University of Southern Queensland

Faculty of Engineering & Surveying

The Selection of Integrated and Sustainable Waste Processing Techniques for Application within Indonesia

A dissertation submitted by

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Abstract

The project analyses various waste processing techniques and technologies and their applicability as an integrated and sustainable waste processing system for implementation within Indonesia. The various effects of a waste management system will have a considerable impact on the sounding environment, community and lively-hood of many people. To ensure the selected processes are suitable, sustainable and well integrated the analysis has incorporated a broad range of aspects, not only the technical principles involved. These aspects have encompassed several principles including the technical and operational, environmental, financial, socio-economic, administrative and legal principles.

The analysis primarily concluded a single-stage high solid anaerobic digestion facility to be the most appropriate waste processing facility for implementation based on the analysed criteria. The report recommends that this facility be operated in cooperation with an adjacent material recovery facility in order to assure socio-economic and ethical issues are minimised. The development of waste processing systems should have a primarily focus to aid the residents of scavenger communities within the dumpsites, via means of employment generation and improvement of sanitary conditions. The key outcomes established within the dissertation concluded a number of aspects which require future study in order for an appropriately integrated and sustainable system to be implemented. This includes further research into the market and requirements for recyclable goods, biogas and compost, as well as investigation into the health issues involved with the household use of biogas.

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Limitations of Use

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Matthew Bates

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Signature

Date

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This project has been completed with the assistance and support of a number of people. I would like to thank Mr. Steven Goh of the University of Southern Queensland who acted as my supervisor, providing gentle guidance and support throughout all stages of this project.

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Matthew Bates

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Nomenclature

MSW	Municipal Solid Waste
RDF	Refuse Derived Fuel
AD	Anaerobic Digestion
MRF	Material Recovery Facility
PM	Particulate Matter
CFD	Circulating Fluidised Bed
BFB	Bubbling Fluidised Bed
SSHS	Single-Stage High Solid
SSLS	Single-Stage Low Solid
ER	Equivalence Ratio
VOC	Volatile Organic Compound
UASB	Up-flow Anaerobic Sludge Bucket
VS	Volatile Solid
COD	Chemical Oxygen Demand
OLR	Organic Loading Rate

Chapter 1

Introduction

1.1 Introduction

The project aims to analyse various waste management processes and technologies to be utilised in the processing of municipal solid waste (MSW) within countries of Indonesia. The project analyses various principles involved with the implementation of these facilities to ensure an adequately integrated and suitable system. The objectives of the project are summarised in point form below. These objectives outline the features produced from this project. Refer to Appendix A for a full version of the project specification.

- Undertake a literary review of the practices of waste management within Indonesia and Southeast Asia, establishing the current environmental, economic and humanitarian issues caused by these practices.
- Research waste management systems and how each component interrelates.
- Research various methods of waste processing and how each process may be adapted to Indonesia.
- Analyse and evaluate the various waste processing technologies based on criteria which encompasses all aspects of possible implementation effects.

- Establish a most appropriate process or technologies for implementation within Indonesia, outlining recommendations for future work and design.

1.2 Rationale

Waste management plays a critical and vital role in the sustainability and health of a society and surrounding environment. In developed nations the management of municipal solid waste is relatively easy to process, with the availability of funds and resources required to implement large scale processing facilities. Developing nations however, are often left behind in this field due to a lack of funds, resources and understanding to adequately and sustainably manage the dramatic augment in waste generation due to a thriving increase in population, urbanisation and industrialism. This is adversely present in the developing countries of Southeast Asia, with only 10% of waste currently being properly engineered and processed (Asian Development Bank 2012*a*). The remaining waste is disposed within non engineered open dumping grounds causing considerable health, safety and environmental problems for the people and environment surrounding these regions of Southeast Asia. As Indonesia and its surrounding countries move into an era of unprecedented urbanisation, it is crucial that an affordable and culturally appropriate method of waste management is developed.

1.3 Overview of the Dissertation

The dissertation is organized as follows:

Chapter 2 presents a synopsis of various literatures relevant to the project topic. This review gives particular attention to the problems associated with the current waste management practices, including the current environmental and humanitarian problems. The review presents particular constraints to the waste management process which have influenced the analysis of various waste processing techniques for application within Indonesia.

Chapter 3 discusses the methodology utilised in the completion of the project. This encompasses the various stages involved and the methods used to obtain the conclusions.

Chapter 4 presents background information on waste and waste management systems. This includes the various processes involved with the handling and treatment of waste, as well as the factors which affect the effectiveness of this system.

Chapter 5 provides detailed information on various processes and technologies used for the treatment of waste. The treatment of waste is a subsection of the waste management system describe in Chapter **??** and the primary focus of this dissertation.

Chapter 6 details various waste and climate data from Indonesia. This data is later analysed in subsequent chapters in order for an appropriate waste processing system to be selected.

Chapter 7 presents a detailed analysis of the various waste processing technologies and their applicability to Indonesia. The chapter outlines specific criteria for the analysis to ensure the selected system could be well integrated and sustainable.

Chapter 8 concludes the report, presenting the conclusions from the analysis and recommendations for future work.

Chapter 2

Synopsis of Literature

2.1 Introduction

In South and South East Asia waste management is a prevalent problem which is often hidden from the sights of tourists (Visvanathan, Trankler, Kuruparan & Xiaoning 2002). In 2002 a study conducted by The Asian Pacific Landfill Symposium, concluded that about 90% of solid waste within Southern and South Eastern Asia is disposed in open dumps (Visvanathan et al. 2002). There has been little development in this area within South East Asia, with a study conducted during 2011 by the Asian Development Bank showing that the overall percentage of waste properly managed remained consistent. The 2011 study also concluded that only about 10% of solid waste ends up in properly engineered and managed landfill sites (Asian Development Bank 2012*a*).

The management of waste within South East Asia has become one of the primary urban environmental issues (Visvanathan et al. 2002). The problem is expected to rapidly increase within the next few decades, with the acceleration of waste generation caused by an ever increasing population, urbanisation and industrialisation (Visvanathan et al. 2002). The Asian Development Bank predicts that another 1.4 billion people will be added to the already 1.6 billion living within Asia by 2050, with over half of Asias population being urban by 2030 (Asian Development Bank 2011*a*). Urban areas of Asia produced approximately 2.7 million cubic metres of municipal solid waste per day within 1999, with this figure estimated to increase to 5.5 million cubic metres by 2025 (Urban Development Sector Unit East Asia and Pacific Region 1999). The World Bank states that, these estimates are conservative; the real values are probably more than double this amount. (Urban Development Sector Unit East Asia and Pacific Region 1999)

2.2 Environmental Issues

The most common effect associated with waste management is the environmental impact. The most evident environmental problem for the dump sites is the extensive build-up of methane within the areas. Although the dumps occasionally employ clay liners, little consideration is given to groundwater pollution, the water table and gas migration (United Nations Environment Programme n.d.). The dumpsites often consist of a build-up of methane gases, contributed by the high percentage of compacted organic and plastic waste (United Nations Environment Programme n.d.). CCH (Centre for Childrens Happiness) a relief organisation working within Cambodia reports that the local dumping ground of Phnom Penh released a constant miasma of smoke (Center for Childrens Happiness 2011). The dump was literally on fire, as the methane produced from the rotting waste burned (Center for Childrens Happiness 2011). This is reported as a common trait among the open dumping grounds within South Eastern Asia, with the same occurrence of uncontrolled methane burning also reported in dumping grounds within the Philippines (Power 2006) and Indonesia (Nas & Jaffe 2002). Many open dumping sites are situated within wetland regions as part of land reclamation initiatives (Johannessen & Boyer 1999). However, many of these wetlands connect to main river systems and farming areas (Johannessen & Boyer 1999). A 2006 analysis conducted by Sustainable Project Management of the surrounding areas of a Pilipino open dumping ground which was closed in 1990, found that the landfill site still contained and discharged heavy metals and other pollutants into the environment and possibly the food chain (Asian Development Bank 2006). This analysis also collected leachate samples from various surrounding areas, with the leachate from the closed dump observed to be dripping in sites of childrens play areas and local farming grounds (Asian Development Bank 2006).

2.3 Humanitarian Issues

Whilst the environmental impacts of the current waste management practices are evident, the open dumping practices also have a vast effect on the poor. In a report on slums, the United Nations Human Settlements Programme states that slums are regularly the recipient of a citys negative externalities, such as the accumulation of solid waste in a citys rubbish dump (United Nations Human Settlements Programme 2003). This land which has little or no economic value remains open for temporary occupancy by people left with no other place of residency (United Nations Human Settlements Programme 2003). These make-shift settlements pose significant risk to the residents from the contaminated air, water and soil, as well as the danger of a collapse from the poorly constructed dumpsite (United Nations Human Settlements Programme 2003). With no other option of living accommodation or means of work, the people forced to live within these dumpsites and scavenge for items which may be resold to receivers who in turn are tied to larger buyers who sell to factories (United Nations Environment Programme n.d.). Daniel T Sicular states that with the rapidly growing economic develop, increasing hardship and poverty are placed upon the bottom 20 percentage of the population (Jellinek n.d.). This 20 percent lack the resources, education, contacts and courage to keep up with the rapid pace of change, and in turn lose their land, jobs and traditional bonds and are forced to move to the city where some become scavengers living on the scraps of others (Jellinek n.d.). Jellinek (n.d.) states that the system of the scavengers allows them to survive, but keeps them trapped within the cycle of poverty, with Hodal (2011) reporting that the dumpsite scavengers within Asia make around 3.50AUD per day.

In a recent article on the inhabitants of a Manila open dump by National Geographic, it was reported that thousands of the slum dwellers living on the rubbish sites make their living by making charcoal from wood scavenged from the garbage dumps (Smith 2012). The undeveloped and primitive method of making the charcoal in open pits exposes the residents to numerous detrimental emissions including carbon monoxide, nitrous oxide, soot, as well as other chemicals formed through the burning of treated wood (Smith 2012). Children of the workers are also forced to work within these areas, missing out on an education to scavenge for nails within the charcoal sell to the local junkyards, continuing the cycle of poverty (Smith 2012). Without this small income that the children provide, families would not be able to provide food for them to survive. Hodal (2011) reports that many of the families within this slum community in Manila earn just a $1.60 per day, well below the Philippines minimum wage of approximately $9 per day (Smith 2012).

2.4 Limitations and Difficulties

Whilst it may be easy to point the blame onto the government for these environmental and humanitarian destitutions, it is well documented that the governments within these developing counties of South East Asian face their own intricacies in overcoming the problems before them (Think Quest n.d.)(Bodelius & Rydberg 2000). With such a critical situation in the management of waste within South East Asia, there can be a predisposition that the practices of the developed world can be applied to these regions to conclude an optimum solution (Bodelius & Rydberg 2000). However the sudden implementation of these methods within developing countries results in the malfunction of facilities and inefficiently managed operations (Bodelius & Rydberg 2000). Despite the cultural divergence in the implementation of developed facilities, developing countries often cannot afford the expenses involved with constructing contained and properly managed landfills and waste management facilities (Pugh 1999).

2.5 Conclusion

These regions demand inclusive research on solid waste landfill management to significantly improve the prevailing environmental and humanitarian tribulations on and around the landfill sites (Visvanathan, Trankler, Basnayake, Chiemchaisri, Joseph & Gonming n.d.). The specific approaches pursued as a result of this research should take into consideration the cultural and climatic differences of the region, in order to ensure that the strategies developed concerning landfill design and operations are appropriate for a transition from dumpsites to engineered sanitary landfills to occur within an Asian context, as well as Indonesia specfically (Visvanathan et al. 2002).

2.6 Chapter Summary

This chapter has presented an analysis of the various problems associated with waste management practices within Indonesia and other countries of South East Asia based on various literatures. The information outlined has provided foundational information utilised for the understanding of the ethical, humanitarian and environmental problems which will be required to be analysed in order for integrated and sustainable waste processing technologies to be implemented. The topics discussed within this chapter have been reflected upon within further analyses in later chapters.

Chapter 3

Methodology

3.1 Introduction

In order to ensure that a thorough analysis of the field was completed, a methodology of the research has been compiled. The focus of the dissertation was to research technologies and processes which can be used in processing waste in a sustainable manner within Indonesia. The methodology ensures that the research was comprehensive, and the selection and development of technology and processes were optimum for the cultural and environmental application.

3.2 Methodology

Initially an understanding of the current waste management processes within Indonesia was established. This was done through the completion of a literary synopsis which comprised of a review of numerous topic-specific literatures. The review compared the information presented within the literatures, allowing for an understanding of the current waste practices and problems associated with the practices to be established. An alternative to this research method would firsthand interaction with the waste management locations and gain an understanding of the waste practices through observation. Whilst the selected method of research does not allow for firsthand contact or experience of the waste management practices, it does allow for a perspective from numerous views and collaboration of data from a variety of sources on a concise time limit and budget. The literary synopsis lead to an analysis of the current waste management methods with an outline of the problems of the current problems associated with the waste practices detailed. These problems outlined the issues that were addressed in the development of a more sustainable waste management method. The problems were reviewed in detail to ensure that a full understanding of the issues could be established for them to be addressed within the analysis.

Following the analysis of various literatures, research was undertaken into sanitary waste management systems. The research comprised of gathering an understanding of what processes were involved with the systems, how each subsection of the system interrelates with one another, as well as factors which affect the systems. This research combined with the literary review lead to the understanding of which aspects of a sanitary waste management system are lacking within Indonesia. The research concluded the need for adequate waste treatment facilities as part of the waste management system are most prevalent within Indonesia.

The established analysis of waste management systems lead to research into specific waste processing techniques and facilities. A comprehensive review of all waste processing techniques was undertaken to ensure an adequate analysis of these processes could be complete.

Following this research, a complete analysis of these waste treatment processes was completed based on their applicability within Indonesia. As there are several possible negative implications of implementing a processing facility, this analysis was required to be as comprehensive as possible. In order to ensure an appropriately integrated and sustainable system was chosen, several key criteria were selected for the analysis. This criteria is outlined within Chapter 7.

Finally, in conclusion to the analysis a specific process was selected based on the outlined criteria. The conclusion also outlined key issues which should be considered for the design and implementation, as well as ideas for future work.

Chapter 4

Background

4.1 Introduction

The management of wastes incorporates several stages throughout the management process. An understanding of these aspects and procedures must be obtained in order for an adequate analysis of waste management technologies and processes are to be completed. This chapter presents a background overview of these aspects including types of waste, waste management systems and the various stages involved with the system, as well as an overview of the waste management hierarchy.

4.2 Municipal Solid Waste (MSW)

Municipal solid waste (MSW) consists of all wastes generated by a municipality. These wastes arise from human and animal actions that are generally solid, and are discarded as useless or unnecessary. This encompasses all types of solid wastes generated by households and commercial establishments, and are usually collected by local government bodies. As outlined within Chapter 2, the primary problems associated with waste management within Indonesia are associated with the treatment and processing of MSW. Therefore the processing of MSW has been the primary focus of this dissertation. (Enviros Consulting Limited 2007)

4.3 Waste Management Systems

A waste management system is a process by which waste is processed. This encompasses the generation of the waste to the final disposal and all stages of treatment and transportation in-between. The associated problems with the management of MSW solid wastes are complex due to the quantity and diverse nature of the wastes, limitations to funding, impacts of technologies, as well as the limitations of implementing a system within a developing country. Therefore for effective solid waste management treatment processes to be designed and implemented, the fundamental aspects and relationships of a solid waste management system must be identified and clearly understood. The functional elements of a waste management system can be separated into six categories. These include: (1) waste generation; (2) waste handling and separation, storage, and processing at the source; (3) collection; (4) separation, processing and transformation of solid wastes; (5) transfer and transportation; and (6) disposal. Figure 4.1 illustrates the interrelationships between these functioning elements. The subsequent sections detail each of these elements and the processes involved. (Tchobanoglous et al. 1993)

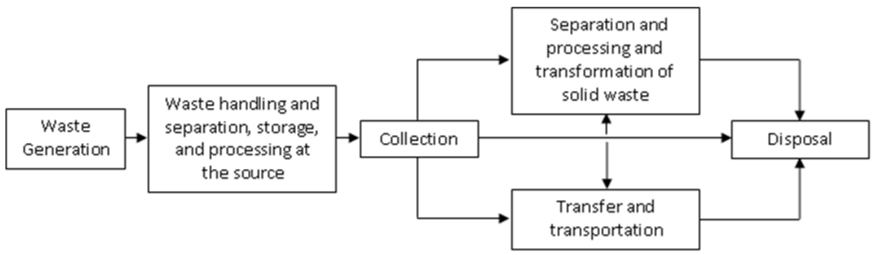

Figure 4.1: Interrelationships between the functioning elements of a waste management system (Adapted from (Tchobanoglous et al. 1993)).

4.4 Waste Generation

The generation of waste encompasses all activities in which materials are identified as no longer of useful value and are therefore discarded. The understanding of the generation of waste is a key component of the design of suitable and sustainable waste processing technologies. The key considerations required for design include the quantities and characterisation of the waste being generated. This therefore requires an adequate assessment of the generation of waste and the characteristics of the wastes is required for the design to be suitable and sustainable. The processes and considerations involved in assessing the waste generation are explained in the following sections. (Tchobanoglous et al. 1993)

4.4.1 Assessment of Waste Generation

The quantities of MSW generated are imperative in the determination of specific equipment, the planning and designing of waste collection routes, disposal and material recovery facilities (MRFs), as well as ensuring compliance with the regions waste regulations and laws. Waste generation is affected by numerous factors which cause variations in the types and quantities of waste collected. In knowing these factors and variations, considerations can be taking into account in the designing of waste processes and facilities to accommodate for the specific waste composition to be processed. (Tchobanoglous et al. 1993)

Waste Generation Factors

Key factors that impact the generation rates and quantities of waste collected comprise primarily of the geographic location and the season within the year, cultural beliefs, practices and legislation, the frequency at which waste is collected and reduction and recycling at the produce source.

Climates and climatic events are affected primarily by the geographic location. This in turn influences the types and quantities of waste generated within the region over the period of time. The variations in climate predominantly impact the quantity of food wastes and green wastes. Geographic locations which encounter tropical weather would obtain larger quantities of green waste where foliage are in bloom for a larger time frame than that of colder climates. These certain types of wastes are also impacted by the season of the year. The growing seasons for various fruits and vegetables vary throughout the various seasons, thus impacting the quantities and compositions of food wastes. As the climate and season will cause variations in the quantities of certain types of solid wastes generated, seasonal sampling of MSW should be conducted to ensure the acquired data will have the most substantial impression on the system. Tchobanoglous et al. (1993) that this information can be obtained through means of a load-count analysis. (Tchobanoglous et al. 1993)

In understanding the cultural beliefs and practices of a region, knowledge of the local waste generation can be acquired. The religious, cultural and social beliefs and attitudes can affect the living standards, average income of the area, the level of education, as well as views towards the environment and recycling which in result affect the composition and quantity of waste generation. Significant reductions in the quantities of solid wastes generated in a region can be produced if the residents are willing to change. This can be observed through the development of social attitudes and lifestyles towards conservation of natural resources and the reduction of the economic burden associated with solid waste manage. Regions where practices, such as household composts and kitchen food waste grinders are held to a degree of importance will have reduced food wastes in comparison to regions which do not uphold these practices. This factor can ultimately reduce the amount of MSW through consistent education on the economic and environmental impacts of waste management to cause a change in social and cultural beliefs and attitudes (Tchobanoglous et al. 1993). Possibly the most important factor impacting the generation of specific wastes is the presence of local, state or federal regulations pertaining to the use of certain materials. Through the encouragement of certain recyclable or restriction of non-recyclable materials, a positive impact on the waste management process can be enforced. Implementations such as reductions in price of products which utilise recyclable materials are one example for reducing the need for landfills within the waste management process. The presence of recycling programs and ethics within a community will influence the amount of waste collected for processing or disposal. (Tchobanoglous et al. 1993)

Another factor which affects the generation of MSW is the frequency at which waste is collected. The amount of space that a household or business has to store waste and the rate at which wastes area removed will affect the way they utilise the space and the rate at which waste is generated. For example if a household is limited to one container to store waste which is collected on a weekly basis, the practices and attitude of that household towards waste may differ to that of those with an unlimited collection service. Whilst the waste generated may in some cases be consistent, the waste collected could differ as the household with a conservative attitude of waste may process biodegradable waste onsite through composting. (Tchobanoglous et al. 1993)

A final key factor that influences the composition and quantity of MSW is the material and design of products at the source. A reduction in waste can occur through the design, manufacture and packaging of products which utilise materials that contain minimalized toxic content and maximise usage life, as well as designs to minimise volume of packaging. The buying patterns of consumers can have an influence on these aspects of design and manufacturing, as a reduction in sales can force companies to seek alternative processes in their design to appeal to the market. (Tchobanoglous et al. 1993)

4.4.2 Waste Characterisation

The characterisation of waste allows for the sources, characteristics and quantities of waste generated to be identified. Through waste characterisation a detailed analysis of the various technologies which may be employed to process the various forms of waste can be completed. The process involved with the study of waste characterisation includes the following:

1. Accumulation of Existing Information
   Through gathering existing information, time and costs can be reduced. Existing information can also act as a reference to validate acquired data. This information can be obtained through sources such as:
   - Company records (waste collection, landfill businesses)
   - Previous studies and documents
   - Local waste ministries
   - Information from comparable communities
2. Generalisation of Waste Generation Sources

- Residential/household
- Institutional
- Agricultural
- Industrial
- Commercial
- Water and waste water treatment plants

These various sources of waste can be divided into waste categories allowing for a more detailed analysis of the specific waste composition to be obtained. Table 4.1 lists the various waste components categorically.

