the environment. Moreover, it is worth finding a proper way of treatment using pyro-metallurgical together with hydrometallurgical techniques that have been applied and investigated in order to recover valuable metal and support from the spent hydroprocessing catalyst.

2 Experimental

An ARDS spent catalyst containing valuable metals like Ni, Co, V, Mo and Al, was obtained from the KNPC. The deposited carbon (coke) and metals on the spent catalyst were determined using thermogravimetry analysis (TGA) and scanning electron microscopy (SEM/EDX), respectively. The composition of the spent catalyst also conformed with inductively coupled plasma (ICP) indicating that a considerable amount of foreign species were deposited (as shown in Table 1). Refinery, ARDS hydroprocessing catalysts have been recovered from a guard reactor (R1), HDM/HDS catalyst (R2) and HDS catalyst (R3) and the final

Table 1: Spent catalysts unloaded from the (ARDS) system.

Properties	Spent catalyst from different reactors				
	R1	R2	R3	R4	Average
Surface area (SSA), m^2/g	100	120	180	200	-
Pore volume (TPV), ml/g	1.1	0.92	0.85	0.66	-
APD, nm	28	25	25	12	-
Composition, wt. %					
Mo	1.73	1.62	6.68	9.31	5.9
Ni	3.99	5.49	5.6	4.9	5.3
V	19.67	26.1	10.49	4.12	13.6
Al	28.56	21.8	31.75	36.6	30.1
Carbon, wt %	25	28	35	45	36.0

hydrocracking (R4) catalyst. All the spent catalysts were mixed in a proportion, which was used for metal recovery [10, 11].

The catalysts were in the form of cylindrical extrudates of approximate diameter of about 0.4 mm and length 5–6 mm, which were deoiled, decoked, crushed, and ground to fine powder (size <500 µm) using standard equipment and procedures [10, 12]. The powdered deoiled spent catalyst was then decoked by combustion of coke under controlled temperature conditions in the range of 300 to 600°C for 8 h in an oxygen atmosphere (i.e., 5% O_2 in N_2). Figure 2 shows a pretreatment process, which is common for all the leaching processes.

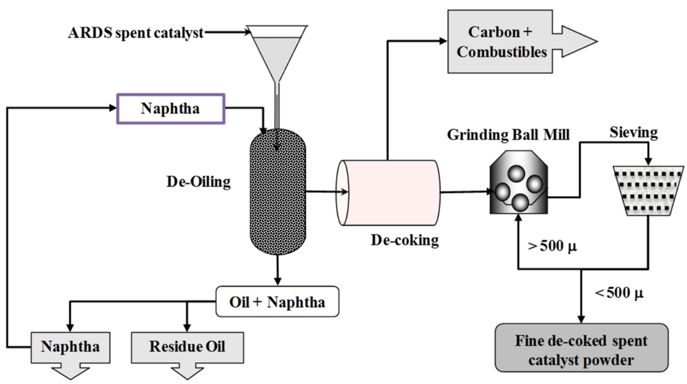

Figure 2: Spent catalyst de-oil, de-coke and grinding before metal recovery.

3 Results and discussion

3.1 Characterization of spent catalysts

Generally, the life of an ARDS hydroprocessing catalyst is about 10 to 15 months. However, global refinery spent catalyst production has increased since heavy crude oil started processing, which deactivates catalysts faster and shows higher metal and carbon deposition [1]. In the present study, the total carbon deposited on the catalyst was measured using TGA, which is at about 43 wt%. TGA/DTA shows two obvious weight losses for all the spent catalysts in the temperature range of 50°C to 800°C (as shown in Figure 3).

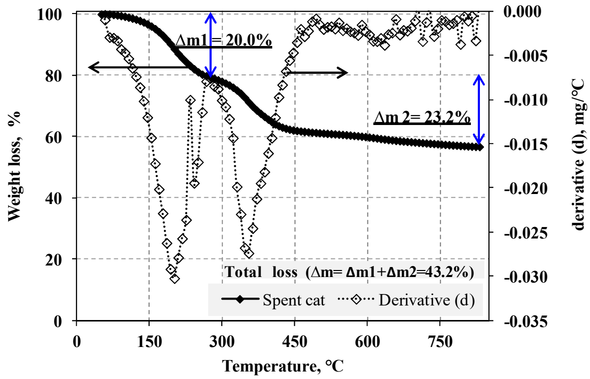

Figure 3: TGA profiles of the spent catalysts recovered from the ARDS process.

TGA results indicated that the first weight loss in the range of 50°C to 260°C is attributed to soft coke desorption, and the second weight loss in the range of 300°C to 450°C, accompanied by exothermic effect, is assigned to medium coke removal. The amounts of coke deposit calculated from TG curves at different stages are shown in figure 3, i.e., 43.2 weight % of the fresh catalyst. On the other hand, SEM-EDAX results confirmed that carbon, V, Ni, P, and Mo (sulfur) are deposited on the surface of the catalyst, which are featured by their Kα X-ray emission lines (keV) (as shown in Figure 4).

Displayed semi-quantitative results from different elements along the line analysis are shown in the figure 4 inset. The V metal is usually deposited on the surface while Ni is distributed more homogeneously indicating the diffusion of Ni

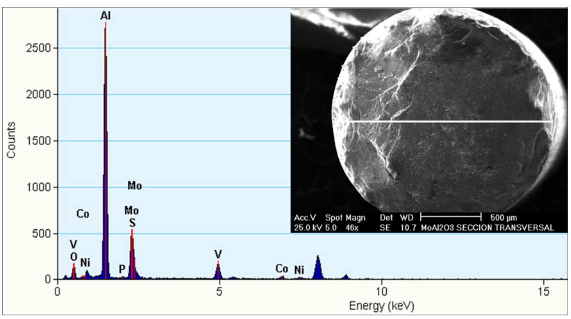

Figure 4: Radial analysis of deposited metals using SEM-EDS analysis.

deeper on the catalytic pore or sites [1, 13]. Since Ni and V complex molecules are present in a porphyrin-type coordination, the distribution of metal deposition is more related to the possible existing form of the metals where V metal in vanadium porphyrins exist as (VO)2+ in which the V atom easily can deposit on the surface of the catalyst/support and get removed faster, which leads to surface deposition of vanadium sulfide near the pore mouth.

3.2 Recycling options for spent hydroprocessing catalysts

A spent catalyst, if it contains only Al, Si, and Fe, can be disposed of without any special precautions or can be used in construction materials. However, in hydroprocessing, spent catalysts mainly contain Ni and V accumulated during their use, then for removal of these elements the below legislative limits is necessary [14, 15]. Hence, before disposal, spent catalysts containing various contaminants need to be encapsulated to avoid their release into water and the environment. There are methods that reduce catalyst waste by using post treatment methods or spent catalyst management such as regeneration, rejuvenation, reuse either in fresh catalyst preparation or reusing in less severe hydrotreating units by cascading before final disposal.

Usually, two major methods have been applied for recovery of metals or separate various components of the spent catalyst, namely, pyrometallurgy and hydrometallurgy. Pyrometallurgical processes require high heating in which the waste catalyst is treated at high temperatures to recover valuable metals and decompose hydrocarbon. These treatments lead to the production of hazardous gases that must be removed from the air with flue gas cleaning systems. This process is considered energy intensive, high-cost and requires high-grade feeds. Hydrometallurgy; it is also called leaching process, involves the selective dissolution of metals from their waste. It involves the use of aqueous chemicals (acid and base) and leaching and/or metal separation processes are carried out at much lower temperatures.

3.2.1 Regeneration, rejuvenation and the reuse of spent catalysts

Regeneration of spent catalysts is a longstanding common process. The process contains pyarolytic oxidation of carbon and sulfur from the catalyst. Regeneration is generally utilized when the metal contaminants are low or negligible on the catalyst. The process holds only a sophisticated temperature (heating rates) and gases (air, nitrogen or oxygen) flow control systems used for moving as well as fixed bed processes in order to burn carbon and sulfur in the presence of oxygen. The controlled temperature is to avoid changes in catalyst properties during regeneration or heating, such as hot spots, active metal sintering, collapsing pores, which prevent surface area reduction and sintering, minimize breakage and attrition. During the regeneration, some of the active metal may react with support particularly promoters (Ni or Co) may react with alumina and form spinel ($CoAl_2O_4$ or $NiAl_2O_4$), which explains why the catalytic activity of the fresh catalysts were not fully recovered after the regeneration of the spent catalyst. Although a regenerated catalyst can either be used in the same process or in other applications requiring less degree of catalytic activity. Therefore, any damage by carbon deposition can be partially repaired via coke burning, which is also known as rejuvenation [16].

Regeneration either can be done within the same plant where it is used (in-situ) or can be off-site, depending on the use after the regeneration. On the other hand, where the metal contaminants are high on spent catalyst regeneration and rejuvenation is not a practical process because catalysts are susceptible to irreversible deactivation caused by adsorption of metal impurities, such as V and Ni. Not only is there a gradual build-up of these impurities in a hydrotreating catalyst but also eventually plugging the pores and generating diffusion limitations. Therefore, a typical first step is to identify and analyse the composition of the spent catalyst in order to find out its regenerability.

A spent catalyst also can be fully re-used in cement manufacturing, building material (porous blocks), asphalt paving, and construction. Therefore, the cement industry is considered to be one of the key sectors where large amounts of spent solid waste catalyst can be effectively used either as an additive or as raw materials in the manufacturing mixture of tiles. Recently, thermal plasma technology has been applied in various industrial applications of waste treatment [17, 18], which cracks or reforms all organic substance and vitrifies inorganic matter into rocks.

However, major production of spent catalysts in residue treatment are mainly from ARDS and residue fluid catalytic cracking (RFCC). Such catalysts are also high in metals, sulfur, and coke along with most of the pores being either plugged or partially reduced. Usually, due to the presence of zeolite in the support RFCC the catalyst has acidic composition and has a higher rate of deactivation. The use of spent catalysts for the preparation of an active HDM catalyst has been reported in previous studies [19]. Such type of catalyst, even without decoking, can be used as the presence of carbon in the support is also known to have a beneficial effect on the hydroprocessing catalyst [20]. In addition, carbon will be burnt during the support calcinations that leads to enhanced larger pores in the catalyst [21]. A flow diagram for spent catalyst re-use with boehmite mixtures was tested for physical, chemical and mechanical properties as well as durability and integrity [19]. The concentration of heavy metals in the above applications of reusing ARDS/RFCC spent catalyst leads to a beneficial effect as a fresh catalyst.

3.2.2 Hydrometallurgical treatment options for metal recovery

Hydrometallurgy treatment, also known as leaching method for recovery of valuable metals from a waste spent catalyst, has more flexibility during the up-scaling and has various options available for the purification and selective recovery by using the following specific chemical treatments.

3.2.2.1 Soda roasting and metal leaching The soda roasting leaching process selectively used to extract V and Mo, while Ni (Co) will remain unreactive as a solid in alumina, which can be further digested in NaOH at high pressure and dissolve (as shown in Figure 5). Using a roasting temperature at 550°C, the yield of recovery for Mo and V with NaOH was more than 95%, while with Na_2CO_3 extraction was more selective to the Mo and V removal without reacting to the Ni and Al [22].

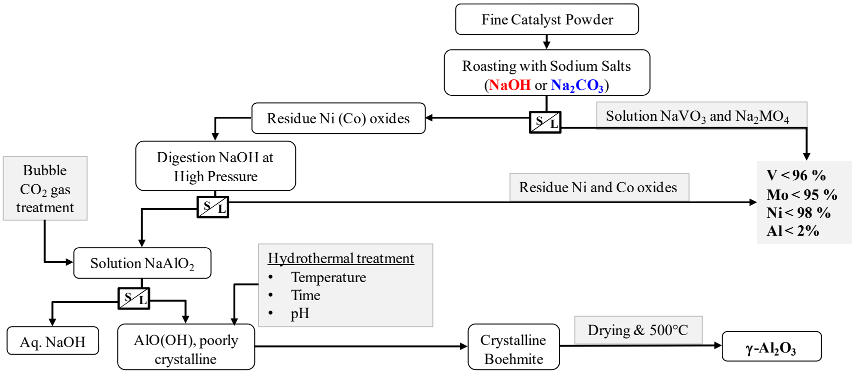

Figure 5: The soda roasting process for metal and high purity alumina recovery.

However, by increasing the sodium carbonate roasting temperature to 700°C the Mo and V recovery reached up to 99%, which made an easy separation for Mo and V. Since Ni and Al do not react with Na_2CO_3, it remains as a residue. A comparison between two roasting agents has concluded that the optimum conditions for maximum recovery of Mo and V metals content were achieved at a reaction temperature of 700°C, 120 min leaching time with 25 % of Na_2CO_3 while using NaOH the optimum conditions are 480°C, 60 min leaching time and 50% concentration. The soda roasting process has an advantage over other processes for the recovery of high quality (purity) boehmite, which properties can be further modified with the hydrothermal treatment based on the type of alumina requirement for further use. Therefore, the roasting technique met the rations of integrated recycling and it has advantages, such as single step operation, high recovery yield of water soluble metals particularly for Mo and V.

3.2.2.2 Basic leaching Ammonium salts based solutions are weakly basic and have a slightly acidic character. Therefore, they can be effectively used as exhilarating leaching agents for surface metal extraction [23]. The leaching was performed by using an aqueous solution of ammonia and ammonium salts with the previously ground spent catalyst (Figure 6). Different metal extraction have been reported as a function of the leaching agent. The use of oxidizing (H_2O_2) agent also was tested, which is environmentally safe and does not produce reaction products except water. In the case of ammonium per-sulfate (APS), it has about 7wt% active oxygen that acts as an oxidizing agent and improves Ni and Al extraction in comparison with other leaching agents, namely, NH_4OH and $(NH_4)_2CO_3$. The different behavior using APS could be due to its strong oxidizing nature, which promotes better dissolution of metals. However, APS also forms oxygen free radicals in an aqueous solution and that adds some advantages for metal recovery but only for V, Ni and Al. This may be explained by the fact that APS is an acidic salt which limits Mo extraction in acidic medium. Thus, ammonia leaching reactions effectively take place at mild basic conditions in the presence of an oxidative ambiance. Hence, the use of ammoniacal solutions in the presence of H_2O_2 (oxidative or bleaching) may reduce the number of separation processes, and this may improve the economy of the process.

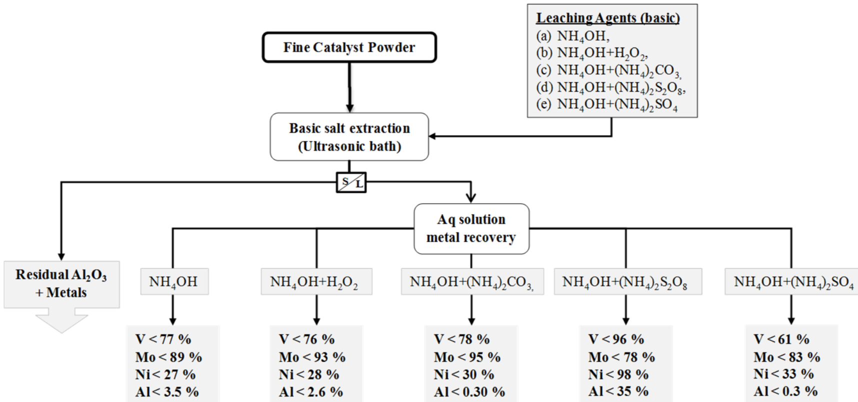

Figure 6: Flow scheme for basic leaching of spent hydroprocessing catalyst.

3.2.2.3 Acidic leaching Acidic leaching of previously ground and de-coked spent catalyst was performed in multiple steps as a function of leaching agents. It was possible to recover almost all metals (Mo, V, Ni and Co) simultaneously with leaching yields of about 95% (as shown in Figure 7).

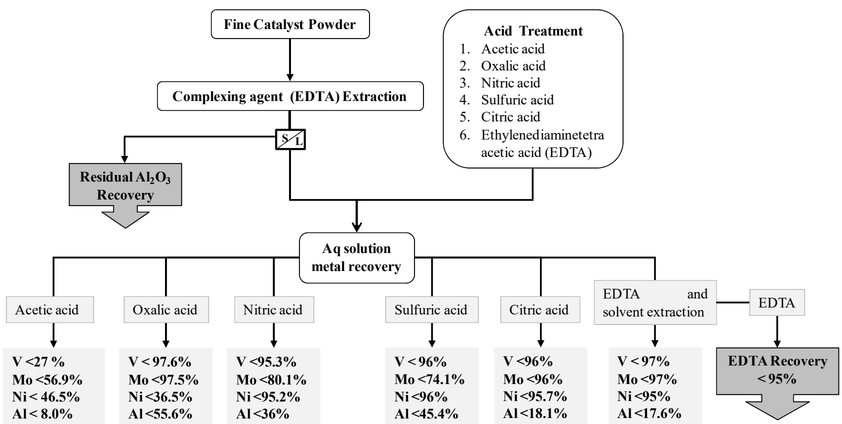

Figure 7: Flow scheme of acidic leaching of spent hydroprocessing catalyst.

The present study successfully showed pure and quantitative recovery of solvents (Cyanex 272) and costly chemicals like EDTA using different stripping steps. However, detailed discussion with deep understanding of the extraction mechanism need to be considered as future work before it can be scaled up from lab level to bench scale. Conventional acid leaching and organic chelation routes also have been compared for the metal recovery and purity, which is significantly high for the chelation technique than for conventional acid leaching [24].

In the acid leaching studies, the efficiencies of organic acids such as citric acid, oxalic acid and ethylenediaminetetraacetic acid (EDTA) are compared with those of inorganic acids, e.g. sulfuric acid (H_2SO_4) and nitric acid (HNO_3). About 97wt% extraction of Mo and V was achieved with both oxalic acid and EDTA, whereas, with citric acid, the recovery was around 92%. The effectiveness (Mo and V extraction) of the five acids used in this study can be ranked in the following order where oxalic acid was highly effective for Mo and V extraction. Although it showed very poor activity for Ni extraction, which follows the order EDTA > Citric acid =H_2SO_4 > HNO_3 > CH_3COOH > Oxalic acid. In aluminum extraction, both organic and inorganic acids showed poor activity. Apart from the high metal recovery efficiency, the use of HNO_3, H_2SO_4, $C_2H_4O_2$ or $C_6H_8O_7$ for metal leaching that has several disadvantages such as chemical cost, and consequences of hazardous chemicals are unavoidable.

Based on the above, the possibility of recycling of total refinery spent catalyst (TSC) was investigated using various steps for metal leaching and the alumina support recovery as bulk solid in the form of boehmite. An optimum leaching efficiency with different leaching methods and their conditions were achieved in order to obtain the maximum recovery of Mo, Ni and V metals. An overall refining catalyst system (cradle-to-grave or creation to disposal) cycle involves a number of key steps (Figure 8) such as catalyst synthesis, reactor loading, activity test run, and unloading, off-site regeneration, reuse, reclamation, and disposal. The full recycling process was shown by a number of steps such as: (A) support extrusion; (B) CoMo/NiMo fresh catalyst synthesis; (C) bench scale catalyst loading and activity testing; (D) unloaded spent catalyst; (E) metal recovery process and; (F and G) recovered alumina and metals from spent catalyst.

Considering the effectiveness in commercial applicability of these steps, the proposed processes will minimize spent catalyst waste generation. Utilization to

Figure 8: Residue hydroprocessing and its spent catalyst recycling steps.

produce new catalysts and other useful materials, recycling through recovery of metals and support in order to achieve the safe disposal of spent catalysts.

4 Conclusions

The development of processes for the minimization and recycling of spent hydrotreating catalyst waste has received increasing attention in recent years due to the hazardous nature and stringent environmental regulations on its disposal. Based on the current study, due to the low process cost, high metal recovery and cleaner environment, hydrometallurgy will displace inefficient pyrometallurgy processes in coming years. The recovery process invariably involves a combination of pyro- and hydrometallurgical operations in order to have fully marketable products of metals and support. The total recycling process demonstrated its ability to reduce hazardous waste disposal to the zero limit and save natural resources with economic benefits. The recovered metals such as Mo. V, Ni and Co could be used in steel manufacture and the alumina could be used for the manufacture of refractories, ceramics and abrasives. The total spent catalysts' recovery process is not only an economical process that recovers metals and support but is also a vital option for waste recycling and re-utilization.

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Waste minimization practices at the National University of Costa Rica

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Abstract

Hazardous materials are substances that are flammable, corrosive, reactive, toxic, radioactive, poisonous, carcinogenic, or infectious. According to the USEPA (United State Environmental Protection Agency), waste is considered hazardous if it has one or more of USEPA's four hazardous characteristics: flammability, corrosivity, reactivity or toxicity. One important source of chemical waste is higher education facilities such universities, where the chemical waste generated in the laboratories (labs) present at least one of the hazardous characteristics listed by USEPA. In order to determine the quantity of laboratories doing waste minimization practice related with the USEPA pollution hierarchy, an initial diagnostic about waste management at laboratories was conducted. The data gathered were used to start a training to laboratory personnel training about EPA-PH (Environmental Protection Agency-Pollution Hierarchy). After training, new diagnostics were performed. The applications of waste minimization practices in the labs were analyzed before and after the training. The most poorly practices performed year by year during the study period were "substitute nonhazardous materials", "chemical treatment" and "distillation". "Redistribute surplus chemical" was performed in 22 labs, 30 labs and 48 labs during the years 2010, 2011 and 2013 respectively as the most common practice. This study showed that training about pollution prevention hierarchy increased the number of labs doing waste minimization practices, prioritizing reduction and prevention from the source. Future research is recommended to define the chemical waste rate generation before and after training as a quantitative indicator of the impact of training sessions upon the overall institutional chemical waste prevention program.
Keywords: hazardous materials, chemical waste management, pollution hierarchy, waste reduction and prevention, laboratories, universities, Costa Rica.

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1 Introduction

Hazardous materials are substances that are flammable, corrosive, reactive, toxic, radioactive, poisonous, carcinogenic, or infectious [1, 2]. In a general sense, waste that contain these materials or substances are considered hazardous because they present a potential risk to humans and/or the environment. A hazardous waste management plan generally separates waste into three broad groups: radioactive, chemical, and biohazardous [3, 4]. The chemical waste includes a wide range of material such as discarded commercial chemical products, process waste, wastewater, or any waste generated from the use of chemicals in medical, dental, veterinary and laboratory procedures that has the potential to pose a chemical threat to health, safety and/or the environment, or is chemically hazardous [5, 6]. According to the USEPA (United State Environmental Protection Agency), a waste is considered hazardous if it has one or more of USEPA's four hazardous characteristics: flammability, corrosivity, reactivity or toxicity [3, 7].

One important source of chemical waste is higher education facilities such universities, where the chemical waste generated in the laboratories present at least one of the hazardous characteristics listed by USEPA [8–10]. Chemical laboratories are the most common type of workplace where a wide variety of chemicals are handled on a routine basis. The quantity of waste generation in universities is smaller comparing with the production in the industrial sector. However, academic laboratories produce relatively small volumes of a variety of waste streams, the exact character of which may not be known in advance. Besides, in most of the cases, universities contain an important numbers of laboratories on campus, each with numerous points of generation (such as multiple laboratory benchtops) that are operated under the supervision of different individuals [9–11]. Some common waste generated on campus include (but not limited to) unused chemicals that are no longer needed, expired chemicals, process waste, broken mercury thermometers, mercury containing devices, heavy metals, spent acids, bases, and solvents which are used in laboratory procedures, oil based paints, aerosol cans, pesticides, oils (motor, cutting, pump, lubricating) and so on [11, 12].

Although some regulations have not recognized the laboratory as a special environment for using chemicals, the OSHA (Occupational Safety and Health Administration) laboratory standard specifies that each institution accountable for handling and disposal of chemicals must develop its own CHP (chemical hygiene plan) to prevent and minimize the waste generation. The waste minimization strategy must incorporate a hierarchical approach to waste reduction [10, 13]. A start point to develop a CHP (in a university campus) is to follow the USEPA EPA-PH (Environmental Protection Agency-Pollution Hierarchy) which contains four principles (1—source reduction, 2—recycling or re-use, 3—treatment and 4—disposal) for waste management [7, 12, 14]. The EPA-PH emphasizes source reduction at the top of the pyramid and disposal at the bottom (as illustrated in figure 1) [3, 7, 14].

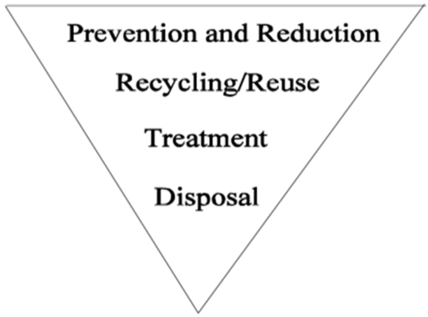


Figure 1: Pollution prevention hierarchy.

The first priority is to reduce waste at the source, with less material entering the waste stream. The familiar concept of recycling, along with composting, is a second priority. A waste is still being generated that must be recycled. It is a better resource management choice to recycle the material than to dispose of it at a landfill. Treatment is a third priority related particularly to hazardous waste. This approach is taken in conjunction with pollution control technologies. Incineration, treatment of sewer discharges, and chemical treatments are included. With solid waste, incineration for energy recovery would be at the same priority level. The lowest priority is land disposal of the final waste stream. This is the most expensive way to use natural resources [12, 14, 15].

As mentioned before, laboratory operations are notoriously difficult to prescribe waste minimization solutions for. Their waste types are numerous, and usually small in volume. Some waste is extremely hazard to handle due to the need for highly reactive agents in some types of research. These challenges are further compounded in pure research labs where there is a high frequency of change in experimental procedures and reagents used. For this reason, in laboratories, much more so than with industrial operations, it is critical to have a strategy for waste minimization and pollution prevention techniques in use [7, 10]. According to this, the main objective of this research was to diagnose the quantity of laboratories doing EPA-PH procedures before and after personnel laboratory training. The results are emphasized in the number of sites applying the first, second and third priorities of EPA-PH which are "prevention and reduction from source", "recycling and reuse procedures" and "treatment".

2 Materials and methods

The NU-CR (National University-Costa Rica) was founded in 1973, which is a public university with 5,000 workers and 22,000 students. An environmental policy which contains commitments and strategies for a better environment and health security was introduced into the university status in year 2003, this policy was a support to create the CMO (Chemical Management Office) in 2006 where efforts are focused to promote an adequate dangerous waste management, an efficient chemical products handling, EH&S (environmental health and safety) programs and so on. NU-CR among others units contains three faculties related with chemical analytical procedures (Natural Science Faculty, Health Faculty and Soil and Forest Faculty). These faculties have different departments where chemical products are handled. Therefore, chemical waste is produced. The university departments are related with the next science fields: chemistry, biology, agricultural, veterinary, toxicology, environmental, soil and forest. With the main objective to develop waste minimization practices at the laboratories, the CMO started in 2010 a strategy containing the following steps:

- chemical waste management diagnostics;
- diagnostic data analysis;
- laboratory personnel training.

2.1 Initial chemical waste management diagnostic

During first semester of year 2010 a first diagnostic regarding waste management in academic instructional and research laboratories was carried out. In order to gather such information, the following tools were utilized: (1) an interview, a questionnaire (personnel of different laboratories fulfilled a form where they were asked information related with chemical waste management); (2) an inspection visit to the laboratories; (3) work sessions with university management authorities; (4) consultation with stakeholders/industry.

2.2 Data analysis

The information gathered during diagnostics was analyzed by the CMO with chemical waste experts in order to identify in a general way the following options:

- Reducing the scale experiments conducted in teaching laboratories.
- Replacing some wet laboratories with computer modeling or some analytical manual procedures for automatic equipment procedures.
- Improving training programs.
- Purchasing chemicals procedures.
- Shipping and transporting laboratory chemical waste.
- Generating chemical waste inventories.
- Creating some mechanisms, such as: (1) developing a better procurement management, especially avoiding over ordering of hazardous materials; (2) substituting hazardous materials with less hazardous or nonhazardous materials; (3) reducing the scale of experiments and protocols as much as possible to achieve research objectives; (4) redistributing, reusing, and recycling of supplies and reagents; (5) improving waste segregation in order to maximize recovery of materials and treatability of waste; (6) disseminating information about the benefits of laboratory pollution prevention efforts.

2.3 Training

Individual laboratory training as well as general training was applied during half a year period (II Semester of year 2010 and I Semester of year 2011) in order to discuss the data gathered during the first diagnostic. Faculty staff, department directors, general laboratory operators (students and workers), purchasing staff, financial staff and so on were trained about EPA pollution prevention hierarchy; its opportunities to improve the actual chemical waste management and to look forward to applying new procedures that can protect their health and the environment around. The training was specially focused on the first, second and third EPA hierarchy steps. According to the prevention and reduction steps, different work sessions were conducted in order to discuss and give information about waste source reduction for changing practices and processes to reduce or eliminate the generation of hazardous waste. The training was based on the following WMP (waste minimization practices):

- RR (recovery, reuse or recycling);
- RSC (redistribute surplus chemicals);
- CS (computer simulation);
- CT (chemical treatment), not distillation;
- D (distillation);
- CIM (chemical inventory management);
- PC (purchase control);
- SNM (substitute nonhazardous materials);
- PL (purchase less);
- RS (reduce scale);
- CE/P (change equipment or procedure).

The quantity of laboratories which were doing the above waste minimization practices was compared before and after the training.

2.4 Other chemical waste management diagnostics

Also, from years 2011 to 2014, new diagnostics were carried out in order to compare the data obtained before and after training. The same methodology criteria and tools used during the first one (year 2010) were applied in the last diagnostics. The number of laboratories during the diagnostics was 60 laboratories (Table 1).

3 Results and discussion

Table 1 shows the study population during the diagnostics. Work sessions with university authorities and national stakeholders (Health National Office, Environmental National Office, Private Waste Treatment and Disposal Companies and Landfill Operators) were carried in order to have a better understanding of the results obtained from each diagnostic and seek for future integral solutions.

Figures 2 and 3 indicate the number of laboratories realizing specific WMPs throughout the 2010–2014 period. These figures indicate that during the study period "CT" and "D" practices were the least applied. However, overall the number of labs performing these practices increased from year to year.

Table 1: Quantity of laboratories during diagnostics (years 2010–2014).

	Faculty	Department (numbers of labs)
Study population	Natural Science Faculty	Biology (10), Chemistry (13), Physics (1)
	Health Faculty	Veterinary (16)
	Soil and Forest Faculty	Soil (10), Forest (5), Vulcanology (1), Environmental (2), Toxicological (2)
Total	3	9 (60)

During 2010, the most frequently applied WMPs were "SNM", "CT" and "D", at that time only 10 laboratories were performing those practices. For the same year the most performed practice was "RSC" at the level of 22 laboratories.

Starting from 2012, subsequent to training carried out during 2010 to 2011, more laboratories were applying waste minimization practices in comparison to those early years; the number of labs performing every type of WMPs notably increased after 2011.

The most utilized practices during 2012 were "RS" and "PL" both performed at 42 labs. For the 2013 and 2014 years the most performed practices were "RSC" and "PC" with 52 and 55 labs, respectively. Likewise, "PC" was the most common practice for 2014.

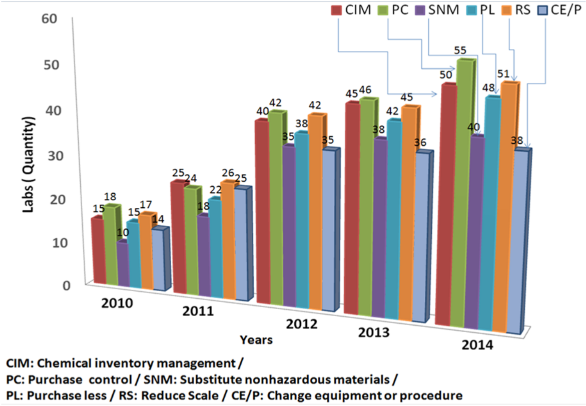


Figure 2: Quantity of laboratories performing six waste minimization practices, period 2010–2014.

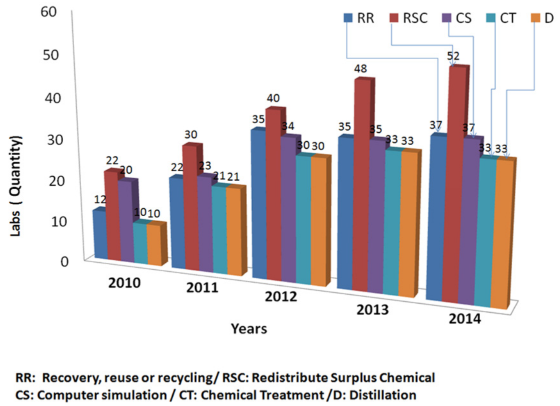


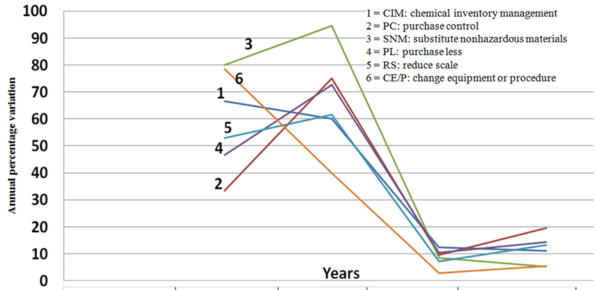
Figure 3: Quantity of laboratories performing five waste minimization practices, period 2010–2014.

Figures 4 and 5 refer to the annual percentage variation for the waste minimization practices evaluated. Practices "CT" and "D" show (Fig. 5) the highest variation (110) throughout the study period. This variation value indicates that when comparing the total number of labs carrying out these practices, 10 labs were doing it during 2010 and 21 labs in 2011. No variation was perceived for "RR" (2013 vs. 2012) Similarly, "CT" and "D" showed no variation (2014 vs. 2013) also standing at 35 total labs. Figure 4, show that "SNM" presented important variations: 80% (2011 vs. 2010) and 94% (2012 vs. 2011); nonetheless, variation decreased to 9% and 5% in the following years. It can be concluded that starting from 2010 and up to 2012 laboratory operators and directors secured important efforts to substitute hazardous materials.

During 2013 the highest annual percentage variation was only 20% corresponding to "RSC" (Fig. 5). In the case of 2014 the highest value is assigned to "PC" with a variation of 20% (Fig. 4).

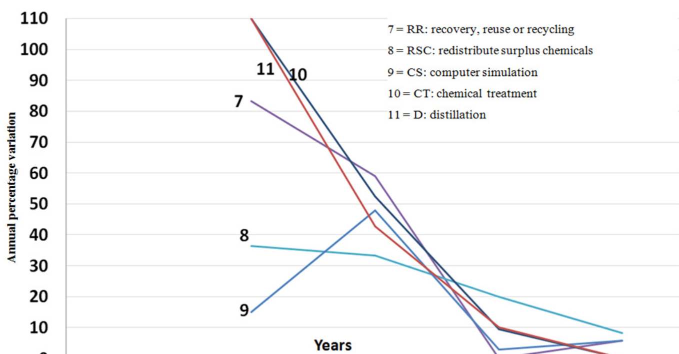
According to the annual percentage variation graphs and the data relative to the numbers of labs doing specific practices (Figures 2 and 3), the first diagnostic (2010) indicated that "RSC", CS" and "PC" were the most implemented WMPs in 22 labs, 20 labs and 18 labs, respectively. "Substitution with less hazardous or nonhazardous materials also named SNMs", a true source reduction measure, as well as "CT" and "D" were less common, only 10 laboratories used.

Although, the annual variation values surely decreased for the 2013–2014 period, this does not mean a decrease in the quantity of labs carrying out waste minimization practices. The decreasing variation trend only evidences the correct assimilation of waste minimization practices by laboratory personnel as a consequence of the institutional training sessions.



	2010	2011	2012	2013	2014
CIM		66.67	60.00	12.50	11.11
PC		33.33	75.00	9.52	19.57
SNM		80.00	94.44	8.57	5.26
PL		46.67	72.73	10.53	14.29
RS		52.94	61.54	7.14	13.33
CE/P		78.57	40.00	2.86	5.56

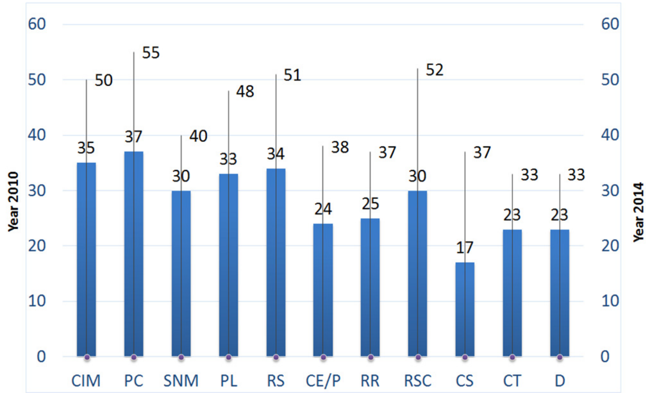
Figure 4: Annual percentage variation for six waste minimization practices, period 2010–2014.



	2010	2011	2012	2013	2014
RR		83.33	59.09	0.00	5.71
RSC		36.36	33.33	20.00	8.33
CS		15.00	47.83	2.94	5.71
CT		110.00	52.38	9.38	0.00
D		110.00	42.86	10.00	0.00

Figure 5: Annual percentage variation of five waste minimization practices, period 2010–2014.

In Figure 6 the black thin line and the indicated numerical value refers to the quantity of labs applying a specific WMP during the year 2014, whereas the thick black bar and the corresponding value represent the differential increase in the quantity of labs performing that same WMP relative to 2010. For example, in the case of “CS”, the 17-point differential increase (black thick bar) results from practice implementation values going from 20 (arithmetic difference between thin line and thick bar) to 37 (black thin line) for the 2010 and 2014 years, respectively.



CIM: Chemical inventory management / PC: Purchase control / SNM: Substitute nonhazardous materials / PL: Purchase less / RS: Reduce Scale / CE/P: Change equipment or procedure/RR: Recovery, reuse or recycling/ SC: Redistribute surplus chemicals/ CS: Computer simulation / CT: Chemical Treatment /D: Distillation

Figure 6: Waste minimization practices performed in the years 2010 and 2014.

According to Figure 6, the number of labs applying “CT” and “D” increase from 10 to 33 for each practice. Despite this increase, this quantity is still low considering the total study population (60 labs); this finding is possibly attributed to the lack of available qualified technicians in most of the labs in order to carry out “CT” (neutralization, precipitation, and oxidation-reduction) and distillations (“D”) procedures. It is important to point out that according to Table 1, 42% of the labs have chemists as part of their laboratory staff.

Figure 6 indicates that by 2014 most laboratories were actively practicing “CIM” and “PC” which is significant in the sense that these practices inherently facilitate bookkeeping of waste inventory and waste generation rates. “PL” and “RS” were also well implemented. Specifically, the quantity of labs embracing “PL” during 2014 was 48 versus 15 for 2010. Labs operators apply an institutional chemical purchase strategy named “to use and buy just the necessary”. It is well to note that a comprehensive “chemical inventory stock” program has been diffused in order to exchange and better redistribute previously unused chemicals within the university community.

In the case of “RS” the 2014 and 2010 figures are 51 and 17, respectively. The evident increase in “RS” practice is in accordance with the global green chemistry initiative which has permeated at the institutional level. For example, a group of researchers at the Department of Chemistry are currently undertaking projects aimed at promoting a shift towards small-scale experiment implementation at the academic laboratory level.

The number of labs implementing “RSC” in 2010 was 22 and 52 in 2014. “CS” is still low ranked with only 10 and 37 out of the 60 total laboratories for 2010 and 2014, respectively. This leaves much room for suggesting the advancement and usage of specialized chemical and engineering software at the academic and research level.

Overall, the general trend going from 2010 to 2014 was clearly an increment in the quantity of laboratories implementing WMPs (Fig. 6).

Some specific waste generation prevention and minimization activities completed after training at the UNA-CR are listed below:

- Substitution of ethidium bromide by proprietary nucleic acid stains (Biotium gelred™) for electrophoresis DNA analysis (Veterinary, Biology and Soil and Forest Departments).
- Substitution of acetamide by stearic acid for freezing-point depression determinations in organic chemistry student laboratory practices (Chemistry Department).
- Substitution of alcohol for benzene and lauryl peroxide for benzoyl peroxide as polymer catalysts (Chemistry Department).
- Substitution of mercury containing Kjeldahl digestion catalysts for mercury-free copper and potassium based catalysts. (Chemistry Department).
- Replacement of toluene by simple alcohols and ketones in organic chemistry laboratory practices (Chemistry Department).
- Replacement of sodium dichromate for sodium hypochlorite as oxidant in various inorganic chemistry laboratory practices (Chemistry Department).
- Usage of peracetic acid and ethanol as an animal cadaver conservative instead of formaldehyde/formalin (Veterinary Department).
- Use of secondary waste containers for chemical waste storage in laboratories.
- Use of non-halogenated solvents instead of halogenated solvents.
- Application of a "Green Chemistry Laboratory Manual" in some chemistry laboratory practices.
- Be wary of receiving external donations of chemicals, accepting only the chemicals that are to be used within the following 3 months.
- Substitution of automatic analysis procedures for manual wet-chemistry procedures, e.g., nitrates by Flow Injection Analysis (FIA) instead of the traditional preparative cadmium column method.
- Use of spent solvent for initial glassware cleaning and fresh solvent for final cleaning.
- Implementation of microscale COD (chemical oxygen demand) analysis methods.
- Mandating the reduction of using reagents containing various toxic metals such as arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver.
- Procurement of state-of-the-art equipment enabling procedures requiring less consumables thus less waste generation.
- Avoiding the use of chromic acid in cleaning solutions and prioritizing the use of detergents, alcohol or just hot water.
- Reusage and recycling of methanol.
- Centralized chemical purchases via the "Chemical Products Office".

- Avoiding generating "unknown" waste by adhering to proper labeling procedures.

4 Conclusions

During this research, the study population comprised 60 institutional laboratories involved in diverse academic and research fields such as biology, toxicology, veterinary, physics, chemistry, environmental sciences, vulcanology and soil and forest sciences.

The less frequently implemented WMPs on a year by year basis (2010–2014) were: "SNM", "CT" and "D".

Redistribute surplus chemicals ("RSC") is the most common practice at a level of 22 labs, 30 labs and 48 labs during the years 2010, 2011 and 2013, respectively. During 2012 "RS" was performed in 42 labs; "PL" was practiced in 55 labs in 2014, both being the most common WMPs for those two years.

The highest annual percentage variation was evidenced in the 2010–2011 period, right before the institutional waste minimization training process. Although the number of labs performing the considered WMPs always increased year by year, the annual percentage variations evidenced in the 2013–2014 period was less than for the 2010–2011.

Waste minimization practices performed as of 2010 were substantially improved after training, especially the following 2 years. Nonetheless, as of 2014 there are still some low-ranked WMPs such as "CT" and "CP" which should be incentivized by expert training along with financial support for acquiring software technologies.

The least performed WMP for the 2010–2014 period was "CS" with a differential frequency of 17 for this 4-year time period. The highest difference corresponds to "PC" with a difference of 37 labs when comparing 2010 and 2014.

As a general conclusion there are significant obstacles to implementing pollution prevention in universities; initial capital requirements, regulatory barriers, immediate production concerns, lack of staff with technical expertise and institutional inertia. As an initial step towards running successful institutional pollution prevention program a diagnostic of the chemical waste minimization practices was undertaken by highly trained experts of the Chemical Products Office. This office together with university authorities, laboratory managers, principals, investigators, students and technicians look forward to implementing simple and inexpensive solutions aimed at chemical waste minimization and overall pollution prevention.

This study showed that emphasizing pollution prevention hierarchy in institutional training sessions increased the number of laboratories implementing WMPs. Currently, the university has a better and more efficient waste management program which prioritizes waste reduction and prevention from the source.

Future research is recommended to define the chemical waste rate generation before and after training as a quantitative indicator of the impact of training sessions upon the overall institutional chemical waste prevention program.

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Proposed management and exemption of radioactive waste in nuclear medicine facilities according to the recommendations of the ICRP Publication 103

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Abstract

The ICRP recommendations deal with issues related to radiological protection of man and the environment against the risks and damage caused by ionizing radiation through the dissemination of its publications that are accepted and implemented by national and international entities. This study aims to evaluate the environmental deposition of radionuclides used in nuclear medicine facilities in the City of Rio de Janeiro and a model will be proposed, at the national level, which aims to implement a radiation protection system for the management and exemption of radioactive waste based on ICRP Publication 103.
Keywords: ICRP, dose limits, reference levels and risk levels, management and exemption of radioactive waste, nuclear medicine, radiological protection, environment.

1 Introduction

The International Commission on Radiological Protection (ICRP) is a non-governmental body independent created in 1928 during the International Congress of Radiology [1], with the main objective to protect human health and the environment against the effects of radiation exposures. The ICRP publishes its recommendations involving aspects related to radiological protection and the risks associated with ionizing radiation in the form of reports, called ICRP Publications [1–3]. The ICRP works closely with other agencies to ensure that its recommendations are published, such as the International Commission on Radiation Units and Measurements (ICRU), which is responsible for defining the quantities and units used in radiation protection and the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), which is responsible for research in the literature on the biological effects of radiation. The International Atomic Energy Agency (IAEA) follows the ICRP recommendations organizing them as standards, so that its recommendations are accepted by the member countries [4].