3. Development of a Sampling Methodology
A sampling methodology is a developed process for sampling the characteristics of the waste. The identification and characteristics of the sampling include:
    - Sources
    - Size of sample
    - Required samples for statistical significance
    - Duration of sampling
    - Period of year that samples are collected
4. Completion of Field Studies
5. Completion of Market Surveys
6. Analysis of Factors Affecting Rates of Waste Generation

(Tchobanoglous et al. 1993)

Table 4.1: Waste Categories (Recreated from Tchobanoglous et al. (1993))

Waste Category	**Description**
Residential and Commercial	
	Continued on next page

Table 4.1 – continued from previous page

Waste Category	Description
Food Waste	Waste from the handling, preparation, cooking, and eating of foods
Paper	Newspaper, high-grade paper (office, computer, etc.), magazines, mixed paper, and other non-usable paper (impregnated wax, carbon paper, thermal FAX paper)
Cardboard	Old corrugated cardboard/craft (recyclable, contaminated)
Plastics	Polyethylene terephthalate (PET) (Soft drink bottles), High-density polyethylene (HDPE) (milk, water and detergent containers), commingled plastics, polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), film plastic
Textiles	Clothing, rags, etc.
Rubber	All types of rubber products excluding vehicle tyres
Leather	Shoes, coats, jackets, upholstery
Yard Wastes	Grass clippings, leaves, bush and tree trimmings, other plant materials
Wood	Waste building materials, wooden pallets
Miscellaneous	Disposable nappies
Glass	Container glass, flat glass (windowpanes), other non-container glass materials
Aluminium	Beverage containers, secondary aluminium (window frames, doors, gutters)
Ferrous metals	Tin cans, appliances, cars, other iron and steel
Special wastes	
Bulky items	Furniture, lamps, bookcases, file cabinets, etc.
Consumer	electronics Radios, stereos, television sets, etc.

Continued on next page

Table 4.1 – continued from previous page

Waste Category	**Description**
White goods	Large appliances (stoves, refrigerators, washers, dryers)
Yard wastes	collected separately Grass clippings, leaves, brush and tree trimmings, tree stumps
Batteries	Household (alkaline, carbon-zinc, mercury, silver, zinc and nickel-cadmium), motor vehicle (lead-acid batteries)
Oil	Used oil from automobiles and trucks
Tyres	Used tyres from automobiles and trucks
Institutional	Same waste categories as residential
Construction and demolition	Dirt, stones, concrete, bricks, plaster, lumber, shingles, plumbing, heating, electrical parts and other building materials.
Municipal services	
Street and alley cleanings	Dirt, rubbish, dead animals, abandoned automobiles
Trees and landscaping	Grass clippings, bush and tree trimmings, tree stumps, old metal and plastic piping.
Parks and recreational areas	Food wastes, newspaper, cardboard, mixed paper, soft drink bottles, milk and water containers, mixed plastics, clothing, rags, etc.
Catch basin	General debris, sand, used oil mixed with debris, etc.
Treatment plant residuals	Water and wastewater treatment plant sludge, ash from combustion facilities
Industrial	Varies with the types of industries within the region
Agricultural	Varies with the types of industries within the region

4.4.3 Assessment of Solid Waste Quantities

Alongside the sources and composition of solid waste, the measure of the quantities of MSW is also an instrumental component of the knowledge required for the design and implantation of a waste management technologies and processes. In the analysis of MSW quantities, both volume and mass are used to quantify the waste. As volume may vary for various compactable waste, such as green and food waste, the degree at which the waste has been compacted or the specific weight in the storage conditions must be referred to. The methods used to assess MSW quantities commonly include a load-count analysis, a weight-volume analysis and a materials-balance analysis. (Tchobanoglous et al. 1993)

Assessment of Solid Waste Quantities

The load-count analysis involves the recording of the corresponding characteristics of waste (waste types, estimated volume) over a specific time period. Scales are also often used to record weight data; this method also employs field data and published data to obtain generation rates. (Tchobanoglous et al. 1993)

Weight-Volume Analysis

Weight-volume analysis measures the specific weight and volume of each load. This method provides improved data on the density of solid wastes at a given time period and location. (Tchobanoglous et al. 1993)

Material-Balance Analysis

In order to obtain reliable data of the generation and movement of solid wastes a detailed materials-balance analysis for each generation source must be completed. A materials-balance method of analysis may be required to be completed in order to confirm compliance with legislative recycling programs. The materials-balance analysis requires a set system boundary around the study unit to be drawn up. The system boundary is a critical component of the analysis as it allows for certain components of the study unit to be simplified. The analysis then requires all activities which occur within or cross the boundary line which will affect the generation of wastes, to be identified (as shown in Figure 4.2). From this the waste generation associated with each activity is identified, and used with appropriate mathematical relationships to determine the quantity of wastes generated, collected and stored. (Tchobanoglous et al. 1993)

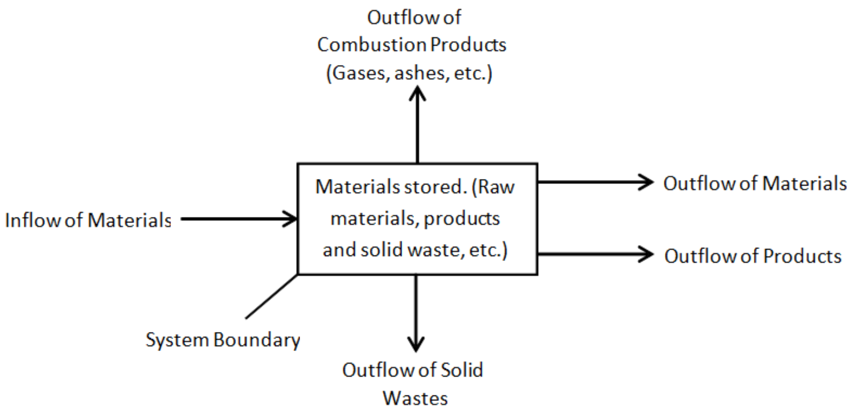

Figure 4.2: Boundaries of a material-balance analysis. (Adapted from (Tchobanoglous et al. 1993)).

4.5 Waste Handling, Separation, Storage, and Processing at the Source

The second functional element of a waste management system is the handling and separation, storage, and processing of the waste at the source. The handling and separation of the waste involves the activities of managing the waste until collection. The separation of the waste involves separating and storing the various components of waste in separate containers, such as recyclable and unrecyclable materials. The process of separation at the source is not currently implemented within Indonesia and therefore for the analysis of waste technologies it has been assumed that the waste to be processed is commingled. (Meidiana & Gamse 2010) In addition to the separation of waste materials, the on-site storage is also of critical importance due to the health concerns and aesthetic conditions. The cost of on-site storage is usually borne by the owner of the site, and is therefore difficult to implement in developing countries.

4.6 Solid Waste Collection

The collection of MSW from its source involves the gathering of solid wastes and recyclable materials, and the transportation of the waste materials to where the collection vehicle is emptied. This location may be a waste transfer station, a processing facility, or final disposal site. The current primary practice within Indonesia is to transport directly from the collection at the source to a final disposal location. As explained in Chapter 2, this creates various environmental, economic and ethical issues. Further details of the collection rates within Indonesia are presented within Chapter 6.

4.7 Separation, Processing and Transformation of MSW

The forth of the functional elements of a waste management systems is the separation, processing and transformation of waste materials. The sorting and processing of solid waste components is a key process in a waste management system. Through the process of sorting, processing and transforming waste materials, recoverable materials and products can be acquired to yield functional elements. Various technologies and processes can be utilised in order to process the waste, and each are explained in detail throughout Chapter 5. This stage of the waste management process has a lasting effect on the quantity of waste dumped in landfills and therefore the environment. The element of separation, processing and transformation of waste is the primary area omitted from the practices of waste management in Indonesia and has therefore been selected as the primary focus of the dissertation (Meidiana & Gamse 2010).

4.8 Transfer and Transport

The transfer and transport element of the waste management system includes two processes: the transfer of wastes from smaller collection vehicles to larger transport equipment, and the subsequent transport of wastes over large distances to a processing facility or final disposal site. The transfer of waste materials typically occurs at a transfer station. Motor vehicle transportation is the most common form of vehicle utilised for waste transportation, as is the case within Indonesia, however some countries do use rail cars and barges for waste transportation. (Tchobanoglous et al. 1993)

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The transfer and transport element of the waste management system includes two processes: the transfer of wastes from smaller collection vehicles to larger transport equipment, and the subsequent transport of wastes over large distances to a processing facility or final disposal site. The transfer of waste materials typically occurs at a transfer station. Motor vehicle transportation is the most common form of vehicle utilised for waste transportation, as is the case within Indonesia, however some countries do use rail cars and barges for waste transportation. (Tchobanoglous et al. 1993)

4.10 Disposal

The final element of a functional waste management system is the disposal of the waste. The ultimate disposal of wastes occur by landfilling, whether the waste is transported directly from the source, residue from compost, anaerobic digestion, combustion, or residual materials from a material recovery facility. Whilst this is the final location of the waste materials, the design of the landfill must be adequate to ensure environment sustainability, as well as meet health and safety criteria. Most landfills currently used within Indonesia are un-engineered and therefore unsanitary and breeding grounds for vermin and insects, as well as present numerous environmental and health problems. Whilst this is a key problem, the pre-processing of waste will reduce these effects, as well as the volume of waste being transported to these sites, allowing for greater opportunities and ease for sanitary landfills to be implemented. (Tchobanoglous et al. 1993)

4.11 Waste Management Hierarchy

The waste management hierarchy is an internationally accepted guide for prioritising waste management practices. The hierarchy sets out the preferred order of waste management practices, with the objective of achieving optimal environmental outcomes (Zero Waste SA 2012). It is widely used as a simple tool to promote strategies which seek to avoid products becoming waste, and to find a use to waste as an alternative to disposal (WasteNet 2011).

The avoidance of waste is the most favourable option within the waste management hierarchy. The rate and volume at which resources are being produced needs to be reduced, coincided with the recognition that all material goods have a price for energy (Zero Waste SA 2012). The reduction of waste is the next most favourable method. The reduction of waste reduces energy required to process the waste and to originally manufacture the goods, thus reducing the volume of waste being transported to landfill. The re-use of products also plays a part in the reduction of energy requirements to process waste, as well as the waste being transported to landfill. The hierarchy recognises the processing and energy recovery of waste as a preferred option to landfill, however acknowledges that prior to this, waste reduction, re-use and recycling are most preferable where applicable.

4.12 Chapter Summary

This chapter has presented an overview of information on waste and waste management processes. The chapter detailed Municipal Solid Waste (MSW) as the primary focus for waste management within Indonesia, and therefore is the primary focus of this dissertation. Waste management systems were also detailed and the various stages involved with this system. The dissertation focuses primarily on the processing, separation and transformation of solid wastes, which is a subsection of a waste management system. The processes involved with the processing, separation and transformation of solid wastes is examine in detail within Chapter 5.

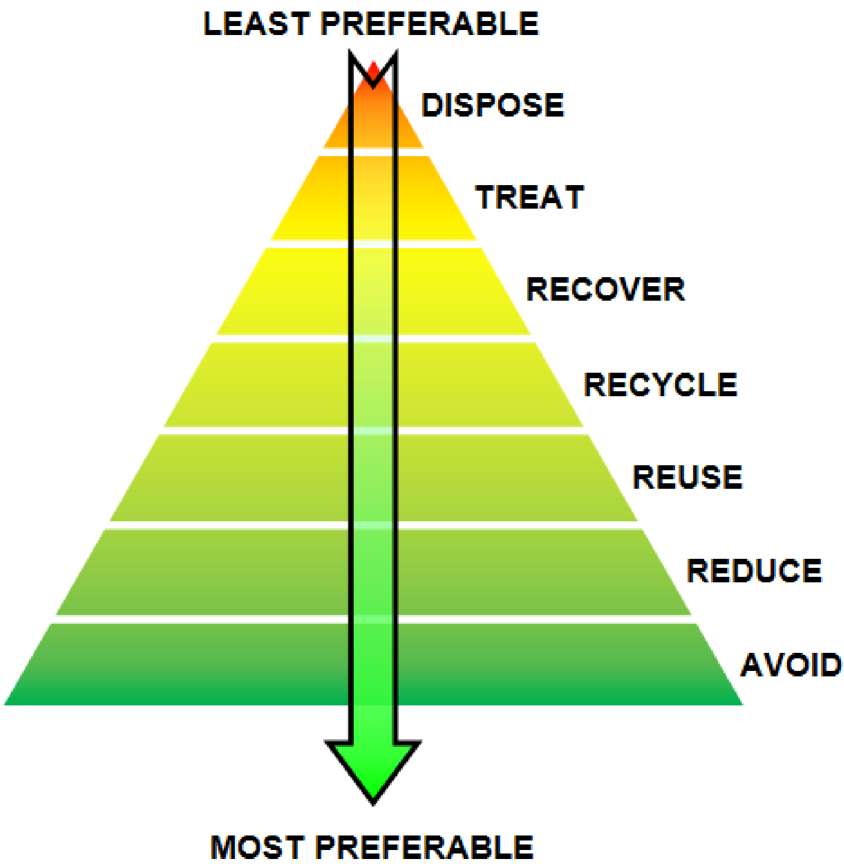

Figure 4.3: Waste Management Hierarchy

Chapter 5

Waste Processing Technologies

5.1 Introduction

The effective management of solid waste involves the application of various methods and processes of treatment. As explained within Chapter 4, the treating of solid waste, including the separation, processing and transformation of the waste, is a subsection of a waste management system. This aspect of waste management is primarily neglected within Indonesia, and due to its crucial importance within a sustainable and integrated waste management system, it has been selected as the primary focus of this dissertation.

The processing or treatment of waste prior to its final disposal can provide several advantages. The processing of solid wastes can reduce the total volume and mass of the waste material that requires disposal, as well as alter its form and improving handling characteristics. This reduction in volume helps to conserve land resources, as well as the cost of transportation to the final disposal site. The processing and separation of solid wastes also allows for the recovery of materials for reuse, as well as energy recovery.

The applied technologies and processes for an integrated and sustainable waste management system must ensure the protection of public health and the environment. In the processing and treatment of MSW, there are two primary subcategories of processing. These include biological treatment and thermal treatment (as shown within Figure 5.1). The biological processes include aerobic digestion and anaerobic digestion, whilst thermal processes include combustion (incineration), gasification and pyrolysis. In conjunction or separately from these processes, material recovery facilities (MRFs) can also be utilised in the recovery and pre-processing of the waste materials. This chapter provides background information and details of these various processes and technologies.

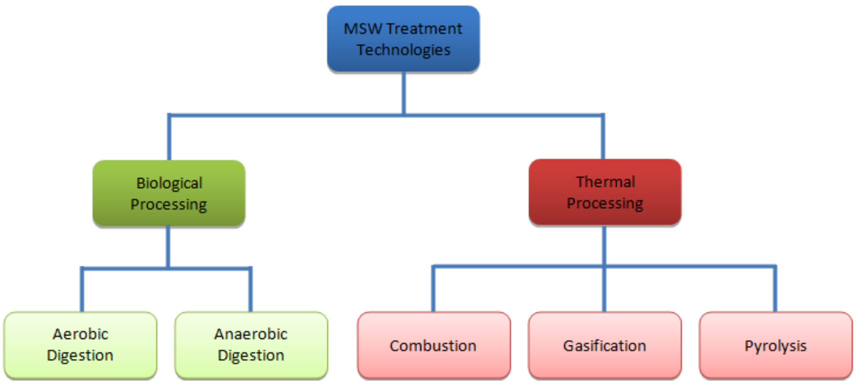

Figure 5.1: The various categories and processes involved with waste processing.

5.2 Aerobic Digestion

5.2.1 Introduction

Aerobic digestion, also known as compositing, is the process by which naturally occurring micro-organisms break down organic waste in the presence of oxygen (O2) to produce a stabilised residue known as compost. During the aerobic digestion process, the organic matter of the waste feedstock is fed upon by oxygen consuming micro-organisms. The process of composting releases large quantities of carbon dioxide (CO2) and water vapour into the atmosphere, and generates significant amounts of heat. The volume of carbon dioxide and water vapour released can amount to half of the initial mass of the waste, hence reducing the mass and volume of the final product significantly. The volume of gaseous emissions, including odours, therefore requires relatively large quantity of processing and management. This section details background information on the composting process, the factors which affect this process, various composting facilities, as well as a broad analysis of the utilisation of this process.

5.2.2 The Composting Process

The compositing process may initiate as soon as the raw waste materials are combined together. With the exception of plastic, rubber and leather components, all organic constituents of MSW can be considered to be comprised of proteins, amino acids, lipids, carbohydrates, cellulose, lignin and inert materials. Under aerobic microbial digestion, the final product is a humus material known as compost. The new cells produced become part of the active biomass involved in the digestion of the organic matter, and upon death become part of the compost material. (Pace, Miller & Farrel-Poe 1995)

The initial stages of composting see the easily degradable wastes and oxygen rapidly consumed by the micro-organisms. The activity of the micro-organisms within the waste materials can be determined through the temperature of the pile or windrow, and the temperature can therefore be used to determine the activity or stage of the aerobic digestion process. The pattern followed by the temperature of the composting materials is generally displayed by a rapid increase to 40-60°C, which is maintained over several weeks depending on the waste materials. The temperature of the compost then gradually decreases to ambient air temperatures, as the active composting process slows. (Nathanson 2003)

The active composting process is followed by a curing period, in which the waste materials slowly decompose. During the curing period waste continues to break down until the remaining micro-organisms consume the final easily decomposable materials. The curing period can be observed after the compost piles or windrows no longer reheat after turning. The curing stage often lasts a period of 3 to 4 weeks and occurs at mesophilic temperatures (**?**). The curing process is a critical component of composting and can result in high levels of organic acid, a high carbon to nitrogen ratio and other factors which can be damaging to use within a soil if shortened. The curing process yields a relatively stable and easy to handle compost product.

5.2.3 Factors Affecting the Aerobic Digestion Process

There are various factors which affect the composting process. These include the oxygen content and aeration of the pile or windrow, the carbon to nitrogen (C:N) ratio, the particle size of the feedstock, the moisture content and temperature of the waste, as well as the time allowed for composting to occur. Each of these factors is explained within the following sections.

Aeration and Oxygen Content

The aerobic digestion process requires considerable amounts of oxygen throughout the initial and maturating stages of decomposition. A limited supply of oxygen to the waste may cause the composting process to become anaerobic. As explained within section xx the anaerobic digestion process is a considerably slower and odorous process. Aerobic composting requires a minimum oxygen content of 5% within the pore spaces of the compost. Various methods and technologies can be utilised to replenish the oxygen levels include rotating the materials, by means of front-end loaders, mechanical agitation or ventilation systems. (Tchobanoglous et al. 1993)

Carbon to Nitrogen (C:N) Ratio

The micro-organisms involved in the composting process require primary nutrients of carbon (C), nitrogen (N), phosphorous (P) and potassium (K). Carbon is used by the micro-organisms for both energy and growth, whilst nitrogen is utilised for protein production and reproduction. The C:N ratio typically ensures that other required nutrients are adequately present. Ideal ratios for active composting are within the range of 25:1 to 30:1. However a C:N ratio between 20:1 and 40:1 has also presented good composting results. Ratios below 20:1 can lead to excess ammonia levels and odours as the available carbon is consumed during the stabilising of the present nitrogen. The compositing process slows dramatically when the C:N ratio exceeds 40:1, as insufficient levels of nitrogen is available for the growth of the micro-organisms. (Tchobanoglous et al. 1993)

Moisture Content

The moisture content of the composting materials should be maintained within the range of 40% to 65%. The moisture is necessary to support the micro-organisms metabolic processes and can become detrimental to the microbes at content levels below 40%. At levels above 65%, the moisture displaces considerable amounts of air within the pore spaces, limiting the movement of air and leading to anaerobic conditions. (Tchobanoglous et al. 1993)

Particle Size of Waste Materials

The particle size of the waste components affects the rate at which aerobic decomposition occurs. With smaller particle sizes the rate of decomposition increases, however can also affect the movement of oxygen within the pile or windrow. Particle sizes with an average diameter of approximately 3 to 60mm allow for optimum composting conditions. (Tchobanoglous et al. 1993)

Temperature

The composting process will primarily occur within two temperature ranges. The temperature ranges include mesophilic conditions (10-40°C) and thermophilic conditions (above 40°C). Each temperature range allows for various types of micro-organisms to survive. During the mesophilic composting process, oxygen thriving mesophilic bacteria break down easy to decompose materials. Whilst mesophilic compositing reaches much lower temperature ranges, it does not reach temperatures required to decompose materials such as manure, which may contain weed seeds, fly larvae or harmful pathogens. Thermophilic bacteria survive at an optimum temperature range of 40°C to 70°C and digest the compounds at a greater rate than mesophilic bacteria. The natural occurring heat encourages the rapid growth of more thermophilic bacteria until all of the original organic material is broken down, leaving a stabilised and consistent nutrient rich soil product. The temperature at which the compost pile or windrow will reach is dependent upon the previously listed factors and therefore can be controlled for an optimum composting process. (Tchobanoglous et al. 1993)

pH Levels

In order for an optimum aerobic digestion process to occur, the pH level should remain within the range of 7 to 7.5. At ranges above 8.5, nitrogen can be lost in the form of ammonia gas. (Tchobanoglous et al. 1993)

Rate of Decomposition

The rate at which composting occurs to produce a finalised compost product is dependent upon the previously listed factors. As a general rule, the entire decomposition and stabilisation of waste materials may occur over a period of a few weeks. Such factors as the compost materials, frequency at which the compost is being turned, temperatures reached and the moisture content will all affect the rate at which composting occurs. (Tchobanoglous et al. 1993)

5.2.4 Composting Facilities

Composting facilities are designed to increase the rate of the naturally occurring biological decomposition by managing the key factors of the composting process. Once the curing process is complete the final product is either used on site or prepared for market. A complete municipal solid waste composting operation includes sorting and segregating, shredding and pulverising, decomposition, product upgrading and lastly marketing. The sorting and segregation operations necessitate the isolation of organic, decomposable waste materials from non-biodegradable substances, whilst shredding and pulverising (refer to Section 5.7) operate to reduce the size of the individual pieces of the compost material. The sorting of MSW is a vital component in the recycling process and the technologies and methods of this operation are discussed in detail within Section 5.7 and the importance of the compost particle size is covered within Section 5.2.3. Composting facilities employ four methods to process the compost. These include windrow systems, aerated static pile systems, turned-aerated pile systems, in-vessel systems and vermicomposting.

Windrow Systems

Windrow systems consist of long piles of waste material on level ground. Each windrow is kept porous through means of periodically turning the materials mechanically. This can be accomplished with the use of a front-end loader; however large facilities typically use specific windrow turning machinery. Windrow composting generally takes about 5-8 weeks for maturation and curing stages of the composting to be completed. Windrow composting requires relatively large areas of land to process. An approximate area of 24 hectares is required for a composting facility to support a community of 250,000. Within the windrow system anaerobic conditions may occur within the centre of the pile if infrequent turning occurs. The anaerobic conditions will slow the decomposition rate and may produce foul odours. (Nathanson 2003)

Aerated Static Pile Systems

Aerated static pile systems induce air into the compost through ducted air systems installed below the base of the pile. Aeration can occur through means of blowing air into the pile, or drawing air through the pile. The process of negative aeration can provide an added benefit of directing the air through odour processing systems. In comparison to a windrow system, the aerated static pile systems have higher capital costs; however have lower overall operating costs. (Nathanson 2003)

Turned-Aerated Pile Systems

A turned-aerated pile system takes advantage of both techniques utilised in aerated static piles systems and windrow systems. This allows for greater consistency in the process control, and produces a greater quality product.

In-vessel Systems

The final systems which can be utilised at composting facilities are in-vessel systems. In-vessel systems are mechanical-type compost systems which promote rapid decomposition within an enclosed structure by forced aeration, stirring and tumbling. Typical enclosed systems can reduce the land area required to complete the composting process by a factor of 6 and can reduce the process time to produce a stabilised product from 5 weeks to 1 (Nathanson 2003). Despite the increased rate of decomposition and reduced land area required, large-scale in-vessel facilities are complex and expensive to construct, operate and maintain. The operation of these systems requires the moisture content and temperature of the compost to be meticulously monitored. In-vessel systems may be equipped with rotating ploughs, vanes, or augers to facilitate aeration and mix the waste material. Some systems also employ compressed air as means to aerate the waste material. (Nathanson 2003)

Vermicomposting

In addition to these systems, an additional method of vermicomposting is become increasingly popular at commercial scales throughout Australia. Vermicomposting is the use of worms to obtain controlled composting of organic wastes. The worms digest the organic materials to produce vermicast. Vermicast may also be known as worm casting, worm humus or worm manure and is the final product of the breakdown of organic matter by an earthworm. Redworms are the most commonly used worm species in the vermicomposting process and feed most rapidly at temperatures of 15-25°C. In comparison to other compost systems, vermicast has a finer consistency and have higher contents of potassium, phosphorous and nitrogen and produce more microorganisms to combat diseases within plants. (Nathanson 2003)

5.2.5 The Utilisation of Aerobic Digestion

Composting can be used in conjunction with other waste treatment technologies. It can be utilised after waste has been treated through a MRF and combined with the non-organic faction of waste treatment technologies. As composting requires organic components, pre-sorting of mixed wastes must initially be conducted. The majority of biodegradable organic material is suitable for composting, however meat scraps, dairy products, fatty foods and cooking oil may cause unpleasant odours and attract vermin to the site.

Prior to the sale of the stabilised compost as mulch or soil conditioner, the compost must be processed further to increase the quality and appearance. These processes include drying, screening and granulating or pelletising. The compost is occasionally marketed within packaging; however bulk sale is more efficient and economical. The marketability is the most problematic component of composting as a key waste management option. Within the United States composting comprises only a small portion of MSW management systems, predominantly due to the low demand for the resulting product. Due to composts relatively low quality as a fertiliser in comparison to inorganic fertilisers, the expense of transportation, and its availability, the demand for compost within the agricultural industry is minimal. Some uses for MSW compost does include landscape mulching, erosion control in parks and golf courses, as well as soil conditioner within nurseries and residential gardens (Nathanson 2003).

Possible negative impacts of composting may occur if adequate technology and processes are not utilised. A high level of moisture within the compost can result in water pollution from leachate, as well as infestations of vermin in event of poor management of the compost system. Provisions should be made in the design and operation of an open compost system to divert leachate to a suitably management location, measures to ensure insect and rodent populations around the site are minimalized, as well as measures to reduce odour problems.

5.2.6 Conclusion

Composting provides a relatively simple process for the treatment of MSW, with the energy required to process the materials primarily generated by naturally occurring biological processes. Besides the simplicity, another key advantage the composting process is the final composting product, due to its ability to increase the organic matter levels of soil. This however, is not always seen as a benefit within developed nations, due to the relatively low demand for such products. Composting does however provide benefits to the application of land, pathogen destruction, possible sellable product, weed seed destruction, and a lower risk of pollution.

5.3 Anaerobic Digestion

5.3.1 Introduction

Anaerobic digestion is the second processes involved in the biological processing of waste. Anaerobic digestion is a process of waste treatment by which micro-organisms break down biodegradable materials in the absence of oxygen. Similarly to aerobic digestion, the anaerobic process considerably reduces the volume and mass of the waste. Anaerobic digestion is a waste-to-energy (WTE) process and is widely used as a source of renewable energy. The digestion process produces large quantities of carbon dioxide (CO_2) and methane (CH_4), known as biogas. Biogas can be used directly as cooking fuel, in combined heat and power gas engines or can be upgraded to natural gas-quality bio-methane. The process of anaerobic digestion, factors which influence the process, types of digesters, the products of digestion, as well as a broad analysis of this process are detailed within the following sections.

5.3.2 The Anaerobic Digestion Process

The processes involved with anaerobic decomposition can be split into three primary stages. These include hydrolysis, acidogenesis and methanogenesis. Throughout the hydrolysis stage of anaerobic digestion, fermentative bacteria convert insoluble organic matter, such as cellulose, into soluble molecules, including fatty acids, amino acids and sugars. The stage also hydrolyses the polymeric matter into monomers, such as cellulose to sugars or alcohols. This stage of the decomposition is a key factor in the rate of decomposition, and is therefore significantly important in the digestion of waste containing high contents of organic matter. Chemicals can be added during this stage in order to reduce the time required for digestion and increase the methane produced. (Tchobanoglous et al. 1993)

The acidogenesis stage of anaerobic digestion, acetogenic bacteria convert the products from the hydrolysis stage into simple organic acids, carbon dioxide and hydrogen. The primary acids produced include acetic acid, butyric acid, propionic acid and ethanol.

Throughout the final, methanogenesis stage methane forming bacteria produce methane by two means. The methane is primarily produced throughout this stage by an acetate reaction whereby two acetic acid molecules are cleaved together. Methane can also be generated throughout this stage via the reaction of carbon dioxide with hydrogen, however is limited to the amount of hydrogen available. This process is shown by Equation 5.1. (Tchobanoglous et al. 1993)

$$\begin{aligned}\text{Organic matter} + H_2O + \text{nutrients} &\rightarrow \text{resistant organic matter}\\ &+CO_2 + CH_4 + NH_3 + H_2 + \text{heat}\end{aligned} \tag{5.1}$$

5.3.3 Factors Affecting the Anaerobic Digestion Process

Similarly to aerobic digestion, there are several factions which affect the digestion process. The conditions and variables must be applied in order to obtain an apposite breakdown of the organic compounds of the waste. The control of these factors enhances the microbial activity, thus increasing the efficiency of the anaerobic process. These factors include the solid content of digestion materials, the temperature and pH levels throughout the decomposition process, the carbon to nitrogen ratio, the mixing of digestion components, the organic load rate, as well as the retention time.

Solid Content of Digestion Materials

The solid content varies based on the type of digester utilised. These digester types are explained within section xx and details the affects which the solid content has on the digestion process. As a standard, low solid digesters require a solid content of 4-8%, whilst high solid digesters require a solid content of 20-40%. (Monnet 2003)

Temperature

The anaerobic digestion process will primarily occur within two temperature ranges. The two temperature ranges include mesophilic conditions (20-45°C) and thermophilic conditions (above 40°C). The mesophilic and thermophilic ranges allow various types of micro-organisms to survive. During the mesophilic range, oxygen thriving mesophilic bacteria break down easily to decompose materials. The mesophilic conditions obtain significantly lower temperature ranges, resulting in temperatures which are unable to decompose materials such as manure, which may contain weed seeds, fly larvae or harmful pathogens. Thermophilic bacteria survive at an optimum temperature range of 40°C to 70°C and digest organic materials at a greater rate than that of the mesophilic bacteria. The natural occurring heat encourages the rapid growth of more thermophilic bacteria until the original organic material is completely digested. (Monnet 2003)

The optimum temperature of digestion may vary depending on the composition of the feedstock, as well as the type of digester utilised. In most AD process, the temperature of the digesting waste should be maintained at a relatively constant temperature to sustain the rate of gas production. Typically thermophilic digestions are most efficient in terms of the rate of loading, retention time and gas production; however they require a higher heat input and have greater sensitivity to operating and environmental variables. (Monnet 2003)

pH Levels of the Waste

The optimum pH levels required for digestion vary between the acidogenesis and methanogenesis stages of anaerobic decomposition. Throughout the acidogenesis phase, acetic, lactic and propionic acids are formed, causing the pH to fall. A pH level below 6.4 can be toxic to the methane forming bacteria. Therefore an optimal pH level for all stages between 6.4 and 7.2 is required. (Monnet 2003)

Carbon to Nitrogen Ratio

As explained, the micro-organisms involved in the composting process require primary nutrients of carbon (C), nitrogen (N), phosphorous (P) and potassium (K). The relationship between the amount of carbon and nitrogen present in organic materials is known as the C:N ratio. Ideal ratios for anaerobic decomposition occur between 20:1 and 30:1. A high C:N ration will result in rapid consumption of nitrogen by the methanogens, resulting in lower gas production. In comparison to this, a lower C:N ratio causes an accumulation of ammonia and pH levels in excess of 8.5, which is toxic to the methanogens. (Monnet 2003)

Mixing of the Digestive Components

The mixing of the components within the digesters increases the contact between the micro-organisms and substrate, improving the bacteriums ability to obtain nutrients. The formation of scum and the development of temperature gradients within the digester can also be prevented by the mixing of digestive materials. In relation to the use of co-digestion methods, the feedstock should be mixed prior to entering the digester to produce sufficient homogeneity. (Monnet 2003)

Organic Loading Rate

The organic loading rate (OLR) is the measure of the biological conversion capacity of the AD system and is measured in Chemical Oxygen Demand (COD) or Volatile Solids (VS) per cubic metre of the reactor. This factor of the AD process is particular important within continuous systems. The use of a feed rate greater than the systems sustainable OLR, yields a low production of biogas due to the accumulation of constraining substances in the digestive. (Monnet 2003)

Retention Time

The retention time of anaerobic digestion is the time required to complete the digestion of the organic waste materials and is dependent upon the above parameters. The retention time typically ranges between 15 to 30 days for mesophilic conditions and between 12 to 14 days for thermophilic conditions. (Monnet 2003)

5.3.4 Types of Anaerobic Digesters

Anaerobic digesters can be categorised into single-stage, multi-stage and batch processes. As well as this, these processes can be classified based on the temperature range of the digestion and the solids content of the feedstock. The processes and applications involved with these various digesters are detailed below.

Single-Stage Low Solid (SSLS)

The biological process of low-solid anaerobic digestion is used to produce methane from the organic fraction of MSW with low solid concentrations. This process involves the fermentation of wastes with total solid concentrations between the range of 4 to 8% (Tchobanoglous et al. 1993). Low-solids anaerobic digestion requires considerable quantities of water to be added to the waste to produce the required solids content range, creating problems with environmental and economic criteria. This method of AD however, can operate with more simplistic technologies than those utilised in high solid systems. Cheaper equipment can also be implemented in comparison to high solid systems, as pumps and pumps can be used in the handling of slurries. This is counterbalanced however, by the need for larger reactors with internal mixing, as well as necessary dewatering and pre-treatment steps, resulting in higher investment costs. (Monnet 2003)

Single-Stage High Solid (SSHS)

Single-stage high solid digesters process fermenting mass with a solid content within the range of 20-40%, in a single reactor. The greatest difficulty of high solid systems is the process of transport and handling the feedstock. Typically the feedstock is transported via conveyor belts, screw conveyors and pumps specifically designed for viscous products. The required equipment is therefore more expensive than that of low solid systems.

The pre-treatment of the feedstock of high solid digesters have a greater allowance for non-organic material such as stones, wood or glass, thus allowing for a much simpler process than low solid systems. High solid pre-treatment only requires the removal of impurities greater in size of approximately 40mm. This produces a lower loss of organic materials during pre-treatment than that required for low solid digesters.

High solid digesters also have the advantage of simpler reactors than low solid systems. As no mechanical devices are required within the reactor to mix the digestive, reactors can be built from much simpler materials and technologies. In order for adequate inoculation to occur, the feedstock must be mixed with the digestive when being added to the reactor. The reactor can also be smaller than low solid systems as no addition of water is required, resulting in no heat required to maintain the temperature within the digester. (Monnet 2003)

Multi-Stage Processes

Multistage AD processes focus on improving the digestion process by introducing separate reactors for the various stages of decomposition. This provides flexibility to optimise each reaction occurring at each stage. The multi-stage process typically utilises two reactors, the first for the hydrolysis phase and the second for the methanogenesis phase. The two reactors allows for a degree of control over the rate of hydrolysis and methanogenesis. For example, throughout the hydrolysis stage, small quantities of oxygen can be introduced to the reactor to induce microaerophilic conditions, thus increasing the rate of hydrolysis.

Due to the separation of decomposition stages, biomass retention schemes can be employed within the methanogenic reactor. A biomass retention scheme aims to achieve high cell densities of methane forming microbes, leading to greater resistance towards inhibiting chemicals, an important variable in determining the biological stability of the digester. Biomass retention can be obtained via one of two methods. The initial method involves the solid content of the reactor being increased by the separation of the liquid and solid retention time, by methods such as recirculation. The second method is known as fixed film reaction. Fixed film reaction involves the suspension of an inert material such as ceramic or plastics within the reactor. The microbes responsible for the digestion of the organic materials are attached to the inert material to promote growth of the methane forming organisms. This method does require the removal of suspended solids after the first stage of digestion.

Multi-stage digesters can also be classified into slow and high solid processes. Multi-stage low solid digesters also present similar advantages and disadvantages to single-stage low solid digesters. The multi-stage low solid process is typically more technologically complex than its single-stage counterpart, thus requiring a high capital investment. This technological complexity does not always yield higher retention rates and production quantities, leading to the primary advantage over single stage systems being the greater control over biological reliability. (Monnet 2003)

Batch Process

The final digestive systems utilised in the anaerobic decomposition of wastes are batch systems. Batch system digesters are initially filled with the feedstock and then left to process through all stages of decomposition with a high total solid content of 30-40% (Monnet 2003). Batch processes can be subcategorised into three other processes. These include single stage systems, sequential systems and up-flow anaerobic sludge blanket (UASB) reactors.

Single stage systems utilise a single reactor for all stages of decomposition. The single stage system processes waste by re-circulating the leachate collected at the bottom of the reactor. This recirculation of leachate is equivalent to a partial mixing of the digestive.

Similar to multistage processes, sequential systems comprise of two or more reactors. Sequential systems involve circulating the leachate from the first reactor, containing high amounts of organic acids, into the second reactor, promoting the methanogenesis stage of decomposition. The leachate from the methanogenic reactor, which is low in acids, is re-circulated to the first reactor after pH treatment. This process promotes inoculation between the reactors, which eliminates the need to combine fresh wastes with digestive. The final subcategory of the batch process is up-flow anaerobic sludge blanket (UASB) reactors. UASB reactors are similar to multi-stage processes with biomass retention. In comparison to multistage processes with biomass retention however, the initial reactor of the UASB system consists of a simple batch process reactor.

Batch processes present a simpler technological and more robust process, resulting in a less expensive process in comparison to other AD digesters. The biogas production of batch processes are significantly less than that of other AD processes, with results in the Netherlands concluding an approximate gas yield of 40% less than that of one-stage wet systems (Monnet 2003).