2 ICRP publications

The ICRP recommendations deal with ionizing radiation, the protection of man and the environment, and serve as a practical character guidance to knowledge of radiobiology and radioprotection [5] to regulatory agencies, management groups and professionals in the field of radiation protection. The ICRP Publication 1 in 1928 contained recommendations that were only adopted in 1958. The ICRP Publications 26 in 1977, 60 in 1991, 91 in 2003, 103 in 2007, 108 in 2008 and 114 in 2011 were important in general regarding radiation protection, in establishing radiological quantities geared to man and the environment, their relationships and methods within a more coherent design possible [5–7].

ICRP Publication 26 quantified the risks of stochastic effects of radiation proposing a dose limitation system along with the principles of justification and optimization. In this publication, there was an anthropocentric vision in which the radiological protection standards recommended by the ICRP were focused only on the human being leaving, in the background, the biota [5].

ICRP Publication 60 defined the concept of practice [4] and proposed changes in its recommendations regarding ICRP Publication 26 based on reviews of radiation exposure risk estimates, expanding its philosophy for radiological protection system keeping the fundamental principles of radiation protection [1, 4]. The ICRP questioned the paradigm of environmental protection because there are controversial statements related the risks to the species that are present in the ecosystem [5].

The ICRP Publication, ICRP 91, presented the development of a unique system of protection of biota giving bases and objectives for radiological protection through ethical principles and scientific evidence, and how this protection could directly or indirectly affect human health, so that national laws were necessarily aggregated to protect the environment from the harmful effects of radiation [5].

ICRP Publication 103 involved a series of approaches to radiological protection that changed important concepts and paradigms in relation to ICRP Publication 60, such as the definitions of the concepts of planned exposure situations, emergency exposure situations and existing exposure situations [7]. The main contribution of this publication was the final breaking of the anthropocentric view that emerged in ICRP Publication 26, because the environmental protection could not be linked to human protection considering the need to develop, with scientific basis, a more specific framework to assess the relationship between exposure and dose and the relationship between dose and effect, and the consequences of the effects caused by radiation in the ecosystem as a whole [1].

ICRP Publication 108 defined the concept of reference animals and plants (RAP), focusing on radiological protection in humans and the environment through selection criteria, description of groups and demonstration of exposure pathways, calculation of conversion factors of activity concentration in absorbed dose rate, the collection and evaluation of information in terms of derived limits on the relationship between dose and effects on RAP, proposing the relationship between dose ranges and any biological damage, added to applications and extrapolations, exposure situations, radiation dosimetry and effects of radiation in RAP [5].

ICRP Publication 114 added the ICRP Publication 108 recommendations, focusing their attention on the behavior of radionuclides in the ecosystem, providing environmental modeling with the transfer parameters for 39 types of radionuclides that were used for the calculation of absorbed dose as a standard for environmental protection [5, 8].

3 Brazilian standards and ICRP recommendations

In Brazil, the Basic Standards on Radiological Protection (BSRP) were approved by the National Nuclear Energy Commission (CNEN, initials in Portuguese and means Comissão Nacional de Energia Nuclear) in 1973, establishing the Basics of Radiological Protection and dose limits following the ICRP recommendations. BSRP were repealed and replaced by the CNEN-NE-3.01 Standard in 1988, entitled "*Basic Guidelines for Radiation Protection*". This standard was based on the recommendations of ICRP Publication 26, which introduced the concept of detriment associated with the probability of occurrence of damage caused by radiation and established the radiological protection principles: justification, optimization and dose limitation [6]. At the beginning of 2005, CNEN approved the CNEN-NN-3.01 Standard, entitled "*Basic Guidelines on Radiological Protection*", along with the regulatory positions, replacing the CNEN-NE-3.01 Standard, being updated by CNEN Resolution 164/2014 [9]. This standard is based on ICRP Publication 60 recommendations. Moreover, the three radiological protection principles were called Requirements [6, 10]. With ICRP Publication 103, however, there are discussions nationwide so that Brazilian standards should be reviewed and appropriate, because Brazil is at a disadvantage in relation to radiological protection worldwide [4], and it is necessary to change the concepts of protection and the weighting values of the particles/radiation and the organs and tissues, in order to update the data related to the damage caused by radiation to humans and the environment [7].

4 Nuclear medicine facilities in Brazil

Nuclear medicine is a medical modality that uses nuclear energy through the use of radioactive substances in the form of non-sealed sources that decay for a given period, for administration of *in vivo* patients or by use of *in vitro* techniques for diagnostic purposes or therapy [11].

The physical structure of a nuclear medical service must have the following dependencies: exclusive waiting room and exclusive toilet for injected patients; handling laboratory and storage of radioactive sources in use; administration of radiopharmaceuticals room; examination room; location for the temporary storage of radioactive waste; adequate room, from the point of view of the radiological protection, physically delimited, located within of the nuclear medicine service, for performing pulmonary ventilation studies; exclusive room for exams with cardiac stress for radiology purposes with radiopharmaceuticals, physically delimited; exclusive room, with individual spaces for radiopharmaceuticals administration and back rest of the injected patient, when using diagnostic equipment by positron emission; and room for therapy with hospitalization, when therapeutic doses of radiopharmaceuticals are administered [12].

5 Management and exemption of waste on the basis of the ICRP Publication 103

Radioactive waste management is defined as the set of technical and administrative activities involved in the collection, segregation, handling, processing, packaging, identification, transport, storage, control, dispense and deposition [13]. It aims to provide greater protection for human beings and help preserve the environment in order to limit possible radiological impacts for future generations [14].

Radioactive waste generated in nuclear medicine facilities in Brazil are classified as Class 1 by CNEN (very short half-life waste – VSHLW), because this waste contains radionuclides with lower half-lives in the order of 100 days, with activity levels or activity concentrations above their respective exemption levels [15].

The exemption of radioactive waste is given by the removal of regulatory control of radioactive materials or objects associated with an authorized practice [9]. After processing in common medical waste due the radioactive decay, it applies to the disposal of solid radioactive materials in urban waste collection system, or in landfills, and liquid radioactive materials in the sewer system [14].

The dose limit aims to limit the exposure of man, restricting the way of how it is exposed to radiation. This concept is applied in control of all radiation emitting sources only for planned exposure situations. The restriction levels and reference levels are intended to protect the man that operates the source. This concept is applied to all situations where exposures occur (planned exposure

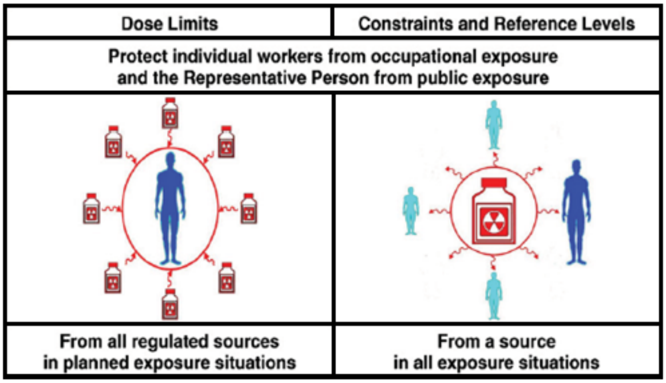

Figure 1: (a) Implementation of the individual dose limit for all sources in planned exposure situations; (b) Application of the restriction levels and reference levels for individuals' protection for all situations [1].

situations, emergency exposure situations and existing exposure situations) [4]. Figure 1 illustrates the contrast of these two concepts.

6 Methodology

In Brazil, the number of nuclear medicine facilities in operation authorized by CNEN at the time of writing this paper is estimated at 400. In this study, only the nuclear medicine facilities in operation in the City of Rio de Janeiro were considered, whose period of research was carried out in January 2016. The number of different types of radionuclides distributed to these facilities was still estimated at 17. In each radionuclide, the following data were provided: radioisotope's name, activity given in milicurie (mCi) and frequency (weekly, daily, biweekly, monthly). Among the types of radionuclides, technetium-99m (^{99m}Tc) is what stands out for being the most widely used due to its physical properties, such as physical half-life (6 hours) and low effective energy (140 keV). Other radionuclides, such as fluorine-18 (^{18}F), iodine-131 (^{131}I), gallium-67 (^{67}Ga), thallium-201 (^{201}Tl), samarium-153 (^{153}Sm) and iodine-123 (^{123}I), also stand out due to their physical half-lives are relatively low and are used both the diagnosis and treatment of patients. A spreadsheet was used to convert the units for activity and frequency in order to estimate the value of the total activity for all radionuclides for the year 2016, so that the quantity of activity was converted from milicurie (mCi) to becquerel (Bq), a unit of the International System (SI), and the frequency of each radionuclide converted to annual.

During the research, a topographic map of the City of Rio de Janeiro in scale of 1:31,000 was used, on which points of identification of nuclear medicine facilities located by regions and districts were marked. It was possible to check the imminence of the facilities to the banks of rivers, channels, lagoons and seafronts, in order to identify the effluent dispersal pathways containing radionuclides released into the sewer system.

This study is under development, which will be carried out the collection of sewage samples to detect the presence of radionuclides originating from Nuclear Medicine facilities in the City of Rio de Janeiro from the analysis by gamma spectrometry. The samples will be taken for analysis in the Real Time Neutron Radiography Laboratory (LNRTR/PEN/COPPE/UFRJ). The mass of each sample will be measured with use of a precision balance of brand Gehaka, model BG 4000, with a sensitivity of ± 0.01 g. The analysis of the samples will be carried out by a spectrometer of brand Canberra, with coaxial high-purity germanium detector (HPGe), model GC3020 (see Figure 2), coupled to a preamplifier, model 2002 CSL, operated at low noise, and a software Genie-2000. The preamplifier is associated with vertical cryostat, model 7500SL-DRC-4, and a dewar with a capacity of 30 L. The multi-channel system to be used will be a DAS 1000 (Digital Spectrum Analyzer) with 8192 channels and an energy range from 50 keV to 2 MeV, amplifying the pulse Gaussian format with fast rise of 8.8 μs from the preamplifier. The voltage to be used for the creation of the depletion area will be 4500 V. The count time of the samples to be collected will be 8 hours. The geometry to be used for placement of the samples is a polypropylene bottle with low background radiation, with a volumetric capacity of 500 mL. The dimensions of the bottle and the height of the sample will be provided for the software Genie-2000 to calculate the volume of the sample. The calculation of the density of the sample will be the ratio of the mass measured on the balance and the bottle volume calculated by the software.

Figure 2: Spectrometer of brand Canberra, model GC3020.

7 Results and discussions

29 Nuclear Medicine facilities in operation were researched in the City of Rio de Janeiro. The North Zone (marked in yellow) has the largest number of Nuclear Medicine facilities in operation with 9 facilities, followed by Downtown (marked in blue) and the South Zone (marked in green) with 8 facilities each, and the West Zone (marked in red) with 4 facilities. Figure 3 shows the map of the City of Rio de Janeiro containing the points of identification of Nuclear Medicine facilities, where Downtown has the greatest concentration of Nuclear Medicine facilities because of the proximity between them, while the North Zone records the greater spread of Nuclear Medicine facilities.

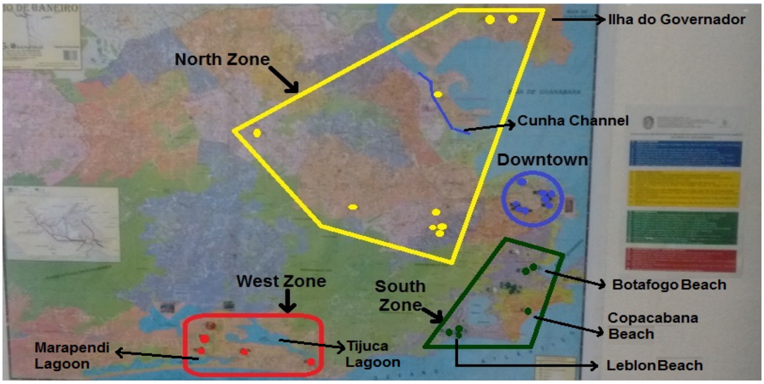

Figure 3: Map of the City of Rio de Janeiro containing the points of identification of nuclear medicine facilities per region: yellow, North Zone; blue, Downtown; green, South Zone; red, West Zone.

The location and the distance between the nuclear medicine facilities and the bank of rivers, channels, lagoons and seafronts were checked on the map. In Downtown, from 8 existing nuclear medicine facilities, 5 are close to the banks in Guanabara Bay. In the North Zone, from 9 existing nuclear medicine facilities, 4 are close to the banks of rivers, 1 is close to Cunha Channel and 2 are close to the seafront on the south of Ilha do Governador. In the South Zone, from 8 existing nuclear medicine facilities, 6 are close to the seafront: 2 at Botafogo Beach, 1 at Copacabana Beach and 3 at Leblon Beach. In the latter, 2 nuclear medicine facilities are close to Jardim de Alah Channel, which connects Leblon Beach to the Rodrigo de Freitas Lagoon. In the West Zone, from 4 existing nuclear medicine facilities, 1 is located within a city natural park and 3 are close to the banks on the lagoons: 1 at Tijuca Lagoon, 1 between Tijuca Lagoon and Marapendi Lagoon and 1 at Marapendi Lagoon.

17 different radionuclides distributed to 29 Nuclear Medicine facilities in the City of Rio de Janeiro were authorized by CNEN and the total number of distributed radionuclides was 185 (see Table 1). The radionuclides that had the

highest distribution were technetium-99m and iodine-131 (present in 24 facilities each), thallium-201 (present in 23 facilities) and gallium-67 (present in 22 facilities). The radionuclides that had the lowest distribution were lutetium-177 (present in 7 facilities), yttrium-90 (present in 5 facilities), chromium-51 (present in 4 facilities), carbon-14 (present in 2 facilities) and tritium-3 and gallium-68 (present in 1 facility each).

Table 1: Types of radionuclides distributed in Nuclear Medicine facilities in the City of Rio de Janeiro. In the right column, the percentage distribution of radionuclides (source: CNEN, link: http://www.cnen.gov.br/instalacoes-autorizadas. Compiled on January 22, 2016).

Radionuclide	Number of radionuclides distributed in nuclear medicine facilities	%
Gallium-67	22	11.9
Iodine-131	24	13.0
Technetium-99m	24	13.0
Thallium-201	23	12.4
Fluorine-18	9	4.9
Samarium-153	16	8.6
Iodine-123	19	10.3
Indium-111	14	7.6
Radium-223	10	5.4
Chromium-51	4	2.2
Iodine-124	2	1.1
Lutetium-177	7	3.8
Yttrium-90	5	2.7
Carbon-14	2	1.1
Tritium-3	1	0.5
Iodine-125	2	1.1
Gallium-68	1	0.5
Total number of radionuclides	185	100.0

Based on the values in the spreadsheet, there were calculated the estimated values of total activities for radionuclides authorized by CNEN for Nuclear Medicine facilities in the City of Rio de Janeiro for the year 2016 (see Table 2). Among the 17 types of radionuclides surveyed in this study, the technetium-99m [total activity = 1.38×10^{14} Bq; average = $(5.74 \pm 3.48) \times 10^{12}$ Bq], fluorine-18 [total activity = 4.18×10^{13} Bq; average = $(5.34 \pm 4.93) \times 10^{13}$ Bq] and lutetium-177 [total activity = 1.76×10^{13} Bq; average = $(2.51 \pm 3.36) \times 10^{12}$ Bq] are the radionuclides who stand out for performing, respectively, SPECT (Single Photon Emission Computerized Tomography) scintigraphy exams, PET (Positron Emission Tomography) exams, and for incorporation of patients with hematological (lymphomas) and solid (lung cancer) tumors submitted to radioimmunotherapy. Iodine-131 [total activity = 1.58×10^{13} Bq; average = $(6.59 \pm 9.42) \times 10^{11}$ Bq] also stands out for its high total activity for use in thyroid incorporation in patients for both scintigraphy exams and for admission to therapeutic room (radioiodine). Carbon-14 [total activity = 1.87×10^{9} Bq; average = $(9.34 \pm 13.00) \times 10^{8}$ Bq] is used to perform breath tests for detection and research of *Helicobacter pylori*, a bacterium responsible for gastric infection.

Table 2: Estimated values of the total activity and the average of radionuclides. Between parentheses is the number of nuclear medicine facilities operating with the radionuclide.

Radionuclide	Total activity (Bq)	Average (Bq)
Gallium-67 (n = 22)	1.08×10^{12}	$(4.92 \pm 4.04) \times 10^{10}$
Iodine-131 (n = 24)	1.58×10^{13}	$(6.59 \pm 9.42) \times 10^{11}$
Technetium-99m (n = 24)	1.38×10^{14}	$(5.74 \pm 3.48) \times 10^{12}$
Thallium-201 (n = 23)	2.16×10^{12}	$(9.41 \pm 10.70) \times 10^{10}$
Fluorine-18 (n = 9)	4.81×10^{13}	$(5.34 \pm 4.93) \times 10^{12}$
Samarium-153 (n = 16)	4.72×10^{12}	$(2.95 \pm 1.65) \times 10^{11}$
Iodine-123 (n = 19)	1.45×10^{12}	$(7.64 \pm 5.21) \times 10^{10}$
Indium-111 (n = 14)	4.98×10^{11}	$(3.55 \pm 3.35) \times 10^{10}$
Radium-223 (n = 10)	1.51×10^{11}	$(1.51 \pm 2.80) \times 10^{10}$
Chromium-51 (n = 4)	2.96×10^{10}	$(7.40 \pm 3.70) \times 10^{9}$
Iodine-124 (n = 2)	1.11×10^{11}	$(5.55 \pm 0.00) \times 10^{10}$
Lutetium-177 (n = 7)	1.76×10^{13}	$(2.51 \pm 3.36) \times 10^{12}$
Yttrium-90 (n = 5)	2.41×10^{12}	$(4.81 \pm 1.65) \times 10^{11}$
Carbon-14 (n = 2)	1.87×10^{9}	$(9.34 \pm 13.00) \times 10^{8}$
Tritium-3 (n = 1)	8.88×10^{7}	8.88×10^{7}
Iodine-125 (n = 2)	1.86×10^{9}	$(9.30 \pm 13.00) \times 10^{8}$
Gallium-68 (n = 1)	1.85×10^{11}	1.85×10^{11}

The management of waste containing radionuclides has not been a very relevant issue in Brazil. However, it is important to note that occupationally exposed individuals (workers) should be aware of the risks of unnecessary exposure or incorporation of unsealed sources used in nuclear medicine facilities. The criteria for segregation, storage and decay of radionuclides present in the waste to permissible levels for exemption in accordance with the CNEN-NN-8.01 Standard is being used as the discard control instrument, since, after the radioactive decay, are treated as hospital waste [15, 16].

The exemption of radioactive waste generated in nuclear medicine facilities is based on the CNEN-NN-3.01 Standard, in line with ICRP Publication 60 recommendations, because the concept of practice is still present and the radiological protection is only focused on occupationally exposed individuals, not taking into account the undue exposure of radionuclides present in the waste that impact on the environment. This is because, even after reaching the limits of exemption, the radionuclides still tend to decay by emitting particles/radiation in the ecosystem according to their activities and half-lives and can go several pathways to get to the individual. The Brazilian standards are outdated in the context of radiation protection and need to be reviewed and must follow the ICRP recommendations that deal with the protection of biota with stricter monitoring of waste arising from nuclear medicine facilities describing the routes of exposure of radionuclides in the ecosystem, the application of concepts Planned Exposure Situations, Emergency Exposure Situations and Existing Exposure Situations, and the relationship of these concepts with dose limits, risk levels and reference levels.

8 Final considerations

The concept of Practice defined by the ICRP Publication 60 is still present in the Nuclear Medicine facilities in Brazil due to accident risks of contamination of occupationally exposed individuals, injected patients and accompanying, by surface contamination and management of radioactive waste arising from the decontamination process and the source fault.

From the point of view of radiological protection, it is necessary that the current Brazilian standards are reviewed and the recommendations of the ICRP Publication 103, so that the concepts of planned exposure situations, emergency exposure situations and existing exposure situations are introduced and incorporated specifically targeting the protection of individuals and the environment from undue exposure of ionizing radiation.

This work is being developed to assess the environmental doses of radionuclides from the nuclear medicine facilities nationwide, through the waste exemption pathways containing radionuclides, in order to propose a model for the implementation of a radioprotection system on the basis of the ICRP Publication 103 recommendations.

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The impact of health services' waste to public health and to the environment

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Abstract

The risks caused by the disposal of healthcare waste have gained great importance for the scientific community, for when discarded inadequately the waste represent potential risks for both public health and the environment. In this context it is worth noting the risks conferred to the health of scavenging workers, public health and the environment. Studies show that disposal of medicine into the common garbage or the sewage contaminates the soil and water resources. The present work aims to analyze the risks of selective collection pickers to the residues of healthcare waste and the risks that these represent for public health and the environment. This is a cross-sectional descriptive study with a quantitative approach. Interviews were conducted through a questionnaire applied to 61 workers of the Pre-Cooperative Associations of Collectors of Solid Waste and Recycle Life. The collected data has been tabulated and analyzed in a descriptive form. The results of this study show a prevalence of 51.0% of women working in associations; 36.0% of respondents aged between 30 and 39, 42.6% have worked for over 10 years in the occupation of collector and 81.0% make use of personal protective equipment. Of the respondents, 23.0% had experienced some kind of accident with healthcare waste; 95.1% say they often find drugs in the workplace and 86.9% of these are medical waste. It concludes that workers are exposed to risks due to the improper disposal of waste from healthcare services. Therefore, it is necessary to strengthen strategies to raise

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awareness about the proper disposal of medicines and medical waste and incorporate existing laws into the management of such waste produced in households.
Keywords: medical waste, occupational health, sewers collectors, environmental health.

1 Introduction

The disposing of waste has huge environmental impacts and can cause serious problems to public health especially for people who work with it. Some people consider the waste as something that has no more value or use. To others, named as waste pickers, scavengers or sewers collectors, garbage is their only source of income. While the population discards the waste as no longer useful, waste pickers aim to transform the material into a livelihood for survival [1]. It is estimated that in Brazil there are about 800,000 waste pickers, with 30,000 of them organized into cooperatives. In 2012 they accounted for 18% of the waste separated for recycling in Brazil [2]. In Brasilia, the capital of Brazil, there are 34 institutions working with recycled materials with the collaboration of approximately 2,362 workers of selective collection, which accounts for the recovery by collection or by organic waste composting process of about 75,000 tons of solid waste in 2015 [3].

Despite doing an extremely important job for both society and the environment the selective collection workers are exposed in their work process to different types of occupational hazards: physical, chemical, mechanical, ergonomic, biological and social. Among the different risks cited, the biological risk deserves more attention as it may be responsible for diseases that affect the intestinal tract caused by [Ascaris lumbricoides, Entamoeba coli, Schistosoma mansoni]; the virus that causes hepatitis [mainly type B], and the virus that causes AIDS [4]. Thus this waste requires special care because it is classified as hazardous waste as a potential source of contamination and spread of diseases.

Health Waste (HW) are residues generated in any establishment that provides healthcare services of human or animal origin. These residues are classified into five groups in accordance with Resolution RDC no. 306 of the ANVISA and Resolution no. 358 of the CONAMA, separated in accordance with their degree of danger: Group A: residues that present a risk to public health and the environment due to the presence of biological agents; Group B: residues that present a risk to public health and the environment due its physical, chemical and physicist-chemistries characteristics; Group C: radioactive residues or contaminated with radionuclides; Group D: all other residues that do not match the previously described groups and Group E are the residues of sharp devices. These HW represent a small parcel around 1% to 3% of the total of the urban solid residues. This number represents a small amount if compared to other types of residues, the great concern is the inadequate segregation that can contaminate other residues that were not contaminated before and the portion generated in the residues that are not accounted for [7].

In addition to the HW presenting risks to the quality of life of scavenging workers it has also become a major environmental problem, as the high amount of these medicines being deposited incorrectly in the ground is directly related to the contamination of the water resources. In addition to soil and water contamination, studies show that some microorganisms are showing resistance to drugs, since bacteria can and often makes changes in their genetic material, as they acquire resistance [8].

Currently in Brazil the standardization of technical guidelines regarding the mandatory pre-treatment of infectious fractions of HW and pharmaceuticals before their final disposal are guided by agencies of sanitary and ambient factors surveillance that act in the preservation of the public health and the environment. However, the management of these residues has not been adopted integrally, in its stages of execution, for the services of health and state and municipal management systems. Furthermore, there is still no established collecting practice of HW discarded by the population. These are often made in the regular waste or in the public sewer system, having thus conferred risks to public health affecting the quality of life and the environment. The impacts caused by the incorrect discarding of HW have already been studied by the scientific community, since the disposal of these in inadequate places allows for the transmission of diseases to humans and pollution of the environment. Thus the work aims to analyze the risks of the exposition of the residues of health for the pickers of selective collecting and the risks that these represent to public health and the environment.

2 Methodology

This present study is a descriptive cross-sectional epidemiologic study with a quantitative approach. The main data collection instruments were made through observations in the field and semi-structured interviews guided by questionnaire surveys divided into three stages, consisting of addressing socioeconomic factors, health hazards and accidents, damage to the environment and the risks to health in the misuse of drugs and needles found in the trash.

Data collection was conducted from November 2014 to early March 2015 in the Recycle Association Life and Pre-Cooperative Association of Solid Waste Pickers [APCORC] both located in the administrative region of Ceilândia – DF. Sixty-one solid waste pickers were interviewed by scholarship students and academic volunteers from the extension project 'Stop, Think, Dispose' from the University of Brasilia, Campus Ceilândia. These examiners were calibrated through meetings with the groups of students and there was a questionnaire validated in 10% of the samples that were later dropped.

All workers from the two associations were invited to participate in this study. The data obtained from the interviews were tabulated and analyzed using the Epidata® software, available for free through the website epidata. The questions and data obtained through the questionnaire were analyzed using descriptive statistics, and nominal variables presented in absolute numbers and proportions and numeric variables in measures of dispersal and central tendency.

The analysis of data was performed in the Statistical Package of Social Science [SPSS] 20.0 adopting the descriptive statistics, with nominal variables presented in absolute numbers and proportions and numeric variables in measures of central tendency [mean and median] and dispersion [deviation pattern].

This research was linked to the academic extension project at the University of Brasilia Campus Ceilândia 'Stop, Think, Discard: a multidisciplinary approach to dialogue among the university, the community and the waste pickers of Ceilândia – DF'. With acceptance of the Ethics Committee for Health Research, Campus of the University of Brasilia – UnB, followed by the Certificate Presentation to Ethics Assessment obtaining approval under the number of 427,624.

3 Results and discussion

With the analysis of the results the prevalence of women representing 59% compared to men who accounted for 41% was revealed. This prevalence of women working in cooperatives is pointed in different studies [9–11]. Hoefel *et al*. [12] found that nearly 85% of women garbage workers interviewed in the Structural Landfill Cooperative – DF are in the reproductive age, up to 49 years old. In this study 72.2% of the women are in the same age group.

About the age of the interviewees, 36.1% are 30–39 years old. Similar results were found in studies conducted by Gonçalves *et al*. [13] and Kirchener *et al*. [14] that prevailed pickers aged 25–45 years. Regarding the level of education, it is observed that 65.56% of respondents had not completed even primary school. These data corroborate with the research previously carried out by Alencar *et al*. [1] and Schmitt and Esteves [15] who noted in both studies that the low educational level of scavengers contribute to the process of social exclusion and interferes directly in the social determinants of health.

With regard to the link with associations to most collectors, 78.1% claim to be linked. These environments according to Castilhos Junior *et al*. [16] represent an opportunity to the collectors to organize and have a representative, thus contributing to the increase in income, social status and self-esteem. 42.62% of the interviewees work with scavenging for more than 10 years between 5 and 6 times a week, ranging from 5 to 9 hours a day totaling 88.52% of interviewees. Similar data are indicated in studies by Castilhos Junior *et al*. [16], Alencar *et al*. [1] and Hoefel *et al*. [12]

Regarding the HW, 95.1% of the workers say they often find drugs in the garbage treadmills in bottles, half a pack or even boxes without apparent use and 89.9% have observed medical materials such as: syringes, needles, blood bags, woven with secretions, medicines and anatomical pieces of human and animal origin (indicated in figure 1). Compatible results are pointed out in the study by Amante [11] at the dump of city Estrutural – DF.

For Ferreira and Angels [4] pathogenic micro-organisms are not only present in waste generated in establishments that provide health services. Home environments are responsible for a large amount of waste that may contain disease-causing agents in the intestinal tract and cause hepatitis [mainly type B]. These are potential risks because they have the ability to resist an adverse environment.

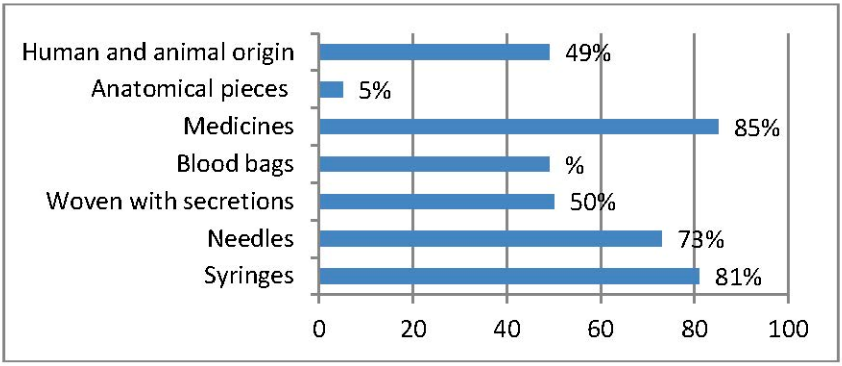

Figure 1: State of residues found in trash.

To Zanon [17], the temporary presence of live primary pathogens in domestic and hospital waste does not mean that such waste can pass them, since access to the host depends on the existence of a transmission path and a gateway. The potential risk of direct transmission of infectious diseases by any type of solid residue depends on the presence of an infectious agent, its survivability in the trash and the possibility of transmission of garbage into a susceptible host.

The Brazilian Regulatory Standard [BRS] No. 6 provides for the use of single protection equipment [SPE]. The use of these is key for protection against the risks that threaten safety and occupational health. Regarding the use of such equipment, it was found that most collectors (88.5%) said they make use of any type of equipment while performing the work.

The types of SPE most cited are gloves, boots and masks (listed in figure 2). These data corroborate the study by Castilhos Junior *et al*. [16]. According to the

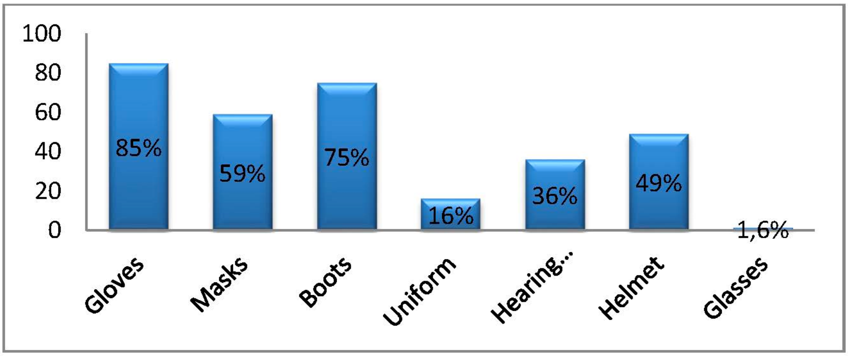

Figure 2: Single frequency usage of protective equipment by the collectors in the associations.

author, the use of some equipment is sometimes not adopted by workers due to heat or relative inflexibility provided by them. For some workers, using gloves does not protect against cuts, they are considered brittle and therefore they tear easily. Moreover, they hamper the use in the separation process of materials which generates greater discomfort to the job being done.

Table 1 presents data relating to accidents caused by medical waste. Among respondents 23% [n = 14] had experienced some kind of accident when handling the waste. Several authors argue that the sharp objects are responsible for most accidents in cooperatives, as well as being the main risk agent for these workers [10, 18–21]. Only 43% [n = 6] of the workers who had accidents went to the health service for guidance. According to them, the fear of contracting diseases, contracting AIDS, to die or be unable to work is important and reflects the vulnerability in which they find themselves. In a survey conducted by Vacari *et al.* [20] the measures taken by the pickers against suffering injuries from sharp residues looking for the clinic, hospital, rubbing alcohol on site, wash the affected area and self-medicate, some mentioned by respondents.

Table 1: Accident frequency with waste health services in Recycle Associations Life and APCORC Administrative Region of Ceilândia – DF.

	Group	
	N	**%**
Accidents		
Yes	14	23.00
No	39	63.90
Did not inform	08	13.10
Looked for help		
Public hospital	03	4.9
Health center	03	4.9
Did not look for help	06	9.9
Did not inform	49	80.3

Regarding the notion of danger facing most workers, 90.2% consider the medical waste to be hazardous to health and 9.8% reported not knowing the risks. Of those who responded affirmatively, the risks reported by them were: 37.5% related to communicable diseases such as HIV, HBV, Syphilis, 23% contamination, tetanus 6.5% and 33% other [bacteria, viruses, life-threatening and leading to death]. Similar data were found in the study by Amate [11] showing concern of collectors about the potential risk of contamination by a human immunodeficiency virus.

Many collectors show concern with regard to health and the possible transmission of disease by handling the waste, but do not make use of single protection equipment [SPE] by considering a distant problem. For several reasons, the knowledge of the danger, for these individuals, it is not enough to change their habits and attitudes in preventive actions [21].

When asked about the possible use of drugs found in the trash (figure 3), it is observed that there is a discrepancy in the reported data. No respondent answered that had ingested medication found in the trash when asked. The shame about saying who had made use of a drug found in the trash can be a possible explanation for this result. This behavior may be related to the vulnerability which workers face and the lack of knowledge of the risks that their use can affect their health and quality of life. Corroborating this statement – in a survey of collectors in Rio Grande, it was revealed that 41% of workers found drugs in the trash and separate them in order to use later. They did not think about the health-damaging residues [22].

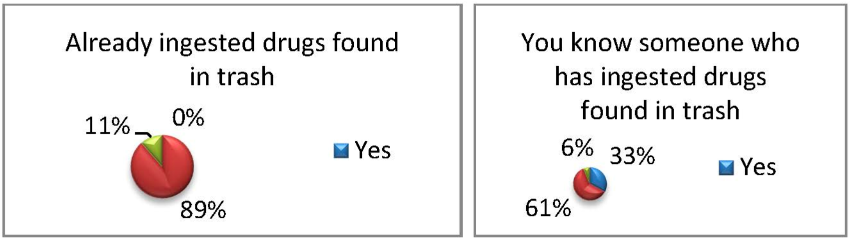

Figure 3: Ingestion of drugs found in the trash by waste pickers from the associations.

In relation to the risks related to human health in the use of drugs found in the garbage, 68.9% reported knowing the risks, including some of them reported this action can harm to health and contaminate the person. When asked about the risks to the environment caused by drugs 32.2% reported knowing about it. Among them were cited pollution of the soil, planting contamination and the delay in the process of decomposition. The disposal of chemical waste, in particular medicines, has aroused great interest in the scientific community as the disposal of these compounds in the environment is a dangerous act and presents health risks to scavengers. In studies conducted by Ueda *et al.* [23], Bueno *et al.* [24] and Duim *et al.* [25] was noted that the sites that are most used by the population to dispose of pharmaceutical waste is household wastes and sewage network .

The large amount of drugs found by scavengers in the present study may also be related to the lack of population on the management and proper disposal of such waste. The regulations of the National Health Surveillance Agency [ANVISA] – established by RDC No. 306/04 responsibility of handling and proper disposal of this waste, but leaves a gap in the legislation as the remains of medicines and RS generated in home environments. In this context more actions involving education and public awareness are required regarding to the correct disposal of medical waste. It is also important that there is a political will of the leaders to enforce the rules and existing health recommendations, supporting those who are already aware of the importance of adopting this behavior and finding ways for the understanding of those who do not know yet.

Regarding the contribution to the social security81.9% reported not to pay it and in some cases do not understand the importance of this contribution to their future, or even, in situations of need. This is an important finding and brings the issue of vulnerability, both by the harsh work and the lack of coverage in the event of damage to health and inability to work. Social security is a social insurance that guarantees to policyholders many ways of protection not only of old age, but also in cases of incapacity for work [26].

For the IPEA [27] there are two reasons that contribute to the low contribution to the social security by collectors. Low income compromising the ability to contribute and the lack of knowledge about the benefits of Social Security. These findings point to the need for programs that encourage these workers to contribute, either through special forms of contribution to this sector, which is constantly on the agenda of the National Movement demands of Solid Waste Pickers, whether through greater awareness of the benefits that social security coverage provides, especially in an activity subject to many physical and psychological risks like this.

4 Conclusions

The discard of HW has become one of the major global challenges, the growth of the population and of the chronic diseases elevate the quantity of medication use and other inputs of health which subsequently will be discarded. The responsible authorities for the maintenance and preservation of the environment and quality of life of the population has been mobilized to make laws which minimise the risks caused by these residues, however has if shown on inoperative and ineffective, since they leave important gaps with respect to disposal of HW produced in indoors that directly affect the work of the pickers and public health. In this sense it is necessary to strengthen the current policies that address the theme of HW, sensitizing the population to the proper disposal of such waste including medicinal products which are used by this group of workers in addition to contaminate the environment.

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Experimental study on the compression properties of degraded municipal solid waste

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Abstract

The compression characteristics of degraded municipal solid waste were studied by using large scale compression apparatus. The municipal solid waste materials were divided into three parts which were: easily degradable, difficult to degrade, and incompressible solid waste material in a geo-environmental laboratory. Three mixture proportions, three different initial densities, four different degraded times, four different pressures, and eight different compression times were selected for the compression test. The test results show that: (1) The total strain of degraded municipal solid waste increases with vertical pressure, and the relationship can be described as a logarithmic model; (2) The total strain of degraded municipal solid waste increases with initial density, and the relationship can be formulated as a linear relation; (3) The density of degraded municipal solid waste increases with degradation time, and the relationship can be expressed as a logarithmic model.
Keywords: experimental study, compression property, degraded municipal solid waste, logarithmic model, linear relation.

1 Introduction

With the steady increase of municipal solid waste (MSW) year by year, a lot of landfills will be constructed at present and in the future. During the construction process and the operation process, accident such as collapse and slip of a landfill happens occasionally. The landfill of Kettleman Hills, located in America, was destroyed by the lateral sliding failure in March 1988. Another accident was the slump of the Manila landfill, located in Philippines. It happened after a heavy rain on July 10th, 2000, and caused 100 people lost their lives and more than 100 people were injured. The reasons which caused the collapse of a landfill have

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much connection with the large deformation of the landfill. Therefore, it is necessary to investigate the compression characteristics of degraded MSW. Sower [1, 2] studied the foundation problem of a landfill, pointed out that the settlement of a landfill consisted of main settlement and secondary settlement, and gave the range of the primary compression indexed and the secondary compression indexed which based on the measured data. Yue and Scanlon [3] analyzed the settlement velocity of a landfill, and proposed a settlement model for the landfill. Gabr and Valero [4] utilized a ring with the diameter and height were 63 mm and 22 mm respectively, and carried out the compression test, and gained the compression characteristics of MSW. Hanson *et al.* [5] overviewed the compression properties of MSW, and analyzed the influence of water content on the compression properties of MSW by indoor test and field test. Hu *et al.* [6] studied the variation of organic matter content and degradation regulation during the degradation process, and analyzed the influence of the distribution and change of void ratio on the compression of MSW. Ke *et al.* [7] studied change regulation of the organic matter content with the depth, and established a simplified calculation formula for the settlement of MSW, and used this formula to analyze the influence of organic matter content and degradation velocity on the biodegradation compression of MSW. Zhang and Chen [8] and Zhang [9] investigated the settlement and deformation mechanism of a landfill, pointed out a settlement calculation model which consisted of the compression settlement under the vertical pressure and the settlement caused by the organic matter degradation, and gave the change regulation of the settlement with time. Chen *et al.* [10] selected the Shenzhen Xiaping landfill as an example, carried out the degradation test of MSW, pointed out a formula to describe the degradation regulation and a method to determine the parameters, built a settlement calculation model for MSW, gained the change regulations of the degradation velocity and the amount of degradation with time. Kong *et al.* [11] studied the long term deformation of MSW, got the linear relationship between settlement velocity and time in the double logarithmic coordinates. Zhan *et al.* [12] carried out the compression tests on 31 undisturbed waste samples from 5 drills in Qizi Mountain landfill, Suzhou, China, and gained the influences of filling age, composition, initial void ratio on the compression index of MSW. Zhang *et al.* [13] considered the actual filling process of a landfill, carried out the research on the calculation method of one dimensional compression, and established a calculation method for one dimensional compression of MSW.

On the basis of aforementioned researches, considering three kinds of mixture proportion, three kinds of initial density, four degradation times, four step loadings, and eight different compression times, using a large scale compression test instrument, a series of compression tests of degradation MSW were systematically carried out in the present paper.

2 Compression test material and test process

2.1 Compression test material

Referring to the main components of the MSW from Tianziling landfill, Hangzhou, China, the MSW samples were artificially made and the components of MSW were divided into three kinds which were easily degradable, difficulty degradable and incompressible solid waste material. Considering the effect of the size, the sizes of all the components were smaller than 1/6 of the diameter of the compression chamber. To simulate the underdeveloped, developing, and developed stage of the development of social economy, three kinds of mixture proportion (MP) were selected (shown in table 1). The composition percentages of every component of the fresh MSW were list in tables 2-4. Stored the mixed samples in plastic bags, sealed, and let them degrade in a natural state for 30, 60, 120 and 180 days, respectively, then the degraded waste samples were gained. Figure.1 shows the degraded samples with different degradation time. Table 5 lists the moisture contents of degraded samples.

Table 1: Mixture proportions of fresh MSW (weight percentage).

	Easily degradable component / %	Difficult to degrade component / %	Incompressible solid waste material / %
First kind mixture proportion (MP1)	50	15	35
Second kind mixture proportion (MP2)	65	10	25
Third kind mixture proportion (MP3)	80	5	15

Table 2: Percentage composition of the easily degradable material.

	Paper	Vegetable	Fruit skin	Grass, tree leaf, and wood
MP1	2	36	9	3
MP2	2.6	46.8	11.7	3.9
MP3	3.2	57.6	14.4	4.8

Table 3: Percentage composition of the difficulty degradable material.

	Textile	Animal bone	Plastics	Rubber
MP1	4.5	4.5	3	3
MP2	3	3	2	2
MP3	1.5	1.5	1	1

Table 4: Percentage composition of the incompressible solid waste material.

	Metal	Brick, stone, and soil	Ceramics	Glass
MP1	1.75	29.75	1.75	1.75
MP2	1.25	21.25	1.25	1.25
MP3	0.75	12.75	0.75	0.75

Table 5: Moisture content of the degraded waste.

Degradation time T / d	30	60	120	180
MP1	68.5	59.3	63.0	62.8
MP2	103.8	92.0	94.0	87.5
MP3	145.1	142.5	153.9	166.4


(a) 30 days (b) 60 days


(c) 120 days (d) 180 days

Figure 1: Degraded MSW samples with different degradation time.

2.2 Compression test process

The experiments were carried out on a large scale compression apparatus, the inner diameter of the compression chamber was 180mm, and the height of the compression chamber was 150mm.

The compression tests were carried out on three kind mixture proportions with three different initial densities (950kg/m^3, 840kg/m^3, and 760kg/m^3). The stepping loadings applied on the first kind mixture proportion sample were 25, 50, 100, and 200kPa, and the stepping loadings applied on the second kind and the third kind mixture proportion samples were 25, 50, 75 and 100kPa. The compression time for every stepping loading was 0.25, 0.5, 1, 2, 6, 12 and 24 hours. Besides, the degradation times were selected as 30, 60, 120 and 180 days.

The compression tests were carried out according to the Chinese specification of soil test [14]. After prepared the fresh MSW materials, weighted every component according to tables 1–4, and then fully mixed. The specific gravity of each component was measured by the pycnometer method [15], and the weighted average specific gravity of the waste could be calculated according to the mixture proportion. The moisture content of the waste was measured by the drying method [15], and the initial void ratio of the waste was calculated by equation (1). The physical properties of the MSW samples were listed in table 6. Mixed the MSW sample well, and then stored it in a fresh keeping bag for degradation. The mixed samples degrade with time, and leachate will generate. Because the leachate has a strong corrosive, the fresh keeping bag can be corroded, therefore, it is necessary to package 4–5 layer plastic bag outside the fresh keeping bag, the plastic bag should be sealed and stored in a natural environment for the setting degradation time. With the development of degeneration, the oxygen in a landfill is gradually depleted, then the landfill is an anaerobic environment, so sealed the sample to simulate the real degradation environment of a landfill.

$$e_0 = \frac{d_s \rho_w (1+\omega)}{\rho} - 1 \tag{1}$$

Here e_0 is the initial void ratio, d_s is the weighted average specific gravity, ω is the moisture content, and ρ is the initial density of the sample.

Table 6: Physical properties of MSW samples.

	Initial void ratio / e_0	Moisture content / %	Specific gravity
MP1	2.1, 2.5, 2.9	60	2.1
MP2	2.1, 2.5, 2.9	134	2.05
MP3	2.1, 2.5, 2.9	207	2.0

Pulled the sample into the compression chamber, compacted the sample by the method of stratified compaction, then added MSW sample, and re-compaction, repeated above process till the chamber was full. During the process of sample loading, tried to keep the initial density of the sample as 950, 840, and 760kg/m^3. Then, laid permeable stone and loading plate on the top of the sample, installed the dial indicator at the plate centre, adjusted the dial indicator and recorded the initial reading, thus the preparation of the experiment was finished.