5.3.5 Products of Anaerobic Digestion

The by-products of AD include biogas and digestate. This allows for AD to be a cost-effective method of biodegradable waste management as both of these by-products can provide financial incomes. In order maximise the value of these products, further processing of both the biogas and digestate may be required. The key factors involved in the AD process vary based on the need for the by-product. These variations in factors are outlined in the subsequent sections, as well as details of the by-products and their uses and applications.

Biogas

Biogas is the gas product yielded from digestion of organic materials under anaerobic conditions, primarily consisting of methane (CH_4) and carbon dioxide (CO_2). Small amounts of hydrogen sulphide (H_2S) and ammonia (NH_3), with trace amounts of hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO), saturated or halogenated carbohydrates and oxygen (O_2) are also occasionally present within the biogas composition. As mentioned, biogas can be used directly as cooking fuel, in combined heat and power gas engines or can be upgraded to natural gas-quality bio-methane. After further upgrading, biogas is able to be utilised within applications designed for natural gas.

Biogas can be used for heating boilers, where the heat can then be utilised within the plant or the water vapour utilised for industrial purposes. Boilers present an advantage due to the lower gas quality requirement. It is preferred that hydrogen sulphide is removed prior to use within the boiler to prevent the formation of sulphurous acid, a highly corrosive compound, in the condensate. Combined heat and power units utilising biogas also necessitate similar quality requirements as that of boilers, however lower hydrogen sulphide content should be present. The utilisation of biogas as fuel for vehicles requires the same type of engine as that used for natural gas. The gas quality of the biogas is however strict, requiring upgrading to achieve natural gas standards. This includes upgrading to obtain a higher calorific value, a consistent gas quality, removal of corrosive elements, as well as removal of any mechanically damaging particles. In developing nations, anaerobic digestion has greater relevance than within developed nations, due to energy being in short supply and expensive to obtain. Anaerobic digestion offers the potential for low-cost energy for cooking, lighting and cooling (Sacher, Isabel, Dumlao & Gensch 2010).

Digestate

Whilst the main purpose of anaerobic treatment of MSW can be seen to be the generation of biogas, a useful by-product of digestate can also be obtained. Similarly to compost, the digestate produced from anaerobic digestion contains a high nutrient content. This product can be utilised as a soil amendment or landscaping, if the appropriate quality is achieved. The composition of the fertilising agents is dependent on the feedstock into the digester and can therefore vary. In order for a high quality digestate product to be obtained, the digestate can be processed into compost. This ensures a complete breakdown of organic components, as well as fixing the mineral nitrogen onto humus-like material, ensuring that a minimal loss of nitrogen is achieved (Monnet 2003).

5.3.6 The Utilisation of Anaerobic Digestion

Similarly to composting, anaerobic digestion can be used in conjunction with other waste treatment technologies. Primarily the process can be implemented after the waste has been processed and sorted through means of a MRF, where the organic fraction of the waste stream can then be processed. All biodegradable materials are able to be processed via means of anaerobic digestion, with the aid of a closed reactor to greatly reduce the release of odours and other environmental impacts.

The by-products of this method of digestion can be useful for energy recovery, and reclamation of land from landfill areas. The use of biogas can be a great benefit to developing nations, with the ability to be utilised in remote areas where electricity access may be limited. The digestate is able to be combined within the composting process to aid in the process of obtaining an adequate level of quality. The marketability of the digestate may have a limited application within Indonesia, however could potentially play a key role in the reclamation of unsanitary landfills.

5.3.7 Conclusion

Anaerobic digestion provides a reasonably simple process for the transformatino of MSW to reusable products, with the energy required for processing primarily generated by naturally occurring biological processes. The digester itself does however require expert design and skilled construction. The final products generated from this process do have great potential to benefit citizens of lower-economic stature within developing nations through the use of biogas. The final digestate product can also be utilised to aid in the reclamation of unsanitary landfills.

5.4 Stoichiometric and Excess Air Combustion

Stoichiometric or excess air combustion is the thermal incineration of waste materials in stoichiometric or excess air conditions. This form of waste processing can be utilised as a WTE process, whereby the heat generated by the combustion process can be utilised for heating or electricity generation purposes. Stoichiometric or excess air combustion is one of the most effective methods in the reduction of volume and mass of municipal solid waste. Combustion as a means of waste management can reduce the municipal waste by approximately 90% in volume and 75% in mass. This section details background information on combustion as a method of waste processing, including the process involved, various types of combustors utilised, the products of combustion, and the factors involved with this process.

5.4.1 Combustion Process

Stoichiometric combustion is the processing of combusting materials with exactly the amount of oxygen required to complete the combustion. The minimal amount of oxygen required to complete the combustion of all components depends of the chemical composition of the waste materials. For example 1kg of carbon requires 2.67kg of oxygen to burn completely; 1kg of hydrogen requires 8kg, and 1kg of sulphur requires 1kg of oxygen (As shown by Equation 5.2 to 5.4). (Tchobanoglous et al. 1993)

For Carbon:

$$\underset{12}{\mathrm{C}} + \underset{32}{\mathrm{O_2}} \quad \rightarrow \quad \mathrm{CO_2} \tag{5.2}$$

For Hydrogen:

$$\underset{4}{\mathrm{2H_2}} + \underset{32}{\mathrm{O_2}} \quad \rightarrow \quad \mathrm{2H_2O_2} \tag{5.3}$$

For Sulphur:

$$\underset{32.1}{\mathrm{S}} + \underset{32}{\mathrm{O_2}} \quad \rightarrow \quad \mathrm{SO_2} \tag{5.4}$$

Due to the inconsistent nature of solid waste, it is practically impossible to combust with stoichiometric quantities of oxygen. The process of combustion must therefore be supplied with excess oxygen to promote mixing and turbulence to ensure oxygen can reach all areas of the waste. Insufficient oxygen will cause some of the combustible products to remain unburned, reducing the efficiency of the combustion and increasing air pollution through the unburned components being emitted into the atmosphere. The highest combustion efficiency occurs when a limited excess volume of oxygen is achieved. An increased excess volume of air reduces the temperature of combustion and increases the loss of energy released into the atmosphere through the flue gas stream.

The majority of waste combustion facilities are designed for continuous-feed operation. In comparison to the less desirable intermittent or batch-feed modes of operation, continuous-feed systems generate a uniform temperature throughout the furnace. This allows for a greater efficiency in the combustion process and reduces damage due to thermal shock on the incinerator components. A generalised process of the combustion of waste materials is shown within Figure 5.2. The waste is initially brought into a storage area by collection trucks. The area of storage is proportional to the size of the processing plant and the rate to waste received to the rate of waste burned and typically provides volume for two days of refuse storage. An overhead crane is utilised to batch load wastes into the feed chute, which directs the loads into the furnace. The crane also acts as a sorter, separating large and non-combustible items from the storage area. The solid wastes from the feeding chute fall onto grates where they are then mass-fired. To control the burning rates and temperatures the oxygen may be induced into the waste via the grates through means of a forced-draft fan, or above the grates. The various gases and particles released from the waste during combustion rise into the combustion chamber and are burned at temperatures greater than 850C. The heat from the hot gases is recovered through a heat exchanger, by which water filled tubes connected to a boiler produce steam which is converted into electricity via a turbine-generator.

Due to the number of hazardous compounds released during combustion air pollution control equipment must be utilised to minimise the amount of these gasses and particles released into the atmosphere. This equipment may include ammonia injection

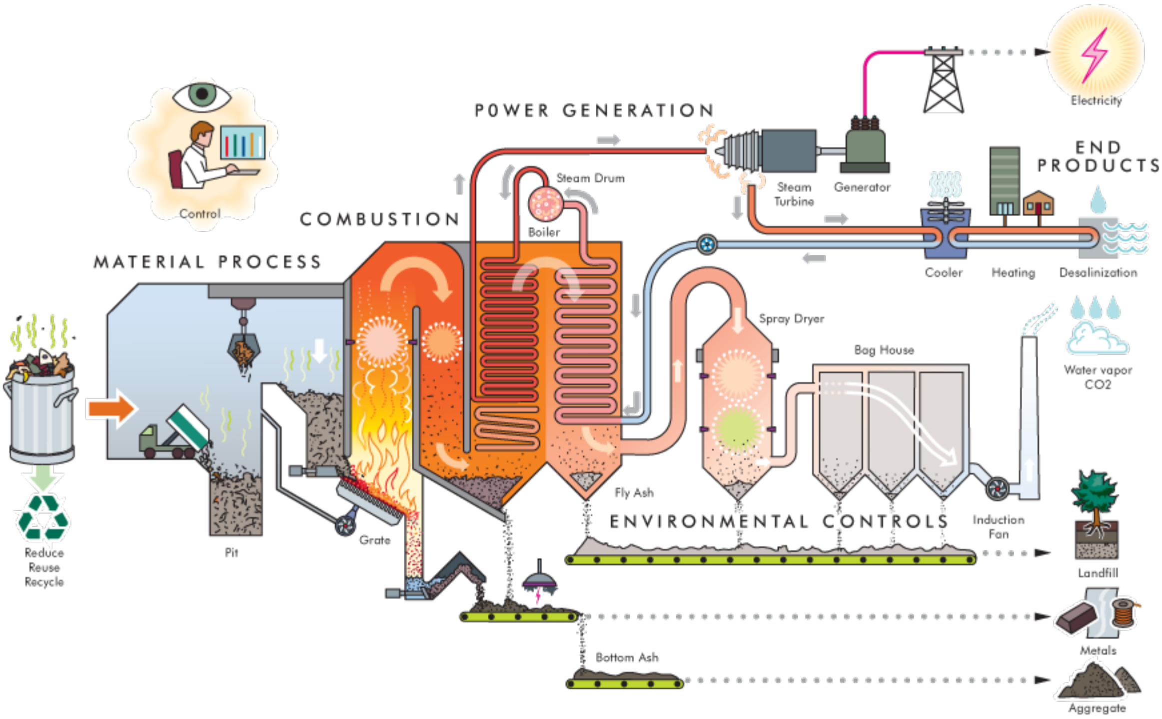

Figure 5.2: Generalised combustion process (sourced from (DELTAWAY 2012)

for control of nitrogen oxides (NO_x), a dry scrubber for sulphur oxide (SO_2) and acid gas control, as well as a fabric filter for particle removal. The end products of this process are cleaned combustion gases which are released into the atmosphere through the stack, and ash which is quenched with water before being removed for landfill or ash treatment facilities.

5.4.2 Types of Combustors

The combustion of solid wastes can be designed to operate from two types of solid waste fuels. These include commingled MSW, known as mass-fired and processed MSW, known as refuse-derived fuel (RDF). Mass-fired systems are pre-dominant among waste combustion facilities; however both methods offer various benefits and disadvantages.

Mass-Fired Combustors

Mass-fired combustors incinerate waste with minimal processing prior to being placed within the incinerator. The crane operator is able to reject obviously unsuitable materials, however it must be assumed for the design of the machinery that any types of material, even potentially hazardous wastes, may be delivered into the system. Therefore the design of the facility must incorporate factors to be able handle these objectionable wastes without damage to the system or personnel. Due to the mixture of waste materials fed into the system, the energy content of mass-fired waste can vary greatly. (Tchobanoglous et al. 1993)

RDF-Fired Combustors

RDF-fired combustors incinerate waste materials which have been processed through mechanical, chemical, biological or thermal processes to produce a product from the organic faction of MSW. This product has an even consistency to meet the specifications of energy, moisture and ash content. Due to the higher energy content of an RDF system in comparison to commingled MSW, RDF combustion facilities can be physically smaller. However due to the need for specifically processed MSW, a greater physical area is required for the pre-processing of the material. The refuse-derived fuel can be produced in a shredded, fluff or dense pellet or cube form. RDF in the form of dense pellets or cubes is easier to store and transport, however is more costly to produce. As the incinerated materials are homogeneous in nature, greater control over the combustion is possible, as well as better performance of the control devices for air pollution can be achieved. RDF-fired combustors have less environmental impact as the pre-processing of the waste allows for the removal of significant portion of metals, plastics and other metals which contribute to harmful emissions. (Tchobanoglous et al. 1993)

Combustion Products

The resultant products of the combustion of waste materials include non-combustible residue, such as ash, and hot combustion gases comprising primarily of nitrogen (N_2), carbon dioxide (CO_2) and water vapour (H_2O). In ideal, stoichiometric conditions of combustion, the derived gaseous by-product includes nitrogen (N_2), carbon dioxide (CO_2), water vapour (H_2O), as well as small amounts of sulphur dioxide (SO_2). Energy recovery from the combustion process can also be utilised. Energy recovery processes are utilised in almost all combustion facilities to assist in the offset of operating and capital costs of air pollution control equipment. The energy can be recovered via the hot flue gases, or from unprocessed MSW via the use of a water-wall combustion chamber or the use of waste heat boilers. In the use of unprocessed MSW energy recovery methods, either hot water or steam can be generated to be used in supplementary applications. Hot water is useful in low-temperature industrial or heating applications, whereas the use of steam is more versatile and can be utilised for either heating or electricity generation.

5.4.3 Factors Involved with Combustion Facilities

There are several factors involved with the design and implementation of a combustion facility. The primary issues relating to this are connected to the positioning, disposal of residues, emissions and economics of the system. This section details these factors for further analysis within Chapter 7.

Location

Location is a key component in the implementation of a combustion facility. Combustion facilities can be constructed and operated within close proximities to residential and industrial developments, however precise care must be taken during operation to ensure all environmental and aesthetic limits are appeased. Ideal locations of these facilities include remote locations where adequate buffer zones to minimise the impact of operation can be maintained. These include remote locations within city limits or within landfill sites. (Tchobanoglous et al. 1993)

Disposal of Residues

Various types of solid residues are produced as a bi-product from combustion facilities. These include bottom ash, fly ash and scrubber product. The management and containment of these solid residuals is a key component to the design and operation of combustion facilities. Typical disposal of ash is done via landfilling. However the ash should be contained within double-lined monofils, which are devoted solely to the disposal of ash, or lined landfills to ensure contaminants do not leach into ground water systems. (Tchobanoglous et al. 1993)

Emissions

Emissions from combustion facilities may occur through means of air emission or liquid emissions. The gaseous and particulate emissions are a result of the operations of combustions facilities and are believed to have serious health impacts. The ability to effectively control gaseous and particulate emission is a key consideration in the locating of combustion sites, and the proper design of emission control systems is a crucial part in the design of a combustion system.

Liquid emissions from combustion facilities can be contributed to wastewater from the removal of ash, runoff from wet scrubbers, wastewater from pump seals, cleaning, flushing and general maintenance activities, wastewater from treatment systems, as well as blowdown from the cooling tower. The proper handling, management and disposal of these emissions is a vital component in the design of combustion facilities and the cost and complexity of the environmental control systems can equal or outweigh the costs of the combustion facilities. (Tchobanoglous et al. 1993)

Economics

The economics of a proposed combustion system must be evaluated to allow for a comparison of the competing systems. The most effective way to examine the various systems is through the use of life cycle costing. This accounts for the operating and maintenance costs of the life of the system. (Tchobanoglous et al. 1993)

Temperature

Typical temperatures reached throughout the combustion process occur at around 815°C and must remain within the furnace for about 1 hour. However, depending on the types of waste incinerated, temperatures may reach values of 1400°C. According to Tchobanoglous et al. (1993) combustion temperatures greater than approximately 1000°C minimise the emission of dioxins, furans, volatile organic compounds (VOCs) and other potentially hazardous compounds within the flue gas.

5.4.4 The Utilisation of Combustion

Facilities which process MSW via means of incineration are typically among the most expensive solid waste management systems. Combustion facilities are dependent upon highly skilled personnel for the operational running and maintenance of the facility. Due to high capital and maintenance costs, they are most prevalently adopted within develop nations. Despite these cost intensive criteria, combustion of MSW does offer several benefits as a method of waste processing. These include an efficient way to reduce the waste volume, and subsequently the demand for landfill, as well as providing opportunities for the generation of energy.

5.4.5 Conclusion

The use of combustion in processing MSW can provide great benefits for deriving energy from the waste materials. As mentioned, combustion can be utilised in conjunction with a MRF or used singularly as a mass-fired facility. The use of RDF allows for a more accurate and controllable combustion process, whilst sustaining the ability for recoverable materials to be obtained from the waste stream. Incineration is however a relatively complex and technologically intensive process, requiring considerable environmental control measures to contain and reduce environmental impacts. The benefits and key considerations involved in the combustion process therefore require careful analysis to ensure the applicability of such a processing facility is viable.

5.5 Gasification

5.5.1 Introduction

Gasification is the controlled partial combustion of waste to produce a gas synthesis known as syngas. This process involves turning organic fuels (such as biomass resources) into gaseous compounds in sub-stoichiometric oxygen conditions. In comparison to incineration, gasification occurs at temperatures typically between $900^{c}irc$C and $1000^{c}irc$C, however can occur up to temperatures of $1400^{c}irc$C. The processes, factors and facilities involved with this process have been detailed within the following sections.

5.5.2 The Gasification Process

Gasification involves the partial combustion of waste materials in sub-stoichiometric conditions to produce a gas synthesis known as syngas. This energy efficient thermal technique generates a combustible gas primarily composing of methane, carbon monoxide, hydrogen, as well as some saturated hydrocarbons. The combustible gas generated from the gasification process can then be utilised for combustion within an internal combustion engine, gas turbine, or boiler under excess-air or stoichiometric conditions.

During the process of gasification, five primary reactions occur (as shown within Equations 5.5 to eq:gas2). The exothermic reactions sustain the heat throughout the process, whereas the combustible gases are generated through endothermic reactions.

$$C + O_2 \rightarrow CO_2 \qquad \text{exothermic} \qquad (5.5)$$

$$C + H_2O \rightarrow CO + H_2 \qquad \text{endothermic} \qquad (5.6)$$

$$C + CO_2 \rightarrow 2CO \qquad \text{endothermic} \qquad (5.7)$$

$$C + 2H_2 \rightarrow CH_4 \qquad \text{exothermic} \qquad (5.8)$$

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad \text{exothermic} \qquad (5.9)$$

Operating a gasifier at atmospheric pressure generates products of low calorific values. The gases generated at atmospheric pressure typically containing 10% CO_2, 20% CO, 15% H_2, and 2% CH_4, with N_2 content being the balance. The remaining products of atmospheric gasification include char containing carbon, the inert materials originally within the feedstock, as well as condensable liquids. The combustible gasses produced at atmospheric pressure characteristically present calorific values of 5600 kJ/m^3. Utilising pure oxygen as the oxidant instead of air, a combustible gas with a calorific value of 11,200 kJ/m^3 can be produced.

5.5.3 Factors Effecting the Gasification Process

There are several parameters which affect the processes of gasification. These include the equivalence ratio (ER), the temperature of the reactor, the composition and physical properties of the waste feedstock, and the composition and the inlet temperature of the gasifying medium. The details involved with these various factors of the gasification process have been outlined below.

Equivalence Ratio

The equivalence ratio (ER) is the ratio between the oxygen content within the reactor in comparison to the oxygen required for stoichiometric combustion of the feedstock. This factor plays a critical role within the gasification process, as it strongly affects the composition of the product gases and thus the chemical energy. Equivalence ratios approaching zero correspond to pyrolysis conditions, while values equalling or greater than one represent combustion conditions. Figure 5.3 represents the syngas composition at various equivalence ratios for the gasification of wood at atmospheric pressure. (Arena 2011)

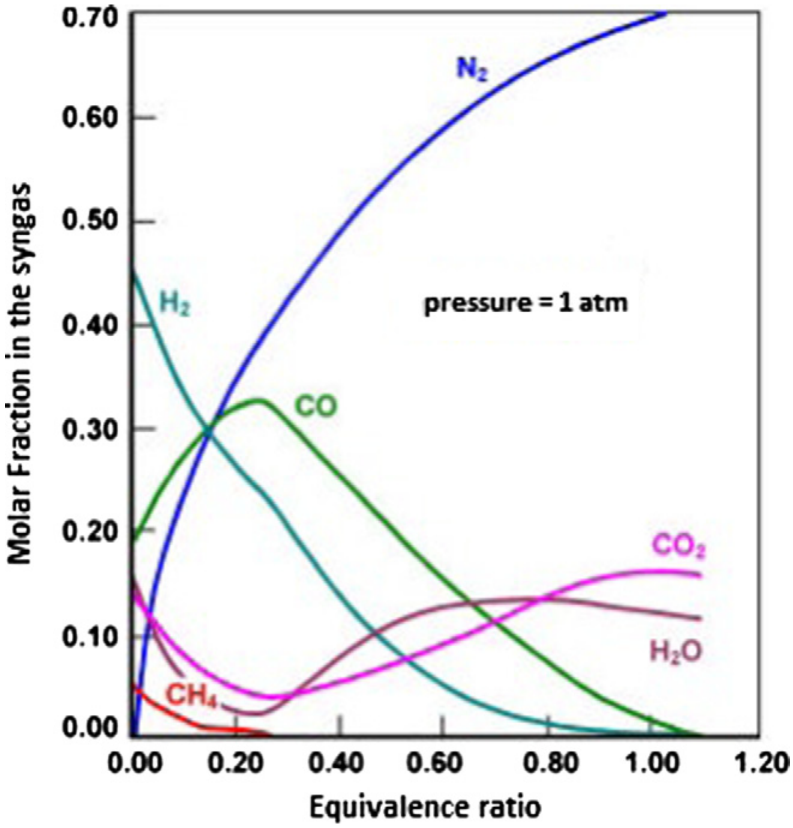

Figure 5.3: Syngas composition at various equivalence ratios (sourced from (Arena 2011))

Reactor Temperature

The reactor temperature is another key factor in the gasification process. The temperature of the reactor can determine the efficiency of the gasification process, the state of the produced bottom ash, as well as the content of tar within the syngas.

Waste Composition and Physical Properties

The composition and physical properties of the feedstock greatly affects the performance of the waste-to-energy gasification process. These properties primarily include the primary composition of the feedstock, the heating value, ash content, moisture content, volatile matter and other contaminant content, and the density and particle size of the waste. Due to these crucial physical properties, gasification facilities typically utilise refuse-derived fuel (RDF) over commingled waste feedstock.

Composition and Inlet Temperature of the Gasifying Medium

The final factor influencing the gasification process is the composition and inlet temperature of the gasifying medium. This factor affects the mass and energy balances of the reactor. Fixed oxidant reactors involves the relation of the inlet temperature and both the temperature profile and the heat recovery from the syngas.

5.5.4 Types of Gasifiers

There are several types of reactors which can be utilised to facilitate the gasification process. These include fixed bed gasifiers, fluidised bed gasifiers, as well as indirect gasifiers and their subsequent sub-categories. This section presents background information on these various types of reactors, outlining the processes involved and their applications.

Fixed Bed Gasifier

Fixed bed gasifiers encompass two categories of gasifiers, including vertical and horizontal fixed bed reactors. Vertical fixed bed reactors are the primary type of fixed bed gasifier used. These types of reactors are subdivided into updraft and downdraft gasifiers. Updraft gasifiers feed the feedstock into the reactor at the top, whilst air is introduced at the base of the reactor. This counter-current gasifier converts the material into a combustible gas during the decent of the feedstock. As a result of the updraft configuration, the tar generated through pyrolytic reactions is carried upward with the flow of generated gases. This produces a syngas product with high tar content. The alternative vertical fixed bed reactor, the downdraft gasifier, introduces the feed stock to the camber from the top, whilst air is feed through the sides of the chamber above the grate. The combustive gas is then drawn under the grate. This co-current gasifier allows for effective thermal cracking of the pyrolysis vapours, due to the downdraft configuration. This method however, does not produce as efficient internal heat exchange as that of an updraft gasifier.

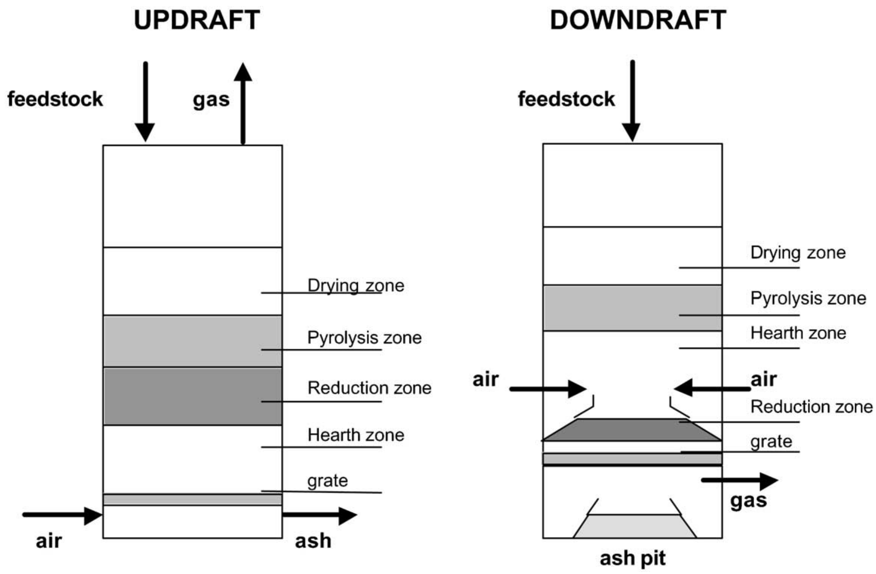

Figure 5.4: Overview of a fixed bed gasifier (sourced from (Belgiorno et al. 2002))

Fluidised Bed

Fluidised bed reactors utilise a fixed bed of find solids, typically silica sand, which is transformed into a liquid-like state by contact with an upward flowing gas. Fluidised bed gasification solves the operational problems involved with high ash contents of feedstock within a fixed bed reactor. This type of reactor also increases the efficiency of the gasification process, achieving an efficiency approximately five times greater than that of a fixed bed reactor. These types of reactors also operate without separate reaction zones, utilising isothermal beds, operating at temperatures within the range of 700 - 900°C. Fluidised bed reactors can also be categorised into bubbling fluidised bed (BFB) and circulating fluidised bed (CFD) gasifiers (see Figure 5.5).

Bubbling fluidised bed reactors utilise a low velocity of upward flowing gasification agent, around 1-3m/s. Due to this and the expansion of the inert bed regards only to the lower part of the gasifier and bed sand and char are not expelled from the reactor due to the low velocity. Circulating fluidised bed reactors utilise a higher velocity of upward flowing gasification of approximately 5-10m/s. The expanded bed consequently occupies the entire reactor and a fraction of sand and char is released with the gas stream.

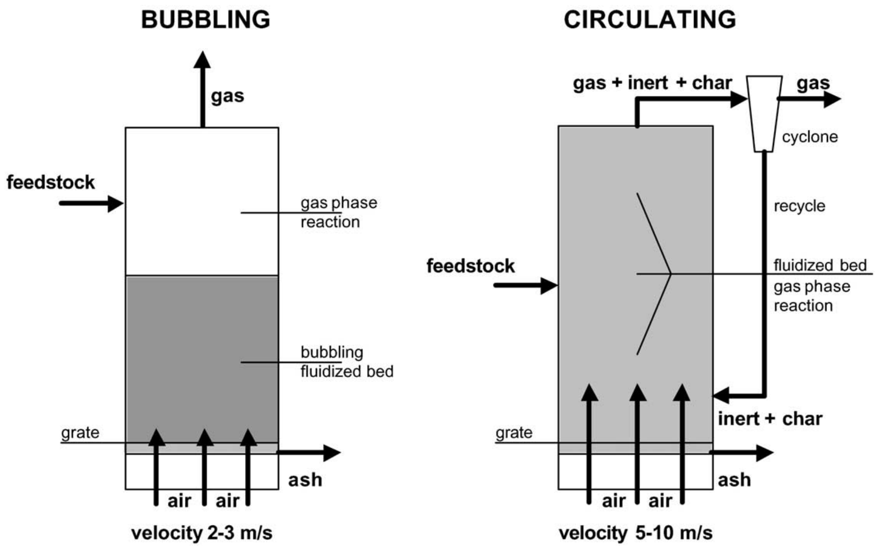

Figure 5.5: Overview of a fluidised bed gasifier (sourced from (Belgiorno et al. 2002))

Indirect Gasifier

Indirect gasifiers use steam indirect gasification to process the feedstock. They are categorised into char indirect and gas indirect gasifiers depending on the type of internal energy source (see Figure 5.6).

Char indirect gasifiers consists of two separate reactors, including a CFB steam gasifier and a CFB combustor. The CFB steam gasifier converts the feedstock into a gas product, while the CFB combustor burns the residual char to provide the heat to gasify the feedstock.

Gas indirect gasifiers utilise a steam fluidised bed gasifier within bed heat exchange tubes. A fraction of the combustible gases mixed with air and burned within a pulse combustor. The hot combustion gases are then used to provide heat to gasify the feedstock.

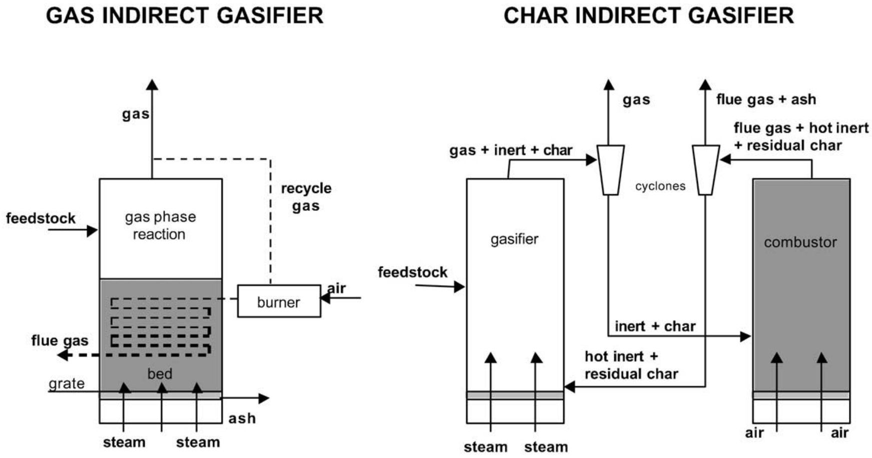

Figure 5.6: Overview of a indirect gasifier (sourced from (Belgiorno et al. 2002))

5.5.5 Gasification Products

The primary product produced by the gasification process is a synthesis gas, known as syngas. Syngas is a mixture of carbon monoxide (CO) and hydrogen (H_2), and is produced from the oxygen gasification of organic materials. Syngas can be utilised to produce organic molecules such as synthetic natural gas or liquid biofuels such as synthetic diesel. Syngas can be utilised for a number of purposes, including burning within a boiler to generate steam which can be used for power generation or industrial heating, as a fuel within a dedicated gas engine, within a gas turbine after reforming, as well as a chemical feedstock.

5.5.6 The Utilisation of Gasification

Similarly to combustion facilities, gasification plants are one of the most expensive types of facilities for the processing of MSW to operate and maintain, and require highly skilled labour throughout these processes. Due to this, gasification facilities are again primarily adopted into developed nations where the availability of funds and personnel to implement such facilities are readily available. Despite this, gasification is an effective process in the reduction of waste materials, and the generation of renewable energies.

In order for an adequate gasification process to occur, it must be ensured that only the organic faction of the waste stream enters the reactor. Therefore it is ideal that this type of facility is used in conjunction with a MRF to derive RDF for the gasification process. The adaption of a MDF and gasification facility would also allow for revenues to be obtained via the sale of recyclable goods.

5.5.7 Conclusion

The utilisation of gasification processing to treat MSW can provide great benefit for deriving energy from the waste materials. It is necessitated that a gasification facility be used in conjunction with a MRF to ensure a reliable stream of biomass is fed into the reactor. The gasification process is a relatively complex and technologically intensive process, requiring considerable environmental control measures to contain and reduce environmental impacts. The benefits and key considerations involved in the gasification process therefore require careful analysis to ensure the applicability of such a processing facility is viable.

5.6 Pyrolysis

5.6.1 Introduction

Pyrolysis is a thermal process by which the waste feedstock is processed through endothermic reactions in the absence of oxygen. In practice, the obtaining of a completely oxygen-free environment is not physically possible, pyrolytic systems are oxygenated at sub-stoichiometric conditions. The use of pyrolysis systems in the commercial treatment of MSW is a relatively new process, with the development of technologies still in infancy stages throughout many developed countries. This section details the applicability of pyrolysis to the treatment of MSW, and the factors and facilities involved with this process.

5.6.2 The Pyrolysis Process

The process of pyrolysis involves the combination of thermal cracking and condensation reactions of organic substances in an oxygen-free environment. In comparison to the incineration and gasification processes, the reactions occurring through the pyrolysis process are highly endothermic, requiring an external heat source. Relatively low temperatures are employed to process the waste, with the reactions occurring at temperatures around 500 to 800°C in comparison to 800 to 1000°C for incineration. These reactions occur due to the thermal instability of the organic substances and produce gaseous, liquid and solid fractions (Tchobanoglous et al. 1993). The gaseous product contains primarily hydrogen, methane, carbon monoxide, carbon dioxide, as well as various other gases dependent upon the waste characteristics. The second bi-product, the liquid fraction, contains tar and oil consisting of acetic acid, acetone, methanol, and complex oxygenated hydrocarbons. With additional processing, this liquid stream can be utilised as a synthetic fuel oil. The final fraction, the solid fraction, is a char consisting of primarily pure carbon, as well as any inert materials initially within the feedstock. The distribution of these product fractions vary greatly upon the temperature at which the pyrolysis reactions occur (as shown within Table 5.1). The suggestion pyrolysis reaction for the organic compound cellulose ($C_6H_10O_5$) is shown within Equation 5.10.

$$3(C_6H_{10}O_5) \rightarrow 8H_2O + C_6H_8O + 2CO + 2CO_2 + CH_4 + H_2 + 7C \qquad (5.10)$$

Table 5.1: Materials balance for pyolysis (adapted from (Tchobanoglous et al. 1993))

Temperature (°C)	**Wastes (kg)**	**Gases (kg)**	**Pyroligneous acids and tars (kg)**	**Char (kg)**	**Mass accounted for (kg)**
480	45.35	6	28	11.2	44.5
650	45.35	8	27	9.88	45.2
815	45.35	11	27	7.82	45.7
925	45.35	11	26	8.015	45.7

5.6.3 Pyrolysis Facilities

Similarly to incineration and gasification facilities, the pyrolysis process can utilise conventional thermal treatment methods such as rotary kiln, rotary hearth or fluidised bed furnaces (FRTR 2008). Whilst the physical similarities between the kilns and furnaces utilised for pyrolysis processing and conventional thermal processing methods are consistent, the facilities use for the pyrolysis of MSW typically operate at lower temperatures and perceptibly lower temperatures (FRTR 2008). Alternatively to these facilities, molten-salt destruction can also be utilised to facilitate the pyrolysis process.

Molten-salt destruction utilises a molten, turbulent bed of salt, typically sodium carbonate, to facilitate the heat transfer and act as a reaction/scrubbing medium to destroy hazardous materials. The process involves the shredded solid waste being introduced with air under the surface of the molten salt, producing hot gases comprising of carbon dioxide, steam and unreacted components which then rise through the molten salt into the waste materials. Following this reaction, the gases are processed through a gas clean-up system before being dispensed into the atmosphere. The other by-products of the pyrolysis process react with the alkaline molten salt to form inorganic products, retained in the melt. The used molten salt contained these ash products is then collected from the reactor, cooled and placed within landfill. (FRTR 2008)

5.6.4 Pyrolysis Products

The primary product produces from the pyrolysis process include gas, liquid and solid streams. The primary product of focus however, is the liquid faction, due to its high energy density and potential for oil substitution. The liquid faction is produced from the pyrolysis process is a viscous by-product, similar to a tar-like substance. This product consists primarily of biomass within its elementary composition, with a marginally higher heating value than that of its solid counterpart. The liquid also contains a complex mixture of oxygenated hydrocarbons, formed from the degradation of lignin and broad spectrum of phenolic compounds. (Natural Resources Management and Environment Department 1994) The second product produced from the pyrolysis process is the solid faction comprising of a char-like consistency. The applicability of this product has limited applications within developed nations, and is therefore alternatively ground to produce slurry with water and stabilisers. (Natural Resources Management and Environment Department 1994) The final product is a combustible gas, consisting of carbon monoxide, hydrogen, methane, as well as other hydrocarbons. These gases require further treatment, usually involved treatment in a secondary combustion chamber, flared and partially condensed. Particulate removal equipment such as fabric filters or wet scrubbers are also required to treat the gas products prior to being dispensed into the atmosphere. (Natural Resources Management and Environment Department 1994)

5.6.5 Utilisation of Pyrolysis

Pyrolysis systems may be applied to a number of organic materials which experience chemical decomposition in the presence of heat. The pyrolysis process is not effective in the destruction or separation of inorganics from the organic medium, and therefore requires pre-processing to produce RDF. There are several factors which may limit the effectiveness and applicability of a pyrolysis facility. These include the moisture content of the feedstock, as high moisture can increase the treatment costs; the particulate size and abrasiveness of the feed materials, as highly abrasive materials can damage the processing unit; as well as the amount of contaminants within the feedstock.

Limited performance data is currently available on the treatment of various materials through pyrolytic means. Therefore the applicability of such a treatment method would require significant research and investigations to determine the efficiency and effectiveness of such facility prior to design and implementation. (Natural Resources Management and Environment Department 1994)

5.6.6 Conclusion

Pyrolysis may be one of the most versatile biomass conversation systems, offering yields of liquid products which can be used directly or upgraded, as well as a combustible gas product. The technology as a form of waste processing offers considerable promise as a waste-to-energy process. The pyrolysis process is however, is in infancy stages of development in terms of applicability to MSW, and therefore requires considerable investigations and analysis prior to implementation within a municipality.

5.7 Material Recovery Facilities

5.7.1 Introduction

Material Recovery Facilities (MRFs) are processing plants which sort recyclable materials for use by end-user manufacturers. MRFs are categories into dirty and clean material recovery facilities. Clean MRFs compliment the recycling process by processing recyclable material which has been pre-sorted at the source from municipal solid waste generated by either commercial or residential sources. In comparison dirty MRFs process mixed MSW to recover recyclable materials. Material Recovery Facilities employ various technologies and methods to separate the various wastes and recyclable materials. MRFs can be implemented as part of an existing transfer station or other disposal facility.

5.7.2 Dirty MRFs

Waste separation and recovery facilities are known as dirty MRFs. Dirty MRFs process commingled MSW to separate recyclable materials from waste. The design of waste separation and recovery facilities are based on various factors. These include the type and quantity of the waste and recyclable materials, the markets demand for materials and their specifications, the material prices and the cost of recovery, as well as the availability of sorting equipment and labour. Material recovery facilities can implement high-end technology solutions or have a greater demand on personnel through the sorting process.

Lower-end technology facilities have a greater dependence on hand sorting. The use of technology within these facilities may be limited to conveyors to transport the waste. Recovery facilities such as these have less capital costs and also allow for greater operational flexibility than systems which utilise higher-end technologies.

MRFs which utilise more advance technologies have greater capital costs, and therefore are more feasible in locations of large waste volumes. These facilities often employ conveyors, screens, fans, water streams and magnets to separate waste components. Sometimes computerised systems are used to recover and segregate aluminium, paper, glass and plastics. (Nathanson 2003)

5.7.3 Clean MRFs

Recycling processing facilities process solely recyclable materials to separate according to type and are processed to meet the requirements of the market. These clean MRFs can also utilise various degrees and types of technologies to process the recyclable materials. In small communities recycling processing facilities may be limited to covered receiving areas with designated storage containers. For communities of larger populations, these processing facilities typically contain processing equipment. (Nathanson 2003)

5.7.4 Unit Operations

The unit operations within MRFs are used for the separation and processing of commingled or separated wastes. Unit operations are designed to modify the physical characteristics of the waste so that the extraction of specific waste components or contaminants can transpire more easily, as well as process and prepare the separated materials for subsequent uses. The various processes and equipment utilised during the unit operations are outlined within Table **??**.