The compression time for every stepping loading were selected as 0, 0.25, 0.5, 1, 2, 6, 12, and 24 hours. For the convenience of description, taking the initial density was 950kg/m^3 and the vertical pressure was 25kPa as an example to describe the test process. Exerted 25kPa vertical pressure, began timing, and recorded the readings of the dial indicator when the compression times were 0.25, 0.5, 1, 2, 6, 12, and 24 hours, respectively. Exerting the vertical pressure with 50, 100, 200kPa, respectively. For every stepping loading, recorded the readings of the dial indicator at the selected compression times.

3 Compression test results and analysis

3.1 Relationship between strain and vertical pressure

For the convenience of description, taking the compression time is 24 hours as an example, relationship between the total strain of the MSW sample and logarithmic vertical pressure are shown in figures 2, 3 and 4. From these three figures, it can be found that the total strain (ε_t) increases with vertical pressure, and the relationship can be fitted into a linear relation, and can be formulated as:

$$\varepsilon_t = a + b \lg P \tag{2}$$

Here *a* and *b* are parameters which have some connections with degradation time, mixture proportion, and initial density.

From figures 2, 3 and 4, it can be found that the curve has a tendency to move upward with degradation time. Under the action of same vertical pressure, the

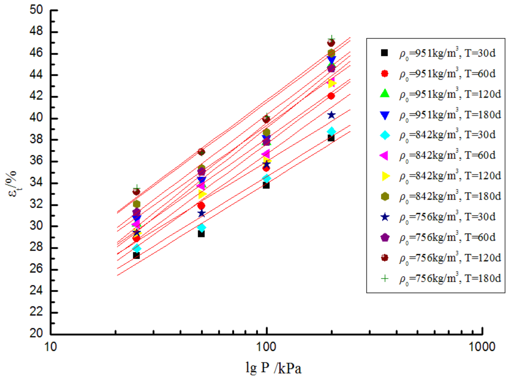

Figure 2: Total strain versus logarithmic vertical pressure for MP1.

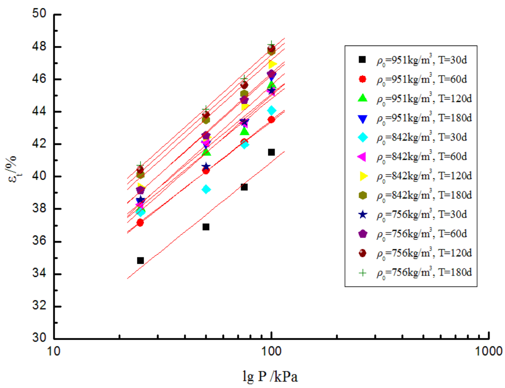

Figure 3: Total strain versus logarithmic vertical pressure for MP2.

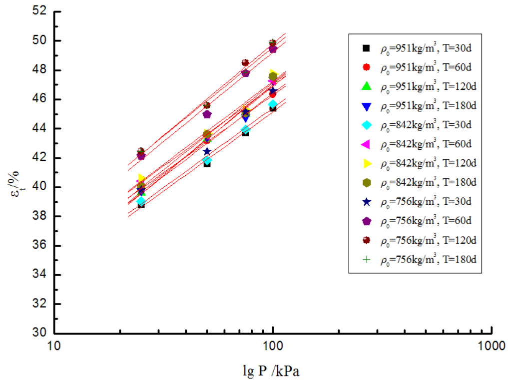

Figure 4: Total strain versus logarithmic vertical pressure for MP3.

longer the degradation time is, the larger is the total strain. This is because the easily degradable and easily compressible components in the MSW sample gradually reduce with the compression time, and converted into gas phase and liquid phase, thus the degradation strain increases and the compression strain decreases, and the total strain increases.

3.2 Relationship between strain and compression time

For the convenience of description, taking the first kind mixture proportion sample as an example, the relationship between compression strain and compression time is shown in figure 5. From this figure, it can be found that, no matter what the vertical pressure is and when the degradation time is, the compression strain increases with compression time, the increasing trend gradually slows down, and the curve finally tends to a horizontal line. From the test data, the compression strain with two hours' compression reaches 95% of the compression strain with 24 hours' compression. From figure 5, it can also be found the compression of MSW

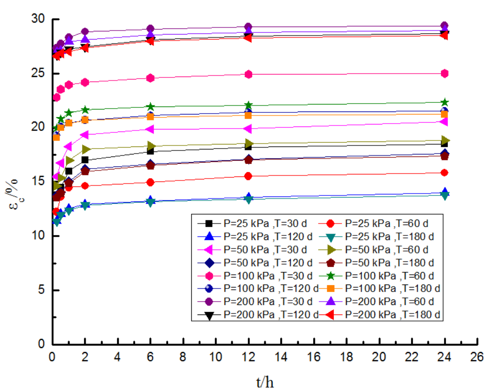

Figure 5: Compression strain versus compression time.

gradually increases with vertical pressure, while the compression increment of MSW decreases with the increase of compression time. This is because the content of easily degradable component gradually reduces with compression time, thus the content of compressible component in the sample is reducing.

3.3 Relationship between strain and density

For the convenience of description, taking the second kind mixture proportion sample as an example, the relationship between the total strain (ε_t) and density is shown in figure 6. For a same stepping load, the four data points are corresponding to degradation times are 30, 60, 120 and 180 days respectively, in the direction from lower left to upper right. The data are recorded when the compression time reaches 24 hours. From figure 6, it can be found that, the total strain of a degradation sample increases with density, and the relationship can be formulated by a straight line. The equation of the straight line is written as:

$$\varepsilon_t = c + d\rho \tag{3}$$

Here c and d are the parameters which have some connections with the mixture proportion, initial density, vertical pressure, and compression time.

Besides, from figure 6, it can be found that, under the action of same pressure, the fitted line for a smaller initial density is in the upper position. This indicates that the total strain and density of the MSW sample increases with the decrease of initial density. In addition, with the same initial density, the fitted line moves to the right upper with the increase of vertical pressure. This indicates the total strain and the density of the MSW sample increases with vertical pressure.

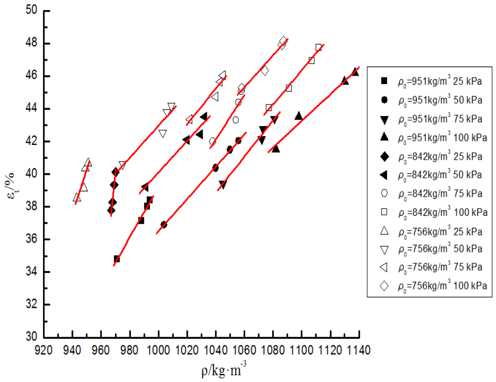

Figure 6: Total strain versus density.

3.4 Relationship between density and degradation time

The relationship between density and logarithmic degradation time of a MSW sample after 24 hours' compression are shown in figures 7, 8 and 9. From these figures, one can find the density of MSW samples increases with logarithmic degradation time, the relationship can be fitted into a straight line, the correlation coefficients are all bigger than 0.9, and the straight line can be formulated as:

$$\rho = e + f \lg T \tag{4}$$

Here e and f are parameters that have some connections with degradation time, mixture proportion, initial density, and vertical pressure.

From figures 7, 8 and 9, it can be found that the curve has a tendency to move upward with vertical pressure. Under the same degradation time, the larger the vertical pressure is, the larger is the density after compression. This is because the MSW sample is compressed more and more tightly with the increase of vertical pressure, and the volume of the sample become smaller and smaller. Besides, at the same vertical pressure and same degradation time, the larger the initial density is, the larger is the density after compression. This is because the larger the initial density is, the smaller is the void ratio, the tighter is the sample.

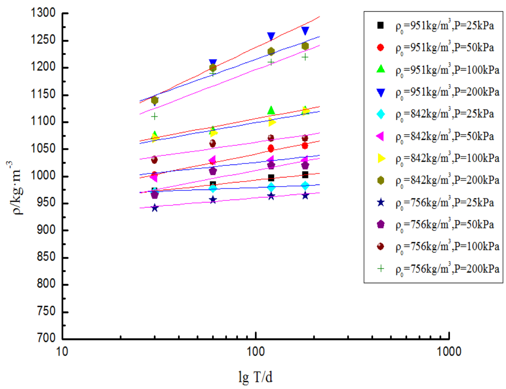

Figure 7: Density versus logarithmic degradation time for MP1.

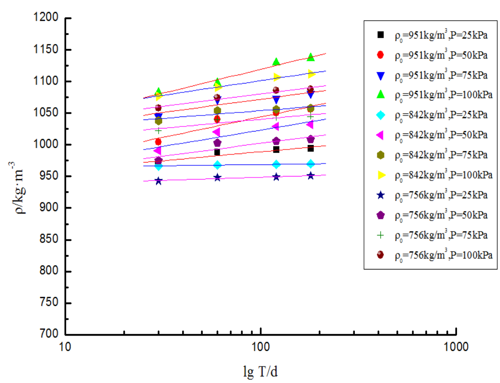

Figure 8: Density versus logarithmic degradation time for MP2.

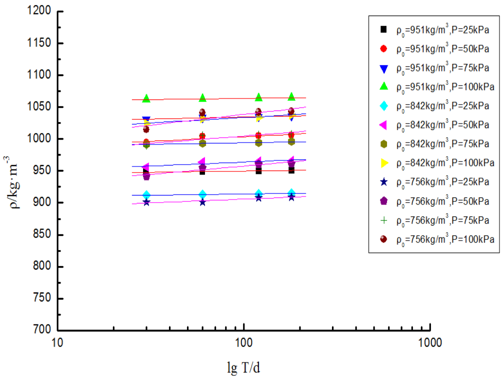

Figure 9: Density versus logarithmic degradation time for MP3.

4 Conclusions

Based on the compression tests on the degraded municipal solid waste, following conclusions can be drawn:
(1) Total compression strain of degraded MSW increases with vertical pressure, and the relationship can be expressed by a logarithmic model.
(2) The compression strain of degraded MSW increases with compression time, the increasing trend gradually slows down, and the curve finally tends to a horizontal line.
(3) The total strain of degraded MSW increases with density, and the relationship can be formulated by a straight line.
(4) The density of degraded MSW samples increases with degradation time, the tendency becomes more and more gentle, and the relationship can be described by a logarithm model.

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Pretreatment of MSW for co-digestion in waste water treatment plants

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Abstract

Co-digestion of organic fractions in existing digesters at waste water treatment plants is already feasible. This study shows the results of waste sorting and large scale tests to investigate the possibility of using parts of residual waste instead of common co-substrates. Most existing digesters have not originally been designed for such substrates. In particular, inert particles can settle in the digester and cause problems in the co-digestion. In a first step residual waste smaller than 40 mm was screened into eight size fractions. Each size fraction was then sorted into relevant fractions. The sorting shows that residual waste smaller than 40 mm contains about 42.5% (w/w) of organics, the residual waste smaller than 25 mm even 51% (w/w). But the sorting also shows 29% (w/w) plastics, glass, inerts and other components in the residual waste smaller than 25 mm which are not suitable for the digestion. In order to separate these physical contaminants a combination of different mechanical separation steps was tested. First a flip-flop screen was used to split the residual waste smaller than 40 mm at 5 mm and 10 mm. The fine fraction was then directed to an air jig and an organic fraction with up to 79% (w/w) volatile solids and an inert fraction with about 6% (w/w) volatile solids was achieved. The organic fraction poses a potential as co-substrate while the inert fraction could potentially be landfilled. The 5-40 mm and 10-40 mm fractions were put on a hard particle separator. The hard particle separator produced a light, intermediate and heavy fraction without increasing the organic content noticeably. However, the light fraction could meet minimum requirements for solid recovered fuel.
Keywords: co-digestion, residual waste, mechanical treatment plant, waste characterisation, waste sorting, particle-size distribution, waste treatment, flip-flop screen, air jig, hard particle separator.

1 Introduction

The European Committee of the Regions reinforces an optimal recycling of organic waste materials through separate collection of bio-waste by 2025 in its "opinion towards a circular economy" [1]. Nevertheless organic waste can still be found in residual waste (RW) while it is already collected separately in more and more countries in Europe [2]. The amount of organic waste in RW is substantial as a selection of data from different European countries show (Table 1). In the analysis RW1 particles smaller 20 mm weren't sorted. The respective author however mentions a significant high content of organics in the fines fraction. Furthermore, this analysis is based on dry matter in contrast to the three other analyses in Table 1. Organics contains more water than other fractions and therefore its content is higher on a wet basis. The results of Table 1 correlate with the findings of Troschinetz and Mihelcic [3], who summarized studies which show that there are about 30% (w/w) of organics in the municipal solid waste (MSW) within the USA and the EU. When the biodegradable components of the paper fraction are also considered as energy resource for digestion[4], this poses an even higher potential for biological treatment.

Table 1: Composition of residual waste (=RW) of different European Countries: RW1 [7] place/time: suburb of Mende Lozère (France) 2004/2005; RW2 [8] place/time: Treviso (Italy) 2005; RW3 [9] place/time: London (UK) 2003/2004; RW4 [10] place/time: Upper Austria 2009, Carinthia 2011.

Fraction (% (w/w))	RW1	RW2	RW3	RW4	Range
Organic waste	9.1	10–16	27.2–42.7	31.4	9–43
Paper	13.5	34–50	19.8–42.4	19.7	20–50
Cardboard	9.8				
Sanitary waste	8.4			5.6	6–8
Plastic	14.8	24–34	8.6–12.5	11.1	9–34
Composites	3.6				3.6
Textiles	3.2	3–8	1.3–4.1	2.9	1–8
Glass	4.2	2–14	3.8–8.6	7.0	0–14
Inert			0.3–5.1	2.8	
Metal	5.4	1–9	2.9–4.5	4.4	1–5
Hazardous materials	1.1		0.1–1.1	0.7	0–1
Fines (< 20 mm RW1, <10 mm RW3)	20.5		0.4–2.8		0–21
Unclassified waste	6.6		6.4–14.3	4.3	4–14
Wood		2–4		7.9	2–8
Waste electric and electronic equipment			0.1–2.9	2.2	0–3

Incineration and mechanical biological treatment (MBT) are the most relevant options to pretreat waste prior to landfilling as requested by the EU landfill directive. Germany and Austria pioneered in the development of MBTs with the reduction of the organic fraction in RW as one main goal [5]. It is therefore interesting to note that no anaerobic MBTs can be found in Austria, while more than 60 have been installed in other countries, like Germany, Italy, Spain, France, Portugal, UK and Norway [6].

In most MBT plants the RW is first shredded and then screened to separate the high caloric coarse fraction (HCF-RW) from a fines fraction. This fines fraction shows a low caloric value (LCF-RW) because the wet organic waste is concentrated in this fraction. Plants without any biological treatment step for the LCF-RW are called mechanical treatment plants (MTP). The HCF-RW is either burned in a waste to energy plant or upgraded to solid recovered fuel (SRF). For an effective anaerobic biological treatment of the LCF-RW it is important to know the exact composition of the input material with focus on the amount of organic waste like kitchen and garden waste. The fines fraction from the first screen can then be further pretreated to both increase the organics concentration and hence the biomethane potential as well as to reduce the amount of physical contaminants which can disturb the process. Mostly the separation of RW into a HCF-RW and a LCF-RW is conducted with a sieve. At the sorting line of Treviso, Italy, the amount of the organic fraction could be increased from 59.1% (w/w) up to 71.4% (w/w) with a trommel screen [8]. Bayard *et al.* [7] showed that after sieving at 70 mm the percentage of putrescible waste could be increased from 29.6% (w/w) up to 66.9% (w/w).

In the last couple of years several authors have demonstrated the feasibility of co-digesting separately collected organic fractions of MSW in existing digesters at WWTPs [8, 11–15]. The difference of co-digestion to common anaerobic digestion is that further substrate is added to the main substrate. In this case the main substrate is sewage sludge (SS). The problem is that more and more countries forbid to use the digested sewage sludge as fertilizer on agricultural fields. In this case the valuable resource biowaste is taken out of the ecological circle. Biowaste can be used at higher value in a mono-digestion plant where the digestate remains clean and low in contaminants and can be used as fertilizer and soil improver. To still utilize existing digester capacity at waste water treatment plants (WWTP) the organics from RW could be considered as an alternative feedstock. The utilization of the organics from RW is currently investigated in a research project which includes a comprehensive characterization of the RW and different options to prepare a substrate which can be used as co-substrate in the digester of a WWTP.

In this paper the results of the characterization of the LCF-RW are presented as well as mechanical separation tests to both increase the concentration of organics and reduce the amount of physical contaminants. The main objectives were to investigate the composition of the waste in different particles size fractions and the suitability of air jigs and hard particle separators to produce an organic rich fraction for co-digestion. The detailed characterization of the waste was important because very little information is available especially in regards to the fines fraction although small impurities can cause troubles in a later co-digestion at WWTPs. These digesters usually were not designed to handle inert particles. More specifically, sand, stones and glass can sink to the bottom and reduce the reactor volume [16–20]. Plastic foils can built up to a scum layer or lead to pipe blockages [19]. The knowledge about very small particles in the millimeter-scale is therefore relevant for the choice and optimization of treatment units.

2 Materials and methods

2.1 Sampling

From October 2014 to December 2015 samples were taken at the MTP in Ahrental/Innsbruck, Austria. Innsbruck has about 120,000 inhabitants and recycling points for a separate collection of plastics, paper, metals, clear and stained glass. A kerbside collection exists for residual MSW and biowaste. Additionally, the MSW of the two districts Innsbruck-Land and Schwaz with about 220,000 inhabitants is also treated at the MTP Ahrental resulting in about 52,000 Mg each year. This study puts its focus on the sorting of the LCF-RW (about 22,000 Mg/a) as it shows the highest content of organics. The samples were taken after the last conveyor belt from the falling stream before entering the container to leave the plant. The prior treatment stations are the storage and mixing in the bunker as well as the crushing and screening process. These steps proved successful in homogenizing the heterogenic waste thereby decreasing the necessary amount for sorting. The minimum mass of one composite sample was calculated according to [21]:

$$\textit{mass (kg) = 0.06 * maximum size of particles (mm), but at least 2 kg.} \qquad (1)$$

As the largest size fraction was defined by a sieve with 40 mm mesh size, the minimum mass of one composite sample was 2.4 kg. The composite samples were put together, mixed, coned and quartered to reduce the mass for a laboratory sample.

In total, 88 samples with a total weight of 264 kg were collected over a year and mixed into 13 laboratory samples which were sorted at the laboratory. In nine of the 13 times the entire waste smaller than 40 mm was sorted as described in Table 2.

2.2 Sorting and particle size distribution

Immediately after sampling the total solids (TS) content was determined by drying at 105°C until at constant weight. The LCF-RW was screened with seven square perforated sieves as shown in Table 2 in order to determine the particle-size distribution. The relative percentages in each particle fraction were multiplied with the particle size distribution to get the absolute distribution of particular waste fractions of the LCF-RW.

2.2.1 Particle fractions between 10 mm and 40 mm

The four coarse particle fractions from 10 mm to 40 mm were sorted into twelve different waste fractions. The fractions plastic and metal were divided into flat (2D) and cubic particles (3D) respectively ferrous (FM) and non-ferrous metals (NFM). The reason for this approach was that these physical properties are important for further mechanical treatment. The fraction “others” contains undefinable particles and particles which haven’t got their own waste category as, for example, compound materials.

Table 2: Particle size categories and waste fractions sorted. FM = ferrous metal, NFM = non-ferrous metal, VS = volatile solids.

Particle size categories (mm)			
10–16	2–4	0–2	0–0.063
16–25	4–6.3		0.063–0.125
25–31.5	6.3–10		0.125–0.25
31.5–40			0.25–0.5
			0.5–1
			1–2
Waste fractions sorted			
Organic waste	Organic waste	VS	
Plastic (and rubber) 2D	Plastic (and rubber)		
Plastic (and rubber) 3D			
Inert	Inert	Inert	
Glass	Glass	Glass	
FM	Metal	Metal	no sorting, just particle-size distribution
NFM			
Paper (and cardboard)			
Textiles			
Wood			
Hazardous waste			
Others	Others	Others	
		Ash	

2.2.2 Particle fractions between 2 mm and 10 mm

The smaller the particle sizes, the more difficult is the sorting. Most sorting methods have only size fractions bigger than 10 mm and call the smaller 10 mm fraction "fines" (as seen in Table 1). In this study the waste was sorted down to 2 mm albeit with a reduced number of six fractions.

2.2.3 Particle fractions smaller 2 mm

To determine the particle size distribution of the waste fraction < 2 mm, the waste was first dried at 105°C and then ignited at 550°C until at constant weight. To analyse the particle-size distribution of the waste particles smaller 2 mm further five sieves were used as shown in Table 2. The advantage of calcining the LCF-RW before analyzing the particle size distribution is that small inert particles, which still were agglomerated with other particles after drying, could be recorded correctly. The disadvantage however is, that small organic but not biodegradable particles as for example plastics cannot be determined since they are burnt.

2.3 Waste treatment

Three times, samples of the LCF-RW were put into flexible intermediate bulk containers to be transported from the MTP Ahrental to the pilot plant treatment units. The first sample of 480 kg was taken in July at up to 40° Celsius ambient temperatures. Consequently, the bulk bag had to be wrapped in cellophane to prevent drying-out of the waste, which would have changed the physical properties. Further two bulk bags of 67 kg and 108 kg were taken in November. The waste was then treated (as illustrated in Figure 1).

The first treatment step was a screening with a flip-flop screen. A flip-flop screen consists of an elastic screen mat which is fixed on carriers which move towards and against each other. As a result, the screen mat is repeatedly tightened and relaxed, so that the waste bounces and in consequence agglomerates are separated. The second advantage is that small waste particles do not float on the large particles due to consistent mixing which allows higher throughputs compared to rigid screens. In the trials two screen options were tested: at 5 mm and 10 mm. The fines fractions from the screening were then further treated at an air jig. The air jig consists of a perforated plate which is impinged from below with compressed air. Due to the fluidization of the air flow, light particles float on heavier particles and are passed through the downward inclination. The heavy particles however are transported upward from the translationally moving plate. The air jig aims to separate the inert components from the organic fraction.

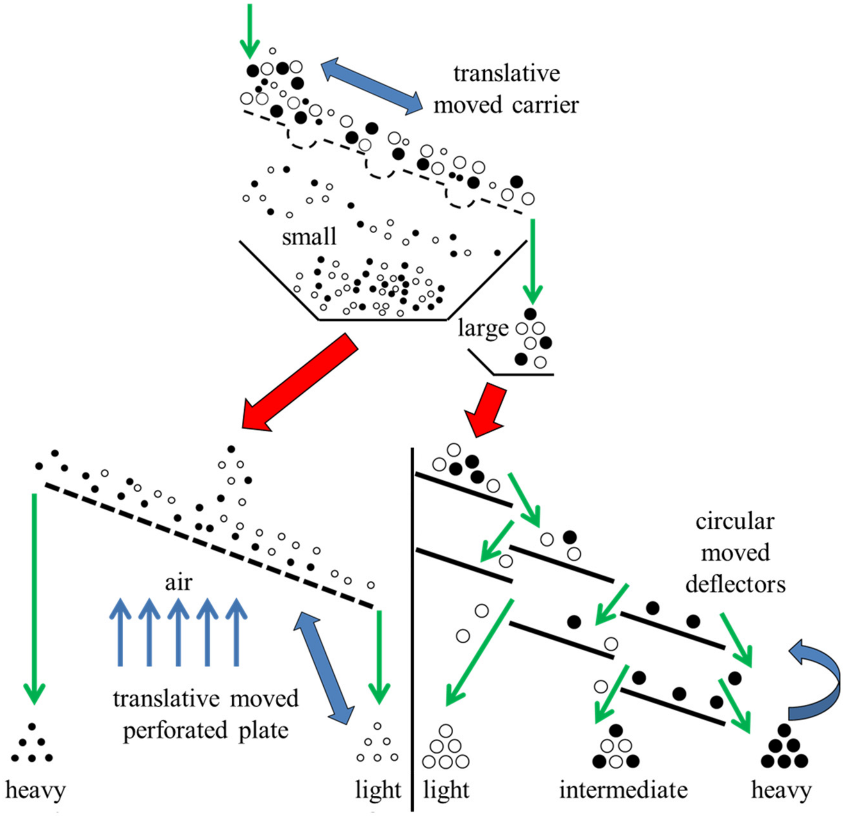

Figure 1: Schematic chart of the flip-flop screen (above), the air jig (left) and the hard particle separator (right).

The hard particle separator has two rows of circular moved deflectors. As a result, heavy particles roll down the plates whereas light and flat particles are thrown back through the plates. The goal of the tests with the hard particle separator was to check whether or not the content of organics can be risen in one of these fractions.

3 Results and discussion

The TS content of the LCF-RW samples was 62.7 ± 4.5% (w/w) with higher moisture contents in winter (up to 72%) than in summer (down to 53%).

3.1 Sorting results of the LCF-RW <40 mm

The particle size distribution in Table 3 shows that 44.5% (w/w) of the waste was smaller 10 mm which underlines the relevance to also characterize this fraction. In the fraction smaller than 2 mm the VS-content was 42.2 % (w/w) of TS which can mainly be counted as biodegradable organics. 20.7% (w/w) of the calcined waste smaller 2 mm are heavy fractions (inert, glass and metal). In an anaerobic digestion these particles could either stay in suspension with the SS/co-substrate mixture or sink to the bottom of the reactor depending on the particle size and the intensity of mixing. Between 2 mm and 10 mm high contents of biodegradable organic waste were analyzed. The concentration of organics was higher in small particle sizes. A sharp increase was noticed at about 10 mm. In contrast the contents of light fractions as plastics, paper, textile and wood increased with larger particle sizes. 85% (w/w) of the metals were NFM as there is a FM separator but no NFM separator installed at the MTP Ahrental.

Table 3: Results of the sorting on LCF-RW. Each number is the average percentage of the sorting on a wet matter basis except 0–2 mm which got sorted after being calcined. WA = weighted average, SD = standard deviation.

Particle-size (mm)	<2	2–4	4–6.3	6.3–10	10–16	16–25	25–31.5	31.5–40	0–40	
Particle-size distribution	11.7	10.7	9.1	12.8	14.6	18.3	9.6	13.3	WA	SD
Organic waste	42.2	77.3	72.5	63.4	38.3	29.6	21.1	9.9	42.5	6.1
Plastic (and rubber) 2D		0.8	1.9	3.9	3.9	5.7	6.7	6.0	3.4	1.3
Plastic (and rubber) 3D					3.9	5.0	5.4	8.7	3.5	0.7
Inert	19.2	15.3	11.6	7.3	4.6	6.3	8.2	6.0	9.3	2.9
Glass	1.3	4.5	8.9	13.8	16.3	14.1	10.5	4.6	9.8	3.1
Ferrous metal	0.0	0.0	0.0	0.0	0.2	0.7	0.2	0.3	0.2	0.3
Non-ferrous metal	0.2	0.2	0.8	0.8	0.8	1.4	2.8	2.2	1.2	0.4
Paper (and cardboard)					15.5	20.3	25.1	33.0	12.8	7.8
Textiles					2.9	2.9	4.1	7.9	2.3	1.3
Wood					3.8	3.8	5.0	7.8	2.6	1.1
Hazardous waste					0.2	0.2	0.3	0.1	0.1	0.1
Others	21.3	1.8	4.3	10.8	11.7	10.0	10.6	13.5	10.6	3.6
Ash	15.8								1.8	6.8
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

3.2 Absolute distribution of particular waste fractions

3.2.1 Characterisation of the LCF-RW

Figure 2 shows the absolute particle size distribution of four clustered waste fractions of the LCF-RW. The values of the absolute distribution on the axis of ordinate are cumulated. The four clustered waste fractions are called "organic waste", "heavy fraction" which could sink to the bottom of the biogas digester, "light fraction" which could lead to a scum layer and a fourth fraction called "others". The fraction "organic waste" consists of the handsorted fraction of organics between 2 and 40 mm and the VS of the smaller 2 mm. The "heavy fraction" includes inert, glass, metal and hazardous waste as batteries. The "light fraction" contains plastics, paper, textile and wood. The fraction ash, which just occurred in the calcined size fraction smaller 2 mm, got counted to the fraction "others". At 25 mm already 92% (w/w) of the total organic waste, at 31.5 mm already 97% (w/w) are reached.

For the investigated MTP a reduction of the sieve for the LFC-RW from 40 mm to 25 mm would lead to a decrease of the annual amount of LCF-RW from 22,000 Mg to about 17,000 Mg. The amount of the organic waste in the LCF-RW would just decrease from 9,300 Mg/a to 8,600 Mg/a with a rise of the concentration of the biodegradable waste from 42.5% (w/w) to 51% (w/w) at the same time. This poses an easily implementable and cheap way for a separation of impurities.

In comparison with the organic fraction the light fraction showed a growth in particle sizes which makes a sieving step between 15 mm and 20 mm very effective to separate this light fraction.

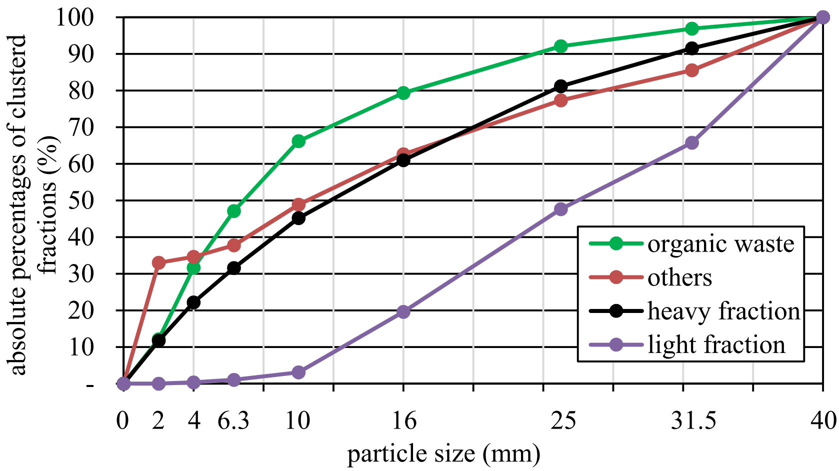

Figure 2: Combination of the results of the sorting with the particle size distribution of the LCF-RW.

3.2.2 Characterisation of the LCF-RW smaller 2 mm

Figure 3 presents the results of the sieving of the fraction smaller than 2 mm. The TS content of the wet fraction smaller 2 mm was 71% (w/w), the VS content 42.2% (w/w) of TS. Therefore, the dried fraction smaller 2 mm was 8.3% (w/w) and the calcined fraction 4.8% (w/w) of the whole LCF-RW. 36% (w/w) of the dried fraction smaller than 2 mm were larger than 1 mm and 65% (w/w) larger than 0.5 mm. After the calcination the glowing residues contained 24% (w/w) of particles smaller 63 µm. These results will be very important for designing waste separation units which focus on very small and heavy particles as sand and glass fragments.

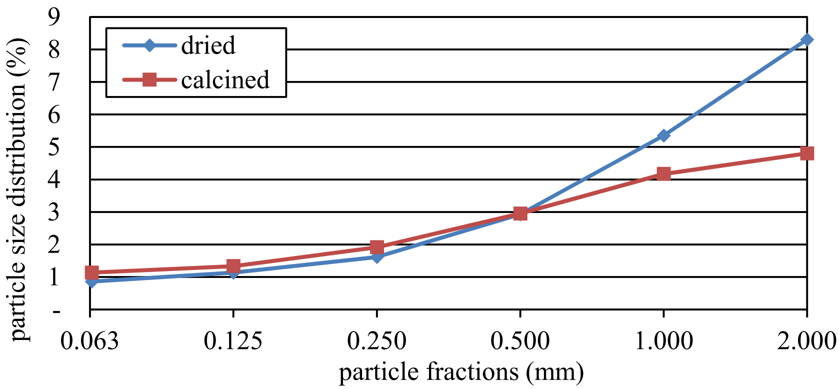

Figure 3: Particle size distribution of dried and calcined LCF-RW smaller than 2 mm.

3.3 Waste treatment

The first and the second test were carried out with 5 mm and the third test with 10 mm mesh size at the flip-flop screen (Figures 4–6). In the third test there was less underflow than in the first two tests although a larger mesh size was used.

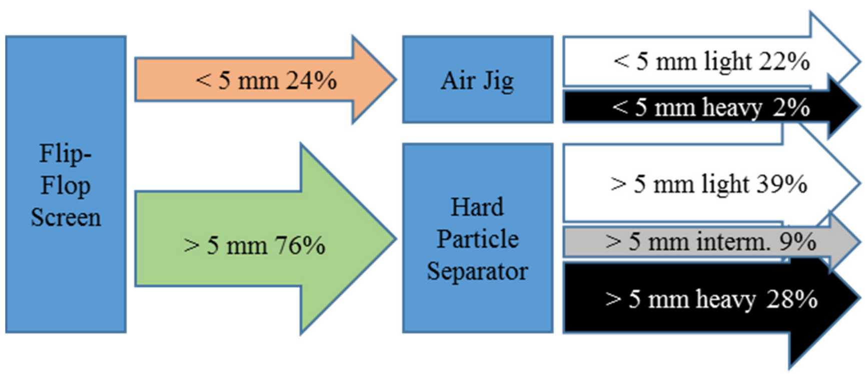

Figure 4: Results of the first treatment test (July; 5 mm mesh size).

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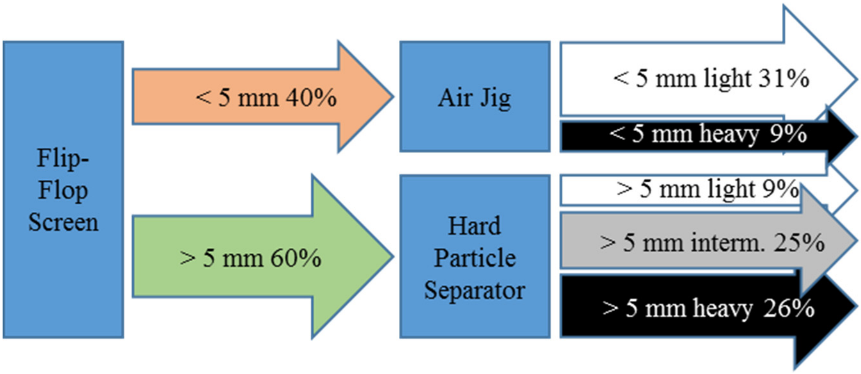

Figure 5: Results of the second treatment tests (November 2015; 5 mm mesh size).

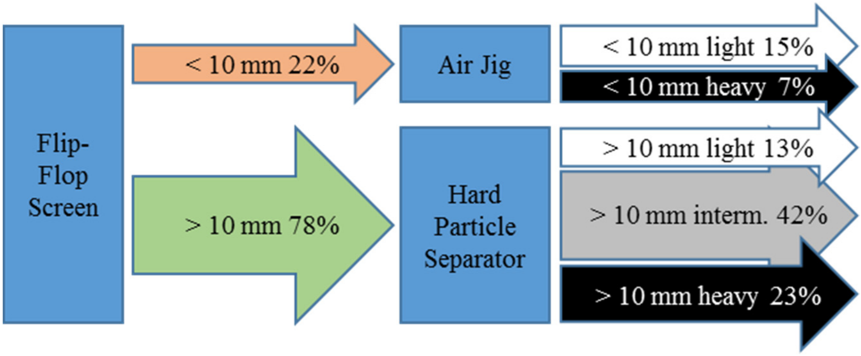

Figure 6: Results of the second treatment tests (November 2015; 10 mm mesh size).

After the screening, the underflow was put on the 600 mm wide air jig and the throughput was accelerated from 300 kg/h in the first test to 410 kg/h in the second and to a final 530 kg/h in the third. The higher the throughput was, the lower was the quality. This quality loss was indicated by light particles which were mainly organic waste that ended up in the heavy fraction smaller 5 mm respectively 10 mm as well as heavy inert particles which ended up in the light fraction.

The results of the VS content of the light fraction confirm this loss of quality, as it decreased from 79.0% (w/w) of TS in the test in July to 41.2% (w/w) of TS in the test in November. The VS content of the heavy fraction smaller 5 mm respectively 10 mm remained constant between 5.3 and 6.5% (w/w) of TS in all three tests. This mix of glass and other inert particles like sand and stones is allowed for landfilling, for example, in the European Union, as it fulfils the limit values of 10% (w/w) VS [22].

The tests with the hard particle separator showed no success in raising the content of organic waste in one of the three fractions between 5 and 40 mm respectively 10–40 mm. However, a light and intermediate fraction rich of plastics and paper (∑=30.5-65.7% (w/w)) was separated from a heavy fraction with a high content of glass and stones (∑=34.0-49.4% (w/w)).

4 Conclusion

In this work detailed characterizations of the low caloric fraction of residual waste for the co-digestion in existing digesters of WWTPs were depicted. It could be confirmed that the content of organics rises with smaller size fractions. The LCF-RW smaller 25 mm contains already 51% (w/w) of organics compared to 42.5% (w/w) in the LCF-RW smaller 40 mm or 30% (w/w) and less in the original RW.

Treatment tests with an air jig to reduce the amount of improper materials in order to produce an organic rich LCF-RW smaller than 5 mm or 10 mm showed that the volatile solids content was raised up to 79%, when a suitable throughput was used. The next steps to investigate the feasibility of co-digestion of LCF-RW in existing digesters at WWTPs are sedimentation tests with different types of stirring and reactor designs to check if problems with scum layers or sediments arise.

Acknowledgements

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The use of low temperature thermal desorption technology in the treatment of drill cuttings

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Abstract

One of the management strategies in handling drill cuttings is the use of low temperature thermal desorption technology which goal is to produce oil-free solids for disposal by distilling off the oils from the cuttings and recovering the oil to be reused as drilling fluid. A retort analysis was carried out on the oily and cleaned cuttings to determine the percentage of oil and water content at the temperatures of 350°C and 500°C.The percentages of oil in the oily cuttings are 11.2, 19.4 and 9.6 at 350°C and 13, 14.6 and 23.0 at 500°C and the percentages of oil in the cleaned cuttings were 0.24, 0.21 and 0.23 at 350°C respectively. The concentrations of chlorides and heavy metals are 820 and 0.002mg/l respectively. The result obtained meets the regulatory requirement of oil on cuttings (OOC) of less than 1% by weight, eliminating future environmental liabilities. This study reveals the efficiency of TDU process in the recovery of oil from drill cuttings.
Keywords: drill cuttings, low temperature thermal desorption unit, oil base mud, retort analysis.

1 Introduction

Oil well drilling operations require the use of drilling mud to aid the drilling process. Drilling fluids are circulated through the drill bit to lubricate and cool the bit, control the formation fluid pressures and to aid in carrying the drill cuttings to the surface. Drill cuttings represent one of the most significant waste streams in the upstream oil and gas industry and they require effective and efficient treatment and disposal [1]. The industry is working with regulators to achieve continuous improvement in its environmental performance, with the ultimate goal of zero discharge. The use of pseudo oil based mud (POBM) has led to improved shale stability and enhanced drilling rates particularly where polycrystalline diamond compact (PDC) drill bits are used [2]. An average drilling performance improvement of 49% was reported by Zupan and Kapila [3] for 311.5mm hole sections in the areas he analyzed. These two characteristics of POBM; better hole stability and faster penetrating rate plus its lubricating nature combine to give superior overall drilling performance [1]. Oil based mud is frequently used for drilling the more difficult exploratory and development wells and such generates large volumes of oil-based formation cuttings [4]. Environmental regulations require that these cuttings be cleaned before their disposal. In many parts of the world today both onshore and offshore drilling operations must have a process in place to ensure cuttings are cleaned properly [5]. To remove these hydrocarbon-based fluids, a technique called thermal desorption is employed. The goal of this technology is to produce oil-free (ultra-low TPH) solids for disposal by distilling off the oils from the cuttings and recovering the oil to be reused as drilling fluid.

Low-temperature thermal desorption (LTDU) also known as low-temperature thermal volatilization, thermal stripping and soil roasting is a remedial technology that uses heat to physically separate petroleum hydrocarbons or oils from oil based drill cuttings or soil [6].

2 Objective of the study

The study aimed at assessing the efficiency of low temperature thermal desorption in oil and water recovery from drill cuttings and to produce oil-free drill cuttings, to meet regulatory requirement for disposal.

3 History of low temperature thermal desorption unit

LTDU was first used at an onshore facility to treat oil- based mud (OBM) and cuttings from an offshore rig on the East Coast of Canada [7]. This new generation technology has enabled operators to not only meet aggressive oil-on-cuttings discharge limitations but also reduce costs through the recovery and reuse of spent base fluid. This technology is a different process from incineration because it uses heat to physically separate the contaminants from the cuttings while incineration uses heat to destroy the contaminants [8]. The low thermal desorption unit (LTDU) provides an environmentally friendly treatment process for oil contaminated drill cuttings as well as settlements contaminated with hydrocarbons. The thermal desorption unit process is briefly described as an indirect thermal stripping process (meaning that the drill cutting will be heated in a controlled chamber, which enables the extraction and recovery of the liquids (oil and water) from the drill cuttings) [2].

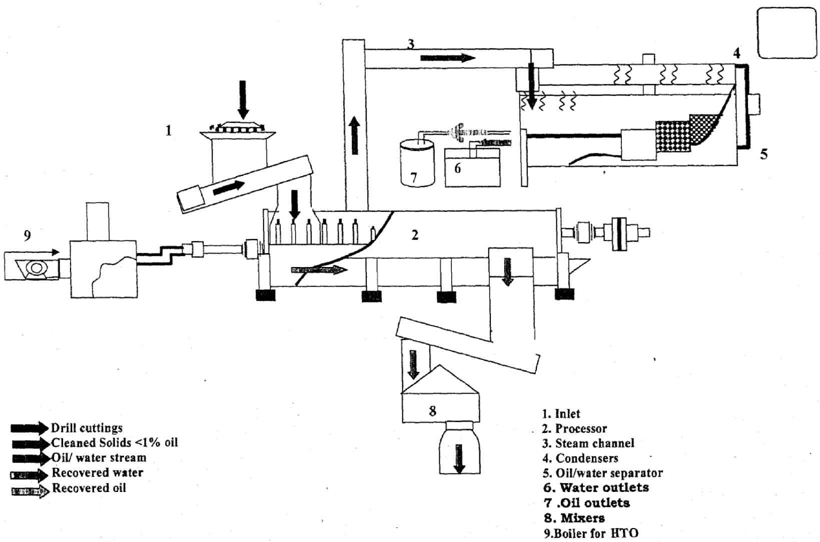

Figure 1: LTDU flow diagram.

3.1 Low temperature thermal desorption process procedure

(i) The cuttings are fed into the feed hopper of the low thermal desorption unit treatment plant using a rotary head forklift.

(ii) The heart of the LTDU is horizontal vessel with a rotating heat exchanger located inside. The heat exchanger is comprised of a hollow shaft and vein through which hot rotating fluid (hot oil) is pumped. The design provides a large surface area for heat transfer to the cuttings being processed. Paddles located on the periphery of the veins convey the cuttings along the length of the processor as the heat exchanger rotates. The processor is capable of processing drilling waste at the rate of 20 to 40 tonnes per hour.

(iii) The heat transfer fluid is heated by 800kw diesel fire boiler located within the processing system. The flow rate and temperature of the heat fluid are controlled by a closed loop system to prevent degradation of the fluid.

(iv) The evaporation of the hydrocarbons and water contained in the drill cuttings takes place between 80 to 280°C and move from the inlet end towards the outlet of the processor.

Airlocks are fitted at both the inlet and the outlet of the processor to prevent the escape of the released vapours. To prevent a flammable mixture forming within the processor as the vapours arise, the processor is purged of any air using nitrogen prior to processing the raw material. The hot vapours released from the raw material are then drawn through a vapour scrubber where the steam and most of the hydrocarbons are condensed.

Any gas not condensed in the vapour scrubs are directed to the boiler for incineration. In the event of a boiler malfunction, gasses that do not condense will be diverted to an activated carbon fitter.

(v) The mixture of water and hydrocarbon condensate generated by process is separated into two streams by multi-stage settlings. To minimize the potential for dust emissions from material handling operations, the cleaned solids arising from the process are moistened using the water recovered by the distillation. There are no discharges to either public sewer or surface water.

(vi) The condensed hydrocarbons are stored in settling tank housed within the processing building.

(vii) The recovered water is used in moistening and cooling down the solids at the outlet end of the treatment unit to prevent dust effect.

(viii) The processed solid is collected and taken to designated construction sites in the free zone or reclamation site for reuse.

(ix) The recovered base oil is taken to the rig site or designated drilling fluid contractor as may be directed by company.

(x) All the operating parameters, temperatures, pressures and the electrical current drawn by the various internal motors are continuously monitored and the data recorded by a computer, which controls the process.

4 Methodology

4.1 Cutting collection

Drill cuttings from shale shakers and centrifuge are collected by empty skips, which are placed at the outlet of the screw conveyer system. The cuttings are transported to the treatment site with Mack Trucks. Samples are collected for testing and analysis using Retort Analysis. The skips are weighed with a weighing balance and off loaded into the treatment bay or stored in the storage bay using a rotary head forklift. The cuttings are thermally processed using a low temperature desorption unit (LTDU).