Table 5.2: Unit operations involved with an Material Recovery Facility (Recreated from Tchobanoglous et al. (1993))

Process/Equipment	**Function**	**Pre-Processing Required**
Shredding		
Hammer Mills	Size reduction of commingled waste	Removal of contaminants and large bulky items

Continued on next page

Table 5.2 – continued from previous page

Process/Equipment	Function	Pre-Processing Required
Flail Mills	Size reduction/bag breaker of commingled waste	Removal of contaminants and large bulky items
Shear Shredder	Size reduction/bag breaker of commingled waste	Removal of contaminants and large bulky items
Glass Crushers	Size reduction of all glass types	Separation of glass from all other waste materials
Wood Grinders	Size reduction of yard trimmings and all types of wood	Removal of contaminants and large bulky items
Screening/Trommel	Separation of over and under sized material; also used as bag breaker for commingled waste	Removal of large bulky items (including large cardboard pieces)
Cyclone Separator	Separation of light combustible material from air stream	Material is removed from airstream containing light combustible materials
Density Separation (Air Classification)	Separation of light combustible material from air stream	Shredding of waste and removal of large bulky items (including large cardboard pieces)
Magnetic Separation	Separation of ferrous materials from commingled waste	Shredding of waste and removal of large bulky items (including large cardboard pieces)
Densification		
Balers	Compaction of paper, cardboard, plastics, textiles and aluminium into bales	Removal of materials not applicable for baling
Can Crushers	Compaction and flattening of aluminium and tin cans	Removal of large bulky items

Continued on next page

Table 5.2 – continued from previous page

Process/Equipment	Function	Pre-Processing Required
Wet Separation	Separation of glass and aluminium	Removal of large bulky items
Weighing Facilities		
Platform Scales	Operational records	
Small Scales	Operational records	

5.8 Chapter Summary

This chapter has detailed the various treatment and processing techniques and facilities involved with the treatment of MSW. This included both biological and thermal processing methods, and the aerobic, anaerobic, incineration, gasification and pyrolysis methods which can be utilised by each of these categories. The various factors involved with each process and facility was also detailed to provide a foundational understanding for the conducted analysis. An overview of material recovery facilities was also presented, however did not present details as in depth as the other processing techniques. This was due to the limited data availability on the market for recyclable goods within Indonesia, and therefore an analysis of this could not be conducted.

Chapter 6

Indonesia Waste and Climate Data

6.1 Introduction

In order for an appropriate analysis of the waste processing techniques to be completed, accurate and reliable data must first be established. This chapter outlines obtained data used for the analysis of the waste processing techniques, including data on the various aspects of waste, as well as climatic data of Indonesia.

6.2 Waste Data

An analysis of appropriate waste management technologies and systems has been completed based on reliable waste data within Indonesia. This data has been obtained from a 2008 report compiled by the Minisitry of Environment (2008). The data conveyed within this report was obtained throughout 2006, and is the most recent year of waste data collected within Indonesia. Prior to this, the last survey completed was within 1989 (Meidiana & Gamse 2010). The obtained data included the generation and composition of waste, waste collection and handling systems, as well as the financial aspects of waste management in Indonesia.

6.2.1 Waste Generation

The data outlined for the generation of waste covered the quantity of waste generated varied throughout the various regions of Indonesia. The specific method utilised for obtaining the data was unspecified, however the various methods involved in the collection of waste information is detailed within Section 6.2.2. Table 6.1 shows the volume and mass of the waste generation of these various regions over the period of 2006.

Table 6.2 depicts the various sources of waste, with the generation of waste within Indonesia primarily dominated by household waste, generating approximately 43.4% of the total waste generated within 2006 (see Table 6.1). The density of the various waste sources was averaged to be approximately 0.33 tonnes/m^3 for household waste, and 0.34 tonnes/m^3 for non-household.

Table 6.1: Volume and mass of waste generated within Indonesia annually (Minisitry of Environment 2008)

Region	**Waste Generation (m^3/year)**	**Waste Generation ($\times 10^6$ tonnes/year)**
Sumatera	8,623,106	8.7
Jawa	29,413,366	21.0
Bali Nusra	1,027,149	1.3
Kalimantan	916,163	2.3
Sumapapua	3,233,774	5.0
Total	43,213,558	38.4

6.2.2 Collection and Waste Processing

Despite the dominant amount of household waste, the total waste generated by households was unable to be collected by collection services for treatment purposes. Table 6.3 outlines the serviced population of the various island regions of Indonesia. As of 2006 only 56% of the total population were serviced by waste collection services. This required that a significant portion of the waste be managed by the individual or community. The various methods of waste management and their percentage of use are

Table 6.2: Generation of waste based on area (Minisitry of Environment 2008)

Area	**Waste Generation ($\times 10^6$ tonnes/year)**	**Percentage of Total (%)**
Housing Area	16.7	43.4
Markets	7.7	20.0
Streets	3.5	9.1
Public Facilities	3.4	8.8
Offices	3.1	8.1
Industries	2.3	6.0
Others	1.8	4.7
Total	38.5	100

shown in Table 6.4. This amounted to 68.9% of waste being transported to landfill, 9.6% buried, 7.2% composted, 4.8% disposed of in rivers, 4.8% burnt and 6.6% of other methods. These conditions of waste treatment, present a high percentage of improper waste treatment processes, leading to unsustainable and unsanitary conditions for the surrounding environment and population.

Table 6.3: Generation of waste based on area (Minisitry of Environment 2008)

Region	**Total Population (x10^6)**	**Population Served ($\times 10^6$)**	**% of Population Served**
Sumatera	49.3	23.5	48
Jawa	137.2	80.8	59
Balinusra	12.6	6	48
Kalimantan	12.9	6	47
Sumapapua	20.8	14.2	68
Total	232.8	130.5	56

6.2.3 Composition of Waste

While the quantity and sources of waste generated play a vital role in the selection of an appropriate waste processing technique, the composition of the waste also necessitates

Table 6.4: Waste disposal methods within Indonesia (Minisitry of Environment 2008)

Method	**Amount ($\times$ 10^6 tonnes/year)**	**Percentage of Total (%)**
Transported to Landfill	11.5	68.9
Buried	1.6	9.6
Composted	1.2	7.2
Burnt	0.8	4.8
Disposed in Rivers	0.5	3.0
Others	1.1	6.6
Total	16.7	100

the types of processes which are able to be utilised. As shown within Table 6.5, the waste stream is primarily comprised of food wastes, accounting for approximately 60% of the total waste stream.

The analysis of the composition of the Indonesian waste stream allowed for the chemical composition to be obtained. The calculations (detailed within Appendix B) yielded the following results for a 1000kg commingled sample of waste:

Without H_2O: $C_{38}H_{58}O_{16}N$
With H_2O: $C_{38}H_{136}O_{56}N$
Without H_2O: $C_{739}H_{1142}O_{319}N_{20}S$
With H_2O: $C_{739}H_{2682}O_{1097}N_{20}S$

This data was then analysed to obtain the organic composition of the waste within a 1000kg sample of waste. The calculations detailed within Appendix B yielded the following results:

Without H_2O: $C_{38}H_{58}O_{16}N$
With H_2O: $C_{38}H_{136}O_{56}N$
Without H_2O: $C_{739}H_{1142}O_{319}N_{20}S$
With H_2O: $C_{739}H_{2682}O_{1097}N_{20}S$

Table 6.5: Composition of the waste stream (Minisitry of Environment 2008)

Waste Component	Amount Generated($\times 10^6$ tonnes/year)	Composition (%)
Food Wastes	22.4	58
Plastics	5.4	14
Paper	3.6	9
Wood	1.4	4
Glass	0.7	2
Leather	0.7	2
Fabric	0.7	2
Metals	0.7	2
Inert Material (dust, dirt)	0.5	1
Other (assumed oils, paints)	2.3	6
Total	38.4	100

6.2.4 Financial Aspects

A key problem with the management of wastes within Indonesia is financial shortage. Prior to decentralisation, the local governments received financial aid to assist the solid waste programs, from the Asian Development Bank, the International Bank of Reconstruction and Development, the Japan International Cooperation Agency and the Japan Bank for International Cooperation. After the decentralisation of Indonesia, the solid waste programs are primarily funded by local government, however the budget for waste management totalled only 2% of the total budget. The needed expenditure is still unable to be obtained with only 40-50% of revenue obtained by collection retribution. These limited funds lead to low level of service of MSW management.

The limited budget allocated to the management of wastes is the cause of many existing problems associated with the management of waste. This includes the inadequate investments for sanitary facilities, low affordability in providing proper sanitary facilities for limited operational and maintenance costs, as well as deprived quality and quantity in sanitary services. In consequence of this, local governments are unable to operate landfills which meet the requirements for sanitary standards. (Meidiana & Gamse 2010)

6.3 Climate Data

The islands of Indonesia consist of an extremely wide variety of geography, topography and climate, ranging from coastal systems to montane forests to swamplands (1). The climate plays a vital role in the effectiveness of some waste processing techniques. It is a key consideration in particularly some biological processes where the moisture content of the waste is a primary factor in the digestion process. Therefore to ensure this consideration is accounted for within the selection analysis, the key climatic data required for this selection process has been obtained. This data includes the average annual temperatures, as well as annual precipitation averages.

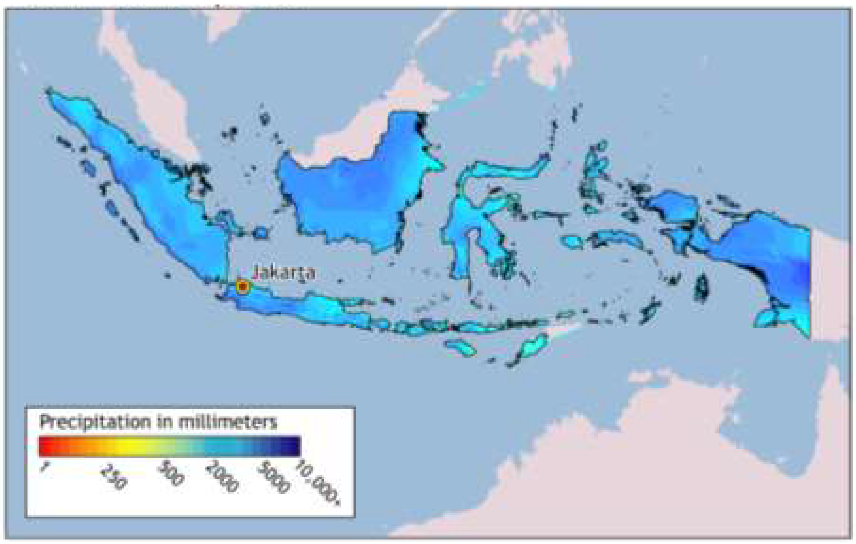

Figure 6.1: Average annual precipitation throughout Indonesia (sourced from Asian Development Bank (2011*b*))

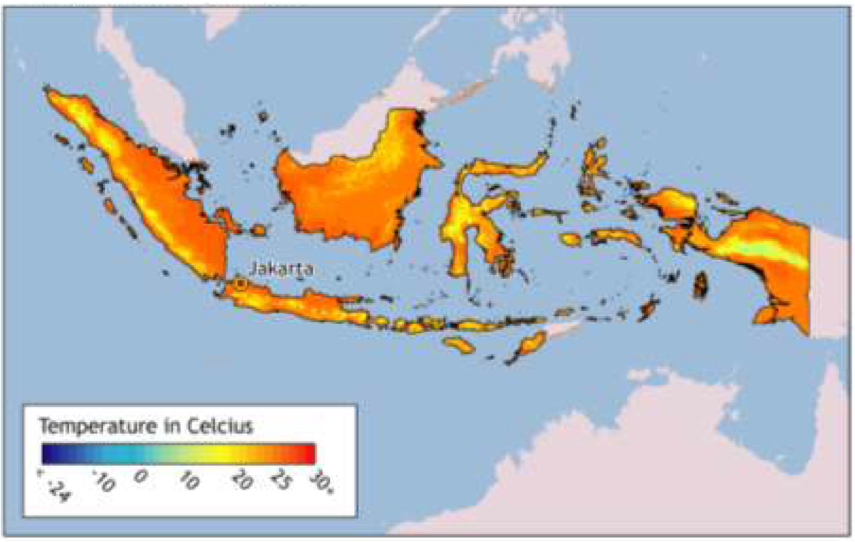

Figure 6.2: Average annual temperatures throughout Indonesia (sourced from Asian Development Bank (2011*b*))

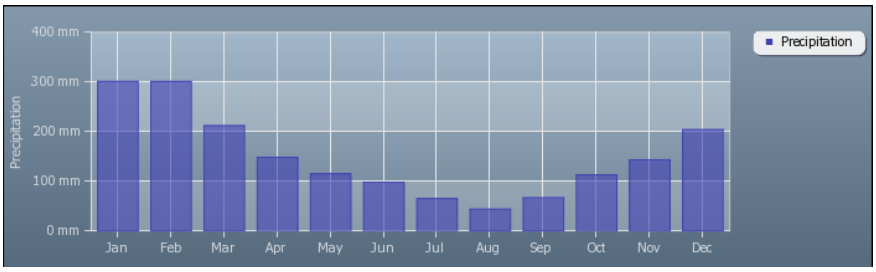

Figure 6.3: Average precipitation values for Jakarta (sourced from World Weather and Climate Information (2012))

6.4 Chapter Summary

Various data obtained for the analysis of the waste processes has been outlined within this chapter. This included aspects on waste services, waste generation, waste characterisation, financial principles and Indonesian climatic data.

Chapter 7

Analysis of Waste Processing Methods

7.1 Introduction

The selection of an appropriate and applicable method of waste processing requires a comprehensive analysis of each waste processing technique. As the various effects of a waste management system within Indonesia will have a considerable impact on the sounding environment, community and lively-hood of many people, a method for analysis has been selected which incorporates these factors into consideration. This analysis has been completed based on the pre-developed waste management selection process known as Integrated Sustainable Waste Management (ISWM). The ISWM concept was developed by WASTE, Advisors on Urban Environment and Development (1999) and presents a method of waste management technology selection not based solely on the technological aspects of design and implementation. Whilst the technological aspect is a key component of selection, the concept also presents other key factors for consideration to ensure an integrated and sustainable waste management system is implemented. The focus of this study analysed technologies to process waste once received from collection services. Therefore the integration of these technologies has been analysed from the perspective that the waste has already been received at the final or temporary deposit site.

7.2 Criteria for Analysis

The selection of appropriate and sustainable waste processing methods and technologies is not primarily applicable to the technical aspect of design. An appropriate and sustainable system must be integrated into the pre-existing waste management system, other urban systems and accepted by government or other involved institutions. In order for a sustainable system to be implemented, it must be ensured that the system is appropriate to the local conditions in which it operates, as well as capable to maintain itself over time without changing the need of resources required (WASTE, Advisors on Urban Environment and Development 1999). To ensure the system is appropriate to the local conditions, the ISWM presents the idea that the technical, social, economic, legal and environmental perspectives must be incorporated into consideration for the selection process. The various aspects required for consideration are detailed below, as outlined within the ISWM concept.

7.2.1 Technical and Operational Principles

The technical and operational aspect of implementing a waste management system should:

- utilise locally manufactured and culturally accepted technology
- be adapted towards the availability of locally available equipment and spare parts
- be aimed towards efficiency and optimum utilisation of equipment
- be adapted to the physical environment, geography and other physical requirements

7.2.2 Environmental Principles

The technologies and systems should:

- be environmentally friendly to ensure the impact of soil, air and water at a local, regional and global level are minimised
- avoid loss of raw materials, energy and nutrients
- follow the waste management hierarchy, ensuring options that promote waste prevention, source separation, re-use and recycling are promoted
- encourage treatment and resource recovery at the nearest location to the source

7.2.3 Financial Principles

The financial management of the technologies and systems should:

- be based on the all beneficiaries contribute principle (explained below)(i.e. the resource recovery sector and the local government should also contribute by paying a profit tax and allocating municipal revenues to waste management)
- be aimed towards the most efficient overall system (i.e. aimed towards the lowest cost per ton to operate, taking into consideration the cost of other affected waste systems)
- ensure the highest productivity of labour and capital in the cultural situation
- lead to a full cost analysis and full cost recovery, including all costs and benefits involved

Developed by WASTE, Advisors on Urban Environment and Development (1999), the all beneficiaries contribute principle is used in place of the polluter pays principle due to the unaffordability of the cost-based tariff in low income societies. The all beneficiaries contribute principle proposes that all groups which benefit from the waste management system contribute to its operation and maintenance. The beneficiaries of an implemented waste management system include citizens, the private sector involved in resource recovery and recycling, as well as local governments. Citizens benefit from the improvement of living conditions, the private sector involved in resource recovery and recycling benefits from profits gained from valuable waste material, and local government benefits from the reduced urban management, health and water supply, treatment and drainage costs. (WASTE, Advisors on Urban Environment and Development 1999)

7.2.4 Socio-Economic Principles

Technologies and systems should:

- be adapted to meet user demands and priorities
- be adapted to local willingness and ability to pay, leading to affordable systems
- incorporate management models which are acceptable to people and institutions involved
- minimise public health risks
- provide to all ethnic, cultural, religious and social backgrounds of the population
- be aimed towards the improvement of working conditions of involved workers
- be aimed towards the generation of income and employment

7.2.5 Institutional and Administrative Principles

Technologies and systems should:

- be aimed towards building the capacity of operators and managers, especially of local authorities
- encourage social privatisation
- allow for involvement of all stakeholders in planning and implementation, especially minority and underprivileged groups
- promote organisational cultures which nurture professionalism, transparency and accountability

- be based on decentralised management, giving sufficient regulatory and financial independence to local governments to improve waste management sustainability
- ensure competitive bidding for waste service provision by the private sector
- encourage incentives, recruitment and promotion based on merit and performance
- promote integration with other urban waste systems

7.2.6 Policy/Legal Principles

Technologies and systems should be supported by:
A legal framework that:

- supports the decentralisation of tasks, authority and finance
- incorporates rules and regulations which are transparent and unambiguous
- encourages the involvement of non-government actors and the private sector
- enables impartial enforcement of the rules and regulations

A policy frame work at a national and local level that:

- encourages decision making at the lowest level of authority, typically the municipality, regarding financial matters and the selection of technologies
- give waste management high priority in both policies and budgets
- recognises the environmental health issues of waste management, necessitating equity in service provision
- recognises the role of non-governmental actors and the private sector involved in waste management
- nurtures accountability of decision-makers to ensure efficient use of public funds
- supports the waste management hierarchy, giving preference to waste prevention, source separation, re-use and recycling, over collection and disposal alternatives

(WASTE, Advisors on Urban Environment and Development 1999)

7.3 Analysis of Waste Processes by Category

Figure 5.1 outlines the categories and the associated processes involved with the treatment and processing of MSW. The primary categories include biological processing, thermal processing and material recovery facilities. The need for a material recovery facility is dependent on the requirement for pre-processing of the selected waste treatment process and will therefore be analysed later within this chapter. To simplify the analysis and selection process, the thermal and biological categories have first been analysed to obtain the most suitable category of waste processing for implementation. The subsequent section analyses these two categories based on the criteria outlined by WASTE, Advisors on Urban Environment and Development (1999).

7.3.1 Technical and Operational Principles

The technical and operational principles play a key role in the applicability of a system. As mentioned within the previous chapter, there are several key elements to the selection of an appropriately integrated and sustainable waste management system in terms of the technical and operational principles involved. This section investigates these principles and how they are integrated into both biological and thermal processing facilities.

Biological Processes

The initial technical and operational principle associated with the implementation of an integrated and sustainable waste processing technique, is the adaption to the physical environment, topography and other physical requirements. Due to the naturally occurring processes utilised by a biological method of waste processing, it can be broadly seen that this criteria is relatively easily achievable. With minimal needs for large processing facilities, open-air biological facilities can be utilised on current landscapes with environmental control measures, such as leachate control, then adapted to meet these boundaries. The primary problem associated with this open-air form of processing, primarily with aerobic decomposition, is the control of moisture contents. Allowing the composting pile or windrow to be exposed to the environment would be problematic throughout heavy rainfall seasons and therefore require some form of control measures to ensure the moisture content remains at an adequate level.

The second aspect involved with the technical and operational principles of selection is the utilisation of locally manufactured equipment and indigenous technologies. The use of naturally occurring processes within biological methods to treat the waste materials relatively reduces the need for advance technologies within the facilities. This proceeds to the ability to utilise more locally available equipment, based on Indigenous technologies, also presenting greater employment opportunities for local residents, as the need for highly skilled labour is diminished.

The efficiency at which the biological processing can occur is a key criterion in the selection process. As previously mentioned, the simplistic means of a biological processing facility would allow for greater utilisation of local equipment and knowledge, greatly increasing the efficiency at which the facility could operate. Some aspects of this however are largely dependent upon the waste materials themselves. A full analysis of these technical aspects has been undertaken within Section 7.4.2, however a broad analysis of this has been undertaken for the purpose of this initial analysis. The primary key factor in the efficiency of decomposition process is the composition of the organic waste, specifically the ratio of carbon to nitrogen. Explained within Chapter 5, biological processes require a carbon to nitrogen ratio between 25:1 and 30:1 for an efficient and optimum process to occur. Determined within Appendix B and detailed in Chapter 5, the chemical composition of the organic waste stream was determined to be $C_{38}H_{136}O_{56}N$. Therefore the carbon to nitrogen ratio of the organic fraction is within the required range for an optimum biological process to occur.

The analysis of the broad technologic principles involved with the use of biological processes as a waste treatment option, concludes that the principles are able to be favourably achieved with the use of such processes. Biological processes allows for a treatment facility to be adapted to the local physical environment, while utilising locally available equipment and technologies.

Thermal Processes

Thermal processes present a greater challenge for the implementation within developing nations. The necessity of modern equipment for processing of the waste materials and for the environmental control of flue gasses and residues has a stringent effect on the efficiency of a thermal facility. This requirement may limit the effectiveness for the implementation of a thermal facility within Indonesia. Stringent equipment requirements may result in little utilisation of locally available equipment and indigenous technologies, reducing the applicability of a thermal process as an integrated sustainable waste management system.

The viability of a thermal process is also dependent on the waste stream and its ability to be utilised within a thermal process. This is primarily dependent on the thermal efficiency obtainable through the thermal processing of the specific waste stream. Based on chemical composition of the waste stream, the thermal efficiency of combustion has been calculated (see Appendix B). The incineration process has been selected for the analysis of thermal efficiency as it already a mature and well established technology (Enviros Consulting Limited 2007). Pyrolysis and gasification are classed as advanced thermal treatment technologies and having only been commercially applied to the treatment of MSW within recent years, the development of these technologies are still in infancy stages (Enviros Consulting Limited 2007). The calculation of the thermal efficiency (refer to Appendix B) of the incineration of the waste stream concluded an approximate efficiency of 82%. In comparison to commercially established incineration facilities, this figure is well within acceptable ranges of efficiencies currently being achieved (Tchobanoglous et al. 1993). Therefore the implementation of an incineration facility as a means of thermal processing would be viable based on the combustibility of the waste materials.

The need for large processing plants in thermal treatments may also have an impact on the local physical environment and topography. The construction of thermal facilities may require the destruction of the physical environment as the facilities are usually required to be situated well away from populous regions due to environmental and health standards. The adaption of a thermal facility to the physical environment and topography, may not only reduce the efficiency of the plant, but may impose consequential environmental and health risks.

Due to the requirement of large commercial facilities involving modern technologies for processing, monitoring and environmental protection, thermal processes are not an ideal process, technologically for implementation within Indonesia. The implementation of a thermal facility may be viable in terms of the combustibility and thermal efficiency of the waste stream; however the other criteria involved with the technological aspects of an integrated sustainable waste management system are not well suited for Indonesia.

Conclusion

The analysis of the technological and operational principles involved with thermal and biological categories concluded biological processing methods to be the most favourable option based on the aspects involved. Biological processes allows for simplistic technologies to be utilised in some of the available processing facilities, allowing for greater utilisation of locally available technologies and equipment. In contrast, thermal facilities would require greater importation of equipment for the installation and operational tasks of the facility, as well as requiring great shifts in the physical environment to accommodate the required large processing facility.

7.3.2 Environmental Principles

The analysis of the environmental principles involved with a waste processing technology is a key consideration throughout the selection process. As developing nations often lack the funds and knowledge to adequately protect from environmental degradation, it is crucial that the selected process adequately minimises environmental impact. This section analyses the various environmental risks associated with each category of waste management, and how these risks can be monitored and reduced within Indonesia.

Biological Processes

The use of biological processes in general presents an environmentally friendly approach to the decomposition of organic material, due to the use of naturally occurring processes. In terms of the processing of the organic faction of MSW, there are several environmental factors that are required to be considered. These include the air quality from gaseous emissions, water pollution from leachate, as well as other potential hazards such as fire from poorly managed facilities. The selection of an appropriately integrated and sustainable waste processing technique also necessitates the analysis of energy uses and recovered throughout the process. These factors and their applicability within Indonesia have been detailed in the following section.

Air Quality

Air quality is primarily related to the odour and particular matter released from the biological processing facility, as well as the greenhouse impact. The greenhouse impact is primarily monitored by the emission of methane at such facilities, as methane has 20 times more greenhouse warming potential than that of carbon dioxide. Well maintained and monitored aerobic decomposition facilities produce low quantities of methane. This adds the benefit of removing organic waste from landfills which usually contain poor oxygen concentrations, producing anaerobic conditions and large quantities of methane. In anaerobic facilities it is ideal that the methane gas is collected for use as a renewable energy source, and therefore ideally no methane is released into the atmosphere through this process. The remaining problems associated with air quality are explained within this section.

The odour problems associated with biological processing facilities can be linked to problems with either process control, containment of odorous areas, odour control technology or the location of the facility. The highest peak of odour emissions commonly occur throughout the mixing and aeration procedures of aerobic facilities, such as the preparation of the feedstock, and during turning of the composting materials. The odour compounds released during the composting process vary slightly based on the chemical composition of the waste materials. In many cases the various chemical components will not be released as odour during processing provided the process conditions are optimised. The facility will therefore require regular monitoring and control throughout the process to ensure an optimum process occurs.

The final factor pertaining to air quality is the release of particulate matter into the atmosphere. Particulate matter is classified by the particle shape or phase (such as fibres or aerosols), the chemical composition, the physical behaviour in the atmosphere (suspended in air or deposited from air), the biological activity (bio-aerosols) and the size of the particle. The greatest concentration of particulate matter released from a biological process occurs primarily during the pre-treatment of the waste materials. Particulate matter is also most present when sufficient moisture levels are not maintained within the pile or windrow of an aerobic digestion process. As the composting process relies on micro-organisms to break down the organic matter, the absence of control measures may allow for pathogens such as Legionella Longbeachae, Aspergillus Fumigatus, Mycobacterium tuberculosis and Hantavirus infections to be aerosol transmitted from the composting materials. These pathogens are capable of causing severe infections within humans, therefore requiring meticulously monitoring and maintenance throughout the process. The problems associated with the release of particulate matter enforce the need for the facility to be located in an area which will minimise effects on the surrounding community and environment, as well as the need for accurate monitoring and maintenance and personnel safety.

Water Pollution

The environmental factor relating to water pollution is primarily concerned with leachate from the organic materials. Leachate is any liquid which has extracted solutes, suspended solids or any other component of the material through which it has passed. In the application of waste management, it pertains to a liquid which has dissolved or entrained environmentally harmful substances from the waste material. Putrescible organics has a propensity to generate leachates which require careful management and monitoring. Food products typically contain sufficient quantities of moisture (evident in Appendix B, pertaining to the moisture content of the waste stream) to generate leachate without the need for additional water. Other organics such as wood, garden and fibrous materials generally form leachates only with the addition of water. The leachates generated from biological processes can be acidic, and can contain metallic compounds present within the organic waste. Alkaline leachates can also be formed from organics with low C:N ratios. The organic compounds may cause the leachate to become high in nutrients, making it a favourable host for bacteria and other micro-organisms. Leachates from biological facilities have the potential to pollute surface water bodies, as well as groundwater systems. The piles or windrows of raw organics may generate large quantities leachate when excessive moisture levels are obtained. Therefore leachate containment and monitoring must be implemented and regulated throughout the facility.

Fire and other Potential Hazards

Due to the ability for methane gases to be generated throughout the biological processing of organic wastes, potential risks of combustion, as well as potential risks to humans from fire or suffocation are present. These risks can attract public and industry concern, while threatening damage or loss of facilities and equipment. Due to these potential risks, NSW, Environment & Heritage (2012) states that it is better to design facilities to avoid the release of these emissions, or at least collect them.

Energy Recovery

The criteria to avoid loss of raw materials, energy and nutrients is favourably evident within the processes involved with biological processing of waste. The naturally occurring processes allow for minimal energy requirements to process the waste materials, with the recoverable products, particularly from anaerobic digestion, allows for energy to be obtained from the process. The use of these processes also allows for a final digestate product, which can be utilised as a soil enhancer. This digestate product allows for the nutrients within the waste materials to be retained and reused for further use.

Conclusion

The analysis of the various environmental factors involved with biological processing shows several key risks which could be imposed to the surrounding environment. These risks can generally be reduced or eliminated with adequate control and monitoring, which can be reliant on technological or labour intensive means.

Thermal Processes

The use of thermal processes presents several environmental impacts, including gaseous and particulate emissions, as well as solid and liquid residues. Many countries which utilise thermal processing facilities have strict standards to regulate the environmental impacts. While Indonesia may not specifically have regulations for the environmental impacts of thermal processing facilities; it must be ensured that a thermal processing facility within Indonesia is capable of achieving environmental standards of those within developed nations. Appendix D outlines the EPA standards for thermal facilities within the United States of America. This section investigates the specific environmental impacts of thermal facilities, as well as the required measures required to ensure adequate standards are achieved.

Air Emissions

There are several criteria pollutants identified by the EPA, which are emitted through the thermal processing of MSW. These include carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide, ozone, inhalable particulate matter, and lead. How these gases are generated and their potential effects on humans are detailed within Table 7.1.

Table 7.1: Air emissions and their effects from thermal facilities

Emission	How it is Generated	Human/Environmental Effects
Carbon Monoxide	Carbon monoxide is generated through the partial combustion of carbon-rich materials in sub-stoichiometric conditions.	Can cause headaches, nausea and even death at high concentrations.
Sulphur Dioxide (SO_2)	Formed by the combustion of fuels containing sulphur.	Sulphur dioxide is an eye, nose and throat irritant and can cause illness or death in high concentrations, if persons are already affect by lung problems.
Particulate Matter (PM)	Formed during the incomplete combustion of fuel and the physical entrainment of non-combustible material.	Can cause visibility reductions and health effects through means of inhaling.
Nitrogen Oxides (NO_x)	Formed by reactions between nitrogen and oxygen in the combustion air.	Can contribute to the formation of nitrate aerosols, which can cause acid fog and rain.

Solid Residues

There are several solid residues produced through the thermal processing of MSW. These include bottom ash, fly ash and scrubber product.

Bottom ash consists of the inert and unburned portion of the MSW stream. Bottom ash is most present in mass-fired facilities, which include large quantities of metals and glass. RDF-fired facilities typically produce considerably less quantities of bottom ash due to the pre-processing of the waste materials. Bottom ash can generally be transported to landfill without processing; however it is possible to recover materials through means of magnetic separation and screening. Bottom ash has also successfully been used for dike maintenance in the Netherlands, and road based construction within the United States.

Fly ash is the solid residues collected via the removal of particulate matter by air pollution control systems. Due to micron and submicron particles being consistent within the fly ash composition, careful handling procedures are required to ensure dust emissions, which may be harmful to the surrounding environment and workers, are avoided.

The final solid residue consistent within thermal facilities is the scrubber product. The scrubber product is the residual matter produced by a wet scrubber used to treat SO_2 within gaseous emissions. This type of solid residue primarily consists of calcium and sodium sulphate formed from the scrubbing reactions, as well as trace organics and heavy metals. Due to the composition of scrubber product, careful management procedures must be enforced to protect the public from contact with these materials. The primary concern is the leachate of these materials into ground water systems after disposal within landfills. The primary elements of concern include arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se), and silver (Ag).

Liquid Residues

The liquid residues arising from thermal processing facilities include the cooling and wash water from wet ash removal systems, wet scrubber discharge from SO_2, wastewater from sealing, flushing and other maintenance activities, wastewater from the boiler, and the cooling tower blowdown. The wastewater from the boiler and cooling tower blowdown are specific to the electricity generation and are also common to other steam turbine facilities. The wastewater generated is considerably less in quantity in comparison to the leachate generated from landfill, however may require treatment prior to discharge to municipal sewer systems.

The wastewater from wet ash removal systems is of concern primarily once the ash has been placed within landfill. The ash can be handled wet or dry, however typically systems use water to quench, cool and control the particulate emissions through handling. If transported to landfill, the water content is transported with the ash, thus resulting in no wastewater at the facility.

The effluent produced via the treatment of the gaseous SO_2 emissions, is separate from the solid residue produced by this treatment system. The treatment of this wastewater consists of neutralisation, precipitation, and settling. The scrubber sludge is dewaters through means of a filter press and dried in multi-effect evaporators, which utilise the waste heat from the thermal process. This practically eliminates the wastewater produced.

The wastewater from sealing, flushing and general maintenance activities is generated by the water used to seal and cool pumps and other equipment, as well as the washing of tipping areas. The wastewater generated by the sealing and cooling of pumps may contain oils and greases, whilst the wastewater from the cleaning of tipping areas may contain traces of organics. This form of wastewater is typically treated by means of settling prior to discharge within municipal sewers.

Water used to produce steam within a steam turbine is required to meet stringent water quality standards within developed nations. These standards pertain to the total dissolved solids content (TDS), the pH level, as well as the alkalinity of the water. The achievement of these standards requires that water treatments systems be utilised to treat water prior to use. Treatment systems typically employ a combination of water softening, ion exchange, precipitation and reverse osmosis units.

The final liquid residue generated from a thermal facility is the cooling tower blowdown. The water is recirculated inside the cooling tower, utilising chromium salt to retard algae growth. The water gradually evaporates as it is recirculated, increasing the content of dissolved solids and chromium. The water is required to be replaced periodically, producing an effluent known as blowdown. Due to the high content of dissolved solids and chromium salts, pre-treatment by reverse osmosis or precipitation is required prior to discharge to municipal sewers.

Energy Recovery

The environmental assessment of thermal processes also necessitates the system avoid the loss of raw materials, energy and nutrients. Thermal processing methods are primarily aimed towards energy generation through the generation of combustible materials or heat dispensed through the heating process. This therefore avoids the loss of energy through the transformation of waste material. The loss of raw materials and nutrients is not favourable in terms of thermal processing however, due to the loss of these through the thermal processing. The use of RDF-fired facilities would aid in the recycling of raw materials, with the MRF facility recovering such materials prior to the thermal processing of the waste.

Conclusion of Thermal Processing

Through the analysis of the various environmental impacts related to the thermal processing of MSW, it can be established that without adequate control measures this form of processing poses serious potential for environmental degradation and health risks for the surrounding population. These risks however can be greatly reduced through means of control measures which are solely technologically reliant.

Conclusion

In comparison of the analysed environmental aspects of biological and thermal processing systems, it can be established that while both categories of processing pose potential environmental risks, these risks are considerably less for biological facilities. The greater reliance on personnel over technological measures for the control of these environmental risks allows for greater ease at which these risks can be controlled. As well as this key advantage, the use of naturally occurring processes throughout biological processing subsequently reduces the need for external energy sources to process the waste materials.

7.3.3 Financial Principles

The financial principles involved with both biological and thermal methods of processing investigates the cost per tonne to process the waste, initial investment costs, and any recovery costs which may be made from the sale of final products, or energy recovery systems. Due to the limited resources on the market value of these products and energy, as well as the required costs, this data has been sourced from a report prepared for the Department of Environment, Climate Change, Energy and Water (DECCEW), by URS, Australia (2012). Whilst the values reflected in this report may not be an accurate measure of the applied costs within Indonesia, it has been assumed that the proportional difference between the costing of various facilities would remain reasonable consistent. It should therefore be noted that the cost analysis conducted was based on previously established results, and does not accurately reflect the costs of implementation within Indonesia. A full cost analysis should be conducted prior to the implementation of such a facility.

The broad costs involved with the implementation of a biological facility are shown in Table 7.2 and 7.3. These costs however are estimated costs for large production facilities within developed nations, and is assumed that with the use of simple technologies and cheaper labour, that these initial costs will be considerably less. The analysed composting facility within Table 7.2 is for an in-vessel composting system. As detailed earlier within this section, an open in-pile system would be the optimum choice for implementation within Indonesia, and therefore costs for a composting facility would be considerably lower than the listed values.

The overall costs involved with the implementation of a thermal processing facility are shown within Table 7.4, 7.5 and 7.6. The prices listed are estimated costs for implementation within a developed nation, however as the requirement for stringent technological processing systems and highly skilled labour is demanded, it is assumed that these costs will remain reasonably similar for the implementation within Indonesia.

Table 7.2: Estimated costs for the implementation of an in-vessel composting facility within the ACT. (Sourced from (URS, Australia 2012)

In-Vessel Composting Facility	
Plant Capacity (wet tonnes/year)	**Initial Investment ($)**
50,000	15,000,000
100,000	25,000,000
150,000	37,500,000

Table 7.3: Estimated costs for the implementation of an anaerobic digestion facility within the ACT. (Sourced from (URS, Australia 2012)

Anaerobic Digestion Facility	
Plant Capacity (wet tonnes/year)	**Initial Investment ($)**
50,000	24,444,444
100,000	46,666,667
150,000	70,000,000

Biological Processes

As well as the overall implementation costs involved with a biological facility, there are several other factors which must be examined to ensure an adequately integrated and sustainable waste processing system is implemented. This subsequent section details these various aspects and how they may be integrated into an implementation within Indonesia.

The initial financial principle required to be incorporated into the analysis is the all beneficiaries contribute principle. As explained, the all beneficiaries contribute principle involves all groups which benefit from the waste management system financially contributing to the operation and maintenance of the facility. Whilst this aspect may primarily be assimilated to the management peculiarities of the facility, several considerations can be included within the selection of a waste processing technology to ensure the feasibility of this principle. The primary issue associated with this method, is the

Table 7.4: Estimated costs for the implementation of a gasification facility within the ACT. (Sourced from (URS, Australia 2012)

Gasification Facility	
Plant Capacity (wet tonnes/year)	**Initial Investment ($)**
50,000	38,888,889
100,000	66,666,667
150,000	97,500,000
200,000	126,666,667
250,000	152,777,778

Table 7.5: Estimated costs for the implementation of an incineration facility within the ACT. (Sourced from (URS, Australia 2012)

Incineration Facility	
Plant Capacity (wet tonnes/year)	**Initial Investment ($)**
50,000	52,777,778
100,000	100,000,000
150,000	150,000,000
200,000	200,000,000
250,000	236,111,111

willingness of the beneficiaries to pay. With a considerable portion of the funding for waste systems received from sources other than the government, it should be considered that the selected waste processing technique be minimalistic to costs. As shown within Table 7.2 to 7.6, biological processes present the most budget-friendly approach to implementation. As well as this, the adaption of locally available equipment and labour intensive processes, biological processing also adheres well to the minimisation of costs.