4.2 Retort analysis

Retort analysis provides a means for separating and measuring the volumes of water, oil and solids contained in a sample of drill cuttings [2]. A known volume of sample is heated to vaporize the liquid components which are then condensed and collected in a graduated cylinder. The total volume of solids, both suspended and dissolved, is obtained by noting the difference of the total sample volume versus the final liquid volume collected. Calculations are necessary to determine the volume of suspended solids since any dissolved solids will be retained in the retort. Relative volumes of low-density solids and weight materials may also be calculated.

4.3 Sampling/analysis of cuttings

A representative sample of oily cuttings was taken from each skip. Individual samples taken from truck load of skips are bulked together to form a composite sample. A retort analysis is made of each composite sample to determine the percentage of oil and water in the oily cuttings.

Also, during operations, in-house retort analysis was performed every four hours on samples of the cleaned cuttings from the LTDU outlet.

5 Results and discussion

A representative sample of oily cuttings was taken from each skip. Individual samples taken from load of skips are bulked together to form a composite sample. A retort analysis was made of each composite sample to determine the percentage of oil and water in the oily cuttings.

Table 1: The result of the retort analysis of oily cuttings for Well A.

S/N		**350°C**	**500°C**
1	Full Retort	322.6g	322.6g
2	Empty Retort	272.6g	272.6g
3	Weight of Material	50g	50g
4	Weight of Full Glass	107.4g	109.9g
5	Weight of Empty Glass	94.6g	94.6g
6	Weight of Oil + Water	12.8g	15.3g
7	Weight of water (ml × 1.0)	8g	8.8g
8	Weight of Oil)	8.8g	6.5g
9	Oil (8/3)*100	9.6%	13%
10	Water % (7/3)*l00	16%	17.6%

Table 2: The result of the retort analysis of oily cuttings for Well B.

S/N		**350°C**	**500°C**
1	Full Retort	322.8g	322.8g
2	Empty Retort	272.8g	272.8g
3	Weight of Material	50g	50g
4	Weight of Full Glass	114.1g	1116.3g
5	Weight of Empty Glass	102.5g	102.5
6	Weight of Oil + Water	11.6g	13.8g
7	Weight of water (ml x 1.0)	6g	6.5g
8	Weight of Oil (6–7)	5.6g	7.3g
9	Oil (8/3)*100	11.2%	14.6%
10	Water % (7/3)*l00	12%	15%

Table 3: The result of the retort analysis of oily cuttings for Well C.

S/N		350°C	500°C
1	Full Retort	322.6g	323.0g
2	Empty Retort	273.0g	273.0g
3	Weight of Material	50g	50g
4	Weight of Full Glass	105.8g	108.6g
5	Weight of Empty Glass	80.1g	80.1g
6	Weight of Oil + Water	25.7g	25.5g
7	Weight of water (ml × 1.0)	16.0g	17.0g
8	Weight of Oil (6–7)	9.7g	11.5g
9	Oil (8/3)*100	19.4%	23.0%
10	Water % (7/3)*l00	32.0%	34.0%

5.1 Low temperature thermal desorption unit operation result

All the oil contaminated drill cuttings are fed via a hopper into the processing unit of the LTDU. They are heated to a temperature of 325°C vaporizing the oil and water.

Table 4: LTDU operation result for Well A.

1	Quantity of treated cuttings in tons	6 18.050
2	Recovered oil in cubic meters	77.5
3	Recovered water in cubic meters	79.1
4	Recovered cleaned cuttings in tons	514.3
5	Oil percentage in oily cuttings	9.6
6	Water percentage in oily cutting	16.0
7	Oil percentage in cleaned, cuttings	0.24%
8	Number of skips used	245
9	Number of hours of effective operations	535
10	Number of hours of downtime	41
11	Average tons of oil cuttings treated per hour	1.2
12	Quantity of recovered oil (in cubic meter delivered)	66.841

Table 5: LTDU operation result for Well B.

1	Quantity of treated cuttings in tons	561.4
2	Recovered oil in cubic meters.	70.4
3	Recovered water in cubic meters	98.1
4	Recovered cleaned cuttings in tons	413.4
5	Oil percentage in oily cuttings	11.2%
6	Water percentage in oily cutting	12.1%
7	Oil percentage in cleaned cuttings	0.21%
8	Number of skips used	205
9	Number of hours of effective operations	2.74
10	Downtime due to Maintenance	599
11	Downtime due to Maintenance	216
12	Number of hours of down time	25
13	Average tons of oil cuttings treated per hour	2.3
14	Quantity of recovered oil (in cubic meter delivered)	70.4

Table 6: LTDU operation result for Well C.

1	Quantity of treated cuttings in tons	644.475
2	Recovered oil in cubic meters	133.2
3	Recovered water in cubic meters	179.1
4	Recovered cleaned cuttings in tons	535.2
5	Oil percentage in oily cuttings	19.4%
6	Water percentage in oily cutting	32.0%
7	Oil percentage in cleaned cuttings.	0.23%
8	Number of skips used	311
9	Number of hours of effective operations	926.5
10	Downtime due to Maintenance	0
11	Number of hours of down time	61
12	Average tons of oil cuttings treated per hour	0.7
13	Quantity of recovered oil (in cubic meter delivered)	118.232

Table 7: Results of laboratory analysis conducted for cleaned cuttings.

S/N	Parameters	Unit	Method	Well A	DPR limits
1	pH		W104	6.95	6 - 12
2	Electrical Conductivity	Mg/cm	W107	11.380	-
3	Salinity as Cl-	Mg/kg	W104	720.0	-
4	Arsenic (As)	Mg/kg	W133	<0.003	5
5	Barium (Ba)	Mg/kg	W133	<0.008	100
6	Cadmium (Cd)	Mg/kg	W135	<0.005	1.0
7	Chromium (Cr)	Mg/kg	W135	<0.002	5.0
8	Lead (Pb)	Mg/kg	W135	<0.01	5.0
9	Mercury (Hg)	Mg/kg	ASTM MD3223	<0.002	5.0
10	Silver (Ag)	Mg/kg	W148	<0.001	0.2
11	Zinc (Zn)	Mg/kg	W135	6.20	50
12	Vanadium (v)	Mg/kg	APHA 3114B	<0.004	-
13	Selenium (Se)	Mg/kg	W135	<0.001	1.0
14	Nickel (Ni)	Mg/kg	W135	<0.004	-
15	Sodium (Na)	Mg/kg	AAS	736.0	-
16	Magnesium (mg)	Mg/kg	AAS	54.0	-
17	Sodium Adsorption Ratio (SAR)	-	Spectrophotometer	9.36	-
18	ESP	(%)	Spectrophotometer	11.360	-
19	Cation Exchange Capacity (CEC)	(Meg/100g)	TITRIMETRIC	20.396	-
20	Oil & Grease	(%)	W130	0.395	-
21	TPH	(%)	W131	0.146	-
22	Calcium (Ca)	Mg/kg	AAS	696.0	-

where: W1 = Work instruction based on "American Society for Testing and Materials ASTM 20th Edition 1999 and American Public Health Association APHA 20th Edition 1998".

6 Discussion

The result of the retort analysis of oily cutting samples made to determine the percentage of oil and water in the cutting show that there was high oil percentage in the cuttings, which is above DPR specification. This is detrimental to the environment if disposed without treatment.

These cuttings were treated using a low temperature thermal desorption unit (LTDU), which minimizes future environmental liability, reduces land requirements and provides for waste reduction and recycling. The treatment resulted in the recovery of base oil, which is suitable for reuse in the fabrication of new drilling mud. The oil content of the processed solids was reduced to about 0.21 percent (%) a figure which is below the D.P.R. requirement of 1%.

Also the results of the third party laboratory analysis of the cleaned cuttings show that the concentrations of hydrocarbons, chlorides and heavy metals did not exceed D.P.R limits.

7 Conclusion

The use of oil base mud has led to improved shale stability, enhanced drilling rate and an average drilling performance of 49% was reported by Zupan and Kapila [3] for 311.5mm hole sections in the areas he analyzed. A new technology called Low Temperature Thermal Desorption Process was introduced which can reduce, the oil content of treated cuttings to less than 1% T.P.H which is in accordance with D.P.R. current limits. The process recovers oil which can be reused in the manufacture of new oil base drilling mud there by reducing the cost of drilling fluid by about 35%. The oil content of processed drill cuttings using Low Temperature Thermal Desorption Unit is below the DPR specification of 1% and the concentration of chlorides and heavy metals did not exceed D.P.R guidelines. The clean cuttings are used for landfills, construction purposes, land stabilization and building up construction sand as in on-fill and backfill. The recovered water is reused in moistening the dry processed clean solids to prevent dusting effect for washing of skips in a close loop process. To date there have been no instance when the concentrations of hydrocarbons, chlorides or heavy metals exceed DPR guidelines. The brand name of the LTDU used is AVA VacuDry Indirect Thermal Desorption Unit. 2007 model.

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The characterization of brewing waste and feasibility of its use for the production of porous ceramics

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Abstract

During brewing large amounts of organic solid waste, including bagasse, yeast, malt and hops residues, among others are formed. The objective of this work is to study this waste and analyse the feasibility of its use as pore-forming material in the manufacture of porous ceramics. The residues from the production of craft beer consist of wet solid waste resulting from the separation by filtration after the mixtures maceration. This material was dried and then characterized using various techniques. Porous ceramic pieces were obtained from green bodies manufactured with mixtures of commercial clay with 10% in volume of residue, formed by uniaxial pressure of 25MPa, with the addition of 6% in weight of water. After a drying period, the samples were heat treated at 950°C following curves similar to those used in the ceramic industry. The compacts were characterized with different techniques. The obtained products have good physical and mechanical properties, with values of porosity, modulus of rupture, permanent volumetric variation and weight loss on ignition, within the range required in the market. The study of the feasibility of using this waste as a porosity former in ceramic tiles indicates that it is possible to use them without modifying the usual conditions of the industry, since the organic material incorporated combusted leaving a very low proportion of inorganic material that does not modify the diagrams with major oxides which remain being those of the clay used as main raw material, and these combustions are slow enough to allow sintering without deformation of the samples.
Keywords: waste, biomass, ceramics materials.

1 Introduction

In order to take advantage of biomass as an energy source for the production of heat, synthetic gas, bio-fuel, etc., different methods of thermal conversion have been used. In the last decade a large number of studies have been conducted in order to analyse physical, chemical and thermal processes that lead to the use of a wide variety of biomass with the highest efficiency [1–3].

As in any complex or multicomponent system, it is important to know how each compound behaves. In this sense the biomass is composed mainly of cellulose, hemicellulose and lignin. These are organic compounds differing in composition and structure, as well as in their thermal behaviour, which has been extensively studied [4, 5]. The proportion of these components change in different biomasses, being in most of them the cellulose which is in higher proportion (38–50%), followed by hemicellulose (23–32%) and lignin (15–25%) [6]. The thermal behaviour of these organic compounds is closely related to their structures. Hemicellulose is the one with the easiest combustion, due to its linear polymeric structure, with short side chains. Meanwhile, cellulose chains present arrangements associated one with each other that make combustion occur at higher temperatures, and lignin, with a closed aromatic polymer structure, is stronger and a heat resistant material. Temperature ranges cited in literature for the reactive decomposition of these compounds are between 200°C and 350°C for hemicellulose, 305°C to 375°C for cellulose, and lignin with the broadest range, between 250°C and 500°C [5, 7]. However, some authors have reported temperatures up to 900°C for heavier volatiles of lignin, considering these as more thermally stable than the other compounds [7]. Temperatures of 510°C, 590°C and 700°C for hemicellulose, cellulose and lignin respectively, have been reported in studies by Peters [8] on pistachio shells pyrolysis depending on the heating rates, concluding that ranges of reactivity temperature of these species move to higher values, as the heating rate increases.

In the brewing a large amount of organic solid waste, including bagasse, yeast, malt and hops are formed. The main destination of this waste is the feeding of cattle. However, several studies have sought more useful destinations for these waste materials. Barbosa-Pereira *et al.* [9, 10] for example have studied the antioxidant properties of extracts obtained from brewery waste stream. Other authors [11, 12] have reported studies on the use of these industrial discards as possible substrates for adsorption of heavy metals.

There are precedents on the incorporation of biomass waste in clay matrices. This addition becomes pore former, because at the operating temperatures its combustion within the brick produces gases and inorganic compounds, resulting in the so called lightweight bricks. In this way, the residue from the production of olive oil [13], wheat straw, sunflower seeds and olive pits [14], grape seeds and cherry pits [15], chipped branches of the vine [16] and rice hulls [17] have been studied.

The objective of this work is to exhaustively study brewing discards and perform a first analysis of the feasibility of their use as pore-forming material in the manufacture of lightweight ceramic materials. To do so, an addition of 10%

waste is studied. Also, the ashes of this waste are characterized since this material will remain in the final product.

2 Materials and methods

The brewing waste are formed for wet solid discards, resulting from the separation by filtration after the maceration of the mixtures. The dried residual material and the commercial clay were characterized by various techniques: optical microscopy (OM) and scanning electron microscopy (SEM) with X-ray electron dispersive analysis (EDS), X-ray diffraction (XRD), differential and thermogravimetric thermal analysis (DTA-TGA) and weight loss on ignition (LOI). The biomass was also characterized by Fourier transform infrared spectroscopy (FTIR), determination of conductivity, pH, and calorific value, and analysis of ecotoxicity.

Optical microscopy observations were made with a Zeiss-Axiotech equipment with a Donpisha 3CCD camera and image scanner. SEM analyses were performed with Philips SEM 515, with an X-ray detector (EDAX-Phoenix).

The TGA-DTA essays were conducted on a Shimadzu DTA-50 analyzer TGA-50 with YC-50 WSI.

The conductivity and pH were measured with SPER SCIENTIFIC Model 860,032 and Altronix TPX-III equipment, respectively, using 10 g of waste in 100 ml of demineralized water, stirring for 2 hours at room temperature.

X-ray diffraction diagram of the powder waste material was obtained with Philips PW 3710 equipment, for values 2θ between 0° and 80°, with radiation CuKα (λ = 1.5406 nm) and Ni filter. The operating conditions were 40 kV and 20 mA. The patterns were analysed by ASTM files (pcpdfwin files).

The calorific value of the waste material was determined by a bomb calorimeter LECO AC-350, following ASTM D-5865 standard.

The FTIR spectra were obtained with a Nicolet 6700, Thermo Electron Corp. equipment, in attenuated total reflectance – ATR mode.

Ecotoxicity tests were carried out by adapting the standard IRAM 29114: 2008. Dilutions were prepared with waste and distilled water in a wastewater ratio of 1:4 and were stirred for 2 hours, then the aqueous extract was filtered to be used in ecotoxicity tests, in concentrations of 25%, 50% and 100%. Filter papers that are saturated with 3.5 ml of the dilution to be tested and 20 seeds of the species rye grass, are placed in a Petri dish and covered. A sample with undiluted residue is also prepared. The seeds were incubated for 120 hours at 24°C, performing 3 repetitions for each concentration. Reference controls were carried out with distilled water. When the test was finished, the percent inhibition of the average elongation of the radicle regarding the average elongation of control (IR) was measured.

Porous ceramic pieces were obtained from green bodies made with mixtures of 10% in volume of residue in commercial clay. The decision to begin the study adding this percentage of residue is based on previous experiences with other biomass waste.

The pieces have been formed by uniaxial pressure of 25MPa, with addition of 6% in weight of water, into moulds of 70mm x 40mm x 18mm. After a drying period, the samples were thermally treated at 950°C with a heating rate of 1ºC/min. The compact bodies were characterized with different techniques: porosity, permanent volumetric variation (PVV), weight loss on ignition (LOI) and mechanical properties, among others.

The porosity of samples was determined according to Standard IRAM 12510. The modulus of rupture (MOR) was performed on specimens to scale according to the aspect ratio set in the standard ASTM C67-03a in a Digimess machine, TG 100L model, in conditions of 500kg, 10 mm/min.

3 Results and discussion

Table 1 shows the semi-quantitative chemical analysis by EDS of brewery residues, ashes and clay used, expressed as percentage of the elements without considering the content of carbon and oxygen in samples. The C content is 60.6% and 24.9% in the residue and the clay, respectively.

Table 1: EDS semi-quantitative chemical analysis.

Elements [wt%]	**Al**	**Ca**	**K**	**Fe**	**Mg**	**Na**	**Si**	**P**
Residue	–	7.5	–	–	4.5	–	50.9	37.1
Ash	–	6.6	11.0	–	8.0	6.3	38.3	29.8
Clay	17.2	1.3	6.2	15.9	2.9	2.4	54.1	–

Although these semi-quantitative tests do not show Na, K and Fe in the residue, these elements were detected in the ash by EDS and XRD, because their proportions in the sample after calcinations are higher.

The results of differential thermal analysis and thermogravimetric analysis are presented in Figure 1. DTA-TGA analysis of the residue shows a wide exothermic peak at 318°C and then other wide peak with two maximum values at 451 and 470°C. The first one has been assigned to the combustion-decomposition of hemicellulose and the other to the co-combustion reaction of cellulose and lignin. The TGA curve shows three weight loss stages, one up to 200°C which corresponds to water and gases adsorbed, a second weight loss assigned to hemicellulose, and a final weight loss up to 600°C corresponding to cellulose and lignin. Although this has a small change in slope, it is not possible to determine from this curve different ranges of reaction for these two compounds. A composition of 11.5% moisture and gases, 45.8% hemicellulose, 37.9% cellulose and lignin and 4.8% of material remaining as inorganic ash is estimated. These results are very important because they indicate that in the bricks, the incorporated biomass burns into a wide temperature range, and not abruptly at a fixed temperature, which allows the slow diffusion of the gaseous products, avoiding cracking in the bricks.

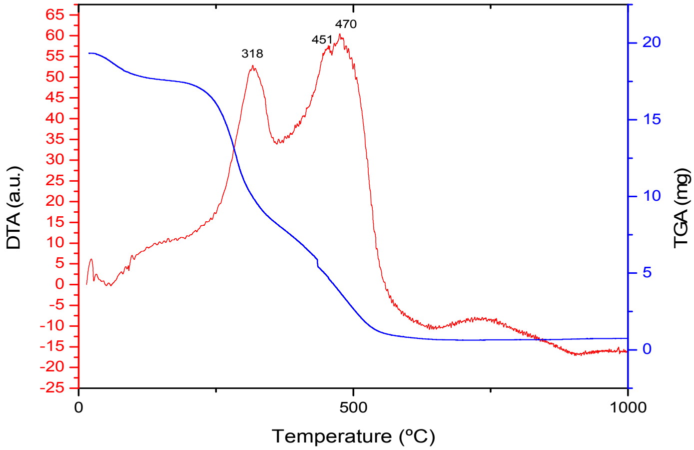

Figure 1: DTA-TGA analysis of the residue.

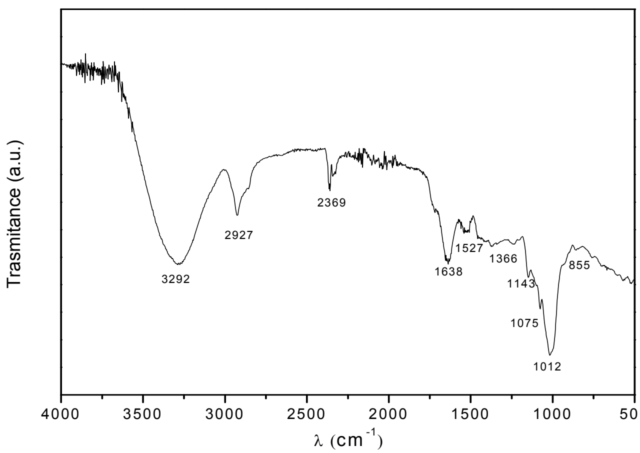

Figure 2: Waste FTIR analysis.

Figure 2 shows FTIR analysis of biomass. The bands have been assigned to the functional groups according to Table 2, wherein the associated polymers present in the biomass are also expressed [18–20].

The calorific value determined for the residual material was 4422 kcal/kg. This caloric contribution during the firing of bricks does not modify the temperatures at laboratory scale due to the material proportions used in these samples.

pH and conductivity were measured for this residue at room temperature and after 2 hours under stirring, obtaining values of conductivity of 1876 µS and pH 4.5 showing that this is an acidic residue, which cannot be deposited uncontrollably in all kinds of soils.

Table 2: Analysis of FTIR. C: cellulose, H: hemicellulose, L: lignin.

λ[cm^{-1}]	**Functional group**	**Polymer – Compound**
855	Glycosidic linkage	C – H
1012	C-O, C=C and C-C-O stretching	C – H – L
1075	C-OH and C-H stretching	C – L
1143	C-O-C asymmetrical stretching	C – H
1366	C-H methyl group bending	C – H – L
1527	Aromatic ring vibration	L
1638	C=O, C-N and C-N-H stretching (amides)	C – L
2359	O=C=O asymmetric stretching	CO_2
2927	C-H aromatic methoxy group stretching	L
3292	O-H and N-H stretching	L

On the other hand, the ecotoxicity test shows that the presence of these residues inhibits the normal development of sensitive species, which is directly related to acidic property.

These three determinations, pH, conductivity and ecotoxicity, are important in order to know the characteristics of this biomass waste in those cases in which it is deposited and maintained in industries directly on the ground in the open.

Figures 3 to 5 show the SEM images of the clay employed in this study, the residue analysed and its ashes, respectively. In these figures, it is possible to observe the fibrous structure of biomass residual grains, and the ashes that maintain the original shape of the grain, although they disintegrate very easily when handling.

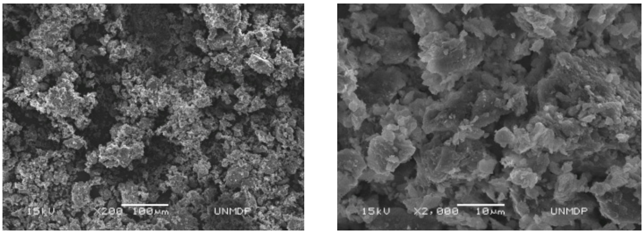

Figure 3: SEM images of the clay.

The X-ray diffraction diagram of the residue (Figure 6), shows the typical structure of this type of biomass, with a single broad peak between 15° and 28° in 2θ, with overlapping small peaks at angles 15.2°; 19.9°; 22.3° and 32.0°. Several authors have identified peaks in this spectra region, studying other biomass, as belonging to low crystalline cellulose. Thus Mtibe *et al.* [21], in their studies on cellulose from corn, have determined the presence of peaks 2θ at 15.7°, 22.6° and 34.9°. On the other hand, Benitez-Guerrero *et al.* [2] have obtained diffraction peak values in their work with natural sisal cellulose fibres (hemp plant) in 2θ 15°, 16.5°, 20.5°, 22.5° and 34.5°.

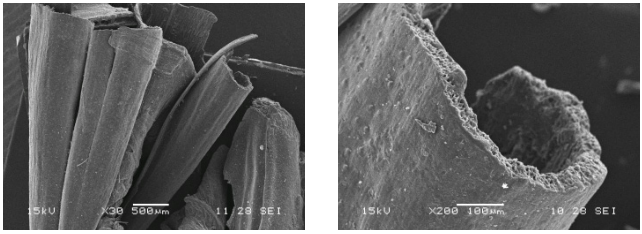

Figure 4: SEM photographs of the brewing waste.

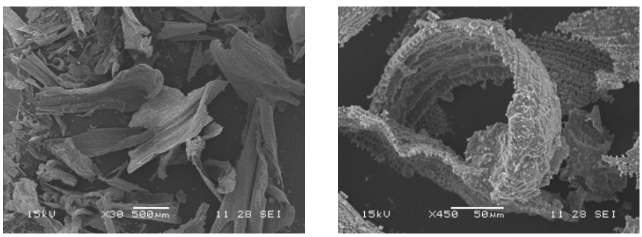

Figure 5: SEM photographs of the residue's ashes.

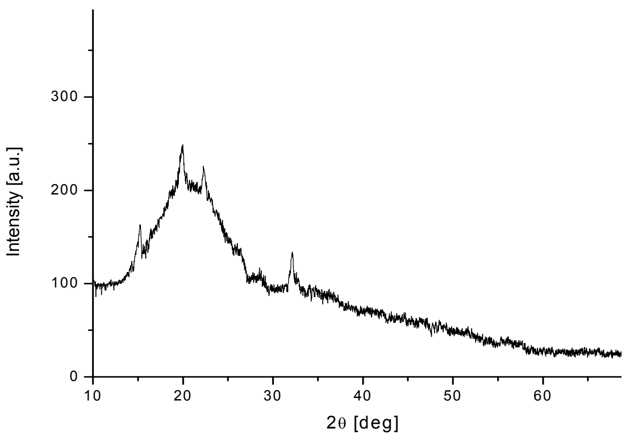

Figure 6: XRD of the brewing residue.

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Cellulose samples from sugarcane studied by Rollin *et al.* [22], show the presence of peaks at angles 2θ 15.1°, 22.2° and 34.3°, that these authors assigned to different planes of the unit cell.

The XRD pattern obtained from the ashes of this residue (Figure 7), shows the presence of diffraction peaks assigned to cristobalite phase (SiO_2, pdf 82-0512), calcium phosphate (Ca_2P2O_7, pdf 45-1061), calcium magnesium phosphate ($(CaMg)_3(PO_4)_2$, pdf 13-0404) and iron oxide (Fe_3O_4, pdf 88-0315). These compounds remain in the brick after the heat treatment.

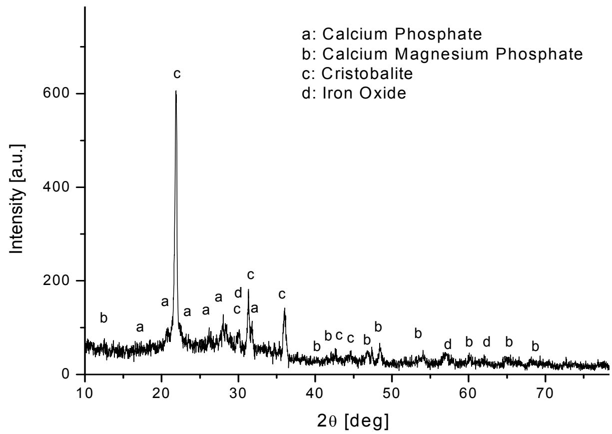

Figure 7: XRD of the biomass ashes.

Figure 8 shows the macroscopic appearance of the bricks obtained with commercial clay and with mixtures of clay and 10% in volume of brewing residue.

The obtained pieces are compact, with intense reddish colour due to the Fe content of the commercial clay, and a greater open porosity in the brick obtained with the residue addition is observed.

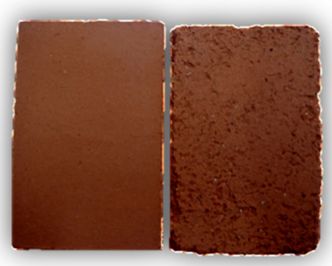

Figure 8: Bricks with clay alone (left) and with 10% of residue (right).

Figure 9 shows optical micrographs of the bricks. The upper images show the bricks without addition of residue, in which the structure is very homogeneous, with internal pores of small size. Lower images correspond to bricks with 10% of waste. In these bricks it is possible to see the presence of numerous pores of various sizes, larger than those in the clay bricks, distributed evenly throughout the structure. These result from the combustion of organic biomass material during the sintering process.

These pores are seen as white areas because they are covered with resin due to sample preparation for observation by OM, that is, the brick pieces are embedded in resin and polished. In the latter micrographs, at higher magnification, the edges of these pores are observed.

Table 3 shows the results of the properties characterization of the obtained bricks.

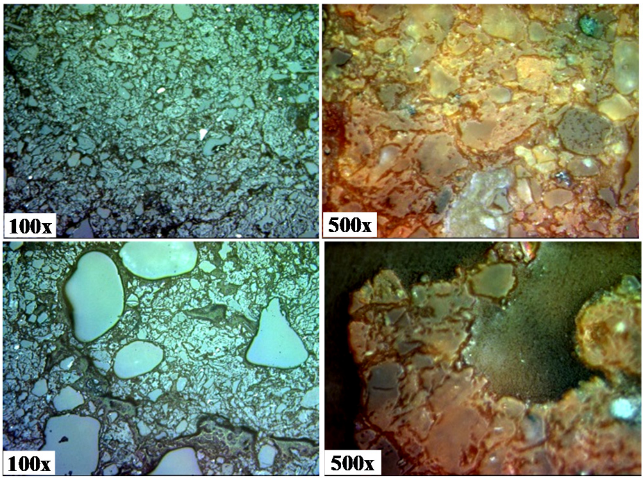

Figure 9: Optical micrographs of bricks. Upper images correspond to bricks without addition of residue and lower images correspond to bricks with 10% of waste.

Table 3: Bricks' properties.

	PVV [%]	LOI [%]	Porosity [%]	MOR [MPa]
RC0	- 4.3	5.3	24.2	10.2
RC10	- 4.7	9.8	30.2	7.7

It is observed that the values of permanent volumetric variation (PVV), loss on ignition (LOI) and porosity of the samples with addition of 10% residue (sample RC10), are higher than those obtained for samples of clay without addition (sample RC0). This result is expected due to the combustion of organic material.

The mechanical resistance measured in this case by the flexural strength (MOR) is lower for the RC10. However, this brick still has a MOR value suitable for market requirements for this kind of materials.

4 Conclusions

In this paper the feasibility of using brewing waste as porosity former in ceramic pieces was analysed. The results show that it is possible to use this residue without modifying the conditions of usual heat treatment in industry, since in the conditions tested the organic material burn leaving a very low proportion of inorganic substances. In addition, the reactions of this biomass with temperature are slow enough to allow the sintering without deformation of the pieces. The products obtained from mixtures of clay and 10% biomass, exhibit good physical and mechanical properties, with values of porosity, modulus of rupture, permanent volumetric variation and weight loss, within the range required in the market for these kinds of products.

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Effects of the aeration on the fluid dynamic behaviour of a multi-zone activated sludge system

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Abstract

Conventional wastewater treatment plants (WWTP) are necessary to modify the wastewater properties in order to make it acceptable for a safe discharge into the environment or a certain reuse purpose. Biological oxidation is the most important of the processes involved in conventional WWTP. Organic substances dissolved in the water are removed by means of bacteria presented in the biological reactor. Air is necessary to enable the reduction of the organic content of the water by the bacteria. Bubbles of air are introduced into the reactor through air diffusers. Air diffusers can account up to 70% of WWTP total energy consumption.

So a deep understanding of the dynamic behaviour of the flow is necessary for optimizing the process and saving energy.

A numerical analysis of the effects of the aeration in the fluid dynamics behaviour of a real multi-zone activated sludge reactor is carried out. The purpose is to identify and analyse the changes originated in the velocity field by the aeration.

A numerical modelling of the activated sludge system located in San Pedro del Pinatar (Murcia, Spain) is developed throughout a general-purpose computational fluid dynamics (CFD) code. The multiphase flow is simulated with a Euler–Lagrange approach; modelling the bubbles as discrete phase. Two simulations, one with aeration and the other without it, are carried out. The numerical results show that the aeration has a notable effect in the performance of the reactor. Changes in velocity field, stagnant zones, residence time distribution or even free surface level originated by the aeration in the reactor are studied. In general, the

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aeration reduced the amount of stagnant volume in the reactor. However, when the aeration is activated, some re-circulating zones are formed, reducing the residence time in the reactor.
Keywords: air bubbles-water interaction, activated sludge system, wastewater treatment plant, numerical modelling.

1 Introduction

Nowadays, people are more concerned about environment. The concept Sustainable Development is taken into account by governments and companies, which make a considerable economical effort to carry out the restrictive environmental laws. In this context, it is clear the necessity of treating city wastewater (sewage) before discharging it into the environment, or even treating it for other purposes such as irrigation. The sewage treatment is carried out in Waste Water Treatment Plants (WWTPs). Conventional WWTPs includes physical, chemical and biological processes to remove physical, chemical and biological contaminants. Biological oxidation is one of the most important processes involved in the treatment. Bacteria and other microorganisms (biological floc) remove organic substances dissolved in the water. The combination of wastewater and biological floc is called mixed liquor. Oxygen is necessary to enable the oxidation of the organic content of the sewage, air bubbles need to be added to the mix. Activated sludge plants are widely used to hold this biological process.

Activated sludge plants can account for up to 70% of total energy consumption of a WWTP, due mainly to the aeration process through the air diffusers [1]. So it is necessary a knowledge of the fluid dynamic phenomena which occur in the plant. This knowledge allows us to optimize the processes, saving energy and guaranteeing an efficient treatment. A numerical modeling of a real multi-zone activated sludge plant is carried out in this work. In addition to the air diffusers, the plant has mixers impellers to improve the mixed process. Computational Fluid Dynamics (CFD) has been widely used for simulating activated sludge systems. Bubble column have been numerically investigated either with Euler–Euler approach [2, 3] or with Euler–Lagrange approach [4]. Euler–Lagrange approach tends to have higher computational cost; however it allows us to study the trajectory of each individual bubble. Regarding the turbulence model, different turbulence model have been studied: Le Moullec *et al.* [5] analyzed two different turbulence models for an activated sludge system; he concluded that Reynolds Stress Model (RSM) gave more accurate residence time distribution (RTD) than the $k - \varepsilon$ model. Despite this, most of the works [6] use the well-known $k - \varepsilon$ model. In the work of Talvy *et al.* [7] a numerical modelling of a full scale oxidation ditch is carried out, simulating the mixer impellers as plane regions with a pressure jump between both sides of the planes.

Using the above mentioned bibliography, this work analyzes the effects of the air bubbles on the fluid dynamic behavior of a real multi zone activated sludge plant. The peculiarity of this plant is the complexity of the configuration: it has four zones, two of them with air diffusers on the ground and the other two without them. The zones are separated by partition walls, which have two holes in its inferior parts. It is interesting to study how the air bubbles modify the flow through the holes. The plant also has two mixer impellers in each zone, adding other fluid dynamic phenomenon to the aeration.

The aim of this work is to study the influence of the air bubbles in the fluid dynamic behavior of the plant. Two simulations are carried out, one with aeration and other without aeration. The hydraulic performance of the reactor is evaluated in terms of stagnant volume (percentage of liquid with low velocity). Other aspects like the influence of the aeration in the free surface level are mentioned. The results obtained provide useful information for the improvement of the efficiency of the plant, taking advantage of the effects produced by the bubbles.

2 Installation description

The numerical modeling developed in this work corresponds to the multi zone activated sludge reactor of the WWTP located in San Pedro del Pinatar (Murcia, Spain), see Figure 1. This reactor holds the biological oxidation of the treated sewage. It is divided into two parallel lanes, each one is formed by four zones. Each zone has two mixer impellers (FLYGT-S460) in two opposite corners. The impellers are installed forming a 20° angle with the wall. The air diffusers (FLYGT membrane EDPM 9'') are located uniformly on the floors of Zone 2 (616 diffusers) and Zone 4 (300 diffusers). The four zones are separated by three partition walls. The first partition wall has 5.53 m height, while the second and third ones have 5.05 m height. All the partition walls have two inferior holes of 0.4 × 0.45 m. So the water can pass to one zone to the next zone either, over the partition wall or through the inferior holes. The outlet weir is 5.43 m above the floor.

Figure 1: Aerial photography of the WWTP where the plant is located.

3 Numerical modelling

3.1 Governing equations

An Eulerian–Lagrangian model is employed for simulating the two phases involved in the problem. The continuous phase (mixed liquor) is governed by mass and momentum principles, while the dispersed phase (air bubbles) is governed by a force balance from the Lagrangian point of view. Both phases are coupled through source terms.

3.1.1 Mixed liquor flow governing equations

The continuous phase is modelled by means of the simplified RANS steady equations:

$$\frac{\partial(\rho U_j)}{\partial j} = 0, \tag{1}$$

$$\frac{\partial(\rho U_i U_j)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \frac{2}{3}\mu\left(\frac{\partial U_j}{\partial x_j}\right)\delta_{ij} - \rho\overline{u_i u_j}\right] - \frac{\partial p}{\partial x_i} + \rho g_i, \tag{2}$$

where U is the averaged velocity and p the relative pressure, difference between the pressure and the ambient pressure. The turbulent stress $-\overline{u_i u_j}$ is provided from the turbulence closure model, assuming that

$$-\overline{u_i u_j} = 2\nu_t S_{ij} - \frac{2}{3}k\delta_{ij}, \tag{3}$$

being ν_t the turbulent kinematic viscosity; S_{ij} is the mean strain tensor, $S_{ij} = \left[\left(\partial U_i/\partial x_j\right) + \left(\partial U_j/\partial x_i\right)\right]/2$, δ_{ij} the Krönecker delta and k the kinetic turbulent energy, given by $k = \sum_{j=1}^{j=3}\overline{u_j^2}/2$. The well-know $k-\varepsilon$ turbulence model is employed to solve the closure problem. So, two additional equations for the transport of kinetic turbulent energy, k, and the dissipation rate of k, ε are included in the modelling.

3.1.2 Air bubbles governing equations

Air bubbles are considered as discrete phase. Many bubbles are released uniformly from the floor of Zones 2 and 4. The trajectory r_p of each bubble is calculated by means of the integration of the force balance on the particle:

$$\frac{dr_p}{dt} = U_p, \tag{4}$$

$$\frac{dU_p}{dt} = F_D\left(U - U_p\right) + \frac{g_r(\rho_p - \rho)}{\rho_p} + \frac{\rho}{\rho_p}U_p\frac{\partial U}{\partial r_p}, \tag{5}$$

$$F_D = \frac{18\mu}{\rho_p D_p^2}\frac{C_D Re_p}{24}, \tag{6}$$

$$C_D = a_1 + \frac{a_2}{Re_p} + \frac{a_3}{Re_p^2}, \tag{7}$$

with $Re_p = (\rho D_p\left|U - U_p\right|)/\mu$ the Reynolds number of the particle. The coefficients a_1, a_2 and a_3 are constants used for smooth particles over several ranges of Re (Morsi and Alexander [8]); $F_D(U - U_p)$ is the drag force per unit particle mass, $g_r(\rho_p - \rho)/\rho_p$ is the gravity force per unit particle mass, $(\rho/\rho_p)\, U_p\, (\partial U/\partial r_p)$ is the force due to the pressure gradient in the fluid.

The dispersion of particles due to turbulence in the continuous phase is simulated using a stochastic tracking model. In the RANS steady equations the velocity of the fluid is composed by a mean velocity U_j and a random velocity fluctuation u_j. When the trajectory of a droplet is integrated (Equation (5)), u_j is kept constant for a certain interval of time t_e, which depends on the characteristic time scale or lifetime of eddies. The lifetime of the eddies is written as $t_e = -t_l \log(r)$. Where t_l is the time scale of the Lagrangian flow, $t_l = C_l \frac{k}{\varepsilon}$, in the turbulence model $k - \varepsilon$, the value of C_l is 0.15. The term r is a random number between 0 and 1. The dispersion is simulated computing each trajectory for a sufficient number of particles (tries).

3.1.3 Interaction between dispersed and continuous phase

The effect of the air bubbles on the liquid is taken into account by means of the incorporation of source terms into the right terms of the equations of the liquid (Equations (1) and (2)). F_i is the momentum communicated from the bubbles to the mixed liquor, this source term is added into the balance of kinetic momentum of the liquid (Equation (2)).

3.2 Computational domain and meshing detail

The domain of the problem includes the four zones described in the previous section, as well as the impellers and the inferior holes of the partition walls. The height of the domain has to mimic the free surface level, so it depends on the liquid flow rate and the aeration.

The mesh is mainly Cartesian and structured. The sizes of the elements vary from 0.02 m around the impellers to 0.14 m in the core of the domain. The mesh has 5.2 millions of elements.

3.3 Solver settings and boundary conditions

The numerical modelling are developed using a general-purpose CFD code, based on a finite volume procedure. The equations are discretized by a staggered-grid scheme. The coupling between mass and momentum equations are solved by the "SIMPLE" algorithm through pressure. The well-known "up-wind" second-order differencing scheme is employed for the convective terms of the equations. The case is considered converged when the normalized residual for mass, momentum and turbulent variables are lower than 10^{-5}.

The sides and ground walls of the domain are treated as non-slip walls, while the conventional symmetry condition it used for the top surfaces, simulating the free surface level behaviour. The usual pressure-outlet boundary condition is used in the exit of the domain. The liquid goes into the domain with uniform velocity through the inlet surface. The mixer impellers are simulated by means of a pressure jump in a plane region, including the azimuthal velocity. The air bubbles are injected uniformly through the grounds of Zones 2 and 4.

4 Numerical results

Two simulations of the biological reactor have been carried out with the numerical modelling developed. Both of them have the same wastewater influent flow rate; in one simulation the air diffusers are working, in the other they are not working.

4.1 Description of the flow

The numerical results show a notable influence of the aeration on the velocity field in the reactor. Without aeration, a vortex is generated in each zone (Figure 2(a)). The vortex is generated because of the jets of the mixers impellers; the pair of mixer impellers of each zone are located in opposite corners of the zone, faced each other; the jets are parallel, but not aligned. This jets misalignment generates a big vortex in the center of the zone. However, when the air diffusers of Zones 2 and 4 start to work, the columns of air bubbles generate an upward force in the liquid. This upward force adds a vertical component to the liquid velocity, splitting the vortex which there was without aeration in two or three smaller and weaker vortex (Figure 2(b)). This phenomenon is stronger in Zone 2 than in Zone 4, because Zone 2 has more air diffusers and therefore more air flow rate.

Another notable effect of the aeration on the liquid is the circulation through the inferior holes of the partition walls. Without aeration, there is hardly liquid circulation through the inferior holes of the second and third partition walls. However, when the air diffusers are activated, the upward force of the bubbles in the liquid generates a depression in the lower part of the Zones 2 and 4 (Figure 3). This depression favours the circulation of the mixed liquor from Zone 3 to Zone 4 and from Zone 3 to Zone 2, producing a recirculation. As explained in the installation description, the first partition wall is higher than the other two, causing two different free surface levels: one for the Zone 1 and another for the other three zones. Without aeration, the free surface level in Zone 1 is a little higher than the first partition wall: a little fraction of the liquid flow rate passes over the wall, while the rest is drawn off by the inferior holes. Nevertheless, when the air diffusers start to work, because of the depression generated on the bottom of Zone 2, all the liquid is drawn off by the inferior holes, decreasing 8 cm the free surface level of Zone 1. The free surface level in the other three zones is not affected by the aeration.

Air bubbles also have influence on the residence time of the waste water in the reactor. The average residence time is useful for calculating which fraction of the reactor volume is active volume (not recirculating volume). Without aeration, the average residence time of the liquid in the reactor is 361 minutes, whereas when the air diffusers are working the average residence time in the biological reactor is 321 minutes. These residence times mean that without aeration the reactor active volume is 82.5%, with aeration the active volume decreases until 73.3%.

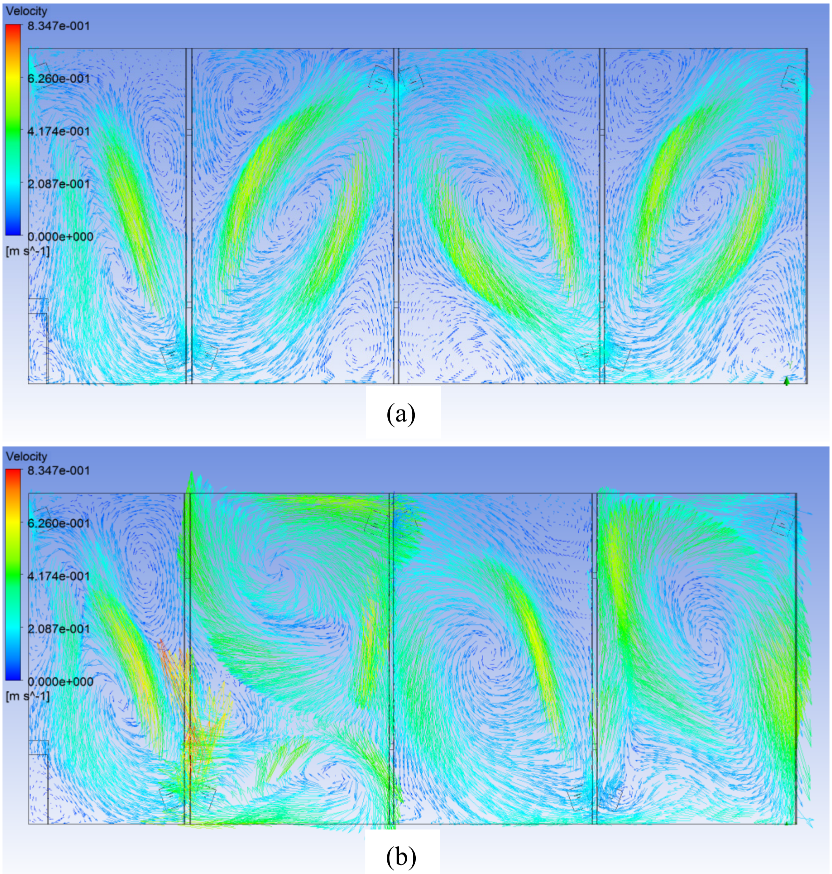

Figure 2: Velocity vectors in the horizontal plane z=2.5 m (a) for the simulation without aeration; (b) for the simulation with aeration. The aeration divides the vortex of Zones 2 and 4 into smaller vortexes.

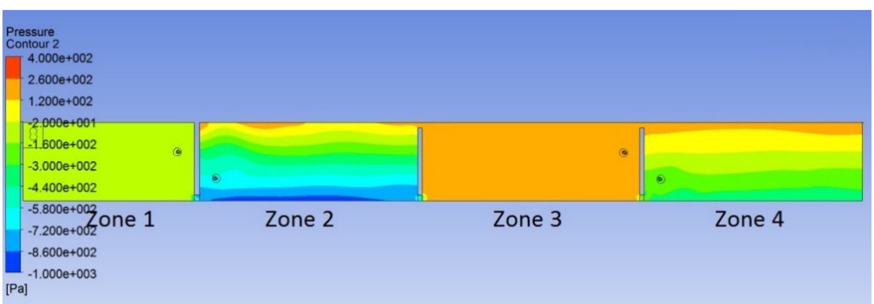

Figure 3: Hydraulic head in the vertical plane y=6 m for the simulation with aeration. It is observed the depressions produced by the air bubbles.

4.2 Effect of the aeration on the reactor performance

A quantitative analysis of the velocity field is carried out. Figure 4 shows the histogram with the percentage of volume of liquid in each velocity range. The aeration has clear effects on the distribution of velocities. Without aeration, most of the liquid has velocity lower than 0.2 m/s. However, when the air diffusers start to work, the percentage of liquid with low velocity reduces, and the averaged velocity in the reactor increases. This increase of motion is due to the upward force of the air bubbles on the liquid, which generates the movement of zones that did not have velocity without aeration.

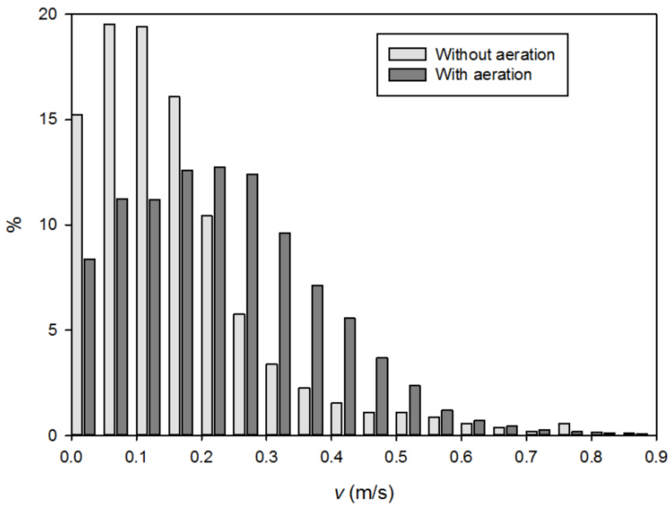

Figure 4: Comparison of the velocity histograms obtained without and with aeration.

The zones with velocity lower than 0.1 m/s are considered as stagnant zones. The analysis of stagnant zones is very important in WWTP, because the sedimentation of the suspended solid is only allowed to take place in stagnant zones. Table 1 shows the stagnant volume in each zone of the biological reactor in the two cases simulated. Without aeration, more than 37% of the liquid is stagnant volume. When the air diffusers are working, the stagnant volume reduces until 19%. Studying the stagnant volume in each zone, it is observed that the zones with air diffusers (zones 2 and 4) reduce their stagnant volume more than the other two zones. This is because the air bubbles induce the movement of the mixed liquor of the zones, and by means of the flow circulation through the inferior holes of the partition wall also reduce the stagnant volume in Zone 3. Figure 5 shows the stagnant volume in the two simulations. Without aeration (Figure 5(a)) the zones with velocity lower than 0.1 m/s locate in the centre of the vortex and the corners and walls of the zones. Nevertheless, with aeration (Figure 5(b)) the stagnant volume in Zones 2 and 4 are greatly reduced.

Table 1: Stagnant zone percentage (v<0.1 m/s) in each zone and in the whole reactor.

	Zone 1	Zone 2	Zone 3	Zone 4	Total
Without air	46.13%	38.93%	35.88%	32.65%	37.45%
With air	48.96%	3.58%	22.97%	9.50%	19.61%

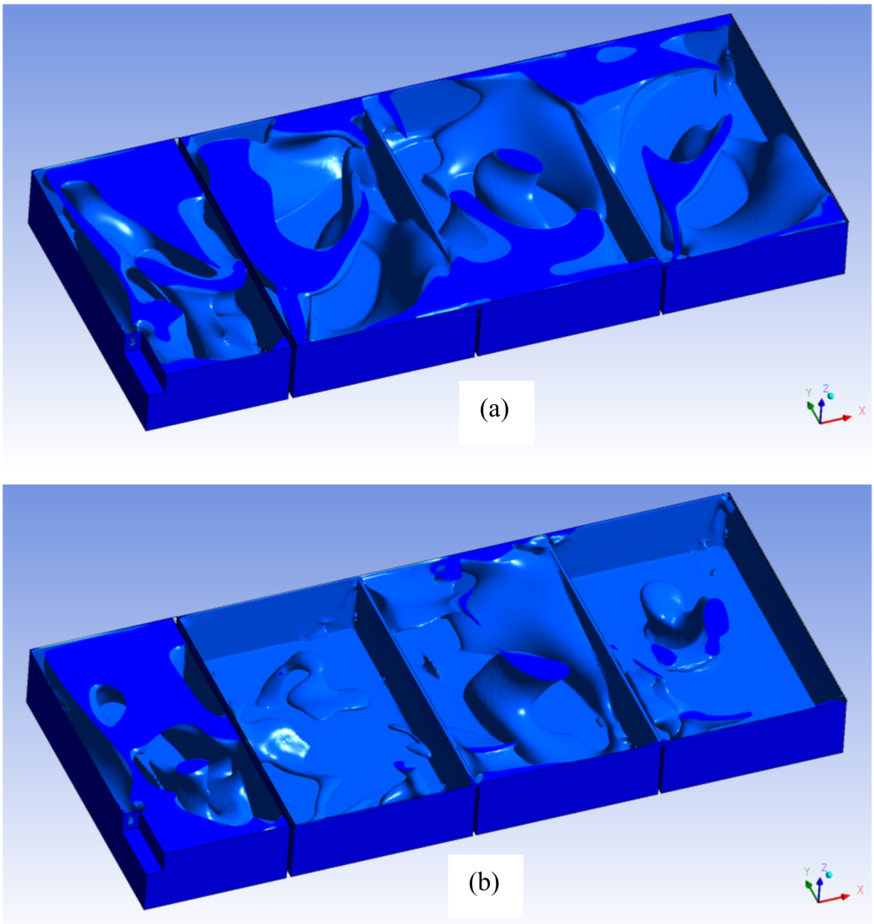

Figure 5: Fluid with velocity lower than 0.1 m/s (a) in the simulation without aeration; (b) in simulation with aeration. The stagnant volume decreases when the aeration is activated.

4.3 Bubble distribution

According to [9], the Euler–Lagrange numerical approach is only possible if the particle volume fraction is less than 10%. Figure 6 shows the bubbles volume fraction in a vertical plane of the domain. As expected, there are bubbles only in the zones with diffusers; being higher bubble concentration in the Zone 2 than in Zone 4 (Zone 2 has 696 air diffusers, while Zone 4 has 300 air diffusers). The particle volume fraction hardly reaches 4%, far less than the limit 10%. One of the advantages of using an Euler–Lagrange model is that it allows us to study the trajectory of each particle. As explained before, air diffusers represent a large fraction of the total energy consumptions in WWTPs. For this reason is important to optimize the aeration, injecting the right mass flow rate of air, keeping the air bubbles in the reactor the necessary time to enable the oxidation, but using as little energy as possible. Reducing the size of the air bubbles injected is possible to increase the residence time of the bubbles in the reactor. However, with small bubbles, the air flow rate per diffuser is lower, thus more diffusers would be needed, increasing the energy consumption. In the biological reactor analysed in this work, where the bubbles diameter is 1.016 mm, the mean residence time of the bubbles in the reactor is 64 s for the bubbles injected from Zone 2 and 68 s for the bubbles injected from Zone 4.

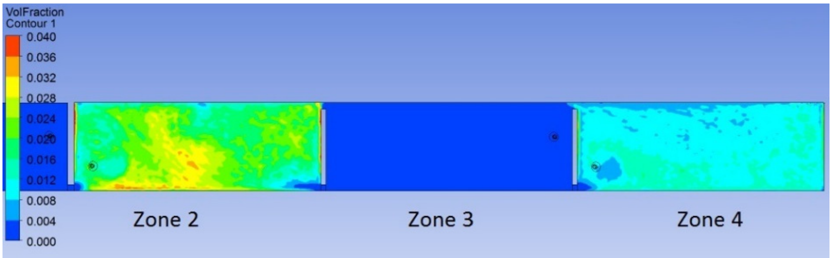

Figure 6: Volume fraction of air in the vertical plane y=6m of the simulation with aeration.

5 Conclusions

A numerical modelling of the multi-zone activated sludge system of the wastewater treatment plant (WWTP) located in San Pedro del Pinatar (Murcia, Spain) is carried out. Relevant parameters as velocity field, stagnant zones or residence time are studied under two different working regimes, without aeration and with the air diffusers working. The following conclusions remark can be made:

- Without aeration, a consistent vortex is generated in each one of the four zones of the reactor. With aeration, the vortexes of the zones with air diffusers (Zones 2 and 4) split into smaller and weaker vortexes, due to the upward force of the air bubbles on the liquid.
- The aeration generates the movement of the liquid through the inferior holes of the second and the third partition walls, this is because of the depression produced by the air bubbles in the zones of the air diffusers.

- The depression generated by the air bubbles on the ground of Zone 2 produces the decrease of the free surface level of Zone 1. Free surface level of Zone 1 is 5.533 m without aeration and 5.451 m with aeration.
- The air bubbles have notable influence in the residence time of the liquid in the reactor, decreasing the active volume from 82.5% (without aeration) to 72.3% (with aeration).
- The aeration generates a decrease in the amount of stagnant volume in the reactor. The amount of liquid with velocity lower than 0.1 m/s without aeration is 37.5%, however, with the air diffusers activated, only 19.6% of the liquid of the reactor has velocity lower than 0.1 m/s.

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Cluster formation of potential assessment for swine manure treatment and biogas generation in an experimental watershed in Rio Grande do Sul, Brazil

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Abstract

This paper presents a proposal for collective systems for handling manure, also called clusters, and consequent generation of electricity from biogas, for a swine herd installed in 2012 in the municipalities of Serafina Corrêa and União da Serra, in the State of Rio Grande do Sul, Brazil. From the preparation of sand, hypsometry and slope maps for both municipalities associated with plotting the location of the swine herds, this work proposed five clusters where the waste of 8,660 animals are conducted entirely by gravity. The biogas generated in the anaerobic treatment is transformed into electrical energy could supply 285 homes whose average monthly consumption is 200 kWh or can be inserted into the internal or external network of property, corroborating in extra income to swine farmers and the sustainability of the activity. From this objective, the job initiates a technical assessment in order to enable these collective treatment systems and reduce the environmental impacts generated by swine activity.
Keywords: swine farming, waste, clusters, biogas, power generation.

1 Introduction

Population growth demands greater food production and consequently the increase in the production of animal protein, especially the use of pork, beef and chicken. In this context, Brazil currently occupies fourth place in the production and export of pork and in 2015 should provide an approximate herd of 39.3 million animals, which will produce about 3.4 million tons of carcasses (USDA [1]).

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According to Kunz *et al.* [2], the tropical climate, low cost of labor, ease of handling and treatment of waste, benefited by large territorial dimensions and the large production of grains, such as corn and soybeans, makes Brazil one of the countries with the best conditions to increase the swine herd. In Rio Grande do Sul, the second largest creator of pigs in Brazil, swine activity is present in virtually all regions, although is more concentrated in the north and northeast, integrated proximity of processing industries (SEPLAG [3]) and associated with small farms, where livestock activity supplements income from agricultural activities.

The increase in density and pig population has caused serious environmental problems since, according Vanotti *et al.* [4] and Williams [5], the application of manure as a source of nutrient aggravates the emissions of volatile organic compounds, particulate matter, pathogens and odor. Furthermore, one of the issues is the evident contamination of surface and ground water and soil when waste is discarded without treatment (Peng [6] Riaño and García-González [7]). Hernandes and Schmidt [8] state that the lack of correct destination for the waste and pollution that can cause, if released, an excess in the soil are the main environmental problems faced by this activity.

According Rodriguez-Verde *et al.* [9], the use of anaerobic digesters sets up one of the most important techniques in the treatment of swine manure. This equipment is able to reduce contaminant power to mitigate the impact on soil, water and air. As a result of this process, there is the generation of products of interest such as biogas, which can be converted into electrical and/or thermal energy and the effluent from the digester, which can be used as agricultural fertilizer.

Considering the above, this paper aims to propose collective treatment systems of swine manure, also called clusters, aiming to transport manure using only gravity as the driving force, being used to generate electricity from biogas to the swine herd installed in the municipalities of Serafina Corrêa and União da Serra, in the northeastern state of Rio Grande do Sul, Brazil. Thus, it is expected to start a technical assessment in order to enable these collective treatment systems and reduce the environmental impacts generated by swine activity.

2 Materials and methods

In this study, we used project information of "Sanitation in Rural Areas – evaluation of pig activities and impacts to water quality in the region spanning the COREDE Serra – projection scenarios and perspectives", started in 2012 and completed in 2014 by the Institute of Environmental Sanitation at the University of Caxias do Sul. The project quoted set up an experimental watershed considering the characteristics of use and land cover, soil science, hydrology, hypsometry, slope beyond the capacity of pigs.

The experimental basin is partially composed of four municipalities: Serafina Corrêa, Montauri, União da Serra and Guaporé, located in the watershed of the Guaporé River, in the northeastern state of Rio Grande do Sul. In these municipalities, information about the swine herd installed in 2012 was obtained from the local environmental agencies.

The location maps of pig farmers and slope in the experimental watershed were adapted from Schneider [10] and elaborated through ArcMap 10 software from the geographical coordinates of the pig farmers.

In this study we used the actual liquid waste generated by the confined animals, using as a basis the growth curve of the animal proposed by the Gompertz model, based on experimental weight gain data (de Freitas and Costa [11], Fialho [12] and de Freitas [13]). In quantifying the manure, BOD and nutrients per animal the information presented in Table 1 was used.

Table 1: Physical and chemical characteristics of swine manure produced per 1000 kg live weight.

Parameter	Quantity
Total volume (L)	84
Urine (L)	39
Specific mass (kg/m³)	990
Total solids (kg)	11
Volatile solids (kg)	8.5
BOD (kg)	3.1
COD (kg)	8.4
PH	7.5
Kjeldahl nitrogen (N_{total}) (kg)	0.52
Ammonia nitrogen (kg)	0.29
Total phosphorous (P) (kg)	0.18
Total potassium (K) (kg)	0.29

Source: ASAE in Perdomo *et al.* [14].

For quantification of waste, BOD and nutrients (nitrogen, potassium and phosphorus), we used the average generation per kilogram of live animal, arranged by Perdomo *et al.* [14]. From the daily generation (DG), the total production per animal was calculated from birth to slaughter, considering a cycle of a 168 day period, the growth curve of Gompertz (de Freitas and Costa [11], Fialho [12] and de Freitas [13]).

Quantification of each component produced by the swine herd was obtained by using the GD of the sum to an animal according to the length of period, multiplied by the herd and the number of lots created in a year, thus obtaining the annual generation.

The evaluation of the methane production potential from manure had reference to a methodology of the adjustment proposed by the National Biomass Reference Center – CENBIO in IPEA [15]. The estimate of biogas production was converted into electrical energy, calculated by adapting the method described by Junior and Domingues [16].

Considering the swine herds installed in the municipalities of União da Serra and Serafina Corrêa and its generated manure load, coupled with the geographic location of plotted herds in the topographic map, collective treatment of waste systems, also called clusters, was proposed, to generate energy from biogas.

3 Results

Hereafter are the results of the potential formation of collective systems for the treatment of swine manure, clusters associated with power generation from biogas in the municipalities of União da Serra and Serafina Corrêa.

3.1 Assessment of the swine herd

Figure 1 shows the delimitation of the experimental watershed of Arroio Lajeado Tacongava and its tributaries as well as the location of the swine herds.

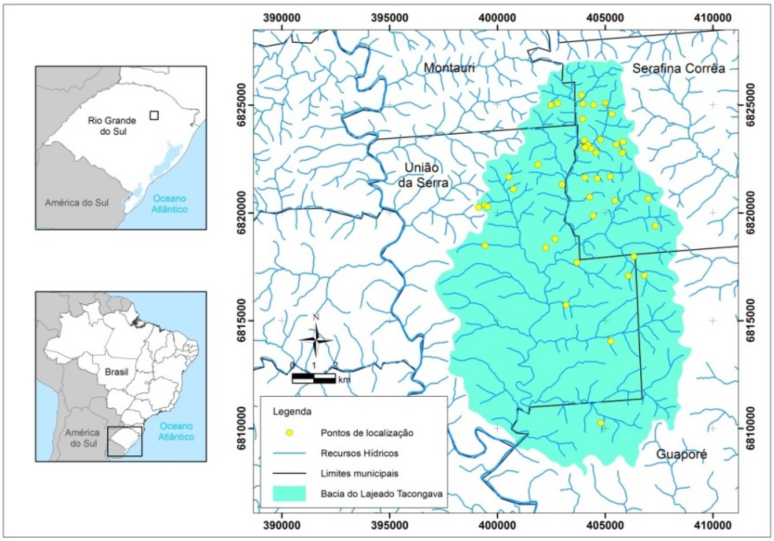

Figure 1: Experimental watershed and pig farmers' location. (Source: prepared by Geise Macedo dos Santos [17], adapted from Schneider [10].)

Figure 1 shows that there are 46 swine herd farms installed in the experimental watershed where almost all are allocated close to water resources. Note that the most significant concentration occurs in the municipalities of União da Serra and

Serafina Corrêa with 15 and 26 pig farming units respectively, which justifies the approach of these municipalities in this study. Table 2 shows the number of animals in both municipalities in the respective stages of pig creation.

As noted in Table 2, the municipality of Serafina Corrêa has a total herd of 11,799 animals distributed in various stages of creation, where the finishing phase is the most significant. The municipality of União da Serra has 6,480 animals, all in the finishing phase. The total swine herd, considering both municipalities, is 18,279 animals.

Table 2: Total pigs in each phase.

Creating phase	Serafina Corrêa	União da Serra
Production unit piglets (sows)	230	–
Sows full cycle	50	–
Complete cycle	1,560	–
Weaners	369[1]	–
Finishing	9,590[2]	6,480
Total	**11,799**	**6,480**

[1]Quantity of a lot. For the total, animals in the year should be multiplied by 8.1 lots.
[2]Quantity of animals created in a lot. For the amount of animals in a finishing phase in a year, multiply by 3.84 lots.

It is worth noting that the bibliography adopts different periods of animals remaining in the breeding sheds. In this work the weaners‘ time was defined as 45 days, equivalent to 8.1 lots per year and finishing pigs considered 95 days, totaling 3.84 lots per year.

The number of lots per year was achieved by dividing the number of days of the year by the number of days that the animal remains in the establishment. Thus to achieve the annual herd it is necessary to multiply the number of animals by the number of lots in the respective phase. For animals from complete cycle matrices the number of animals in the year is considered. However, the periods can vary according to the particularities of each integrator or property.

3.2 Generation of manure, BOD and nutrients in the experimental watershed

Table 3 shows the generation of waste, BOD and nutrients according to the cities.

As noted in Table 3, the city of Serafina Corrêa is responsible for generating 61.5% of the manure, resulting from the significant swine herd installed there.

Table 3: Manure, BOD and nutrients generated in the experimental watershed in the period of one year.

Watershed	Manure (kg/year)	BOD (kg/year)	Nitrogen (kg/year)	Potassium (kg/year)	Phophorous (kg/year)
Serafina Corrêa	21,143,213	816,390	136,942	47,402	50,035
União da Serra	13,248,219	488,922	82,012	28,389	29,996
Total	**34,391,432**	**1,305,312**	**218,954**	**75,791**	**80,031**

3.3 Proposition of collective systems of waste treatment (clusters)

Through the slope map it was possible to evaluate the possibility of formation of collective manure treatment systems. Figure 2 shows the slope map with the location of the swine herds in the city of Serafina Corrêa, where it is noted that there is a possibility of formation of three clusters of pig farmers. According to the location of points, there is sharp relief that favors manure transport by gravity, without needing investments in booster pumps or other technologies.

Figure 3 shows the slope map with the location of the swine herds in the municipality of União da Serra.

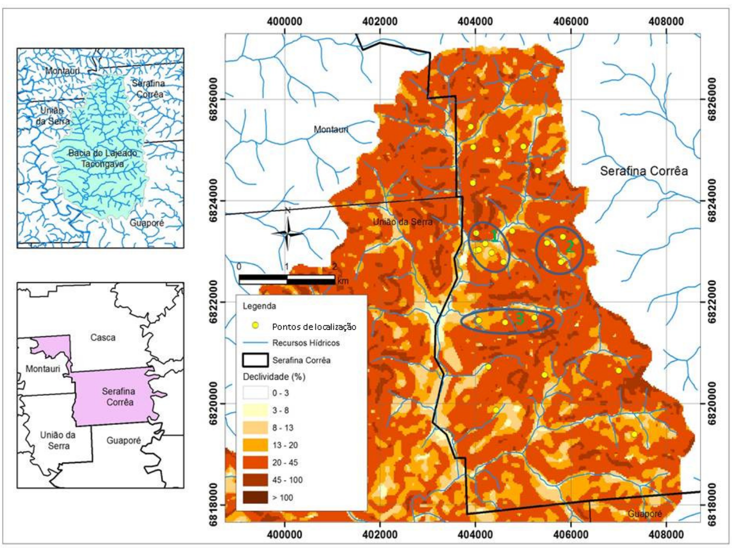

Figure 2: Slope map and location of pig farmers in Serafina Corrêa. (Source: prepared by Geise Macedo dos Santos [17] adapted from Schneider [10]).

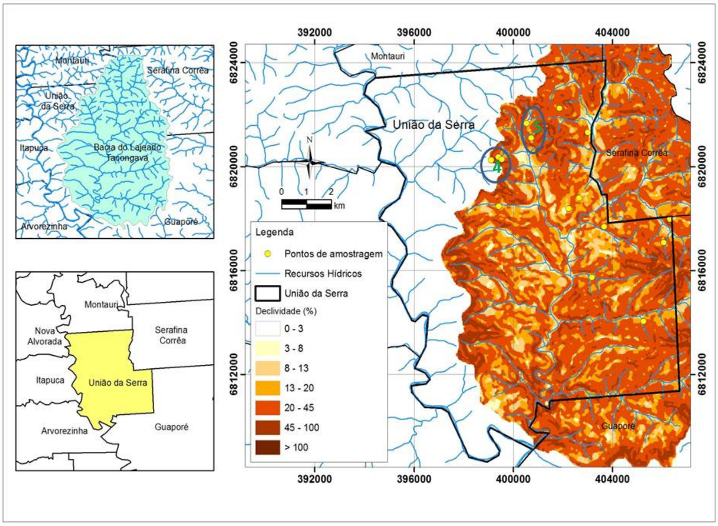

Figure 3: Slope map and location of pig farmers at União da Serra. (Source: prepared by Geise Macedo dos Santos [17] adapted from Schneider [10].)

According to Figures 2 and 3, there is the possibility of forming 5 clusters of pig farmers, which enables driving of gravity for a single manure treatment system in each cluster. This helps reduce installation and maintenance costs of the equipment. Table 4 shows the collective treatment systems proposed with its capacity of pigs.

Table 4: Clusters of pig farmers proposed for the municipalities of Serafina Corrêa and União da Serra.

	Finishing	Piglet production unit (sows)	Complete cycle	Pig farmers	Cities
Cluster 1	2,900	250	1,560	7	Serafina Corrêa
Cluster 2	1,030	–	–	4	Serafina Corrêa
Cluster 3	860	–	–	3	Serafina Corrêa
Cluster 4	1,120	–	–	3	União da Serra
Cluster 5	940	–	–	2	União da Serra

– No animals in this phase in the cluster.

According to Table 5, cluster 1 is the most significant and involves 7 pig farmers, including a herd of 2,900 animals in finishing, 200 sows in the piglet production unit and 1,560 animals in full cycle. After weaning, the piglets in the piglet production unit are referred to other properties for growing and finishing.

For each cluster, the generation of manure, BOD, nutrients and potential of biogas generation for later use in the production of electricity was calculated. These results are shown in Table 5.

Table 5: Parameters analyzed in clusters.

Parameters analyzed	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Total
Manure (ton/year)	8,008	2,243	1,758	2,289	1,921	**16,219**
BOD (kg/year)	327,806	86,776	64,887	84,505	70,923	**634,897**
Biogas (m^3/year)	368,603	103,279	80,923	105,389	88,451	**746,645**
Electricity (kWh/year)	339,156	95,028	74,458	96,969	81,385	**686,996**
Nitrogen (kg/year)	20,086	5,311	10,884	14,175	11,896	**62,532**
Phosphorous (kg/year)	19,034	5,032	3,767	4,906	4,118	**36,857**
Potassium (kg/year)	20,086	5,311	3,976	5,179	4,346	**38,898**

As shown in Table 6, 16,219 tons of manure are produced in clusters, containing 634.8 tons of BOD and a total of 138.2 tons of nutrients (nitrogen, phosphorus and potassium). In this way, 746,000 cubic meters of biogas can be generated annually. If the biogas was transformed into electricity, it could generate 686 MWh of electricity and be enough to supply 285 houses whose average monthly consumption is 200 kWh.

4 Conclusion

From the results obtained, the viability of forming five clusters to treatment of pig manure was observed, using only gravity as the driving force for transporting the manure to the treatment system. Among the products of the treatment of waste has been the generation of biogas, which is converted into electrical energy and can be inserted into the domestic distribution network or external to the property, corroborating in extra income for pig farmers and the sustainability of the activity.

In addition to the electrical energy, thermal energy could be generated to be used in the properties to maintain the temperature inside the sheds during the winter but during the summer there could be an excess of biogas. Therefore, in this work, we opted for the generation of electricity during the year.

In these clusters, with the generation of biogas and subsequent transformation into electricity, it would be possible to supply 285 homes for a year considering an average monthly consumption of 200 kWh. However, more studies are necessary about the economic viability, to assess the initial investment and the return time of the proposed investment.

It is worth noting that to get more accurate results it is necessary to work with experimental data generated in the laboratory or in a pilot study for each parameter analyzed, considering that there are variations according to the region's climate as well as small variations in the composition of the manure, which directly affects digester performance. With respect to the calculations in this work, a dilution of the waste was not considered because it could vary in the pig properties.

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An assessment of crop residue characteristics and factors militating against efficient management in the Ikara local government area of Kaduna state, Nigeria

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Abstract

This study assessed the nature of crop residues and factors militating against its management in Ikara local government area. The ten wards in the study area were used for the study. A sample of 380 farmers was surveyed by means of a questionnaire which was administered using convenient sampling techniques based on population size. The study revealed that in Ikara LGA, Kurmin Kogi has the highest amount of crop residue with 48,328 kg amounting to 26.20% of the total crop residue generated. It was also observed that cereals contributed the highest source of crop residue with maize, millet and guinea corn as the major constituents. The study also shows that most of the farming households still engage in inefficient management practices such as open dumping and burning of their agricultural waste. However, there still exist some efficient agricultural waste management in the study area as some farmers reuse their crop remnants. Nearly one-third of the farmers reported that lack of awareness or ignorance of the benefits and strategies of crop residue management is one of the reasons for poor utilization of crop residues in the study area. The current management option is not perfect and the existing framework to ensure adequate management system and the collection facilities is not available. Crop waste is still collected without separation at the source, treatment facilities are limited and the collected waste is mostly dumped haphazardly in open areas or in most cases burnt before the next farming season. It is suggested that intensive mass literacy programmes on the economics of crop residue management be undertaken in the study area. Also, by involving the farmers and other stakeholders, the

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government should come up with appropriate policies and legislative measures to discourage dumping and burning of crop waste.
Keywords: waste, crop residue, management, environment, Ikara local government area.

1 Introduction

The by-products of agricultural activities are usually referred to as "agricultural waste" because they are not the primary products. This waste chiefly takes the form of crop residues (residual stalks, straw, leaves, roots, husks, shells, etcetera) and animal waste (manure). Agricultural waste management is the collection, transportation, processing, treatment, recycling or disposal of agricultural waste materials to reduce their adverse effects on human health, amenities and environment. Agricultural waste represents valuable resources as ground cover to reduce erosion, fertilizer to nourish the crops, source of energy among others [1].

Crops residues include remnants obtained during harvesting and crop processing waste. With advances in biotechnology and bioengineering, some resources, which could have been classified as waste, now form the basis for energy production [2]. It is estimated that, Nigeria has about 71.2 million hectares of available agricultural land, out of which about 36 million hectares of land are being currently utilized for agricultural production [3]. The large quantities of crop residues produced in Nigeria can play a significant role in meeting its energy demand. Most of these residues are biomass, which contains enormous amounts of energy [4]. However, it is unfortunate that these residues are neither utilized efficiently nor properly managed effectively in all developing countries, including Nigeria [5]. The prevailing practice is usually to burn this waste or leave it to decompose. This burning or decomposition, apart from amounting to a colossal waste of resources, contributes to environmental degradation and pollution and this poses hazards to both humans and the environment.

Crop residue management is a growing public concern in many countries in Africa, including Nigeria [6]. The first goal of any crop residue management system is to maximize the economic benefit from the waste resource and maintain acceptable environmental standards. To be practical, the system must also be affordable and suitable to the environment. Agricultural crop residues characteristics and management have been well investigated in European and American agricultural cultures. However, investigation of these issues for academic and policy purposes in many developing countries is usually taken for granted. For sustainable agricultural and environmental management, such issues can no longer be overlooked. That is the basis of this study using Ikara local government area of Kaduna state as the spatial focus.

1.1 Research problem

A major challenge for many countries is how to increase agricultural production without degrading the environment. This is a global issue; hence there should be a greater adoption of environment-friendly intervention and technology in massive food production [7]. One of such environment friendly intervention is effective management of crop waste. In addition, many farmers now view the practice of residue utilization for energy regeneration as an extra cost with small returns, and that the best way is to get rid of the residues is a least effort method like dumping, open burning and others [8]. But the hazards to the environment by such practices can no longer be ignored. This is even more appropriate as a number of agricultural and biomass studies have concluded that it may be appropriate to remove and utilize at least a portion of these residues for energy production, providing a large volume of low cost materials [9].

A number of related studies are accessible and a few of them are examined to put this study in proper perspective. A study by Kwaghe *et al.* [10] on economic analysis of agricultural waste management among farming households in Jere local government area of Bornu State, Nigeria, showed that about 62.5% of respondents generate crop residues while reuse is the major waste management method while other farmers still practice dumping and burning of their farm waste. The quantities of crop residues were 161. It is also suggested that government should involve the farmers and other stakeholders to come up with appropriate policies and legislative measures to discourage dumping and burning of agricultural waste.

Informed opinion and observation revealed that the level of crop residue management and recycling in Kaduna state and Ikara local government area is very low. This could be as a result of inadequate knowledge on crop waste disposal, management and recycling strategies by the farmers [11]. More importantly, inadequate understanding of the characteristics, volume and other attributes of crop residues make it difficult to adopt sustainable management approaches. Also Ikara like any other northern Nigerian society is agrarian where several tons of crop waste, considering HRWC [12] position on waste management are either abused or left unused. This is the gap this research intends to fill to advance the frontier of knowledge on waste management, sustainable agricultural practices and environmental policy making processes.

1.2 Study area

Ikara is located on Lat. 11°22'N and 11°31'N of the equator and Long. 8°21'E and 8°28'E of the Greenwich meridian. Ikara has seven (7) districts namely, Ikara, Saulawa, Auchan, Kurmin Kogi, Furana, Pala and Paki (see Fig. 1) and ten (10) wards which are Ikara, Janfalan, Pala, Kurmin Kogi, Saulawa Rumi, Auchan, Kuya, Paki and Saya-Saya. Ikara lies on the high plains of Hausa land, of height ranging from 550 to 750meters showing a general regional slope to the south and a relative relief of 30 to 45 meters. The area is drained by river Kaduna and characterized by high stream frequencies and drainage density. Ikara has a tropical continental climate. The annual rainfall is about 1200–1400mm and the seasonal characteristics affect the vegetal cover [13]. The economy of Ikara local government area revolves around agriculture. About 80% of the population in the study area engage in farming. The agricultural activity in the study area can be categorized into arable, tree crop and livestock farming. Crop farming is the main agricultural activity in the area. Crops are produced both during the rainy and the dry season. A lot of farming takes place in the study area where most of the farm products supplied to the capital city of Kaduna are produced [14].

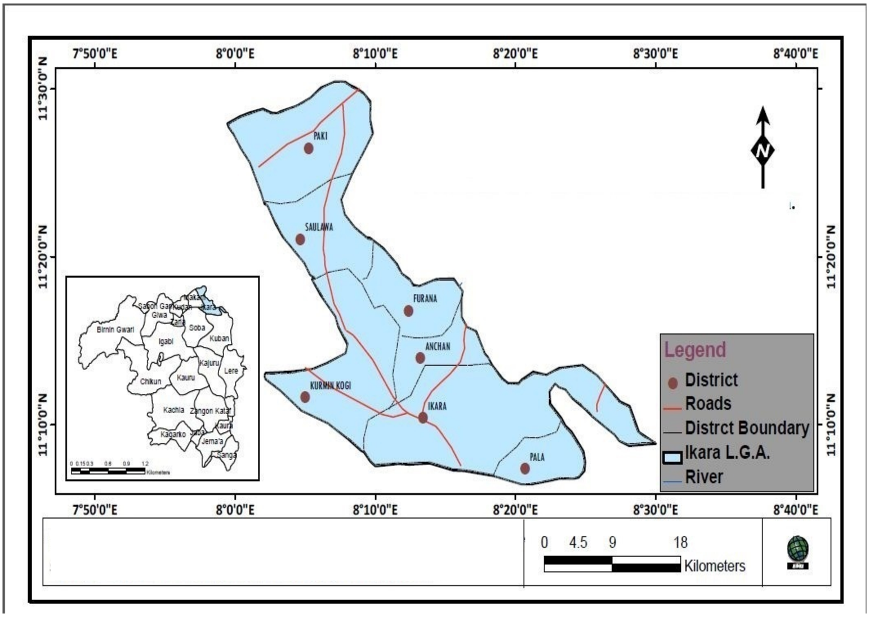

Figure 1: Ikara local government area: study area. (Source: modified from the administrative map of Kaduna state.)

2 Methodology

In order to achieve the aim and objectives of the study, the research utilized majorly primary data. A pretext questionnaire was administered to 380 respondents across the ten (10) wards in the study area which are Ikara, Saulawa, Auchan, Kurmin/Kogi, Janfalan, Pala, Saya-Saya, Kuya, Rumi and Paki using the Krejcie and Morgan (1970) method of determination of sample size. The questionnaire was administered using a convenient sampling technique whereby allocating the questionnaire to respondents was based on population size per ward.

Data entry, coding, cleaning and test for normality was made following standardized procedures. Quantitative and qualitative statistical methods were employed to analyze the information collected from the field. In order to examine the factors militating against efficient waste management in the area, content analysis of response obtained from farmers was undertaken which are later subjected to descriptive statistics such as tabulation. All statistical analysis was carried out using SPSS 17. Statistical test for significance was carried out at 5% level of significance.

3 Results and discussion

3.1 Socio-economic characteristics of farmers

The socio-economic characteristics of the respondents include the sex, age, occupation of farmers other than farming and educational qualification of farmers. Table 1 shows that the farmers at Ikara local government area are predominantly male as attested by 96% of the farmers, this is basically as a result of the cultural and religious setting limiting the involvement of female farmers in most rural areas in the Hausa dominated Muslim communities in northern Nigeria as deduced from the responses of the 4% females.

It was also observed that 49% of the farmers in the study area are over 40 years old, 20% are within the age bracket of 31–40 while 31% fall within the age bracket of 21–31, which indicates that most of the farmers are old and apart from 20% and 27% that engage in civil service and business enterprises other than farming, 42% are solely farmers. Indeed, as revealed by Table 1D, 19% of the respondents have no formal education, 28% have Quranic education, 32% have attained first school certificate, 17% have attained SSCE while 4% have acquired tertiary qualifications. The farmers with tertiary certificates are all located in the local government headquarter and are predominantly subsistence based.

Table 1E shows the responses of farmers with respect to the type of agriculture practiced. From the responses it was clearly observed that 96% of the farmers in the study area are predominantly subsistence while 4% are commercial. However, it was also observed that most subsistent farmers also sell some of their products, although on a very small scale. On the other hand, 4% of the respondents are commercial farmers and they make use of large area of land and are usually involved in both crop farming and animal rearing for commercial purposes. Table 1F shows the acres of land used by farmers in the study area. It can be clearly seen that because of the small scale nature of farming of the farming households, most of the farmers in the study area use 1–5 acres of land as attested by 87% of the respondents.

In the socio-economic characteristics of the respondents, it can be clearly seen that Ikara LGA depicts the true characteristics of a rural settlement, characterized by low educational qualification. It however, contradicts other characteristics of rural areas as portrayed by Solano *et al.* [15] that rural areas are where the youths have migrated or classify rural areas as zones of high propensity for out migration because in the study area over 51% of the respondents are youths actively involved in agriculture, although they combine it with trading and schools.

Table 1: Socio-economic characteristics of respondents in the study area.

A. Sex	Frequency	Percentage (%)
Male	364	96
Female	16	04
Total	**380**	**100**
B. Age	**Frequency**	**Percentage (%)**
20–30	116	31
31–40	77	20
41 and above	187	49
Total	**380**	**100**
C. Occupation of farmers other than farming	**Frequency**	**Percentage (%)**
Civil servant	74	20
Business	104	27
Student	36	09
Others	06	02
None	160	42
Total	**380**	**100**
D. Educational qualification	**Frequency**	**Percentage (%)**
No formal education	74	19
Quranic school	106	28
Primary	122	32
Secondary	63	17
Tertiary	15	04
Total	**380**	**100**
E. Type of farmer	**Frequency**	**Percentage (%)**
Subsistence	364	96
Commercial	16	04
Total	**380**	**100**
F. Farm size in acres	**Frequency**	**Percentage (%)**
1–5 acre	329	87
6–10 acre	46	12
11–15 acre	05	01
Total	**380**	**100**

Source: field survey 2014.

3.2 Characteristics and composition of crop residue in the study area

Table 2 revealed that corncobs are the major residue generated with 25.53%. The corncobs residue is made up of maize, sorghum and millet. While the least crop residue generated are tree trimmings with 2.89%. Corn is the major crop planted in the study area, because of the environmental advantage and its high demand in the area under study. Hence, this accounts for corn cobs being the most commonly generated crop residue in the study area.

Table 2: Type of crop waste generated in the study area.

Type of crop waste	Frequency	Percentage (%)
Corncobs	97	25.53
Sugarcane bagasse	59	15.53
Groundnut shells	70	18.42
Leaves and grasses	28	7.37
Other crop residues	102	26.84
Tree trimmings	11	2.89
No response	13	3.42
Total	**380**	**100**

Source: field survey 2014.

3.3 Volume of crop residue in the study area

Table 3 presents the estimated quantity (kilograms) of crop residue generated in the study area by the farming households. The total volume of crop residue generated in 2013 is 184,500 kg. From table 3 it can also be clearly seen that farmers in Kurmin Kogi generate the highest volume of crop residue (48,328 kg) equivalent to 26.19% of the total. This is because most farming households are commercial responsible for producing most of the food crops sold and consumed in the study area and marketed at nearby urban centres like Makarfi, Kubau and Kaduna (the state capital). The crop residue from Ikara and Saulawa wards are 27,450 kg and 23,627 kg respectively. It can also be observed that despite the population of farming households considered in Ikara, its percentage contribution in relation to other wards is 14.87%. This is because it is the most urbanized part of the LGA, hence other land uses affect land for farming.

The work of Kwaghe *et al.* [10] revealed that the estimated quantity/tonnage of agricultural waste for farming households in Jere local government area of Borno State is 264 tonnes (264,000 kg) with crops accounting for 161 tonnes (161,000 kg) of waste and animals accounting for 103 tonnes (161,000 kg) of waste. This shares close similarities with the quantity of crop residue generated in Ikara local government area though with higher values which may be attributed to the difference in ecological zone. Ikara is in the north central while Jere is in the north east.

Table 3: Volume of crop waste generated in the study area.

Wards	Estimated volume of crop waste (Kg)	Percentage in relation to other wards (%)
Ikara	27,450	14.87
Saulawa	23,627	12.81
Auchan	12,345	6.69
KurminKogi	48,328	26.19
Janfalan	12,000	6.50
Pala	4,500	2.44
Saya-Saya	21,350	11.57
Kuya	3,800	2.06
Rumi	7,600	4.13
Paki	23,500	12.74
Total	**184,500**	**100**

Source: field survey 2014.

3.4 Sources of crop residue in the study area

In the study area several crops were responsible for the residue generated. Figure 2 revealed that cereals are the major source of these residues with maize, millet and guinea corn as the major constituents as attested to by 49% of the respondents. Similarly, root crops such as sweet potatoes and Irish potatoes accounted for 16% of the crop residue. However, when post-harvest waste of potatoes is compared with its original planting quantity it was realized that potatoes gets to the final consumer almost without undergoing much post-harvest handling. Irish potatoes although not favourable to the climatic condition, were found grown in Kurmin Kogi and Janfalan wards. Vegetables and sugarcane contributed 12% and 13% of the crop residue generated while 10% was

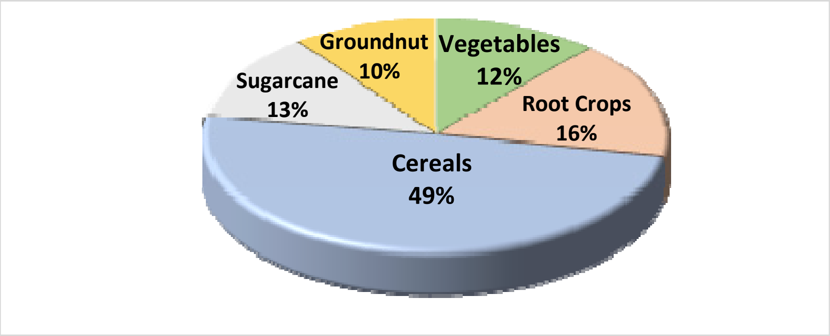

Figure 2: Sources of crop residue in the study area.

contributed by groundnut. Based on the type of waste generated after sorting, it can be deduced that maize is the major crop planted in the 2013 farming season in Ikara local government area of Kaduna state. This was subsequently confirmed through personal interview with the farmers and data obtained from the questionnaire survey.

The result obtained differs from the work of Adeoye *et al.* [16] in Minna, Niger State where the researchers found out that groundnut was the major contributor of crop residue in Kontagora zone, rice was the major contributor in Bida zone and maize is the major contributor in Shiroro zone. The result however shares close similarity with that of Kwaghe *et al.* [10], in Jere local government area of Borno state where maize was by far the highest contributor to crop waste

3.5 Crop residue management

The majority of the households representing 48.16% indicated that they reuse residues generated from their farming activities (Table 4). Most of them feed their livestock with the straws and stalks. Burning is also a predominant management option as claimed by 27.89% of the respondents. This agrees with the work of El-Haggar *et al.* [8], where the researchers noted that despite the management options available to farmers in Egypt, many farmers view the practice of residue utilization as an extra cost with little financial returns and therefore the preferable way is to get rid of the residues is by dumping and open burning. About 15.26% of respondents in Ikara bury their crop residue especially in Janfalan and Saulawa wards where excavation pits are found while other management options such as dumping accounts for 8.68%. From this result, it can be seen that a huge amount of residues is mismanaged by the farmers of the study area. This is because for a crop residue management to be effective it must maximize the economic benefit from the waste resource and maintain acceptable environmental standards [6].

Table 4: Disposal methods adopted by respondents in managing crop residue.

Disposal methods	Frequency	Percentage (%)
Burning	106	27.89
Burying	58	15.26
Reuse	183	48.16
Others	33	8.68
Total	**380**	**100**

Source: field survey 2014.

However, Figure 3 shows that among the respondents that reuse crop waste, 94 farmers indicated that they sell them while 43 use these crop waste as cover crops, 25 use them as animal feed while the remaining 21 adopt multiple uses such as fencing of farm yards and houses, poultry mats, domestic uses etc.

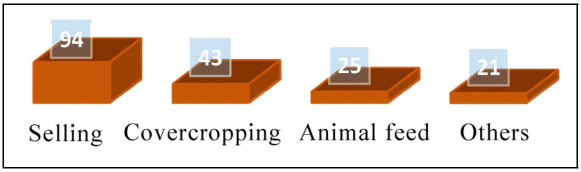

Figure 3: Reuse options of crop waste.

3.6 Efficiency of crop waste disposal technique

Table 5 shows the self-assessment of crop waste management methods of farmers in the study area. From the opinion the management of crop waste in Ikara is ineffective (poor and very poor) as attested by 52.36% of the respondents. This is because as indicated by Shafiul and Mansoor [17], agricultural waste forms the potential renewable energy source as biomass. Therefore, putting the huge quantities of biomass resources, mostly in the form of crop residues which are currently disposed by burning or dumping, to energy production could potentially increase the energy supply. It also confirms the statement of Jekayinfa and Omisakin [18] that agricultural waste in most developing countries, including Nigeria are not properly managed. On the other hand, 47.63% (very good and good) indicated effective management of crop residue.

Table 5: Opinion of respondents on management of crop residues.

Management option	Frequency	Percentage
Very good	105	27.63
Good	76	20
Poor	185	48.68
Very poor	14	3.68
Total	**380**	**100**

Source: field survey 2014.

3.7 Factors militating against efficient crop residue management

Having established that crop residue management techniques adopted are inefficient, the study also investigated some of the possible factors affecting the proper utilization of crop waste in the study area. The responses of the farmers are presented in Table 6. The result shows that 31.58% reported that ignorance of the efficient/sustainable management methods and benefits of such management is the major factor as most farmers are not aware of the economic benefits of these residues such as for sale and energy regeneration and as cooking gas.

Therefore, this ignorance on the benefits of crop residues makes them to subscribe to inefficient crop residue management such as burning and open air dumping. Improper planning of farm yards was reported by 31.32% which indicated that some farm yards are not well situated and in some cases are too far from waste management facilities which make crop management efficiency difficult. On the other hand, 21.31% of the respondents indicated that lack of disposal facilities on the farm yards such as composting pits is a major factor militating against efficient management of crop residue. The remaining 15.79% of the respondents indicated that indiscipline of farmers is a factor affecting effective crop residue management.

Table 6: Factors affecting crop residue management.

Factors affecting crop residue management	**Frequency**	**Percentage**
Lack of disposal facilities	81	21.31
Improper planning of farm yards	119	31.32
Lack of awareness on agricultural disposal methods	120	31.58
Indiscipline of farmers	60	15.79
Total	**380**	**100**

Source: field survey 2014.

4 Conclusion and recommendations

The management of crop residues in Ikara local government area of Kaduna State appears inefficient given the multiple benefits they could otherwise provide. The current management option is not perfect and the existing framework to ensure adequate management system and the collection facilities is not available. Crop waste is still collected without separation at the source, treatment facilities are limited and the collected waste is mostly dumped haphazardly in open areas or in most cases burnt before the next farming season. Furthermore, reuse of agricultural waste will minimize cost and ensure a healthy environment for the farming communities. Based on the findings of this study, chances are that crop residue management in the study area can be improved. It is suggested that intensive mass literacy programmes on the economics of crop residue management be undertaken in the study area.

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A review of the current digestate distribution models: storage and transport

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Abstract

Over the past few years, the biogas sector has experienced an important growth in the number of biogas installations all over Europe, and consequently, the quantity of digestate also has had a significant increase. In Europe, biogas production by anaerobic digestion (AD) is a common source of renewable energy and the current amount of installations is around 13,000. Together with biogas, digestate is one of the two main by products resulting from the biogas process. The digested effluent is a liquid product rich in nitrogen (N), phosphorus (P), potassium (K) and micronutrients. Therefore, there is a wide variety of digestate utilization depending on the quality, the origin of the feedstock, the operating conditions of the process as well as the phase of the by-product. The most common end uses are biofertilizer and soil amendment, due to its essential characteristics and when the quality is adequate for agriculture use. Before land application, environmental and agronomic reasons affect the storage of the digestate for a required period of time, in the biogas installations or near the area of application. Hence, the increasing production of digestate, the low solids content of whole digestate and the vulnerability of several land areas to the amount of nitrate and phosphate in Europe, convert the biofertilizer into a bottleneck for the biogas sector, due to the difficulty for its management.

This paper contains an extensive review of the technical literature regarding digestate distribution. The objectives of this paper were to identify and analyse the current digestate distribution systems; storage and transport in Europe.
Keywords: digestate, digestate distribution, storage, transport.

1 Introduction

Biogas production by anaerobic digestion (AD) is a common source of renewable energy. Biogas energy may have several benefits; it reduces pollution from agricultural and industrial activities, generates green energy reducing the usage of fossil fuels, and also permits the production of biofertilizer, decreasing the utilization of mineral fertilizers. In Europe, the number of biogas installations reached in 2013, 13378.7 units and the biogas primary energy produced was 13.4 Mtoe [1]. Biogas can be produced in different installations such as anaerobic digesters, wastewater treatment plants or landfills sites. Consequently, and as a result of the AD, two valuable products are produced; biogas and digestate. Biogas is a gaseous fuel that can be burnt directly to produce electricity and heat [2], used as a transport fuel, or purified for injection into the gas grid, and digestate is a highly valuable biofertilizer [3], rich in both organic matter and in macro- and micronutrients. There is a wide variety of digestate utilization depending on the quality, the origin of the feedstock, the operating conditions of the process as well as the type of digestate. Although it is considerate a high quality biofertilizer, other uses have been proved, in different studies, such as a soil amendment [4] or soil fuel [5].

The increasing number of biogas installations involves an increase in the amount of digestate that is obtained. Thus, an average of approximately 20 cubic meters of digestate can be produced per year and kilowatt of installed electric capacity. An average biogas plant using renewable raw materials with a capacity of 500 kW_{el} produces about 10.000 tons of digestate per year [6]. Moreover, digestate usually has low dry matter content and low nutrient concentration. For these reasons its storage, transport and application are expensive [7].

The aim of the present paper is to provide information concerning the current distribution models for digestate. The technical information used for the implementation of the paper was resulting and based on peer-reviewed scientific literature and technical reports with relation to current digestate distribution models.

2 Background and objectives of digestate distribution models

Management of digestate involves several topics such as storage, processing, transportation, utilization, economics, and environmental quality.

Digestate has high water content and consequently high volume compared to its fertilizer value, so it requires large amount of space for storage facilities at the biogas installation or close to the area of utilization. Before the utilization of digestate, it is stored and several factors affect the required storage period, such as environmental restrictions for application, digestate stabilization, geographical location, soil and crop type, and digestate demand. The storage of digestate entails a significant cost for the biogas system, as well as occupation of land, for example a biogas installation of 500 kW requires 4 ha for storage facility [8].

Mostly, the treatment of digestate aims to reduce volume and concentrate nutrients. Partial processing will reduce the volume of the digestate, for example through solid- liquid separation of the whole digestate, and complete processing will recover nutrients (N, P, K), so some technologies are available today at the market such as composting, drying, evaporation, ammonia stripping, and membrane separation. The cost of installation and operation of several of those techniques are high, due to adequate machinery, high energy consumption and reagent consumption.

On the other hand, and regarding digestate transportation, the cost of transportation is a critical factor for the viability of biogas plant, due to the water content of the digestate, thus the efforts to minimize the cost of the logistics of digestate are essentials to be able to make more profitable the product and the biogas sector.

The quality of digestate defines the possible end-use. The main practice is land application due to the characteristics of the effluent of AD, because it is rich in nitrogen, phosphate and potassium, but on the other hand it may content some heavy metals [9], antibiotics [10], organic pollutants [11] or pathogens that can limit digestate utilization [12]. In many parts of Europe, livestock production is concentrated and intensive, and creates a permanent excess of nutrients, making such areas highly vulnerable from the point of view of nutrient pollution of ground and surface waters [13]. The amount of ammonium-nitrogen contented in digestate limits the use of digestate due to environmental regulations which control the environmental risk regarding nitrates, where the maximum amount of nitrogen that can be supplied to the land is 170 kg N/ha/year, and it is regulated by the council directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC). The required storage capacity and the compulsory season for spreading in different countries in Europe, that it is related to the quality of digestate (as shown in table 1). Furthermore, phosphorus contented in digestate affects the quality of surface and ground waters, and it also limits the use of the anaerobic digestate for fertilizing proposes. Phosphorus, which is responsible for eutrophication, has also to be considered in the digestate management and it is regulated by the European directive of Water Framework Directive (2000/60/EC, WFD). In addition, environmental regulations regarding heavy metals also apply to the digestate quality, it has been regulated since June 1986 by the European directive 86/278/EEC on the protection of the environment, and in particular on the soil, when sewage sludge is used in agriculture. Furthermore, in some countries there are national and local regulations regarding the environmental parameters and also the agronomical ones are defined in order to limit the use to sewage sludge with a high organic matter content and good level of nutrients. Pathogens are controlled by the Regulation (EC) No 1069/2009 of the European parliament and of the council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation).

For these reasons, some European countries have developed standards for the regulation on digestate; Germany (RAL GZ 245 Digestate from biowaste, RAL GZ 246 Digestate from energy crops), Sweden (SPCR 120 Biowaste digestion residues) or United Kingdom (PAS 110) for example.

Table 1: Examples of national limits regulating nitrogen loading on farmland, required storage capacity for digestate, and its spreading season [14].

COUNTRY	MAXIMUM NUTRIENT LOAD	REQUIRED STORAGE CAPACITY	COMPULSORY SEASON FOR SPREADING
Austria	170 kg N/ha/year	6 months	28/02–25/10
Denmark	170 kg N/ha/year (cattle) 140 kg N/ha/year (pig)	9 months	1/2–harvest
Italy	170–500 kg N/ha/year	90–180 days	1/2–1/12
Sweden	170 kg N/ha/year (calculated from livestock units per ha)	6–10 months	1/2–1/12
Northern Ireland	170 kg N/ha/year	4 months	1/2–14/10
Germany	170 kg N/ha/year	6 months	1/2–30/10 Arable land 1/2–14/11 Grassland

Hence, the main objective of digestate distribution models is to optimize the management of the digestate, from an environmental and economical perspective, to guarantee the viability of the biogas system.

3 Digestate

3.1 Digestate characteristics

Digestate is the liquid-solid by-product produced through the AD of organic material. The anaerobic effluent contains macronutrients (N, P, K, Ca, S and Mg) and micronutrients (B, Cl, Mn, Fe, Zn, Cu, Mo and Ni). Usually, its characteristics depend on the input material, operating conditions of the AD process and digestate processing techniques. The nutrient composition of the feedstock affects the biogas composition and specific methane yield, as well as the composition of the digestate [2]. The substrates commonly used in AD include manure, agricultural waste, energy crops, waste from food-processing industries, sewage sludge and organic municipal waste [15]. Depending on the AD process and the feedstock, the dry solids content can vary in a considerable wide range of about 3.5 to 13% [6].

In general, the anaerobic digestate is rich in nitrogen (N), phosphorous (P) and potassium (K). After solid-liquid separation the liquid part contains high N percentage and the solid part contains high P content. In addition, the presence of heavy metals (Cd, Cr, Pb, Ni, Hg, Cu, Zn) and organic pollutants can be found [16].

Table 2 shows some of the characteristics of the digestate.

3.2 Types of digestate

Digestate, based on its physical properties, can be classified as whole digestate, liquid fraction or liquor, and solid fraction or cake, and their characteristics rely basically on the solid-liquid separation technique applied.

On the other hand, digestate can also be classify, depending on the source of feedstock, such as agriculture-based digestate (manure and crops), digestate from food and municipal waste, and digestate from waste water treatment plant.

Table 2: Digestate characteristics [12].

	ABSOLUTE VALUES	CHANGE a)
DM (%)	1.5–13.2	- 1.5 to -5.5
Organic DM (%DM)	63.8–75.0	-5 to -15
Total N (%DM)	3.1–14.0%	b)
Total N (kg Mg -1 FM)	1.2–9.10	≈0
Total NH_4^+ (kg Mg -1 FM)	1.5–6.8	?
NH_4^+ share on total N (%)	44–81%	+10 to +33
Total C content (%DM)	36.0–45.0	-2 to -3
C:N ratio	3.0–8.5	-3 to -5
Total P content (%DM)	0.6–1.7	b)
Total P (kg Mg -1 FM)	0.4–2.6	≈0
Water soluble P (% of total P)	25–45	-20 to -47
Total K (%DM)	1.9–4.3	b)
Total K (kg Mg-1 FM)	1.2–11.5	≈0
Total Mg (kg Mg-1 FM)	0.3–0.7	≈0
Total Ca (kg Mg-1 FM)	1.0–2.3	≈0
Total S (kg Mg-1 FM)	0.2–0.4	?
pH	7.3–9.0	+0.5 to + 2 units

a) In comparison to undigested liquid animal manures, absolute values.
b) Increases with degree of DM degradation.
DM = Dry matter. FM = Fresh matter. ? = No data found/no data available.

Table 3: Substrate parameters influencing digestate composition [12].

SUBSTRATE PARAMETER	IMPACT ON DIGESTATE COMPOSITION
Organic waste	• low total solids (TS) content • low percentage of organics in TS
High amount of abattoir waste	• high nitrogen concentration • high percentage of ammonia in total nitrogen
High amount of manure	• low total solids (TS) content • considerable nitrogen concentration
Energy crops	• high total solids (TS) content • high percentage of organics in TS (VS/TS ratio)

3.3 Use of the digestate

There is a wide range for utilization of digestate, which depends on the quality and the origin of the input substrate, as well as the type and characteristics of digestate. The most common use is land application such as fertilizer and soil conditioner [4], only if heavy metal content (Cd, Cr, Pb, Ni, Hg, Cu, Zn) and organic pollutants make it suitable for agriculture use.

Moreover, digestate can also be converted into compost [17], used for growing medium for plants and for land regeneration. Other studies proved uses such as solid fuel such as a promising alternative after its drying and pelletizing [5]. Digestate can also be used as building material. In addition, after separation of the digestate, the liquid phase may have different end-uses. It can be spread directly to the land as N-rich fertilizer, or recirculated to the AD process as process water, or further treated to obtain concentrates or pure water [18].

4 Parameters for digestate logistics

The influence of the logistics in the feasibility of the biogas systems is quite important due to its high cost. A proper management of the digestate will guarantee a reduced cost of the overall economics of the biogas system. Several parameters influence the logistics for the digestate:

- Digestate treatment;
- Storage installations and demand;
- Transportation modes and distances;
- Biogas plant location and place of digestate utilization;
- Digestate utilization and application.

5 Digestate processing

Digestate processing technologies can play an important role in the management of digestate by providing water reduction, nutrient management, proper storage, or/and enhance quality. The installation of a digestate processing technology is due to the impossibility of spreading digestate near the biogas plant, and consequently digestate have be to be transported longer distances for its disposal. Nowadays several treatment technologies are being used at the biogas sector, and the selection of the suitable technology will highly depend on the digestate characteristics, location, local conditions, energy requirements, chemical addition requirements, end- user and investment cost. The water content of the digestate has a decisive influence on the costs of the treatment of digestate [19]. Digestate processing is not a standard or defined process, it depends on the requirements of a specific biogas installation, local conditions and applicable regulations, and it can consist of a single process or a combination of several techniques. Moreover, digestate processing can be partial, primarily for the purpose of volume reduction, or it can be complete, refining digestate to pure water, a solid biofertilizer fraction, and fertilizer concentrates [20]. Partial treatment is less energy demanding, cheaper and, in regions where there is a surplus of phosphorus, it is the most economical conditioning technology [21]. A partial treatment is the solid-liquid separation process, and it is usually the first step in the digestate processing, which divides the digestate into a concentrated phosphorus rich solid phase and a nitrogen rich fluid phase, and it aims to dewater the digestate, and allows handling nutrients separately [22]. Thus solid-liquid separation provides a lower transport cost [23], due to the reduced water content, as well as simpler storage conditions [18].

In addition, other technologies are available at the market, which main to recover nutrients (N, P, K) such as composting, drying, ammonia stripping, evaporation, and membrane filtration technologies. Generally, these technologies entail high investment cost, huge energy requirement, high maintenance cost, and large amount of chemical reagents [7]. For this reason, they are economically feasible for biogas plants with capacities higher than 700 kW [12].

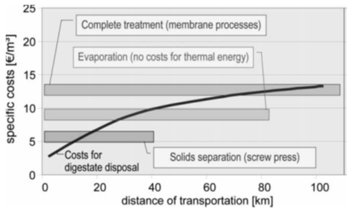

Figure 1: Comparison of cost ranges for specific treatment options versus costs for digestate disposal [18].

6 Digestate storage

Digestate, which is generated continually through the AD process, has to be stored properly until the growing season or vegetative growth, which is the only appropriate time for its application as a fertilizer, due to crop nutrient requirements and to avoid nutrient losses. Hence, biogas plants must have proper facilities with the required storage capacity, or in an alternative case, digestate could be transported and stored in a headland tank on field close to the destination point. In case the storage facility is located in the biogas installations, a storage facility for a 500 kW_{el} biogas plant may need around 4 ha of dedicated space [7].

The storage systems have to be designed based on digestate production volumes, digestate type, digestate demand, land availability, crop type, geographical area, soil type and environmental restrictions. The volume of digestate, which is produced during the processes, depends on the input material and the frequency with which the digestate storage facilities are emptied. Reference values for the mass loss of the input substrate related with the digestate that is obtained are 3% for manure and 20 to 30% for silage, and for cereal grains, 70 to 80% mass loss may be expected [6]. The type of digestate also impacts on the storage facility, whole digestate and liquid fraction of digestate are usually stored in storage tanks, lagoons or flexible storage bags, and on the other hand solid fraction of digestate is stored in covered flat concrete areas or inside buildings. Finally, and depending on the crop, the best time for digestate application generally is during growing season, to avoid nutrient leaching and runoff into ground water. For this reason, European legislations demand a storage capacity for 6 to 9 months, due to seasonal variations [24].

In addition, digestate storage facilities must be built with materials and characteristics that guarantee the water tightness, to avoid water and soil pollution. In some countries several environmental measures may also be required such as spillage, waterproof liners, and leakage detector to be place at the storage facility.

Furthermore, during the storage period some emissions may occur, if digestate is stored in open tanks, and the emissions rely on the pH, temperature, dry matter content, nitrogen content and storage characteristics of the digestate. An effective method for minimizing emissions is the installation of air tight storage covers, which allow reducing the gaseous emissions (CH_4, N_2O, NH_3) by 90%, and 55–100% of NH_4-N retained in the digestate [25]. Another advantage of installing storage covers is that, they also avoid the accumulation of rain water, and consequently the dilution of the digestate and the increment of the volume. The cover material of the storage facility can be a membrane, concrete, steel or a floating cover of straw, clay granules or plastic on top of the liquid surface [26]. Basically, proper storage preserves value and qualities of digestate, and prevents losses of ammonia and methane to the atmosphere, nutrient leakage and nutrient run off, as well as emissions of odors and aerosols [27]. Basically, covered digestate storage decreased the emissions from digestate storage tank by 65% as opposed to open storage [28].

The most common storage systems are lagoons, storage tanks, and flexible storage bags. Lagoons are outdoor pits or ponds. Generally, lagoons are deep pits, with a sealed bottom and sides which allows to storage digestate, and a waterproof membrane or layer is installed, for protection proposes. Polyvinyl chloride (PVC) membranes or concrete are the adequate waterproof component to avoid leaching. Furthermore, the size of a lagoon is based on the volume of the total digestate entering into the lagoon, and precipitation and runoff volumes. They can be built above or below ground, whereby below ground lagoons are not visible from outside, and consequently the landscape impact is therefore minimal. Besides, lagoons can be covered or uncovered, with flexible covers. Covered lagoons offer significant environmental benefits reducing ammonia loss, methane emissions and odor, as well as it avoids the increment of water content in digestate due to rain water. An important consideration is that earth settlement or even earthquakes cannot damage lagoons easily unlike any other digestate storage due to the construction materials. An alternative to lagoons may be storage tanks, which can be built partly above ground or buried in the ground. The first option may prove cheaper to construct than tanks buried in the ground, but digestate would need to be pumped to aboveground stores [29]. Storage tanks can be built with different materials such as concrete or steel. Poured concrete can be designed with cylindrical shape on site, and precast concrete panels that are formed at an off-site factory can be transported and tipped up vertically on site. Steel is another option as building material for storage tanks, which can be erected either as bolted together panels or as welded steel panels. Furthermore, steel can be stainless steel or coated with an epoxy paint system or with a glass-fused-to-steel coating. Steel tanks can be joined to the concrete foundation by means of an embedded ring cast into the tank foundation. Depending on the country, the storage installations must have a synthetic liner to avoid leaching as a preventive environmental measure. Finally, flexible storage bags are air-tight facilities used to storage digestate. They are built several meters below ground as the storage tanks and the material which they are built is PVC-coated polyester fiber with high tensile strength. Mostly, another component is installed in the storage facilities, and it is mixing system which avoids sedimentation and reduction of the capacity of the storage facility, as well as it gives homogeneity to the digestate before use and. The facilities analyzed before aims to storage the liquid fraction of the digestate or the whole digestate, so regarding the solid phase it is stored in covered flat areas or buildings with a slight floor slope to recollect the leachate.

7 Transportation modes

Once digestate is generated and stored, it has to be transported to the destination point. The transportation of digestate is an important cost of the overall biogas production economics, due to the high water content of the digestate [30]. Figure 2 shows the relation between the costs of digestate related with the distance to be transported. So, digestate processing has an important impact on the cost of transport, when they aim to reduce water content recover nutrients of the digestate. However, the high water content leads to comparatively high costs for transport and spreading of the digestate. For example, the transport cost can be reduced by separating the manure into a nutrient-rich solid fraction and a liquid fraction [22].

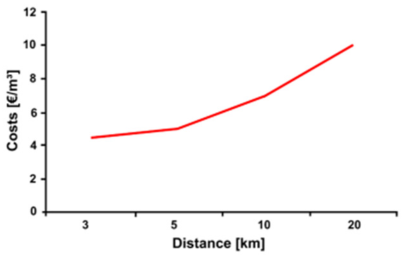

Figure 2: Relation between distance and cost of digestate transportation [2].

The mode of transport varies depending on the distance to the place of utilization, the type of digestate, and digestate processing. The most usual modes of transport are tractors, dumpers, trucks, bulk transport, and pipelines. Nowadays, the most common form of digestate transportation is by truck [31]. The following table shows the most common modes of transport used for digestate transportation, and the estimation on the transport cost depending on the type of vehicle and its capacity.

Pipeline transport of digestate can be considered as an alternative way for the transportation of digestate [31]. Pipelining of biomass has a significant economy of scale, with a scale factor less than 0.5 whereas truck transport has no economy of scale: more material simply requires more truck trips, with no or very minor variation in unit cost of transport [33]. But on the other hand, pipelines are also beneficial for large scale transport over longer distances [34]. In case the selection of the transport mode is by pipelines it is important to consider the digestate processing technics to be applied as dilution increases and solids concentration drops, the viscosity of the digestate is reduced, giving lower pumping costs. More dilute digestate require a larger diameter pipeline, requiring additional capital investment [34].

Table 4: Estimating transport costs, depending on the type of vehicle and its capacity [32].

MODE	CAPACITY (m^3)	CONSUMPTION (Diesel/h)	POWER (CV)	Cost (€/h)
Dumper	20	15	320	31.9
	25	16	375	34.0
	30	17	400	36.9
Truck with trailer	16	15	320	30.2
	22	16	375	32.3
	27	17	400	35.1
Tractor	16	16,8	140	26.9

8 Distribution models

Nowadays different distributions models are applied depending on the specific biogas installation, geographical area, type of feedstock and digestate, and economics. Digestate distribution models are not a standard method which can be useful for all the biogas plants, and bad choices about how digestate is distributed can be critical to the viability of an AD project. Hence, it is important to analyse the characteristics of each biogas installation to develop a proper digestate management plan which should be integrated in the fertilizing plan of the farm in the same way as mineral fertilizers and it must be applied at even and accurate rates [27].

The most common distribution models are:

Option 1: Whole digestate is stored in a digestate storage tank for a time period and then transported to farmlands by trucks and spread on farmlands using conventional methods for spreading liquid manure [18]. The AD company will be the responsible of the digestate management.

Option 2: Whole digestate, after its storage, is pumped and translated through buried pipelines to land fields and spread it on land by methods for spreading liquid manure. The AD company will be the responsible of the digestate management.

Option 3: Digestate after partial processing (solid-liquid separation) will be handling different depending on the phase. Solid fraction can be applied directly to land by the AD company, or it can be dried or composted. The processing of the solid fraction can be managed by the AD company if the required installations are in the biogas installations, or it can be managed by another company. On the other hand, liquid digestate can be recirculated to the process or transported and spread it to the land, by the AD company, or it can be further processed. Mostly, the processing of the liquid fraction is realized by another company or a waste water plant.

Option 4: The AD company produce digestate which is managed by a company that is the responsible of the transport and application of the digestate. Frequently, such companies are in charge of the feedstock supply as well.

Option 5: The AD company treat livestock from different farms, and the owners of the farms are in charge of the supply of the feedstock as well as the return of the digestate to the lands.

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Short-term and long-term studies of the co-treatment of landfill leachate and municipal wastewater

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Abstract

The impact of the pre-treatment of landfill leachate on the co-treatment of landfill leachate and municipal wastewater was investigated through a short-term and a long-term study. The short-term study aimed to mimic the shock load of leachate on the wastewater treatment process. The leachate pre-treatment was achieved by coagulation and air stripping to remove partial chemical oxygen demand (COD) and ammonia. The long-term study aimed to investigate the effectiveness of leachate pre-treatment on nutrient removal of the wastewater treatment process in a long-term operational condition when air stripping was used as a means of pre-treatment. From the short-term study, it was found that at low mixing ratios (0.5% and 1%), pre-treatment did not produce any significant difference from the one without pre-treatment. When the untreated leachate mixing rate was increased (5% and 10%), the system was not able to achieve full nitrification during one cycle. However, the pre-treatment of leachate lowered the ammonia in the influent, therefore allowing for full nitrification. The long-term study demonstrated that even at a 10% mixing ratio, the high ammonia concentration in the leachate did not have a negative impact on the nitrification process. Due to the high non-readily biodegradable portion of COD in the leachate, the majority of the COD from the leachate ended up in the effluent thereby decreasing the effluent quality. It was found that at a 2.5% mixing ratio of leachate with wastewater, the overall biological nutrient removal process of the system was improved without compromising the COD removal efficiency.
Keywords: landfill leachate pre-treatment, biological nutrient removal, air stripping, landfill leachate to wastewater mixing ratio.

1 Introduction

Landfill leachate is produced by the seeping of liquids through landfilled waste. Rain water, melted snow percolating into the waste, the original water content or humidity of the waste itself, the degradation and compaction of the organic fraction, all contribute to the generation of leachate [1, 2]. Landfill leachate contains dissolved organic matter, inorganic macro components, heavy metals, and xenobiotic organic compounds such as halogenated organics. These contaminants play an important role in groundwater and soil pollution. Due to the complexity of the pollutants in the leachate, the treatment of landfill leachate is complicated, usually requiring various processes to reduce COD, nitrogen, and phosphorus all of which make the treatment of landfill leachate expensive.

The conventional landfill leachate treatment includes physico-chemical treatments and biological treatments. Physico-chemical treatments are usually used to reduce suspended solids, colloidal particles, colour, and certain toxic compounds. However the cost associated with this type of treatment is usually high. Current leachate treatment options include recycling and re-injection into the landfill cells, on-site treatment, discharge to a municipal water treatment facility, or a combination [3]. Co-treating the leachate together with municipal sewage is preferred for its easy maintenance and low operating costs. In addition, the degradation of organic pollutants is favoured because of the dilution and adaptation ability of the activated sludge [4]. However, considering that high concentrations of certain compounds (e.g. ammonia and toxic compounds) may inhibit the activated sludge treatment process, many wastewater treatment plants require the leachate to be pre-treated before it can be mixed and enters the municipal wastewater treatment process. It is believed that pre-treating the leachate is beneficial for the subsequent biological treatment at the plant.

Coagulation is widely used as a pre-treatment prior to biological treatment in order to remove non-biodegradable organic matter. Aluminium sulfate, ferrous sulfate, and ferric chloride are commonly used as coagulants [5]. Several studies have been conducted on the examination of coagulation for the treatment of landfill leachates. Those studies are aimed at performance optimization, i.e. selection of the coagulant, determination of operational conditions, evaluation of the effect of pH, and investigation of the addition of flocculants [6]. Depending on the landfill age and type of coagulant, the COD removal rate is in the range of 20 to 90%.

Air stripping is the most commonly used method for eliminating a high concentration of NH_4^+-N in the wastewater. In many applications, air stripping has been used successfully in the removal of ammonium nitrogen present in the leachate [7]. However, there are a few drawbacks to this technology. One drawback is the exhausted air which is mixed with NH_3 needs to be treated with either H_2SO_4 or HCl before it is released into the atmosphere. Other drawbacks are the calcium carbonate scaling of the stripping tower when lime is used for pH adjustment, and foaming when a large stripping tower is used [8].

As of this date, very few studies provide actual evaluations of the effect of the pre-treated leachate on additional biological treatment [9–11], a step that is considered necessary when dealing with leachate's complex characteristics. Most of the research evaluates the biodegradability of the leachate based only on a relationship between the BOD to COD ratio of the effluent as an indicator of the treatability of the leachate by biological means. There is a lack of information on if and how the leachate affects the biological nutrient removal process in wastewater treatment. This especially applies to the nitrification process, as nitrifiers are very sensitive to the environment. In addition, the benefit of pre-treating leachate to the wastewater treatment process has not been well studied. Therefore, the goal of this research is to investigate the short-term and long-term impact of leachate on the nutrient removal from municipal wastewater by comparing: 1) the leachate with and without pre-treatment; 2) different mixing ratios of leachate with wastewater.

2 Material and methods

2.1 Wastewater and leachate characterizations

The wastewater used for this research was from the SouthEnd Wastewater Treatment Plant (WWTP) in Winnipeg, Canada. It was delivered to the lab twice a week. Leachate was obtained from the Brady Road Landfill weekly. Both wastewater and leachate were stored in a cold chamber. The characteristics of wastewater and leachate are shown in Table 1.

Table 1: Characteristics of wastewater and leachate.

Parameter	Wastewater	Leachate
pH	7.5 ± 0.1	7.2 ± 0.1
COD (mg/L)	400 ± 210	1939 ± 108
TSS (mg/L)	196 ± 15	336 ± 203
BOD_5 (mg/L)	198 ± 35	248 ± 20
TN (mg/L)	45 ± 5	759 ± 56
$N\text{-}NH_4^+$ (mg/L)	36 ± 4	646 ± 84
TP (mg/L)	6.6 ± 1.5	6.7 ± 1.1

2.2 Leachate pre-treatment

2.2.1 Short-term test

The pre-treatment of leachate was achieved by chemical coagulation followed by air stripping. Chemical coagulation was carried out using ferric chloride solution. Jar test was carried out to determine the effective pH and ferric chloride dosage. The pH of leachate was first adjusted to 5.0 using an 18% w/w hydrochloric acid (HCl) solution. Then 500 mg/L of ferric chloride solution were added to the leachate. Rapid mixing was then applied for 3 minutes followed by slow mixing for 15 minutes. Finally, the leachate was allowed to settle for 30 minutes and the supernatant was drawn for the next treatment. For air stripping, the pH of leachate was first adjusted to 11 using a 25% w/w solution of sodium hydroxide (NaOH).

This was followed by 48 hours of aeration. Then the pH was neutralized to 7.5 using an 18% w/w HCl solution.

2.2.2 Long-term test

Due to the consideration of operational costs in real practice, pre-treatment leachate using chemical coagulation was eliminated in this study. Air stripping was used as only pre-treatment method for leachate. The air stripping method was same as described above.

2.3 Reactor setup

2.3.1 Short-term test

One sequencing batch (SBR) reactor was used to simulate the conditions of a biological nutrient removal (BNR) system. Waste activated sludge (WAS) was taken from the WestEnd WWTP, a BNR wastewater treatment plant, in Winnipeg to seed the reactors. The SBR reactor had a 4 L working volume with an HRT of 12 hours. The SBR was operated with 4 cycles per day and SRT of 10 days. Each cycle included feeding (5 minutes), anaerobic (1.5 hours), aerobic (4 hours), settling (20 minutes), and decant (5 minutes) periods. The SBR was fed with wastewater. The temperature was maintained at room temperature (20 ± 1°C), and the Dissolved Oxygen (DO) concentration over 4 mg O_2/L during aerobic phase. This reactor was operated and monitored for over 30 days (3 times the SRT) before starting the kinetic testing to ensure stable conditions.

For the kinetic test, the biomass from the SBR reactor was divided into three 1 L beakers, one served as control while the other two served as testing reactors. The Control reactor was fed only wastewater, while each one of the two testing reactors was fed with a specific mixture percentage of wastewater and leachate (either untreated or pre-treated with the combination of air stripping and chemical coagulation). The leachate to wastewater mixing ratios (by volume) were: 0.5%, 1%, 5% and 10%. Two sets of controls are reported in the discussion for untreated and for pre-treated tests. Since there were four mixing ratios to evaluate, one day the tests were done for 0.5%, 1% and a control. On a different day, the tests were carried out for 5%, 10% and a second control.

There were at least 7 days between each test to allow the recovery of the biomass. During the testing period, samples were taken from each of the reactors at 15 min intervals.

2.3.2 Long-term test

Three sequencing batch reactors (SBR) with working volumes of 3 L were setup. All three SBRs were seeded with the sludge from the WestEnd WWTP and were operated under the same condition as the SBR operated in the short-term test. Three SBRs were fed with wastewater and operated for over a month to reach a stable stage before the experiment. SBR1 served as a control reactor which was fed with wastewater only. SBR2 was fed with the mixture of wastewater and raw leachate. SBR3 was fed with the mixture of wastewater and pre-treated leachate. Three mixing ratios of leachate (with and without pre-treatment) with wastewater of 2.5, 5 and 10% were tested. The test with a mixing ratio of 2.5% lasted for 22 days. This was followed by the test with a mixing ratio of 5% for 38 day and then one with a mixing ratio of 10 % for 57 days.

In order to understand the performance of each reactor, kinetic tests of treatment cycles were carried out. Samples were taken from each reactor at 30 min intervals. The parameters monitored included pH, soluble COD, ammonia nitrogen ($N\text{-}NH_4^+$), NO_x (nitrite + nitrate) and ortho-phosphate ($P\text{-}PO_4^+$).

2.4 Analytical methods

COD, total nitrogen (TN), and total phosphorus (TP) were measured using HACH® digestion vials. BOD_5 and total suspended solids (TSS) measurements were carried out following laboratory procedures according to the Standard Methods [12]. $N\text{-}NH_4^+$, $P\text{-}PO_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$ was measured using an automatic flow injection analyser Quick Chem 8500, LACHAT Instruments.

3 Results and discussion

3.1 Short-term study

Figure 1 presents the results when untreated and pre-treated leachate was mixed with wastewater at different percentages. Control represents the reactor with only wastewater as influent. Mixing leachate (either pre-treated or untreated) with wastewater at 0.5% and 1% ratios did not produce any significant difference in the ammonia influent concentrations or the system response (Figures 1a and 1c). However, when the mixing ratio was increased to 5% and 10% with untreated leachate (Figure 1b), it can be seen that the ammonia influent concentration increased 2 to 3 times the value of the control. Additionally, the system was not able to achieve full nitrification in one cycle (ammonia concentrations in the effluent were 3.6 mg/L and 20.4 mg/L, respectively). This could be due to the higher concentration of ammonia in the influent. The nitrification rate was calculated based on the slope of the curves. Since the nitrification rates of 5% and 10% treatments were comparable to the rate of the control, the nitrification inhibition probably did not occur. A longer aeration period would be needed for the full conversion of ammonia at these higher concentrations.

As shown in Figure 1d, the pre-treatment of leachate lowered the ammonia in the influent, thus allowing full nitrification under the same operational condition. It was concluded that in the case of shock load (i.e. one time addition), pre-treatment of leachate is necessary when the mixing ratio of leachate with wastewater is higher (5% to 10%), to assure the performance of nitrification at the wastewater treatment plant.

In terms of soluble COD (sCOD) removal, systems fed with the pre-treated leachate also provide a better removal than the ones with untreated leachate. The effluent sCOD concentration after the 5.5 hour operation with the pre-treated leachate in all cases was lower than 50 mg/L, which is very close to the control values (Figures 2c and 2d). However, for the ones with untreated leachate, the sCOD in the effluent was in the range of 50 to 92 mg/L (Figures 2a and 2b).

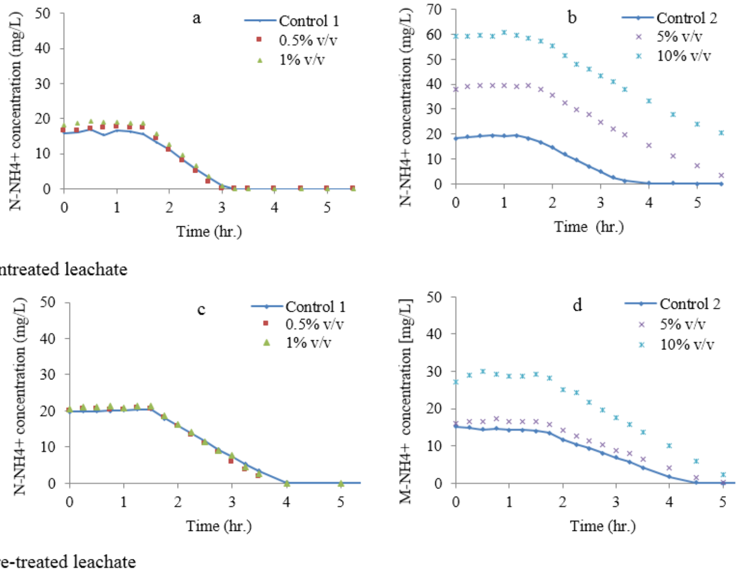

Figure 1: Ammonia degradation at different mixing ratio of leachate with wastewater.

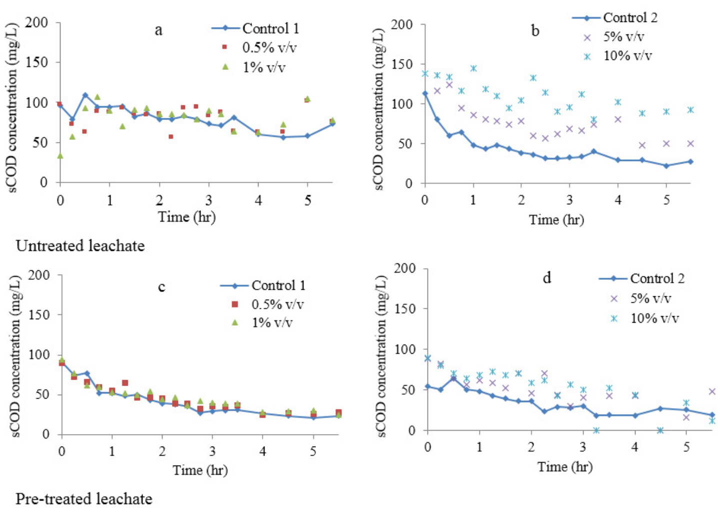

Figure 2: Soluble COD degradation at different mixing ratio of leachate with wastewater.

The pre-treatment, by both air striping and chemical coagulation, was effectively reduced the soluble COD and ammonia concentrations of the leachate. Without the pre-treatment, mixing the leachate with the municipal wastewater increased the influent values of sCOD and ammonia to a point where removal by biological means was not achievable in the normal operation time of the BNR system.

3.2 Long-term test

3.2.1 COD removal

The COD removal rate of the control reactor SBR1 was fairly constant, within the range of 81–87% (Figure 3). Air stripping was used to pre-treat the leachate, which had no significant impact on the COD content of leachate. Therefore, SBR2 and SBR3 had fairly similar COD concentrations in the influent and both reactors also showed similar COD removal rates at each mixing ratio. In comparison to SBR1, the COD concentrations in the influent of the SBR2 and SBR3 increased approximately from 100 mg/L to 200 mg/L with mixing ratios from 2.5% to 10%. At a mixing ratio of 2.5%, both reactors achieved similar COD removal rates of SBR1 of 87%. However, when the mixing ratios were increased to 5% and 10%, the COD removal rate of both reactors decreased to around 80% and 63% respectively. This was probably due to the fact that a major part of COD in the leachate was non-readily biodegradable (rbCOD) (Table 1). Increasing leachate mixing ratios increased the non-readily biodegradable COD content in the influent which resulted in the decreased COD removal rates in SBR 2 and SBR3.

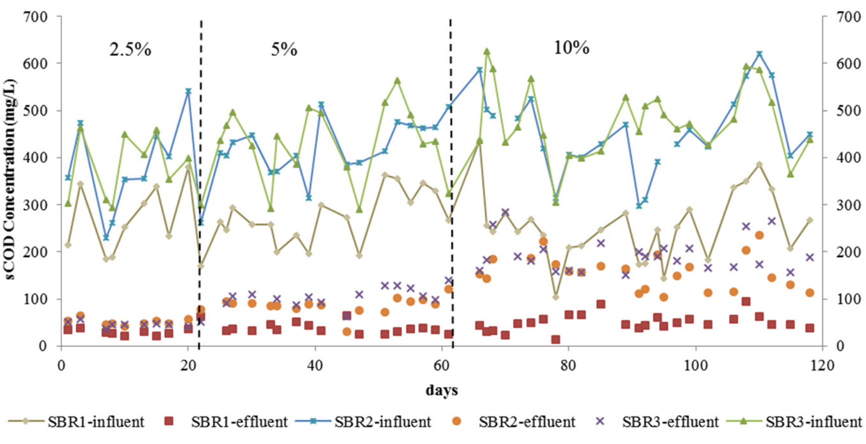

Figure 3: COD profile at different mixing ratio.

3.2.2 Nitrogen removal

Only wastewater was used as a substrate for the control reactor SBR1 throughout the experiment. Therefore, the influent ammonia concentration of SBR1 was fairly constant (Figure 4). Pre-treatment of leachate with air stripping significantly decreased (about 80%) the ammonia concentration of leachate. Therefore, the ammonia concentration in SBR3 was only slightly higher than the control reactor SBR1 (Figure 4). Whereas SBR2 which received the mixture of raw leachate and wastewater, had a much higher ammonia concentration in the influent. At a 10% mixing ratio, the average $N\text{-}NH_4^+$ concentrations of the SBR2 were 111 mg/L. Regardless of the different $N\text{-}NH_4^+$ concentrations in the influent, all three reactors showed excellent $N\text{-}NH_4^+$ removal performance throughout the experimental period. The kinetic study at 5% and 10% mixing ratio showed that all three reactors were able to fully remove ammonia in three hours (data not shown). The nitrification rates of three reactors are presented in Table 2. It was observed that with similar influent $N\text{-}NH_4^+$ concentration, the nitrification rates of SBR1 and SBR3 were very close, and they were in the range of 3.3-4.3 mg/g VSS hr, whereas the nitrification rate of SBR2 was approximately 8.3 mg/g VSS hr which was significantly higher than that of SBR1 and SBR3. The increased nitrification rate of SBR2 indicated that the system was able to adapt to the increased ammonia load.

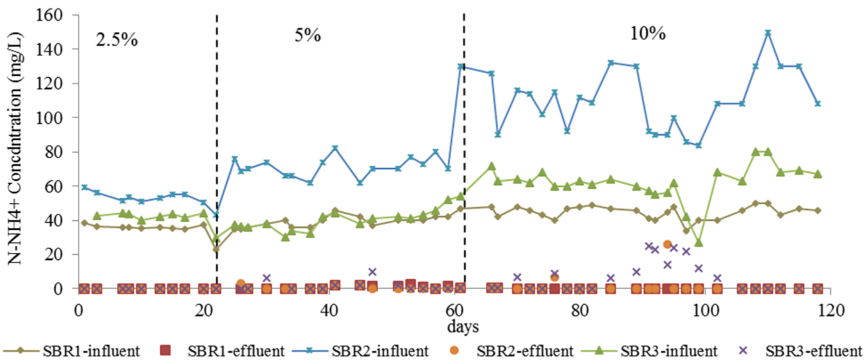

Figure 4: Ammonia ($N\text{-}NH_4^+$) profile at different mixing ratios.

Table 2: Reactors nitrification rate (mg/gVSS hr) at different mixing ratios.

	Mixing ratio	
	5%	10%
SBR1 (control without leachate)	3.4	3.3
SBR2	8.0	8.3
SBR3	3.5	4.3

At the completion of this part of the experiment, testing on SBR 3 was continued for another 12 days. The goal of this test was to examine the effect of no pH adjustment after pre-treatment of leachate on the nitrification of the system. This test was conducted in order to reduce the amount, and thereby the cost, of the chemical used for pH adjustment in the industrial setting. After pre-treating the leachate by air-stripping for 48 hours, the pH of the leachate was approximately 10.5. The pH of the influent, after the leachate was mixed with wastewater at a 10% ratio, was close to 9.0. The pH of the reactor was in the range of 8.5–9.5. It was observed that in 2 days, the SBR 3 started losing nitrification. On day 5, the SBR3 lost about half of its nitrification capacity, i.e. only half of the influent ammonia was converted to nitrate. No further deterioration of nitrification was observed until day 12. In terms of the COD removal, no significant difference was observed compared to the previous test. This test demonstrated that the pH adjustment of the leachate after pre-treatment was crucial for the subsequent treatments with wastewater, as nitrifiers are very sensitive to pH.

Certain degrees of denitrification were observed in all three of the reactors and only nitrate was detected (i.e. nitrite was not detected) in the effluent of all the three reactors. Although the influent ammonia concentration of both SBR1 and SBR3 were comparable, it was observed that SBR 3 had better denitrification performance than SBR1 as shown in Table 3. This could be due to the fact that the additional COD from the leachate in SBR3 facilitated the denitrification, even though the majority of the COD in the leachate was non-biodegradable. This was also reflected in the denitrification performance of SBR2. SBR2 was mixed with untreated leachate which increased the influent ammonia concentration, whereas SBR1 and SBR3 were not. Therefore, the overall nitrogen removal rate of SBR2 was lower than SBR1 and SBR3. However, SBR2 had the best denitrification performance among the three reactors. It had the highest nitrogen removal with an average 54.6 mg/L at mixing ratio of 10%. It was concluded that the observation of better denitrification performance in SBR2 and SBR3 than SBR1 was due to the additional COD in the leachate which promoted the denitrification.

Table 3: Average nitrogen removal during the experiment.

Mixing ratio	SBR1 (mg/L)	SBR2 (mg/L)	SBR3 (mg/L)
2.5%	20.6 (±0.9)	32.1 (±5.3)	24.0 (±4.4)
5%	24.1 (±3.8)	41.1 (±6.3)	26.2 (±4.2)
10%	23.9 (±4.6)	54.6 (±16.3)	35.5 (±8.4)

3.2.3 Phosphorus removal

The phosphorus concentration in the leachate was very low with an average of 6.7 mg/L, which was in the same level as that of wastewater. Therefore, the phosphorus concentrations in the influent to all three reactors were in the same range.

Control reactor SBR1 showed poor phosphorus removal throughout the experiment with an average removal rate of 35%. This suggested that the wastewater did not have sufficient rbCOD for the biological phosphorus removal. On the other hand, at mixing ratio of 2.5%, both reactor sSBR2 and SBR3 showed excellent phosphorus removal (close to 100% removal rate). The kinetic study showed (Figure 6a) that the anaerobic phosphorus release of SBR2 and

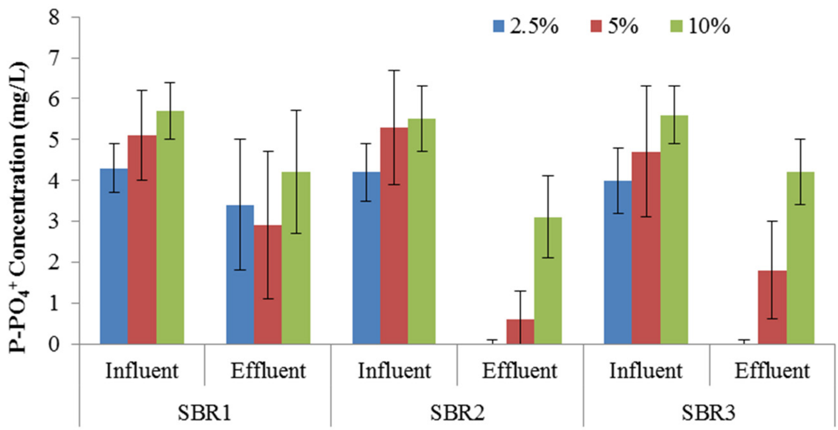

Figure 5: Phosphorus (P-PO_4^+) profile at different mixing ratios.

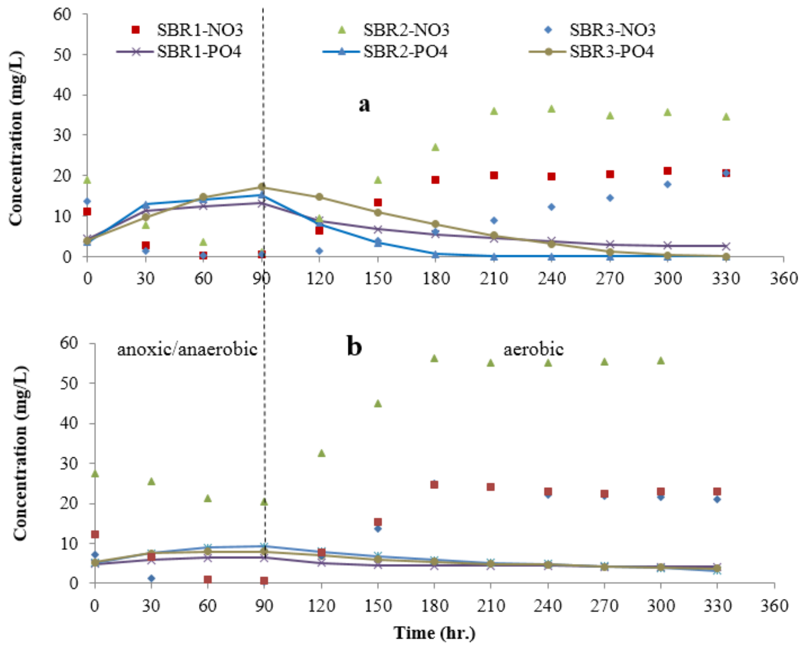

Figure 6: N-NO_3^- and P-PO_4^+ cyclic profile of the reactor at 2.5% (a) and 10% (b) mixing ratio.

SBR3 were up to 17.2 and 15.2 mg/L respectively. This indicated the existence of phosphorus accumulating organisms (PAOs) in the systems. The small portion of the biodegradable COD from the leachate might have helped the phosphorus removal process in SBR2 and SBR3. The leachate used for this stage (2.5% mixing ratio) was collected from the cells that were used for biosolids disposal. Therefore, the rbCOD in the leachate was fairly high compared to the leachate used during the rest period which was taken from different wells (cells). The further kinetic study at 10% (Figure 6b) showed that very little anaerobic/anoxic phosphorus release occurred in all the reactors. This indicated that the population of PAOs was significantly decreased. This was likely due to the low availability of the rbCOD in both wastewater and leachate. In addition there was a competition of the rbCOD between the denitrification microorganisms with PAOs since both groups of microorganisms existed in the reactors. The full removal of nitrate during the initial 1.5 hr anoxic /anaerobic period in both SBR1 and SBR3, as well as the particle denitrification in SBR3, indicated that denitrifiers out-competed the phosphorus removal microorganisms (Figure 6).

4 Conclusion

The shock load (short-term) study showed that at low mixing ratios (0.5 % and 1% of leachate to wastewater), regardless of pre-treatment, there was no impact of leachate on the overall wastewater treatment process performance due to the high dilution of the wastewater. When the mixing ratio increased to 5% and 10%, the system supplied with the untreated leachate was not able to achieve full nitrification during one treatment cycle. On the other hand, full nitrification was achieved in the system fed with pre-treated leachate as the pre-treatment lowered the ammonia concentration in the influent. The long-term study demonstrated that the system was able to gradually adapt to the increased ammonia concentration in the influent. Therefore, even at a 10% mixing ratio, the high ammonia concentration in the leachate did not have a negative impact on the nitrification process. Full nitrification was achieved in both reactors that co-treated wastewater mixed with leachate with/without pre-treatment. In terms of COD removal, the increased mixing ratio of leachate to wastewater resulted in decreased effluent quality. This was due to the high fraction of the non-readily biodegradable COD in the leachate. It was found that at a 2.5% mixing ratio of leachate with wastewater, the overall biological nutrient removal process of the system was improved without compromising the COD removal efficiency.

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Wastewater treatment and reuse in Alicante (Spain)

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Abstract

The treatment of wastewater in the province of Alicante (Spain) has experienced a positive evolution during the last few decades in that it was able to treat the volumes generated by the increasing population and adapt itself to the provisions of the CEE Directive 91/271. The implementation of the network collectors and the wastewater treatment system has meant that the province has been able to treat a total of 119 hm^3, which means 2.7% of all the water treated in Spain during 2014. It has also resulted in a large number of plants being built with tertiary treatment, and even more advanced treatments that improve the quality of water with a view to future use. The increase in the quality of treated water occurs because of these improvements and aims not only to preserve the natural environment with appropriate discharges to the regulations, but also to form a model of an integrated water cycle system where reclaimed water can be returned to the system for different applications. Given the water scarcity in the area the ability to reuse this treated water is a key element in ensuring certain water demand as this new resource could be used for urban (street cleaning, watering gardens) or agricultural uses (irrigation) without having to resort to drinking water so lacking in this area. That is why this paper examines and evaluates the situation of wastewater treatment, and the later use of this reclaimed water in the province of Alicante, as this is a clear example in efficiency in the treatment and utilization of wastewater.
Keywords: wastewater, treatment, non-conventional resource, reuse, water cycle, tourism, Alicante.

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1 Introduction

Water, considered ancestrally as an unlimited renewable resource, has acquired, from the second half of the twentieth century, an aspect of a natural, economic and social good, characterized by its limited value and for being limiting as well (Rico *et al.* [1]). In the Spanish Mediterranean region, water has become a critical resource for the socio-economic development of this area, especially for the tourism and agriculture sector (Hernández [2]), but has also become a problem due to its scarcity. This province has a significant need for water resources, given the scarcity of its own resources due largely to climatic factors (Olcina and Rico [3]). In addition, tourism, a fundamental pillar on the Mediterranean coast, can generate a triplication of the population during the summer holidays. Besides this, an increase in demand due to agricultural development in the area has also been recorded, which, resulting from intensive cultivating systems, has led to an increase in arboreal and vegetable species in the area (Rico and Hernández [4]). This substantially affects the consumption demand and the subsequent treatment of the wastewater generated, so the infrastructure must be tailored for these flow peaks. In order to be able to ensure those new demands we have had to find new sources of supply, such as those called non-conventional resources. Reusing wastewater, after it has been properly treated, is one these new resources. In this way, the effluent from the wastewater treatment plant, which previously was discharged to a channel or to the sea, returns in order to be reintegrated into the hydrosocial cycle.

Water collected in urban agglomerations is called urban wastewater and it stems from the discharges of domestic activity often mixing with commercial, industrial, and agricultural activities, integrated in the urban nucleus, and also storm water (Trapote [5]). Urban wastewater, although it has a more or less stable composition, varies influenced by factors such as eating habits, water consumption, use of cleaning products at home, or on the day of the week or time of day. These differences are critical in order to choose the suitable treatment to use and the future uses for which it is targeted. Each contaminant has a different impact on water and its removal is key, depending on its destination. Technological improvement in treatment systems, especially from an advanced tertiary treatment, by combining ultrafiltration and desalination, has led to an increase in the potential uses of reclaimed water.

The proceedings that could be undertaken to increase the availability of resources are in the treatment and reuse of wastewater in agriculture, urban use (street cleaning, irrigation of parks and gardens) and other uses (golf courses, medians of roads and highways) which most likely has short-term benefits (Rico [6]). Since the last quarter of the last century, a thesis has repeatedly been proposed that the advanced treatment of municipal and industrial wastewater provides a treated water of such quality that should not be wasted, but used for beneficial purposes (Asano [7]). Furthermore, the treatment and reuse of these resources excel in economic and ecological advantages compared to seawater desalination and, despite the cost reduction of the latter technology, the difference between the two solutions is still maintained thanks to the simultaneous progress of recycling (Angelakis *et al.* [8]). Moreover non-conventional resources, like reuse, in this area can help to relieve sociopolitical conflicts generated by the need to bring water from other basins in order to ensure supplies. The development experiencing this new resource has been going on since the late twentieth century, due in part to the fulfillment of the EU directive 91/271/CEE on the treatment of urban wastewater that has been instrumental in the drive to treat wastewater in Spain, whose competences are transferred to the autonomous communities and are also undertaken to treat wastewater before it is discharged or reused.

Through this paper we aim to clarify the developments that have been subjected to water treatment processes which have been going on in recent years in the southeast Spain, and the use of reclaimed water as an alternative resource. After studying the development of wastewater treatment and reuse, the study is exemplified by the case of the city of Alicante.

2 Evolution and current situation

One of the main incentives that has made the treatment process evolve is the rule that regulates it. Legislation relating to wastewater treatment has strengthened substantially in recent decades, both in Europe and Spain; these regulations being a boost in implementing systems of wastewater treatment in order to achieve the ecological "well-being" waters within a framework of sustainability.

In Europe, the Water Framework Directive 2000/60/EC, the European Community Directives 271/91/EC and 98/15/EC on sanitation and treatment, are mandatory references for the required quality of the treated water. These standards lay down an imperative timetable, according to which, prior to 31st December 2005, all the treatment plants would have had to have a secondary treatment for all towns having more than 2,000 equivalent inhabitants (h-e), and over 10,000 (h-e) in coastal areas. The parameter (h-e) is equivalent to 200 litres of wastewater per day, or in contamination, 60 grams of BOD_5 (Bio-chemical Oxygen Demand) per day. However, it should be noted that there is still no regulation establishing the minimum quality requirements of providing treated water intended for reuse. A fact that has not been remedied yet in the Water Framework Directive 2000/60/EC by not paying enough attention to non-conventional sources. At the European level, and in compliance with Directive 91/271/CEE, very encouraging levels water treatment are being reached, and non-compliance is being punished by substantial fines.

The treatment of wastewater in the Valencian region has experienced a positive evolution during the last two decades in relation to the degree of population, treated volumes and degree of compliance with EEC Directive 271/91. A turning point was the execution of the Director Plan of Sanitation and Treatment (1992) which, in turn, developed the Law of Sanitation Wastewater of Valencia (Law 2/1992, 26th March), which also involved establishing the Public Entity Wastewater Treatment (EPSAR). In a first phase (1992–1993), actions were put in place in municipalities with more than 10,000 inhabitants, and in a second stage formed in the years to 2005, actions were focused on correcting the problems of purification and sanitation in towns with fewer than 2,000 inhabitants. This also included the construction of small plants in neighborhoods and residential areas on the coast which lacked such a basic service. In both phases, the overall level of treatment most often used was the secondary (biological), and from 2005, a new cycle has promoted tertiary systems, sometimes including desalination, to encourage greater reuse of flow regenerated for agricultural, urban and recreational uses. For financing those projects, Law 2/1992 established sanitation tax returns which are intended to ensure the functioning of the existing treatment facilities and to contribute to the financing of new ones. The amount of the fee is based on the volume of water consumed for urban use (domestic, commercial, industrial) and its calculation can differ depending on the population served and the pollution load generated. For this fee EPSAR entered, in 2014, more than 265 million euro, with the operating costs of sewage treatment plants (148 million euro), construction of new facilities (39 million euro) and other staff costs faced, etc. The average cost of wastewater treatment in the Valencian region during 2014 was 0.34 €/m^3.

Currently, existing plants are capable of regenerating the wastewater produced by over 6,500,000 h-e, compared to 4,400,000 in 2000. Capacity has also increased to reduce the pollutant load, which was favored in 2005 that the sewage eliminate 500,000 tons of sludge in suspension and 92% of the $DB0_5$ (biodegradable organic matter) of treated wastewater. According to the EPSAR [9], responsible for the management and operations of wastewater treatment plants and other facilities, in 2014 the volume of treated wastewater in the Valencian region stood at 419.81 hm^3 (fig. 1), of which 119.35 hm^3 correspond to the province of Alicante. Considering the evolution of the volume of water treated, a significant increase has been observed since the early nineties, linked to a real estate boom and the population increase in that time. Although the population has been growing, a downward trend can be observed in recent years, mainly linked to a decrease in consumption of urban water.

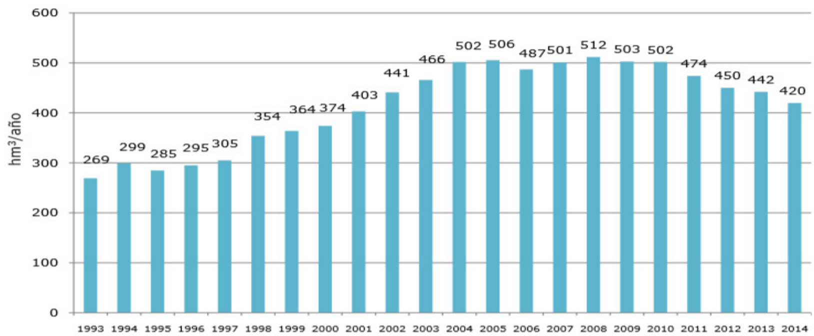

Figure 1: Evolution of treated water in the Valencian region.

3 Reusing water

Direct reuse of reclaimed water is increasingly used internationally and is a widespread practice in Spain, a Mediterranean country with a high variability of availability and water balance deficit (Morales *et al.* [10]). In this case, reusing water represents an increase in the availability of water in coastal areas where the treated water is discharged into the sea, allowing for the replacement of reclaimed water as drinkable water, leaving this last for uses that require higher quality water and avoiding the discharge of treated water into the river or sea with the environmental implications that entails.

In Spain, the specific legislation governing the use of wastewater is collected in the Royal Decree 1620/2007, which conforms with the legal framework for the reuse of treated water. In this direction, this royal decree defines these resources as "*treated wastewater that, in this case, has been subjected to a process of additional or complementary treatment allowing quality to adapt their future intended use*". The treatment process required for wastewater to be reused is called "regeneration" and is returning, partially or completely, the level of quality that it used to have before consumption, recovering qualities that make it useful to address certain uses. The qualities of reclaimed water set out in Annex I.A of RD reuse total 14, grouped into five types of use: urban, agricultural, industrial, recreational and environmental. This standard also provides in Chapter II the forbidden uses which are: for human consumption, except in the case of catastrophe; own use in the food industry except for water process and cleaning; use in hospital facilities; filtering for growing shellfish aquaculture; recreational and bathing water; use in cooling towers and evaporative condensers except as provided in this industrial use in the standard; use in fountains and ornamental plates or public interior spaces of public buildings; and any other use that the authorities consider carries health risks or harm to the environment.

From the point of view of management, the use of reclaimed water has been contemplated and promoted by different public statements from municipal ordinances, such as Madrid or Lanzarote, regional management plans or the National Plan for Water Reuse driven by the Ministry of Agriculture, Food and Environment with which it is intended to achieve the reuse of 1,130 hm^3 of treated water in the last planning cycle which ends in 2015.

In the case of the reuse of treated wastewater, there has been an enormous development of water treatment infrastructures in the Valencia and Murcia regions (Pérez *et al.* [11] and Rico and Hernández [4]), resizing them in order to increase regenerated flows according to population growth experienced in recent decades. This has allowed that the Segura River Basin to be positioned as the only Spanish watershed where nearly 100% of wastewater is treated and reused (Olcina and Moltó [12]). This system has already been used in this area for years for optimizing the resource for obtaining water – depending on the degree of treatment which can be used in terms of quality – mainly for irrigation. It also allows better quality water to be reserved such as from conventional sources to urban uses, thus decreasing dependence for example on the waters of the Tajo-Segura transfer. Therefore, the reuse of reclaimed water is considered to be one of the practices best suited with the principles of sustainable development (Seguí [13]), although its use is limited by the rules and the social rejection that occurs for domestic use due to health reasons (Baeza [14] and March *et al.* [15]).

Alicante has been reusing wastewater for more than three decades in order to satisfy the agricultural demands, by using technological approaches that are pioneers internationally. Different irrigation entities have granted a volume of 66 million m^3/year, while the irrigation of golf courses, highway medians and gardens consume another 4 million m^3/year (Rico *et al.* [1]). The most important initiatives for reuse are in the regions of the Vinalopó, Campo de Alicante, Marina Baja and Bajo Segura, where abundant water treatment plants are subjected to the heavy use of wastewater. For example, the general user community of Sax has set as a priority in its activities the preservation of water, including the full use of all the resources provided by the treatment plant of Villena, which in turn regenerates wastewater for the municipalities of La Canada and Campo de Mirra. It also assumes a prototypical hydraulic complex built in 1980 by the IRYDA in the Middle Vinalopó and Campo de Alicante, which can be raised by several driving systems adding up to 400 meters. The reclaimed waters of the treatment plant of Rincón de León (Alicante) goes to areas of irrigation in Agost and Monforte del Cid, with costs near to 0.18 €/m^3 that are entirely assumed by the farmers. A much more favorable agreement exists for the irrigators of Marina Baja, thanks to the systems of existing wastewater reuse in the region, based on the transfer of clean water in exchange for residual wastewater at zero cost benefit. The agreement was decisive and an imaginative technical solution, consisting of the construction of the treatment plant of Benidorm in the foothills of Sierra Helada, at 135 meters above sea level. This allows injecting water without pumping or using elevations in the pipes of the Irrigation Community Canal Bajo del Algar to irrigate 2,400 ha of citrus and persimmons. In return, the Consorcio de Aguas de la Marina Baja (1978) is benefitting by of the transfer of clean water from the Guadalest-Algar system, which is vital to maintain the supply of drinkable water in tourist resorts such as Benidorm, Villajoyosa and Alfaz del Pi (Rico *et al.* [16]).

4 Case studies: Alicante

The city of Alicante forms a very representative model in terms of wastewater treatment and reuse because, due to its location, the city has had to implement its capacity for water treatment and reuse in order to satisfy the demands of both urban and agricultural uses. It has two treatment plants called Monte Orgegia and Rincón de León which are responsible for treating over 18,000,000 m^3/year received (fig. 2).

The treatment plant of Monte Orgegia serves the northern part of the municipality of Alicante and the towns of San Juan de Alicante, Mutxamiel and Campello. It is a conventional treatment plant using activated sludge and anaerobic digestion. It has a capacity of 60,000 m^3/day, divided into the primary treatment and secondary treatment in two parallel lines. Line A has a capacity of 36,000 m^3/day and it was recently executed during the enlargement of the

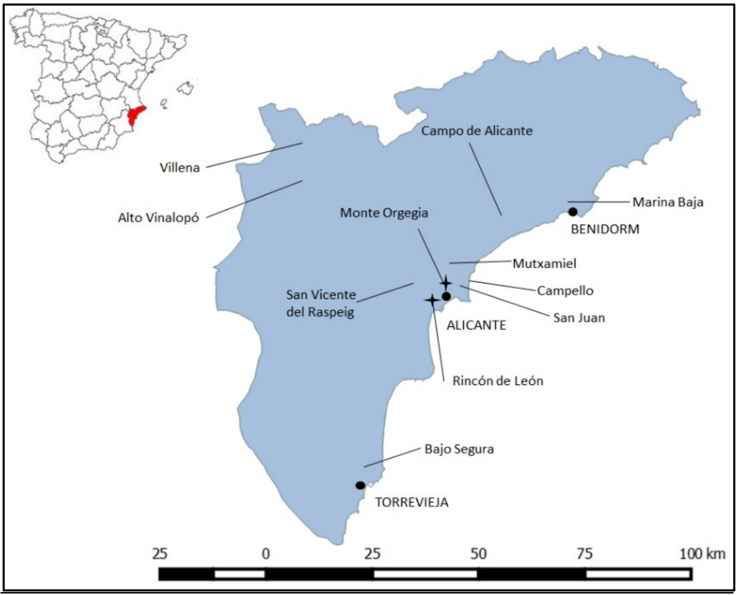

Figure 2: Location.

facilities in 2006. Line B is able to treat 24,000 m^3/day, which corresponds to the capacity of the former plant, which opened in 1989. The facilities of Monte Orgegia essentially comprise the following process steps: water line, sludge line and gas line. The raw water entering the plant is driven by the pumping stations of Condomina and the Pla.

The wastewater treatment plant of Rincón de León collects water from the south of the town of Alicante and the town of San Vicente del Raspeig. It is a conventional treatment plant using activated sludge and anaerobic digestion. It has a treatment capacity of 75,000 m^3/day that in the primary decanted off and the biological process is divided into two lines: Line A of 50,000 m^3/day, corresponding to the last enlargement in 2011; and line B 25,000 m^3/day corresponding to the old plant opened in 1982. In order to allow treatment of desalination and reuse of treated water flows input to the plant were subdivided according to their different salinity. Anaerobic sludge stabilization in this plant has resulted in the production of biogas. This fuel is used for heating the sludge digestion and mainly for the production of electricity. It has two cogeneration engines with an average power output of 2 MWh/year. This energy is fully utilized within the facilities (consumption).

Plá drive is connected to both treatment plants. In this way wastewater from a part of the city can be pumped to the treatment plant that is receiving less flow at the time. This model is very useful especially during holiday periods considering that Monte Orgegia plant that receives water from the coast that increased its flow with the arrival of tourism and is not able to treat the entire flow received. The following chart shows the flows treated in recent years for the two plants that treat wastewater from the city of Alicante. By analyzing data from this graph with the plant Monte Orgegia (fig. 3), variations are observed in the treated flows due not only to variable flow rates received from the pumping Pla, but also other factors, such as the anomalous data 2006 matching with the expansion of the plant, a consequent increase in flow rate given the new treatment capacity, and finally a decrease probably due to decreases in the urban water consumption. That is why the data from 2000 and 2013 hardly differ, even though the plant now has more capacity and the population has increased in this period by more than 55,000 inhabitants (INE [17]).

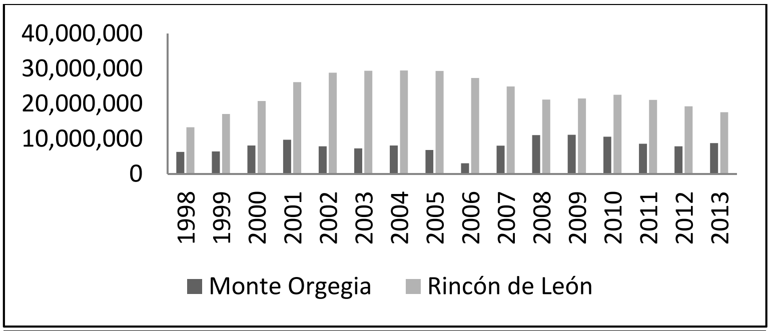

Figure 3: Volumes of wastewater treated in Monte Orgegia and Rincón de León.

The need to improve water quality for certain agricultural use led to the construction of the regeneration facility of treated water in Rincón de León (IRAD). The maximum production of desalinated water is 25,600 m^3/day plus an additional 13,000 m^3/day of ultra-filtered water. Four lines use reverse osmosis; this way the high content of salinity (2,800 µs/cm) of the wastewater that reaches the treatment plant is reduced to 600 µs/cm, thereby obtaining a high quality resource for watering all sorts of agricultural production. This facility is owned by EPSAR and reclaimed water is available on-demand from the communities of irrigators Agricoop and Aralvi for the Campo de Alicante and Middle Vinalopó, and another 7,000 ha of the Irrigation Community of Levante in the town of Elche, at a cost not exceeding 0.10 €/m^3. These irrigation communities have the ability to mix the effluent deposits in each of the processes provided by IRAD with water of a certain quality depending on the needs of the type of crop.

Table 1 lists the reclaimed water intended for agricultural and urban reuse of the various treatment plants of Alicante. The reuse of water from the Rincón de León plant is primarily intended for agricultural use, while water from the Monte Orgegia plant spreads its flow between agricultural and urban use. A clear increase of these flows can be appreciated, although all the water treated is yet intended for other new uses.

Table 1: Reused flows.

	Rincón de León				Monte Orgegia	
YEAR	Agricultural Irrigation		TOTAL IRRIGATION	URBAN USE	TOTAL IRRIGATION	URBAN USE
	AGRICOOP	ARALVI				
2003	2.550.176	3.568.980	6.119.156	38.731	402.970	43.668
2004	2.682.781	3.158.038	5.840.819	27.894	385.700	66.831
2005	3.419.429	3.818.917	7.238.346	19.595	1.171.217	156.348
2006	4.402.163	4.047.552	8.449.715	29.130	1.421.583	250.219
2007	3.487.785	3.238.521	6.726.306	19.540	946.813	412.613
2008	3.620.018	4.041.599	7.661.617	44.928	1.040.963	592.022
2009	3.235.427	2.962.306	6.197.733	49.845	704.867	631.260
2010	2.420.826	2.067.212	4.488.038	45.354	565.812	750.946
2011	2.920.812	2.613.934	5.534.746	37.407	761.206	858.902
2012	3.467.576	3.063.073	6.530.649	40.850	1.006.370	903.305
2013	3.647.780	1.968.620	5.616.400	53.703	1.031.635	996.360

As has been said before, although not using all the reclaimed water that could be used, which in recent years has reached approximately 25% of the treated water of Alicante (fig. 4), the city is a pioneer in this field and has a Director Plan for Water Reuse (2002–2003) that is promoting the construction of this dual network of reused water. The water company of the city Aguas Municipalizadas de Alicante (AMAEM [18]), is responsible for implementing this plan, by which more than 70% of the green areas of the city are watered with reclaimed water.

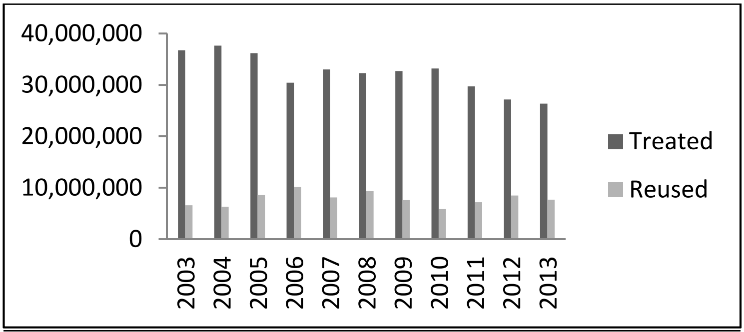

Figure 4: Treated and reused water in Alicante.

Other innovations in this area are the antipollution deposits. This region of Spain suffers, usually in the fall, episodes of high-intensity rainfall in a short amount of time. This generates a large quantity of runoff water that ends up in the sewage system where treatment plants do not have time to treat the water from these avenues. These waters also drag pollution from the streets. In order to solve this problem and be able to treat and use all the water, two processes have to be undertaken. Firstly the antipollution deposit of San Gabriel, built in 2011 and capable of storing 60,000 m^3. And secondly the flooded park of La Marjal, opened in 2015 with a storage capacity of 45,000 m^3. This park stands out for its environmental sustainability and is a highly acclaimed urban solution that works as a park during the year and becomes a lake thanks to a system of collectors that collect water from the street of the beach of San Juan during the floods, to further pump this water to the treatment plant. This way the treatment plan would be able to treat all the rainwater and it is not wasted. Through these measures, it seeks to promote the use of this alternative resource against the consumption of drinking water to meet certain needs. In addition, the process of reuse of reclaimed water is an economic, energy and environmental savings and that has tripled in recent years the area devoted to parks and green spaces (Hidraqua [19]).

5 Conclusions

In a scenario of rainfall shortage, a hydric deficit derived from climate change and its effects in the Mediterranean areas, an evaluation and eventual mobilization of all available water resources stands as a social priority and territorial objective. Moreover, in this area with growing calls for both urban and irrigation water, demands that have grown linked to urban and population development during the last few decades. In this urban-tourism sector, of great importance for the eastern coast of the Iberian Peninsula, conventional resources like water from reservoirs, aquifers and transfers are in principle the most exposed to periods of drought. In comparison, the use of unconventional resources, as the reuse of reclaimed water, is presented as an alternative to adapt to scarce and erratic rainfall. That is why the wastewater treatment systems, favored by the legislation that regulates them, have suffered a great evolution overlooking to obtaining better quality water for both discharge and subsequent reuse. Once the desired quality is reached, this reclaimed water has been used for both agricultural irrigation and in some urban uses such as street cleaning or the irrigation of green areas, replacing volumes of water from conventional sources that can now be used in primary needs such as ensuring the supply.

In the Valencian region, in 2015, of 419.73 hm^3 of treated water, only 34.73% is reused. Of these reused resources, 91.87% is intended for agricultural use and only 6.75% for urban use. Regarding indirect reuse (discharged into channels) (118.42 Hm^3) represents 28.21% of the total treated water. By provinces, Alicante is the region with most water reuse (46.26%), second is Valencia (34.86%) and Castellón with only 7.97%. This result is logical, considering that Alicante is the province of the Valencian region that has less conventional resources, and is therefore the one that uses more alternative resources. In this regard, the Valencian region shows it is missing an easily usable application that may demand this type of non-conventional water resource. In addition, if it is bound to the cost of production of this resource that it is of 0.34 €/m^3 (five times cheaper than drinking water), it is therefore being left out as an alternative source from an environmental and economic term. More so, considering the current economic situation that can benefit in reducing costs through the use of this resource.

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Removal of sulphates from acid mine drainage using desilicated fly ash slag

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Abstract

The removal of sulphates from acid mine drainage (AMD) using desilicated fly ash (DFA) was investigated. The effects of DFA solid loading, residence time and removal temperature were investigated. A 2% DFA solid loading gave the highest sulphate removal of 75% at a temperature and residence time of 35ºC and 90 min respectively. The maximum adsorption capacity for DFA was found to be 147.06 mg/g DFA. The sorption mechanism followed the Langmuir isotherm and pseudo second order kinetics. The Gibbs free energy and enthalpy for the sorption was found to be 17.26 and 125.096 J/mol respectively. This research showed that DFA was an attractive alternative adsorbent for sulphates in AMD.
Keywords: desilicated fly ash, adsorption, sulphates, isotherm.

1 Introduction

Sulphate contamination in water is prevalent in mining activities. Water effluent from gold mines and platinum mines have been shown to have a sulphate load of at least 2 g/L [1, 2]. There are many problems which are associated with high sulphate content in water and these include laxative effects when concentration is above 500 mg/L and scaling effects [3]. Sulphate removal has traditionally been through use of membrane separation and by sulphate salt precipitation [4, 5]. The major disadvantage of applying these technologies for the removal of sulphates from sulphate and acid rich effluents is the start-up and operational costs [6]. Fly ash (FA) has been shown to be a cheap alternative for the removal of sulphates from acid mine drainage (AMD) but the major disadvantage is the high fly ash

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solid loading [7] which results in reduced efficient mass transfer [8]. In this research desilicated fly ash (DFA), the residue from leaching of silica from FA was used as an adsorbent. The adsorption isotherm, kinetics and thermodynamic parameters of the sulphate adsorption using DFA was also investigated.

2 Experimental

2.1 Materials

Acid mine drainage was obtained from a local gold mine in the West Rand of South Africa. Ethanol, concentrated hydrochloric acid, sodium chloride, barium chloride, sodium sulphate and glycerol were supplied by Rochelle Chemicals. DFA was prepared by leaching of silica from FA using 3M KOH, 500 rpm agitation speed, 25 L/S ratio, leaching temperature of 100°C for 6 h [9].

2.2 Equipment

Batch adsorption tests were carried out in conical flasks using a Thermostatic shaker set at various temperatures. Mineralogical analysis of DFA was done using a Rigaku Ultima IV difractometer. pH was measured using Metler Toledo dual meter (Sevenduo pH/conductivity meter with a Metler Toledo InLab Pro ISM pH electrode probe). A UV Visible spectrophotometer (PG Instruments T60) was used to assay for sulphate ions.

2.3 Sulphate analysis

The Environmental Protection Agency (EPA) method 375.4 was used to analyse for sulphates.

2.4 Effect of DFA solid loading on adsorption of sulphates

0.4–2.4 g of DFA was added to a separate 100 ml solution of AMD. The solutions were agitated at 200 rpm using a thermostatic shaker maintained at 25°C for 2 hours. After 2 h the agitation was stopped and the solution pH was measured. The solutions were then filtered using vacuum filtration. The filtrate was then analysed for sulphates.

2.5 Effect of residence time and temperature on the adsorption of heavy metals

4 solutions of 100 ml AMD with 2 g each of DFA were prepared. The solutions were agitated at 200 rpm using a thermostatic shaker maintained at 25°C for 30, 60, 90 and 120 min respectively. At the end of each agitation time the solution pH was measured. The filtrate was then analysed for sulphates.

The above procedure was repeated at 35°C and 45°C to see the effect of temperature on the adsorption of sulphates.

3 Results and discussion

3.1 XRD characterisation of DFA

Figure 1 shows the XRD diffractogram of FA and DFA.

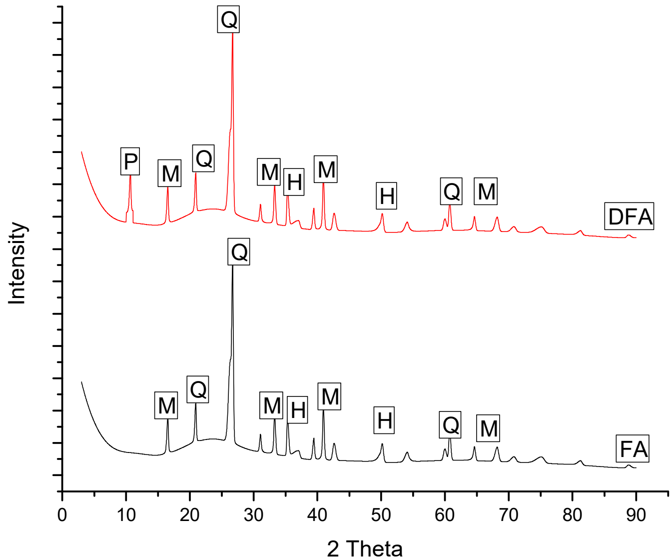

Figure 1: XRD diffractogram of FA and DFA (M=Mullite, Q= Quartz, H=Haematite, P= Phillipsite K).

The XRD analysis of DFA showed no major differences with the parent FA except for the peak at 11° which was identified as zeolite Phillipsite K. Phillipsite K constituted 25.8% of the crystalline phase of DFA. Therefore DFA is an impure zeolite. The Phillipsite is of the potassium type since silica extraction was done using KOH.

3.2 Effect of DFA solid loading

Figure 2 shows the variation in sulphate removal with solid loading at 25°C.

There was an increase in sulphate removal with an increase in solid loading because there were more adsorption sites available. The optimum effective solid mass loading of DFA for sulphates removal from AMD was found to be 2 g/100 ml AMD which resulted in 56.7% removal. The removal at 2 and 2.4 g/100 ml AMD was found to be statistically insignificant and hence the solid loading of 2 g/100 ml AMD was used for subsequent experiments. Sulphate removal from waste water has also been shown to be pH dependent [10]. Figure 3 shows the variation of pH with solid loading.

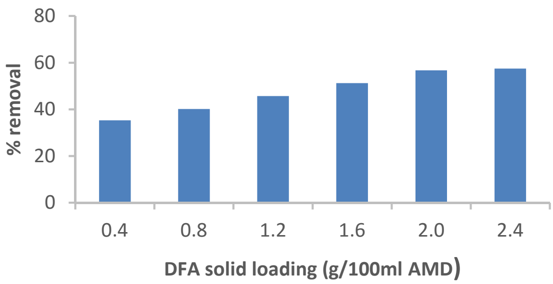

Figure 2: Variation in sulphate removal with DFA solid loading at 25°C.

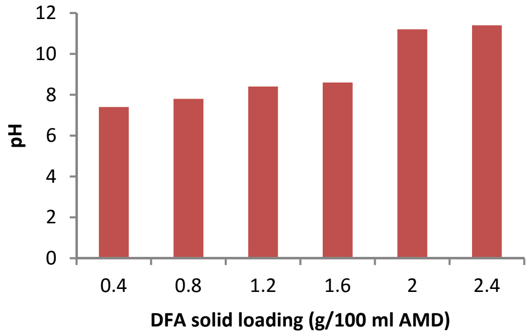

Figure 3: Variation of pH with solid loading.

Only the 2 and 2.4 g/100 ml AMD solid loading had the minimum required pH for effective sulphate removal [9] hence it was only at these solid loading that the sulphate removal was above 50%. DFA is capable of removal of sulphates though it contains Phillipsite whose surface is negatively charged. This is probably due to a mix of adsorption and precipitation of sulphates since DFA has a pH of 12.28 [11].

3.3 Effect of residence time

Figure 4 shows the variation in sulphate removal with time.

There was an increase in % removal with time up to 60 min. This was due to the increased contact time between the adsorbent and adsorbate. The % SO_4^{2-} removal after 60 min remained stable signifying that equilibrium was reached at that stage. The slight decrease in % removal after 60 min can be due to the slight desorption occurring after fast equilibration.

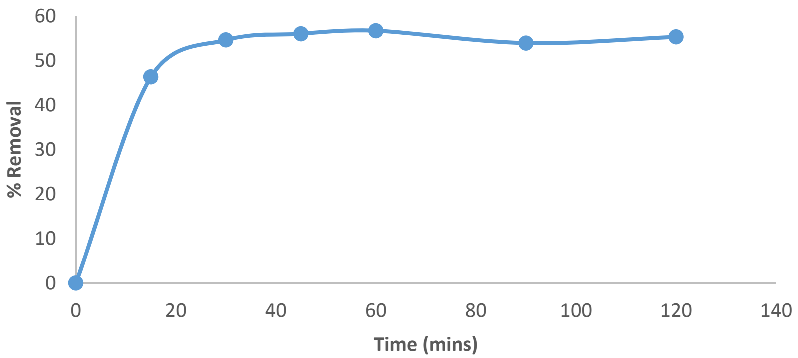

Figure 4: Variation in sulphate removal with time at 25°C at 2 g/100 ml AMD solid loading.

3.4 Effect of temperature

Figure 5 shows the variation in metal removal with adsorption temperature.

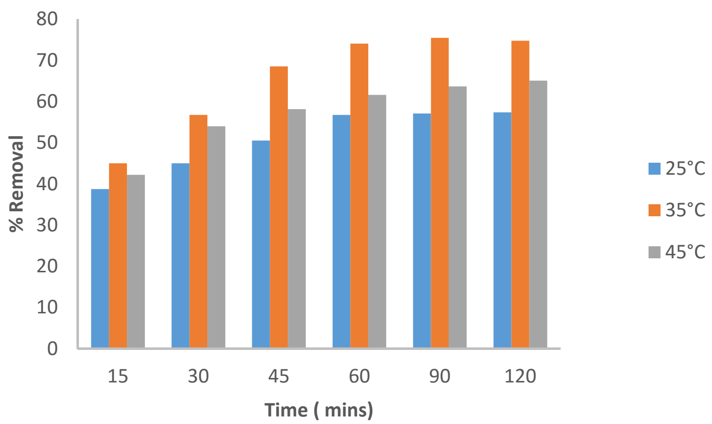

Figure 5: Variation in sulphate removal with adsorption temperature.

There was an increase in the sulphates removal with an increase in temperature from 25 to 35°C followed by a drop in sulphates removal at 45°C. The first increase was due to more energy being supplied for the process since the adsorption process was endothermic. The decrease at 45°C was due to the increased solubility of sulphates with an increase in temperature [12].

3.5 Adsorption isotherms

The adsorption data at 35°C (highest removal) was then fitted to the Langmuir and Freundlich isotherms. Table 1 shows the Langmuir and Freundlich parameters.

Table 1: Langmuir and Freundlich parameters at 35°C.

Parameter	Langmuir	Freundlich
R^2	0.9999	0.9989
n		30.98
R_L	0.28	

Both the Freundlich and the Langmuir isothem fit the adsorption of sulphates onto DFA as the corelation coefficient for for both isotherms was above 0.99, however, the Langmuir isothem best fit the adsorption data as it had an equilibrium constant less than zero (R_L) whilst the adsorption intensity (n) for Freundlich was greater than 10 [13, 14].

3.6 Adsorption kinetics

The adsorption data at 35°C was then fitted to the pseudo first and second order kinetic equations. Figures 6 and 7 show the pseudo second order and first order plots respectively.

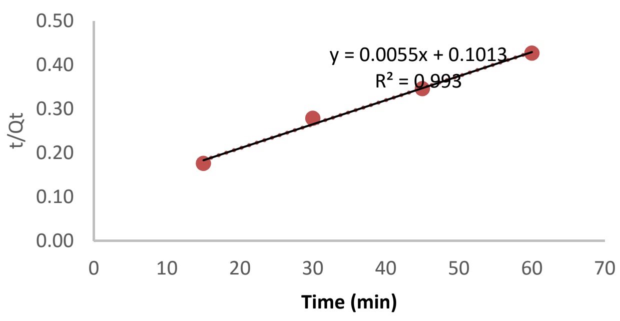

Figure 6: Pseudo second order plot.

The adsorption of sulphates onto DFA fitted the pseudo second order kinetic plot indicating a chemisorption process. This was further supported by the calculated equilibrium adsorption capacity for the pseudo first and second order kinetics were 318 and 181.8 mg/g respectively against an experimental value of 147.06 mg/g.

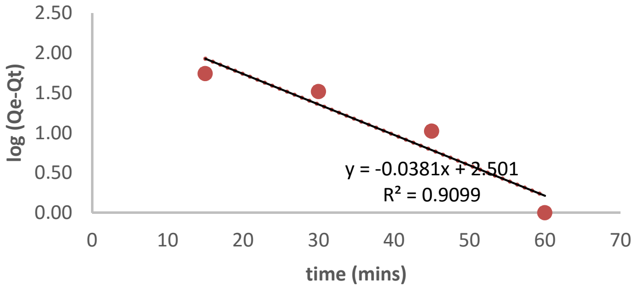

Figure 7: Pseudo second order plot.

3.7 Adsorption thermodynamics

Table 2 shows the thermodynamic parameters.

Table 2: Thermodynamic parameters of sulphate adsorption onto DFA.

Unit	Value
ΔG^0 (kJ/mol)	-18.96
ΔH^o (J/mol)	125.09
ΔS^o (J/mol)	42.47

The negative Gibbs free energy showed that the adsorption process was thermodynamically spontaneous, whilst a positive enthalpy value showed that the process was endothermic. A positive entropy value showed that there was high affinity for sulphates by DFA.

4 Conclusion

DFA can be used as an adsorbent for sulphates in AMD. A 2% solid loading of DFA was found to be the optimum. The process followed Langmuir isotherm and was characterised by pseudo second order kinetics indicating a chemisorption mechanism. The process was thermodynamically spontaneous and was endothermic. The significant reduction in solid loading (2%) as compared to 50% for FA represented a significant improvement in the process.

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Evaluation of the influence of method preparation in properties of heterogeneous ion exchange membranes

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Abstract

In order to produce membranes with good features, this study aimed to evaluate the influence of the method of preparation of heterogeneous anion exchange membranes (AEMs). Membranes were prepared by spread coating and casting methods. In the latter method, different solvents were used: tetrahydrofuran (THF) and dimethylformamide (DMF). Membranes with different quantities of anion exchange resin (AER), 50% and 35%, were prepared. The characterization of the AEMs was performed by means of conductivity, ion exchange capacity (IEC) and swelling. Membranes prepared by coating showed lower conductivity, possibly due to the degradation of some functional groups of the AER during processing because of high temperatures. Evaluating the solvent influence, the membrane obtained in DMF had the highest conductivity. The IEC of membranes prepared by casting method was very similar, showing that this is not a parameter influenced by solvent exchange. It was noted that coated membranes had lower IEC, reinforcing the hypothesis of losing functional groups during processing. Finally, membranes prepared using THF as solvent showed higher swelling than those using DMF because THF evaporates quickly leading to the formation of small voids where water accumulation is favored. The coated membranes had the lowest swelling since these membranes do not use solvent in their preparation. Lastly, it can be inferred that the choice of the methods and/or the solvents can modify AEMs properties. Among the methods, the most satisfactory was casting due to the possibility of functional group loss by thermal degradation during the coating process. Concerning the solvents, DMF has been demonstrated the best one for casting process since it does not provide large voids which increase the swelling

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and reduce the conductivity. Ultimately, the best membrane was obtained by casting method with 50% of AER with conductivity, IEC and swelling of $2.17.10^{-3}$ $S.cm^{-1}$, 1.58 $meq.g^{-1}$ and 59.8%, respectively.
Keywords: anion exchange membrane, membrane preparation, membrane characterization, method effect, solvent effect.

1 Introduction

For many years, electrodialysis (ED) has been used on a large industrial scale for water desalination, wastewater treatment and a large number of applications in biotechnology as well as food and beverage industry [1]. Ion exchange membranes play a leading part in an electrodialyzer, and the ED performance strongly depends on the characteristics of ion exchange membranes [2].

Heterogeneous Ion Exchange Membranes (IEMs) consist of fine ion exchange particles embedded in an inert binder polymer such as polyethylene, phenol resins, or polyvinylchloride. Heterogeneous IEMs are characterized by the discontinuous phase of the ion exchange material. These membranes can easily be prepared by mixing an ion exchange powder with a dry binder polymer and extrusion of sheets under the appropriate conditions of pressure and temperature or by dispersion of ion-exchange particles in a solution containing a dissolved film forming binder polymer, casting the mixture into a film and then evaporating the solvent [3].

The research on heterogeneous IEMs has grown because they are less expensive to produce, easily manufactured and have better mechanical strengths and good dimensional stability when comparing with the homogeneous ones [4]. Another advantage of heterogeneous IEMs is that during their preparation it is not used hazardous chemicals as, for example, fuming H_2SO_4 or chlorosulfonic acid to prepare Cation Exchange Membranes (CEMs) or chloromethyl ether and trimethylamine to prepare Anion Exchange Membranes (AEMs). Although heterogeneous IEM are easily prepared and have great mechanical strength, their electrochemical properties are slightly inferior to homogeneous membranes. Heterogeneous type membranes, however, are essential in industries due to their high mechanical strength and ease of handling [5].

The properties of IEMs are substantially determined by two parameters that are the basic material they are made from and the type and concentration of the fixed ionic moiety (ion exchange resin). The basic material determines to a large extent the mechanical, chemical, and thermal stability of the membrane. The type and the concentration of the fixed ionic charges determine the permselectivity and the electrical resistance of the membrane, but they also have a significant effect on the mechanical properties of the membrane and their swelling in solution [3]. Hosseini *et al.* [6] showed that the solvent type can also modify the IEMs properties; besides, Vyas *et al.* [7] observed that ion exchange resin particle size can also modify IEMs properties.

In this paper, anion exchange membranes using the same base polymer were prepared using the same type and particle size of anion exchange resin, but from two different methods of processing: laminating spread coating and solvent evaporation (casting). The objective was to determine the differences in membranes properties with the same composition originated by changing the method of production. In addition, in the casting method, membranes were prepared using two different solvents, tetrahydrofuran (THF) and dimethylformamide (DMF), in order to assess its influence on the properties of the membranes.

The main difference between the preparation methods lies in the fact that as the coating method requires application of high temperatures for the membrane formation, on the other hand, the casting method produce membranes by simple solvent evaporation at room temperature. With respect to the solvents, they have very different boiling temperatures, 66°C for THF and 153°C for DMF, requiring special care during handling the mixture until the beginning of the solvent evaporation and stabilization of the membrane film. The main advantage of using THF is that it solubilizes the polymer and the plasticizers easily even at room temperature while for solubilization in DMF is necessary heating to about 60°C. In contrast, the main advantage of DMF in relation to the other solvent is that it is considerably cheaper, costing half value.

2 Materials and methods

2.1 Membrane preparation

The base polymer for all prepared membranes was polyvinyl chloride (PVC) obtained from Braskem®: Norvic® P55LM. The anion exchange resin (AER) was A400 supplied by Purolite®. Prior to membrane formulation, AER was dried in oven at 40°C for 24 hours, milled in a ball mill during 1.5 hour, sieved at 200 mesh, and then dried again at 40°C for 24 hours.

Membranes were prepared by spread coating lamination (coating) and solvent evaporation (casting) methods, in the latter method, the membranes were prepared using two different solvents: THF and DMF. In the composition, membranes contain, in addition to PVC and anion exchange resin, plasticizer to make the membrane flexible. In total, five membranes were prepared, three of them containing 50% of anion exchange resin: one by the coating method, another by casting with THF and the last one by casting with DMF, named CO50, CA50T, and CA50D respectively. Once the membrane prepared by coating was not stable, two other membranes have been prepared, in this time with 35% resin, one by coating and other by casting with DMF, named CO35 and CA35D, respectively. Table 1 presents a summary of the compositions and methods of obtaining the membranes.

The anion exchange membranes (AEMs) preparation by coating method started mixing the PVC with plasticizers and AER. It was also used 1.5% of a dispersant. After physical mixture of all components, formulation was coated in an oven at 190°C during 5 min and resulting on a membrane.

The AEM prepared by solvent casting method, using THF as solvent proceeded by dissolving polymer and plasticizers into solvent at room temperature for 1 hour. This was followed by the addition of AER. The blend was then mixed at room temperature for 30 minutes to obtain uniform particle distribution in the polymeric

Table 1: Specifications of prepared membranes.

Membrane	AER* amount (%)	Preparation method	Solvent
CO50	50	Coating	-
CA50T	50	Casting	THF
CA50D	50	Casting	DMF
CO35	35	Coating	-
CA35D	35	Casting	DMF

*AER: anion exchange resin.

solution. Then, the mixture was cast onto a clean and dry glass. The membrane was obtained after solvent evaporation at room temperature. Using DMF as the solvent, the AEM obtainment process was very similar to the previous one, employing THF as solvent. Indeed, the difference was related to the temperature concerning the polymer and plasticizers dissolution into the THF that occurred at 60°C in contrast to room temperature for DMF.

All membranes were storage in deionized water prior to characterization. Besides, a reinforcing fabric was used to increase mechanical properties of all prepared AEM in this research.

2.2 Membrane characterization

The prepared membranes were characterized and their performance evaluated by the tests described below. The measurements were done in three samples of each membrane and the average results will be presented in results and discussion item.

2.2.1 Morphology study

A scanning electron microscopy (SEM) was used to investigate the cross section morphology of the membranes. SEM micrographs were obtained in equipment JEOL JSM-6510LV using 10 kV of energy. Previous to analysis, membranes were dried, underwent cryogenic fracture and then were coated with gold.

2.2.2 Conductivity by impedance spectroscopy

The conductivity of the membranes was measured by AC impedance spectroscopy using a Solartron 1260 analyzer with software Zplot®. AC impedance spectroscopy consisted in measuring the changes in electrical impedance of a sample of membrane upon a variation in frequency from 1 to 10^7 Hz and bias voltage of 1000 mV. The data was reported in the complex plane (*Z*', *Z*") [8, 9]. Samples, with 18 mm length and 5 mm width, where hydrated by soaking in deionized water during 24 hours and then clamped between two stainless steel electrodes. During the measurements, the environment was kept at 20°C and 100% of relative humidity. The conductivity σ of samples was calculated from the impedance data, using the relation:

$$\sigma = \frac{d}{R.S} \quad (1)$$

where d is the thickness, S is the face area of sample (length multiplied by width) and R is the resistance derived from the low intersect of the high frequency semi-circle on a complex impedance plane with the Re(Z) axis [10].

2.2.3 Ion exchange capacity (IEC)

IEC indicates the number of milli-mol of exchangeable charge in 1.0 g of dry membrane. Firstly, samples were dried in oven at 40°C for 24 hours and then weighed, after cooling in desiccator under room temperature until constant mass. In the sequence, the membranes were equilibrated in deionized water for 72 hours; then, they were immersed for two days in 1M KOH aqueous solution to convert the membrane into OH^- form. The membranes were then washed with deionized water to remove excess of alkali. In the next step, samples were equilibrated in 0.02 M HCl aqueous solution for 48 hours and the anion exchange capacity determined by back titration with 0.005M NaOH aqueous solution [11]. The ion exchange capacity of the AEM was calculated by:

$$IEC = \left(\frac{a}{W_{dry}}\right) \tag{2}$$

where a is the milli-mol of ion exchange group in membrane and W_{dry} is the weight of dry sample of membrane (g) [6].

2.2.4 Water content

The water content was measured as the weight difference between the swollen (W_{wet}) and the dried (W_{dry}) membranes. The membranes were equilibrated on deionized water, at room temperature for 72 hours, weighed and then dried at 40°C in oven until the constant weight was obtained [12]. The following equation was used to calculate de water content:

$$Water\ content\ (\%) = \frac{W_{wet}-W_{dry}}{W_{dry}}\ x\ 100\ . \tag{3}$$

3 Results and discussion

3.1 Morphology study

Analyzing the SEM images for the membranes cross section, shown in fig. 1 2,000 times increased, it can be seen that membranes prepared using solvent exhibit little voids. In CA50T membrane, prepared with THF, the gaps are larger due to rapid solvent evaporation without time to polymer accommodation. For CA50D membrane, prepared with DMF, these spaces are also observed; however, they are fewer in amount and smaller in sizes.

It can also be seen, in fig. 1, that in membranes prepared by casting the polymer is not completely surrounding the AER particles. On the other hand, in coated membranes, resin particles are completely encased in the polymer matrix. In addition, in membranes obtained by casting the polymer phase is continuous, while CO35 and CO50 matrix phase membranes present surface irregularities that possibly will lead to lower mechanical properties.

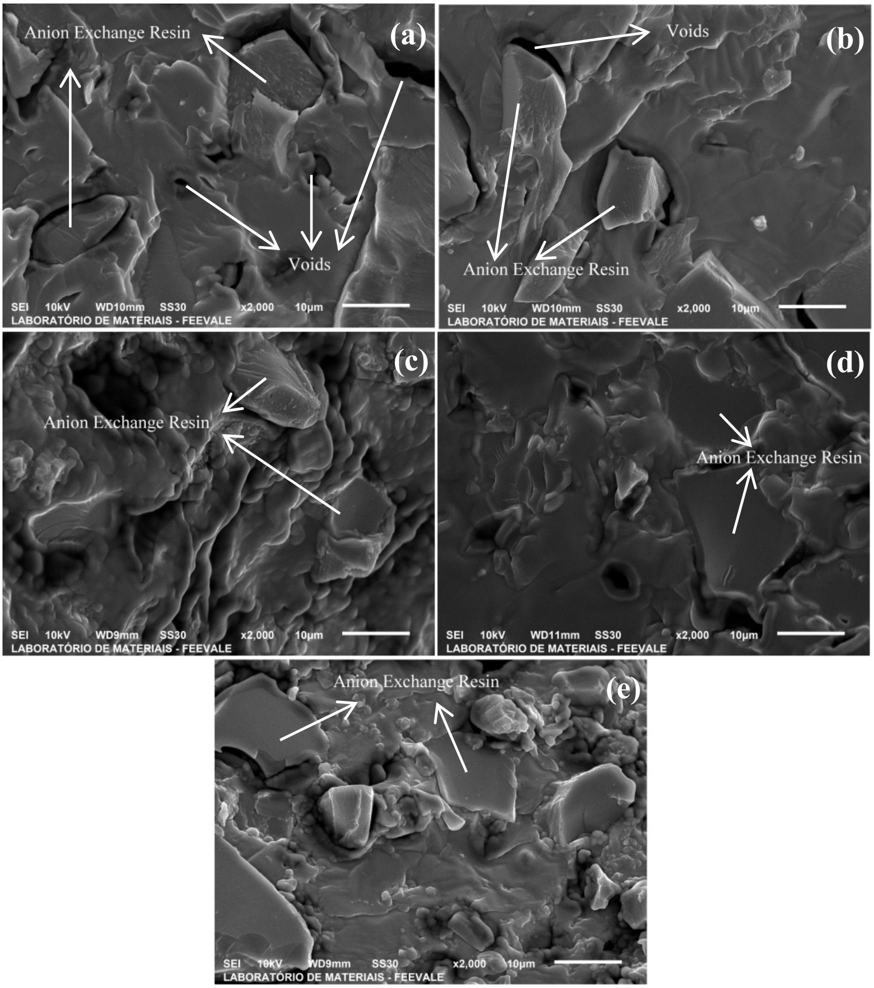

Figure 1: SEM images of CA50T (a), CA50D (b), CO50 (c), CA35D (d) and CO35 (e) membranes with an increase of 2,000x.

Membranes' conductivity, IEC and swelling, measured as described before, are presented in table 2 and will be discussed below.

Table 2: Membranes properties.

Membrane	Conductivity ($S.cm^{-1}$)	Ion Exchange Capacity ($mmol.g^{-1}$)	Swelling (%)
CO50	6.15×10^{-4}	1.38	56.5
CA50T	7.93×10^{-4}	1.56	67.4
CA50D	2.17×10^{-3}	1.58	59.8
CO35	1.84×10^{-4}	1.23	44.1
CA35D	1.60×10^{-3}	1.16	46.6

3.2 Conductivity by impedance spectroscopy

As it was already presented, conductivity was calculated from resistance measurements. For each membrane, measurements were performed on three samples and, illustratively, fig. 2 shows representative curves of only a sample of each membrane for visual comparative purpose.

From fig. 2, it can be observed that CA50T and CA50D membrane samples showed similar resistance, about 33 kΩ each one. However, when the conductivity is calculated, one should take into account that the dimensions of the sample have to be considered in the calculation. As the referred dimensions may slightly vary from one sample to another, different sample conductivities for the same measured resistance may be obtained. The CO50 membrane, despite containing the same amount of AER, showed greater resistance: 65 kΩ. Finally, membranes with 35% of AER, CO35 and CA35D, presented resistances of 103 kΩ and 266 kΩ, respectively. These differences among the membranes will be discussed concerning only the calculated conductivity and not the minimum differences in size of the samples.

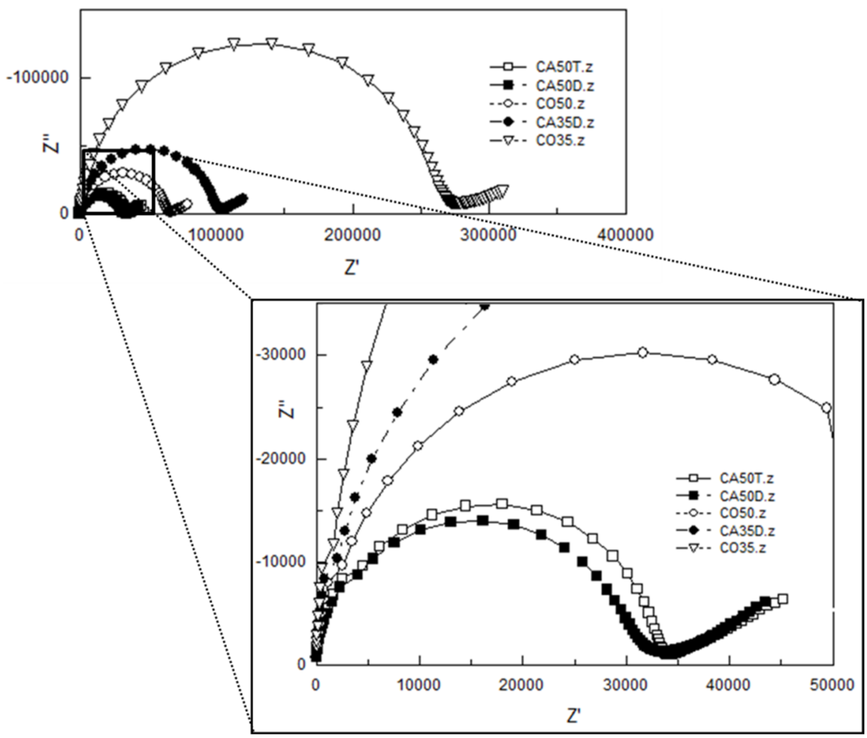

Figure 2: Representative complex impedance responses of membranes.

Thus, from the resistances and the exactly dimension of each sample the conductivity was calculated. As it can be seen in table 2, the membranes prepared by coating, CO50 showed lower conductivity than CA50T and CA50D membranes. Since membranes with equal amount of ion exchange resin with the same particle size should present similar conductivities [7], the difference found may be due to the fact that some functional groups of the ion exchange resin have been degraded as a result of high temperatures during processing, or because the AER particles were partially encapsulated [13, 14]. In fact, the hypothesis of encapsulation can be seen in the SEM images.

Evaluating the solvent influence, the membranes prepared using THF, that rapidly evaporates even at room temperature, had the lowest conductivity comparing with those prepared using DMF. The rapid solvent evaporation might have caused the existence of small voids in the membrane morphology, which led to fewer functional groups per membrane area and, consequently, to a lower conductivity. The SEM images presented earlier show these gaps, corroborating this hypothesis.

The conductivity in heterogeneous membranes is due to the presence of ion exchange resin in the polymer matrix [7]. However, it is well known that PVC is an excellent insulator, employed, for example, in the insulation of electrical cables [15]. Thus, by comparing these membranes conductivity with membranes reported in the literature prepared from other base polymers, certainly it will be found different conductivities.

3.3 Ion exchange capacity (IEC)

Regarding the ion exchange capacity (IEC), it is known that this property is due to the amount and size of ion exchange resin particle in the membranes [4, 7]. Besides, the IEC of heterogeneous membranes is in the range of 1–2 $mmol.g^{-1}$ dry membrane [3]. In this research, it was noticed that membranes prepared by the casting method, CA50T and CA50D, presented very similar values, showing that for this polymer and for these solvents, IEC is not a property influenced by solvent exchange in this research. Since this parameter is assessed in terms of membrane unit mass, the existence of voids does not affect the results. Contrary to the conductivity that is measured according to a specific area, the IEC is evaluated by mass.

It was also noted that CO50 membrane had a lower IEC than the ones prepared by casting with the same amount of AER, reinforcing the hypothesis of functional group loss or AER encapsulation. For CO35 and CA35D membranes, the IEC values were quite similar, 1.23 $mmol.g^{-1}$ and 1.16 $mmol.g^{-1}$, respectively.

3.4 Water content

According to the literature and in consonance with IEC results, the swelling occurs due to the AER amount once the base polymer is hydrophobic [16]; the PVC water absorption at 25°C in 24 hours varies from 0.05% to 0.10% by weight [17]. In this research, the membranes CA50T and CA50D presented water absorption of 67.4% and 59.8% by mass, respectively. This difference is due to the fact that the THF evaporates quickly, leading to the formation of small voids, in which the accumulation of water is favored.

Comparatively, CO50 membrane, which does not use solvent during preparation, not allows water accumulation in small voids. Additionally, this lower water absorption also occurs because of reduction of active sites which may have been degraded during processing or may have been encapsulated (shown in conductivity analysis).

In turn, CO35 and CA35D membranes showed, as expected, lower swelling values in comparison to other membranes with higher AER proportion. In addition, the fact that the membrane prepared by coating presents lower swelling than casting was noticed once more.

4 Conclusions

It is noticed that both method of obtaining membranes, spread coating lamination or solvent evaporating (casting), and the solvent used in the casting process, can modify the membranes properties. When preparing heterogeneous anion exchange membranes using PVC as matrix, it was found that, among the methods, casting presented to be the most satisfactory one due to the possibility of the loss of functional groups by thermal degradation during processing via coating or due to AER encapsulation. Concerning the tested solvents, the best suited for casting process was DMF which does not provide large voids with subsequent decrease of the conductivity and increasing swelling over to required values. Finally, the membrane with better properties obtained was CA50D. This membrane was prepared by casting method using DMF as solvent and presented conductivity, IEC and swelling of $2.17.10^{-3}$ $S.cm^{-1}$, 1.58 $mmol.g^{-1}$ and 59.8%, respectively. This membrane possibly will present the best performance in the ED process among the synthesized and evaluated membranes, providing a better quality in the effluent treated by this technique.

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Understanding recycling behavior: a study of motivational factors behind waste recycling

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Abstract

Globally, waste volumes are increasing rapidly and the World Bank estimates a 70% global increase in municipal solid waste up to 2025. Waste may have serious environmental consequences and there is a strong correlation between solid waste generation rates and greenhouse gas emissions. These two observations alone indicate that this development is not sustainable. Recycling is one of the most important actions currently available to reduce the environmental impact of waste. While, waste recycling in OECD countries is reported to be approximately 22% on average, many developing countries have recycling rates in the range of 1–3%. A key aspect in succeeding with any recycling effort is how authorities and other actors relate to both informal and formal waste workers. This paper reports on the findings of a systematic literature study with the aim of exploring waste recycling behavior, with a special focus on motivational factors, both physical and psychological, behind recycling. Three levels of descending importance for recycling have been identified, where two are vital for success, and the third is desirable; 1) a well-designed infrastructure for recycling 2) specific recycling knowledge, and, 3) a general understanding of environmental aspects. Any attempt to implement or improve recycling systems and/or recycling behavior, needs to consider these aspects and the insights gained through this research may provide decision makers with practical assistance. The paper also contributes by providing academia with a framework for further studies on the behavioral aspects of recycling.
Keywords: behavior, motivational factors, recycling, waste management.

1 Introduction

Waste can be both a problem and an asset. If waste is not taken care of properly, it can harm both people and the environment. Consequently, waste should be recovered as much as possible, either as material, humus and nutrients or energy. Waste can thus be seen as an important resource. Taking into account the growing population, which in just over ten years between 1999 and 2011 increased by 1 billion people and reached 7 billion people (UN 2015) and is estimated to be 9.7 billion by 2050, the increasing of industrialization and urbanization [1] man can no longer afford to manage waste as waste, but has to use it as a resource.

"*The Tragedy of the Commons*" stems from Garrett Hardin's article from 1968 in which he referred to a resource which is owned by no one and but everyone has access to [2]. This means both taking too much from a common resource, but also putting too much into it. Hardin stated that "*in a reverse way, the tragedy of the commons reappears in problems of pollution*". He believed that in order to avoid destruction, humans would have to change their values and ideas of morality [3]. For many years the public concern for environmental protection and sustainable development has been genuine, but despite this unsustainable development trends persist [4]. For example, the quantity of municipal solid waste is expected to reach 2.2 billion tons per year by 2025, and even if countries like Cambodia, Algeria and Morocco collect more than 70% of urban waste, more than 95% of it is dumped in landfills or elsewhere without further treatment [5]. However, the recycling trends in some western countries are beginning to reach relatively high levels [6]. The increasing urbanization in the developing world, will accentuate the waste problem and the need to recycle. For example, in greater Shanghai, there are now over 23 million people, and in their household waste they leave 60–70% of food waste components [7]. There is clearly a dire need to remove this part of the waste stream and to convert it into useful resources such as biogas and/or compost, rather than dump it in a landfill.

Waste recycling systems are often dependent on consumers' or end users' more or less voluntary labor to function, which is especially true for residential recycling [8]. For example, considerable household waste must be sorted in the home before it can be left at curbside collection points or drop-off centers. This sorting work is mainly carried out by the people in the individual household. Sometimes it even requires that people travel a short or a long distance by car to leave the sorted waste at special collection points. However, recycling is also found at people's places of work. For example, the construction industry accounts for a significant portion of the total amount of waste in the developed world and hence sorting at the workplace is crucial to optimizing waste as a useful resource.

For recycling to be successful, whether at home or at work, there are several very different aspects to consider. These are aspects such as physical features, behavioral patterns, levels of knowledge, attitudes and perceptions and the complex interrelation between them [9]. Nevertheless, also demographic characteristics and social norms matter [1] as well as incentive schemes [10], policies [11] or how mature the recycling society is [12].

The purpose of this paper is to explore waste recycling behavior in general, as well as to study how recycling behavior is affected by different motivational factors, both physical and psychological. The end point will be to present a model which discriminates between different recycling characters based on the results of the study.

2 Research methodology

This paper is based on a systematic literature study. Literature studies can describe the state of knowledge in a particular area and are suitable for answering questions of a qualitative nature, finding holes in the research field, and providing a base for future research [13–15]. A systematic literature study differs from an unsystematic literature study in the sense that the systematic study tries methodically to overcome biases in the review and content analysis processes. In order to explain the research question from a structured literature study relevant texts must be found [16].

While there has been at least one other recent literature review on the subject of waste prevention [17] this research provides a broader view of the individual recycler, whereas Wilson *et al.* have concentrated more on business attitudes and behaviors. There has also been a literature review on the determinants of recycling behavior [18] carried out 20 years ago. Since over 80% of the articles referenced in this paper have been written and published in the twenty years which have since passed, and the Hornik *et al.* [18] article adopted/was based on a quantitative appraisal, this research provides an updated picture and a more qualitative point of view. Scientific work is perishable [19] and an update of similar areas of research may be required.

Due to the inclusion and exclusion criteria, the search engine's general limitations, and common language barriers there may plausibly be other literature reviews conducted in the area which have been overlooked.

2.1 Literature search

To find relevant texts, the database LUBsearch was used. LUBsearch is an online database at the library at Lund University in Sweden and includes articles, journals, books and other resources, both electronic and in print. The inclusion criteria for the literature search were that only peer reviewed articles published in scientific journals, written in English with both abstracts and full texts were used. Both qualitative and quantitative articles were included in the search. Only peer-reviewed material was used to guarantee the quality of the articles. The exclusion criteria were any articles written or published after completing the data search.

2.2 Sample selection

The keywords used for the sampling was taken from the purpose explanation of the paper; The purpose of this paper is to explore waste recycling behavior in general, as well as to study how recycling behavior is affected by different motivational factors, both physical and psychological. The end point will be to present a model which discriminates between different recycling characters based on the results of the study. Initially used were the words: “waste”, “behavior” and “motivational”, which produced 203 references, unfortunately many of them had main topics not related to waste handling, but to other matters, for example, attitudes to shopping, which had some impact on waste, but the waste issues were neither discussed nor analyzed in any greater detail. In a second search the word “recycling” was added to capture the area in a better way. More searches were done to see if it was possible to capture the area even better and words as “environment”, “challenge”, “sustainability” or “barrier” were added separately, but each one resulted in either too small a sample or there was only a marginal difference. Account has been taken of the differences in spelling between British and American English.

The final search resulted in 82 references from 34 different journals and seemed to cover the area satisfactorily. Several articles reappeared, however, and the number of individual articles was 76. The number of journals was still unchanged and they could be categorized into six groups (see table 1). Some of the journals on the other hand overlapped, for example, “Journal of Environmental Psychology”. In those cases the journal was filed either under environmental journals or psychological journals depending on the institution the author represented or the majority of authors represented.

Table 1: Articles by type of journal.

Journal types	**# Journals**	**# Articles**
Waste oriented journals	11	45
Economic or business oriented journals	4	7
Psychological oriented journals	4	7
Consumer oriented journals	4	6
Design and architectural oriented journals	3	3
Other	8	8
Total	**34**	**76**

The first step in the selection was carried out as a preliminary assessment of titles and reading the abstracts. After the initial selection four articles were deemed not to fit in and removed from the study.

In the second step the articles were read through to get an overall idea of the study. A standard scorecard was used when screening the articles and the keywords of each study were identified. The aim was to identify the details, similarities, and differences in each individual study and to exclude articles not fit for the purpose. The final sample consisted of 62 studies that were considered appropriate to answering the research purpose.

The keywords were collected and covered 133 different words or combinations of words. They were divided into categories of a similar nature. The categories then formed themes to be used in the analysis.

3 Analysis

All of the screened documents were sorted for relevance and categorized as inputs to the detailed analysis. The keywords of the articles were categorized into 14 larger groups. All the groups were not used in the later analysis, only those which in a broad logical sense could explain the behavior of recycling (a help or an obstacle to a desired practice). For example (as shown in table 2), different

Table 2: Articles by continent, decade and research method.

Continent	No.	Published	No.	Method	No.
America	23	70s	1	Survey	49
Asia	9	80s	1	Interview	10
Europe	40	90s	18	Experiment	3
		00s	21	Case study	5
		10s	31	Literature review	2
				Modeling	2
Total	**72**		**72**		**72**

Table 3: Keyword categories.

Name of category	Example of keywords	Comment
Background factors	Adolescent Aging	Included in the analysis since it may impact recycling behavior.
Behavior	Behavior change Observed behavior	Not included in the analysis since behavior is the object of this study rather than an explanatory factor
Communication/ information	Communication strategy Marketing communications	Included in the analysis since it may impact recycling behavior.
Design	Drop-off recycling Recycling program design	Included in the analysis since it may impact recycling behavior.
Incentives	Willingness to pay Anticipated guilt	Included in the analysis since it may impact recycling behavior.
Location of study	USA Dublin	Not included in the analysis.
Research method	Case study Cluster analysis	Not included in the analysis
Subject area	Environmental psychology Environment	Not included in the analysis
Theory	Grounded theory Self-determination theory	Not included in the analysis
Waste categories	Domestic waste Electronic waste	Not included in the analysis. The type of waste may, however have an impact, but it is not sufficiently explored in the literature and therefore the category is dropped.
Other	Segmentation Multilevel	Not included in the analysis. This category includes keywords that are unlikely to affect recycling behavior and that do not belong to any other category.

research methods where not considered an important category to explain recycling behavior. In the 62 studies considered six different methods were used, and even though the survey method was far the most common one, there is nothing that speaks against the other methods as completely satisfactory.

3.1 Background factors

The most common background factors, age and gender, are debated if they have an impact on recycling behavior or not. In some studies, there are differences and in others there is not. Furthermore, some researchers have found that older people have a higher recycling partaking and for others it is the other way around, the same goes for gender [20]. However, age probably has an impact if we study the really old, when physical limitations increase, as these possibly affect recycling behavior [9]. Nevertheless, there are some background factors that seem to explain some differences in recycling behavior, such as social class and religion [21, 22]. However, even if some authors have found significant differences in what way exactly the studies have been limited and it is hard to draw any far-reaching conclusions. Solid waste recycling is predominantly an urban phenomenon [23], and hence "place-of-living" might be another background factor worth mentioning. However, this factor is generally disregarded in most research studies, or studies are only conducted in a single location. The global trends of increasingly older population, urbanization, and a growing middle-class, are challenges that might change the basic conditions for recycling.

3.2 Communication and information

Overall, the level of knowledge seems to have an influence on the propensity to recycle [10, 18]. Information can increase environmental awareness and ecological behavior; this is shown for example by Wandmacher *et al*. [24]. They reported an increase in recycling efficiency of about 15–25% due to new information labels [25]. Information appears to have two aspects; one theoretical and one practical. The theoretical aspect informs people about the benefits of recycling and its impact on the environment, and the practical communication informs people how and where they can recycle. Since the theoretical part of information facilitates the understanding of the bigger picture, it is possibly the basis for moral or natural incentives; see the Incentives section. The practical information on the other hand, tells the story of details, and will probably not affect any higher moral to recycle, but facilitate the actual doing. The two different aspects seem to affect differently. To recycle, the latter seem to be necessary, but the former less so [9, 26].

3.3 Design

The design of recycling facilities can have an impact on recycling behavior. In some cases, the physical design aids recycling behavior [27, 28], such as the introduction of curbside collection, sorting bins specially designed for indoor use to reduce the problems of confined recycling space, or recycling equipment designed for a specific environment, e.g. by using air-filled tires on recycling bins in construction sites to increase maneuverability. Design can also trigger the psychological willingness to recycle, for example, by adding a fun factor to recycling. There have been examples of bins painted like cows [29] and a bottle bank arcade machine: both increased waste and recycled material [30]. In the former example four waste bins were painted as cows with the advertising slogan “Feed the Cows”. In the second example a bottle collection bin was remodeled to resemble an arcade machine. In other cases, designs are vital, for example, access location or access points are often placed at a level that prevents people with limited physical mobility such as elderly or disabled people from recycling [9]. Since the number of people over the age of 65 is expected to nearly triple between 2010 and 2050 to about 1.5 billion people, the need for design for the elderly seems to be urgent [31].

3.4 Incentives

Waste recycling is seldom considered to be an exciting task and it is fairly easy to cheat. To increase interest and recycling rates authorities and other stakeholders sometimes want to introduce incentives to motivate individuals to perform as favored. Incentives can be remunerative, moral, coercive or natural. The remunerative incentives are usually based on repayment when recycling (deposit systems) or decreased costs by volume- based waste fees (less waste, lower cost). Moral incentives occur when a certain choice is regarded as the right thing to do, it is right to recycle for the benefit of the environment or viewed as immoral when not performed. Coercive incentives are the risk of some sort of punishment for wrongdoing. Finally, natural incentives are things such as curiosity, mental or physical exercise, admiration, fear, anger, pain, joy, or the pursuit of truth, etc. The outcome of monetary incentives varies between different studies. Moral incentives seem to play a lesser role [26], and natural incentives have not been studied in depth, although joy or fun factors seem to have some influence as described above.

4 Discussion

Any attempt to clarify and explain why one person recycles and another does not, is certainly a complex task. However, the literature describes in different ways how recycling behavior is affected by different factors. Each factor can be seen as relying on both internal and external conditions. Take, for example, the case of fun design, where the design itself is an external factor, but the increased willingness to use it would rather be described as an internal natural incentive. In order to condense the findings of this study, the author proposes a model based on two aspects explaining recycling behavior; simplicity and motivation. It seems logical that if motivation is high and the task of recycling is simple, recycling rates would be high, and vice versa. The factors discussed earlier may affect one or both of these aspects. At first glance, it may be tempting to see motivation as a predominantly internal condition, while simplicity would be an external condition. However, this would oversimplify the picture and ignore internal aspects of simplicity and external aspects of motivation. For example, information affects simplicity in a rather obvious way; good information, e.g. a distinct sign or a well-written pamphlet will guide the recycler to perform correctly. After a few times the recycler knows how to behave and external information has become internal knowledge. The following two sections will further develop the concepts of simplicity and motivation.

4.1 Simplicity

Simplicity is how easy it is for a recycler to actually recycle waste. This is affected by factors such as the distance to recycling facilities, container design, time required, and knowledge about what and how to recycle. There are few people who strongly oppose recycling [8, 12, 26] and most people are prepared to make small efforts to recycle, for example, they are prepared to spend time at home on recycling or having extra bins in their homes or gardens [32]. For any society or entity that wants to initiate recycling routines, the first step must be to satisfy the need of how and where [33–36]. This is not always as simple or clear as it seems; an article by Howenstine [8] describes that in a survey with students from Illinois University, three out of four respondents did not know the location of a single drop-off site, although there had been one across the street from the university for many years.

A short distance to bins is obviously a matter of simplicity, which is shown in several articles and many countries have introduced curbside collections, which have proven effective. However, as González-Torre and Adenso-Díaz [37] also point out, if the common drop-off site is near enough, the benefits of curbside collection decrease. The design of bins can also have an impact, especially for groups with physical limitations, such as older people. For them, the access point for putting waste into a bin might be at a critical height or they might need easier wheelie bins for curbside schemes [9]. This is something that must be taken into account since the world population of older people is increasing. An estimation by Wolfgang Fengler of the World Bank is that the number of 60–79-year-olds will increase by 1.6 billion by 2050 [38].

Changes in recycling fractions and lack of knowledge of how some materials or items should be recycled can also prevent people from recycling [33, 39]. Practical, adapted information is important and if not present, can be something that even works against recycling [40]. Information about how to recycle should ideally use different designs, texts, pictures, illustrations, etc. for the convenience of the individual, since people process information in various ways [41, 42]. It is also evident that if municipalities want to increase their recycling rates, they must plan long-term communication campaigns to encourage and maintain the recyclers in the long run [42]. New designs can also help to reduce the need for detailed information, such as the reverse vending machine, where people do not need to separate cans and bottles [43].

4.2 Motivation

Motivation can be both internal and external. Internal motivators include environmental values beliefs and attitudes, for example, environmental knowledge, anticipated guilt or altruism. External motivators are all the reasons that externally affect recycling attitudes, intentions, and behaviors, such as monetary incentives, community pressure or laws and regulations.

A general awareness of the positive environmental aspects of recycling seems to be widespread at least in a theoretical perspective [8, 22]. This general knowledge does not seem to be enough to make people more motivated to recycle [22, 44] though some researchers have found significant, albeit weak effects [45]. It seems the knowledge has to be more specific of how recycling affect the environment and an understanding or presumption that the recycling execution has a positive effect regardless how small. Another explanation to the differences in behavior in the group that have a general environmental concern is more indirect. Elgaaied [46] has found that anticipated guilt seems to play a major role in people's intentions to recycle. Anticipated guilt was also found to be a link between facilitating conditions and intentions to recycle, i.e. the better the facilities, the guiltier the people would feel about not recycling.

Environmental laws and regulations seem to have a major impact on people's behavior. People tend to see environmental issues as moral issues, and both law and morality serve to channel our behavior [47]. Both law and morality have their different incentive systems, where law mainly acts by threat of sanctions if we disobey legal rules, and morality works by providing the individual who acts badly with a bad conscience or guilt, and good acts may result in virtuous feelings or praise. This works optimally if the two patterns of law and morality are in alignment with another, which they seem to be in the mind of most people in the environmental arena [47].

Establishing whether monetary incentives are effective or not seems to differ between different researchers. There are many who do not consider it very important [11, 48] and others who believe it to be an effective way to deal with recycling. Saphores *et al*. [49] for example, favor a deposit system for e-waste.

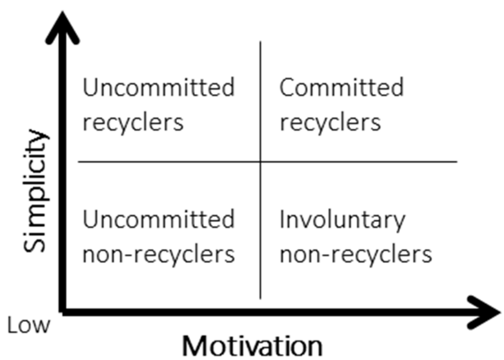

Figure 1: Recycling behavior model.

Based on the aspects of simplicity and motivation, the characteristics of four different recycling behavior can be distinguished and explained. These four recycling characters can be described as:

- Uncommitted non-recyclers;
- Uncommitted recyclers;
- Committed recyclers;
- Involuntary non-recyclers.

The uncommitted non-recyclers and the committed recyclers are, as groups, easy to understand, they follow their beliefs or lack of beliefs and behave accordingly. The other two groups are different. The involuntary non-recyclers are a group of people who believe in recycling but do not recycle, often because of a lack of recycling facilities or perceived lack of vital parts of it, such as suitable recycling instructions [46]. The uncommitted recyclers on the other hand perform the task without any strong beliefs in recycling. There is a tendency (at least in the developed world) that recycling has become such a common practice and so easy to perform that it is almost habitual [26].

Recycling seems to be dependent on simplicity and motivation, and high recycling rates should be achievable if motivation is high and the conditions to execute the task are simple. But as figure 1 shows, simplicity is vital for recycling whereas motivation seems to be more of a nice-to-have feature. Many studies have shown that individuals with the same level of motivation behave differently due to the simplicity of the task [46]. It has also been found that regardless of attitudes, people recycle if the conditions to do so are simple enough [26].

Motivation should not be ruled out, however, as in all human activities motivation can induce actions to bring about the facilities or knowledge needed to perform the desired task [10]. This is regardless of whether it is to find the nearest bring site, lobby for curbside collection or build your own compost heap. Uncommitted recyclers, on the other hand, will probably not be motivated enough to adapt very quickly to change, or the slightest inconvenience in recycling facilities will result in decreased recycling rates [40].

To increase recycling rates, different courses of action must be used, depending on what group is addressed, but for all groups, having a recycling infrastructure is a must [9]. Involuntary non-recyclers probably do not need as advanced system to initiate recycling behavior as uncommitted non-recyclers. For the latter group it would need to be almost as simple to recycle as not to recycle [50] since it is very rare that people are directly opposed to recycling and make an extra effort *not* to recycle [12, 26]. Uncommitted non-recyclers are possibly not open to much information about the benefits of recycling [9]; for this group it is inevitably better to get the system in place and thus make them begin to recycle. To give uncommitted recyclers more information about the benefits of recycling might be more successful due to positive reinforcement. They are already engaged in recycling behavior, and if this behavior gets them some positive feed-back, then they are more likely to engage in that same behavior again [4]. They might even end up as committed recyclers one day. Positive reinforcement is probably also be an effective way for committed recyclers to maintain their motivation and recycling behavior [22].

5 Conclusions

In the simplest of worlds there are detailed directions on how to act in any given recycling situation However, this is seldom the case and there is no universal method to stimulate recycling [8]. The conditions around recycling are dependent on external and internal conditions that differ between places and people, but the general characteristics of a recycling system seem to follow a pattern regardless of the people involved. So even if it is not possible to provide specific instructions in a given recycling situation, there are some important principles that should be used when recycling situations are introduced or developed.

First of all, most people consider recycling to be a low priority task [9] and tasks with lower priority have a tendency to not be performed if the task is perceived as inconvenient. Therefore, it is important to design recycling facilities as close to the recycler as possible and facilities should be equipped to work in a given situation, for example, with lower access points. Secondly, it is important to have knowledge about how and where to recycle; uncommitted recyclers or non-recyclers tend to have less or obsolete information that prevents them from recycling. Even if motivation and understanding are in place, without knowledge of how to recycle, it still does not work [33]. Finally, a contributing step is to establish a deeper understanding of the environment and the impact of recycling to gain or maintain a general level of motivation, which might further increase recycling.

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Author index

Adabor E. S. 173
Al Mutairi S. 73
Al Qallaf Y. 73
Alberruche E. 27
Al-Kandari S. 73
Alves L. 49
Amponsah S. K. 173
Arahuetes A. 371
Araiza J. A. 109
Arranz J. C. 27
Aruya E. I. 333
Asante-Darko D. 173

Barabadi A. 161
Bockreis A. 277
Brandtweiner R. 1

Caligaris M. 299
Carmo A. S. 243
Carra S. 323
Celso F. 391
Chigbo C. O. 289
Choy Y. K. 97
Corte J. F. 391
Cristóbal A. 299
Cruvinel V. R. N. 255

da Silva A. X. 243
da Silveira G. M. 391
de Macêdo E. M. L. 243
de Martins R. M. 391
Ding Z. 265
Dlamini S. Q. 13
do Nascimento F. T. 391

Engelseth P. 135

Falayi T. 383
Fernández-Naranjo F. J. 27
Flach M. V. 391
Fouzy H. 73
Frausto Martinez O. 187
Freire L. 49

Galato D. 255
García M. 205
Garmabaki A. H. S. 161
Giese S. 187
Gómez A. 311

Hamilton R. 147
Heuss-Aßbichler S. 85
Huber A. L. 85

Jahno V. D. 391
Jia H. 359
Johansson K. 401
John M. 85

Kaiser A. S. 311
Khajuria A. 57
Koch C. 187
Krumay B. 1

Lei S. 265
Lu J. 161

Madon I. 195
Marafi M. 219
Martins N. C. 391
Meirer M. 277
Messina S. 205
Mora J. 231
Morley M. 147
Müller W. 277

Noche B. 345
Ntuli F. 383
Nwoko C. O. 289
Nwosu O. U. 289

Okayama T. 123
Ottosen L. M. 37

Pelozo G. 299
Poveda M. 359

Quaranta N. 299
Quintern M. 147

Ramos H. M. P. 255
Rana M. S. 219
Rodrigues L. B. 391
Rodrigues M. A. S. 391
Rodríguez J. 231
Rodríguez V. 27
Rodriguez-Lascano Y. 205
Rojas-Valencia M. N. 109

Salas C. 231
Saldaña C. E. 205
Sánchez F. 311
Sánchez J. E. 109
Schirmer M. 187
Schneider V. 311
Seaton B. 147
Sgobbo A. 61
Sibaja J. 231
Sigvardsen N. M. 37
Simatele D. 13
Steenbeck T. L. 187

Thwanane U. 383

Ulloa H. 205
Unsen M. 299

Vadillo L. 27
Vazquez E. 49
Vianello E. A. 243
Viedma A. 311
Vilanova Plana P. 345

Wang Y. 265
Wu D. 265

Yan L. 265
Yousef K. 73
Yuan F. 161
Yuan Q. 359
Yusuf R. O. 333
Yusuf Y. O. 333

Zanoni N. 311
Zhang F. 161
Zhang Z. 265

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