The second principle associated with the financial aspects of a waste processing facility is the efficiency of the overall system. The process should be geared towards the most efficient system, leading to the lowest cost per tonne to operate. Both methods of

Table 7.6: Estimated costs for the implementation of a pyrolysis facility within the ACT. (Sourced from (URS, Australia 2012)

Pyrolysis Facility	
Plant Capacity (wet tonnes/year)	**Initial Investment ($)**
50,000	51,666,667
100,000	88,888,889
150,000	129,166,667
200,000	166,666,667
250,000	194,444,444

biological processing produce sellable products to aid in the offset of processing costs. The specific sale prices for biogas and compost materials were unable to be obtained and therefore a complete analysis of this principle was unable to be achieved. It was however established that as a comparison between thermal and biological processes, it can be concluded that for application within Indonesia, biological processes would be the most efficiency system in terms of cost per tonne to produce. The availability of cheap labour and the minimal need for advanced technological processes would greatly reduce the production costs. As well as labour costs, environmental control processes will also be a key component of the operational costs of the facility. This will primarily comprise of leachate control, as all other environmental factors can be relatively maintained based on the correct operational procedures of the facility.

The processing facility should also ensure the highest production of labour and capital in the local situation. In cooperation with the technical principles of the biological process, this aspect can be seen to be determined by the ability for employees to operate equipment. As the biological processes are able to utilise locally available technologies, this may be obtained relatively easily. A full analysis should be incorporated into the planning and implementation phases of the facility to ensure all criteria are accurately met.

Thermal Processes

As well as the overall implementation costs involved with a thermal facility, there are several other factors which must be examined to ensure an adequately integrated and sustainable waste processing system is implemented. This subsequent section details these various aspects and how they may be integrated into an implementation within Indonesia.

The initial financial principle required to be incorporated into the analysis is the all beneficiaries contribute principle. The all beneficiaries contribute principle involves all groups which benefit from the waste management system financially contributing to the operation and maintenance of the facility. Whilst this aspect may primarily be assimilated to the management peculiarities of the facility, several considerations can be included within the selection of a waste processing technology to ensure the feasibility of this principle. The primary issue associated with this method, is the willingness of the beneficiaries to pay. With a considerable portion of the funding for waste systems received from sources other than the government, it should be considered that the selected waste processing technique be minimalistic to costs. Shown within Table 7.2 to 7.6, the implementation costs involved with thermal processing facilities are considerably high in comparison to its biological counterpart. Thermal processing also requires stringent equipment requirements for the processing of MSW, which may increase expenses not only from the cost of the equipment, but the transportation cost to import the required technologies to Indonesia. Higher labour costs may also be required within a thermal processing facility due to the greater need for skilled labour and training expenses to educate labourers on the equipment and required processes. As mentioned within the environmental analysis of thermal processing systems, these facilities are typically required to be located in situations well away from populous areas to reduce possible health risks. This may also induce extra costs to the transportation required to transport the waste to the processing facility. These factors combined with the considerably high costs for selection (Tchobanoglous et al. 1993), the costs involved with thermal process can be deemed to be considerably high.

The second principle associated with the financial aspects of a waste processing facility is the efficiency of the overall system. The process should be geared towards the most efficient system, leading to the lowest cost per tonne to operate. All thermal processing facilities are primarily focused on the generation of products for the generation of energy. The specific prices and market within Indonesia for these products were unable to be obtained, and therefore a complete analysis of this principle was unable to be completed. In order for an economically viable system to be implemented it should be ensured that the revenue obtained from these products offsets the production costs considerably.

The processing facility should also ensure the highest production of labour and capital in the local situation. In cooperation with the technical principles of the thermal process, this aspect can be seen to be determined by the ability for employees to operate equipment. As explained previously, the need for highly skilled labour within a thermal processing facility is a key factor in the operational of such a system. This strays from the ethical issue of employing residents of local scavenger communities, and is therefore is not a preferable option for a selected system. A full analysis of this criteria should be analysed however if such a facility is implemented.

Conclusion

In analysing the financial aspect of thermal and biological waste processing techniques, it has again been concluded that biological processing offers the greatest opportunities for these principles to be met. Biological processing presents the most economically friendly process to the implementation and operational tasks of a facility, whilst incorporating the ethical aspects of operation. This analysis however was conducted based on estimated results and therefore the design of a facility should incorporate a full cost analysis prior to implementation.

7.3.4 Socio-economic Principles

The primary issues associated the socio-economic impacts of a waste processing facility within Indonesia are the livelihood and living conditions of the surrounding residents.

As there is a strong scavenger presence within the landfills of Indonesia, which survive solely on the income generated from the sale of materials found within the dumpsites, it is crucial that the impact which a waste treatment process would have on their lives is taken into consideration. Whilst the most technologically beneficially process may be attractive to the development of Indonesia, the ethical effects which this has on the broad community and culture may not be appropriate. This section investigates the means by which the implementation of biological and thermal processes will affect these aspects of Indonesia.

Biological Processes

The initial socio-economic principle outlined involves providing to all strata of the population, regardless of ethnic, cultural, religious or social background may not directly apply to the implementation of a waste processing technique, due to the specific location within the waste management system. It should be ensured however that the design and implementation of a facility should not adversely impact a particular stratum of the community in a deliberate manner, and the management of the facility ensures for equal employment opportunities. The primary concern previously outlined is the adverse effects that may be had on the local residents who scavenge the dumps for recyclable materials. The removal of this waste stream would consequentially remove the income of these residents. Biological processing provides the advantage of only processing the organic portion of the waste stream, however as outlined within Chapter 5 pre-processing is required to achieve optimum results. Ideally pre-processing would be completed through the use of a MRF, located adjacent to the biological facility. The combination of a MRF and biological processing facility would require that the resident scavengers be given priority of employment placements, to ensure adequate socio-economic principles are achieved. It should also be ensured that adequate and respectable pay rates, in comparison to the wages collected from the scavenging activities are offered to allow residents to see the benefits of such a facility.

The second socio-economic principle of minimising risks to public health is achievable on a greater scale with biological processing, than that of the current waste management practices. As an appropriately implemented and managed biological facility controls and reduces the gaseous, particulate and leachate releases, a biological processing facility would considerably reduce public health risks. The ability to implement and maintain the environmental control systems involved with the biological processing should also be accounted for as a consideration in the capability to minimise public health. Where applicable the implementation and maintenance of the control systems should ideally be capable of being operated and monitored by employees with minimal training, reducing the need for technical and skilled operators. The environmental considerations are detailed within the environmental analysis of this section, and as seen, these control systems are relatively technologically basic. This reinforces the relative ease at which public health risks may be minimised by the use of biological processes.

The socio-economic principles also outline that the system should be adapted to user demands and priorities, as well as the local willingness and ability to pay. Whilst a direct study on these aspects have not been conducted, it has been concluded that due to the economic status of the Indonesian population, the willingness and ability to pay for expensive waste processing facilities is going to be considerably low. Further analysis of the financial aspects involved are detailed within the financial section of this chapter.

The selected waste processing technique should also improve the working conditions of system operators, and be geared towards income and employment generation. These aspects of the socio-economic principles can again be primarily related to the improvement of the working conditions and employment of scavengers located on the dumpsites. As mentioned, the generation of jobs should primarily be focused towards the employment of scavengers. This would require a more labour intensive process over a technologically concentrated process. This criterion is able to be well adapted into a combination MRF and biological processing system. The means of a labour intensive MRF facility would utilise the employable skills of local scavengers, allowing for less training requirements than that of a technologically intensive facility. A biological facility would also greatly improve the working conditions of the scavengers, with the correct safety measures and equipment, as well as controlled waste processing methods to reduce the health problems currently associated in their working environment.

This analysis indicates that the aspects of biological processing favourably cover the socio-economic principles involved with the implementation of integrated and sustainable waste management technologies. As mentioned in previous analysis of principles, it has been reiterated that the combination of a MRF and biological process is ideal for the implementation of an integrated and sustainable waste management system.

Thermal Processes

As analysed within the socio-economic analysis of biological principles, the principle of providing to all strata of the population, regardless of ethnic, cultural, religious or social background may not directly apply to the implementation of a waste processing technique, due to the specific location within the waste management system. It should be ensured however that the design and implementation of facility should not adversely impact a particular stratum of the community in a deliberate manner, and the management of the facility ensures for equal employment opportunities. The primary concern related to this is the adverse effects on the local residents who scavenge the dumps for recyclable materials. This is most prospective in the removal of the waste stream from the dumpsites which scavengers operate. The removal of the waste stream would consequentially remove the income of these residents. As thermal waste processes can be operated with the use of either mass-fired facilities, or RDF-fired facilities, the removal of non-combustible material prior to processing, is not essential. Due to the adverse effects of a mass-fired facility would have on the income of the scavengers; the implementation of one would ideally require considerable employment opportunities for these residents. Alternatively to this option, an RDF-fired facility could be utilised in conjunction with a MRF. Utilising this option would provide greater employment opportunities for the scavengers, resulting in the preferred option for the socio-economic aspects of thermal processing. The employment opportunities should ensure adequate and respectable pay rates are offered, to allow residents to see the benefits of such a facility over their current working environments.

The minimisation of risks to public health is also achievable on a greater scale with thermal processing, than that of the current practices, if the required environmental control systems are able to be implemented and maintained correctly. Individually thermal systems produce harmful emission and residues, detrimental to the health of the surrounding citizens and environment. With the use of environmental control measures, these emissions and residues can be treated and reduced to produce negligible effects. The capability for these control measure to be implemented and maintained presents another socio-economic difficulty. As outlined within the environmental analysis of this chapter, these control measures usually require considerable technological equipment, as well as careful handling procedures for the containment and processing of residues. These criterions rely heavily on skilled labour for the operation, monitoring and maintenance of these technologies, thus reducing the employment opportunities for the scavengers.

The socio-economic principles also outline that the system should be adapted to user demands and priorities, as well as the local willingness and ability to pay. Whilst a direct study on these aspects have not been conducted, it has been concluded that due to the economic status of the Indonesian population, the willingness and ability to pay for expensive waste processing facilities is going to be considerably low. Further analysis of the financial aspects involved are detailed within the financial section of this chapter.

The selected waste processing technique should also improve the working conditions of system operators, and be geared towards income and employment generation. These aspects of the socio-economic principles can again be primarily related to the improvement of the working conditions and employment of scavengers located on the dumpsites. As mentioned, the generation of jobs should primarily be focused towards the employment of scavengers. This would require a more labour intensive process over a technologically concentrated process. The utilisation of a mass-fired thermal facility would not be ideal for this criterion. Due to the heavily technologically intensive process, the need for skilled labour would be greater, and thus reducing the employment opportunities for the residents of the scavenger communities. A RDF-fired thermal facility would provide a greater inducement for the generation of scavenger employment opportunities. With the need for a MRF, scavengers would be able to utilise their current knowledge of recyclable goods to aid the recovery process. A RDF-fired facility however, is still dependent on advanced technologies and processes which stray from indigenous technologies within Indonesia. This again would reduce employment opportunities for the scavenger community locals, as the need for skilled labour and technological reliance is crucial. A well implemented thermal facility however, would greater improve the working conditions of the scavengers. The technologically reliant process would reduce direct handling with the waste, thus reducing the possible safety issues associated with such procedures. In order for safety to be ensured correct handling, operational procedures, as well as safety equipment must be provided to employees. Without the enforcement of these procedures, a thermal processing facility could potentially impose greater health risks than the scavengers current working environment. The ability to enforce these procedures produces another socio-economic problem, with the need for copious training and education to allow for employees to comprehend the need for these procedures.

The analysis of the socio-economic aspects involved with the design and implementation of a thermal processing facility concludes some complications involved with such a facility. The generation of employment for residents of local scavenger communities would generally not be effective due to the need of skilled labour and technologically intensive processes, and this would require strict operational procedures requiring assertive education and training for employees. The use of a RDF-fired facility would be the most favourable option, allowing for scavengers to utilise their established skills and abilities in new their employment. The reduced employment generation would most-likely result in negative impacts on the livelihood of the scavenger communities, who mostly are solely supported by the money generated through the sale of recyclable materials.

Conclusion

The analysis of the socio-economic principles involved with the implantation of a thermal and biological facility again yielded biological processing as the most favourable option. Biological processing of the waste material allows for a greater involvement of the local community throughout the planning and implementation stages, as well as greater employment opportunities within the facility itself. It also favourably appeals to the ethical issues involved with removing the waste stream from the dumpsites, allowing for greater opportunities for facilities to be located on-site where the scavengers can easily relocate employment to the new waste processing facility.

7.3.5 Institutional/Administrative Principles

The majority of the criterions associated with the institutional and administrative principles involved with an integrated and sustainable waste management system are primarily related to the business and management aspect of such system or facility. Due to this, the institutional and administrative principles were not completely analysed within the scope of this dissertation. Some of these aspects however, were directly related to the selection of an integrated and sustainable waste processing facility, and therefore have been included in the following analysis.

The primary concern related to the selection of an appropriately integrated and sustainable waste management process based on the institutional and administrative is the ability of the process to be geared towards capacity-building of operators and managers, specifically of local authorities. The aspects involved with this principle focus back to the technological perspectives of selection. The utilisation of a highly technologically intensive process would require specific training and education for the local authorities. This thus necessitates the need for skilled personnel to assist in the phasing of local authorities in operator and managerial positions, as the technologies stray from the culturally accepted Indigenous technologies. Due to the less technologically concentrated process, biological processing provides a greater advantaged within this area over that of a thermal system.

The second key aspect which may be incorporated into the selection of a waste management system is the allowance for involvement of all stakeholders in the planning and implementation of the system, particularly weaker and underprivileged groups. This principle primarily relates to the socio-economic aspects of selection. The facility should principally allow for the involvement of the scavenger communities throughout the planning and implementation stages. This would allow for the residents to feel a part of the boarder community, allowing for the need for the facility and the benefits that the facility would provide to them to be clearly portrayed. This aspect again would be critically favourable to a biological facility utilising indigenous technologies.

The use of this type of process would allow for the involvement of the residents of the scavenger communities to be more dynamically involved throughout the planning and implementation process. The indigenous technological process would provide for a greater understanding of technologies and processes by the residents, allowing for an active incorporation of them throughout the development and implementation stages.

The remaining principles involved with the institution and administrative principles of an integrated and sustainable waste management system are primarily related to the managerial side of the planning and implementation. Therefore this aspect is beyond the scope of this report and has therefore been omitted. These aspects should be prioritised within the planning of such facilities, however do not play a key role in the selection of appropriate technologies. Based on the analysis conducted, it can be concluded that the use of a biological processing facility would be the optimum choice for the institutional and administrative principles involved in the selection of an integrated and sustainable waste processing facility.

7.3.6 Policy/Legal Principles

Similarly to the institutional and administrative principles, the legal principles involved with the implementation of an integrated and sustainable waste management system are primarily inclusive to the planning and development stages of the process. Indonesia is a signee of the Kyoto Protocol, requiring that countries meet their targets of greenhouse gas reduction annually and that actual emissions have to be monitored and precise records of trades are completed (United Nations 2012). To meet these standards, and reduce environmental degradation, Indonesia has several laws set out in relation to environment and waste management (shown within Appendix D). The availability of these laws is limited and was therefore unable to be examined for the purpose of this dissertation. It should be however included within the design and implementation stages of the facility to ensure all requirements set out by law are achieved.

7.3.7 Conclusion

The analysis of the principles involved with the implementation of an integrated sustainable waste management system of a biological and thermal processing facility concluded biological processing to be the obvious choice for implementation within Indonesia. Biological processes favourably cover the aspects involved with each process, in comparison to its thermal counterpart. The individual processing technologies involved with biological processes are further analysed within the following section of this chapter.

7.4 Analysis of Biological Waste Processing Methods

7.4.1 Introduction

The analysis of thermal and biological waste processing categories as part of an integrated sustainable waste management system concluded that the most appropriately feasible option for implementation within Indonesia to be biological processing. As explained within Chapter 5, this category of waste processing incorporates aerobic and anaerobic digestion. These two categories have been further analysed within the subsequent section, based on the principles involved with the selection of an integrated sustainable waste management system, as outlined by WASTE, Advisors on Urban Environment and Development (1999). These principles again include the technical and operational, environmental, financial, socio-economic, institutional and administrative and legal principles.

7.4.2 Technical and Operational Principles

The technical and operation principles are a crucial element to the analysis of an integrated and sustainable waste management system. Due to the limited resources and funds available to developing nations, technologies and equations have to be viable for application within the culture. This section analyses these principles involved with both aerobic and anaerobic digestion methods, and presents a conclusion based on these technological principles.

Aerobic Digestion

As outlined within Chapter 5, aerobic decomposition can be conducted on a range of technological levels. This can range from the utilisation of front-end loaders, to in-vessel systems to aerate and monitor the various content levels within the compost. Composting offers a considerable advantage to the technical and operational principles of an integrated waste management system. Due to the relatively simple set up process and the aeration methods which can be utilised, static pile or windrow systems would be a suitable process, technologically able to be adapted into the current waste management system with relative ease. In-vessel systems are complex and expensive to construct, operate and maintain, in comparison to their static pile systems and therefore would be technologically challenging to implement within Indonesia.

The effectiveness of the implementation of a composting facility is based on the ability to monitor and maintain the factors affecting the composting process. These factors have been outlined in Table 7.7, as well as detailed within Chapter 5. The subsequent paragraphs detail the technological aspects of how these factors may be incorporating into the design, as well as how they may be maintained and monitored sustainably throughout the life of the facility.

Table 7.7: Various technological factors involved with aerobic digestion

Design Consideration	**Comment**
Particle Size	The particle size of the solid waste should be within the range of 25 and 75mm for optimum results.
C:N Ratio	Initial C:N ratios between 20 and 30 present optimum results. Lower ratios ammonia is released and biological activity is impeded. Higher ratios may reduce the production of biogas.

Continued on next page

Table 7.7 – continued from previous page

Design Consideration	**Comment**
Bleeding and Seeding	The time required for composting can be reduced by seeding with partially decomposed wastes within the range of 1 to 5%.
Moisture Content	The moisture content should be kept within the range of 50 to 60% throughout the composting process.
Mixing and Turning	Mixing of the composting materials is required to reduce drying, caking and air channelling. This should be completed on a regular schedule or as required. The frequency of the mixing or turning is dependent on the type of composting facility.
Temperature	Best composting results are achieved through ensuring the temperature of the pile remains at a temperature between 50 and 55°C throughout the initial days of composting and between 55 and 60°C throughout the active composting process.
Control of Pathogens	The death of all pathogens, weeds and seeds within the composting materials is possible, if properly conducted. To ensure this, the temperature of the compost must be maintained between 60 and 70°C for a period of 24 hours.
Air Requirements	For optimum results, 50% of the initial oxygen delivered into the pile should reach all components of the composting material.
pH Control	To achieve an optimum composting process, the pH levels should remain within the range of 7 to 7.5. To minimise the conversion of nitrogen to ammonia gas, the pH level should not rise about 8.5.

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Table 7.7 – continued from previous page

Design Consideration	Comment
Degree of Decomposition	The degree of decomposition can be estimated based on the final drop in temperature, the self-heating capacity, the amount of decomposable and resistant organic matter in the composted material, the change in oxidation-reduction potential, oxygen uptake, growth of the fungus Chaetomium gracilis, and the starch-iodine test.
Land Requirement	Land requirements for a facility with the capacity of 50 tonnes/day will be 1.5 to 2.0 acres.

The particle sizes of the solid waste components are required to be within a set range of 25 to 75mm in order for an optimum composting process to occur. As the waste arriving at the facility will be of various sizes and will not necessarily be within the correct range for optimum composting, pre-processing of this is required. This will require some form of technology for pre-processing, however as outlined within Chapter **??** this able to be completed with simplistic technologies, but thus increasing the need for labour.

The C:N ratio is based on the chemical composition of the waste stream. Initial C:N ratios between 20 and 30 present optimum results. As shown within Chapter 6 the waste stream has an estimated carbon to nitrogen ratio of 30:1. This represents a ratio within the range for an optimum composting process to occur.

The processing of bleeding and seeding can be achieved by mixing the pre-processed waste ready for composting with partially decomposed wastes. This can be completed with the use of pre-existing front-end loaders at landfill sites, therefore is able to be incorporated into the locally available technologies.

The moisture content of the decomposing wastes is required to be monitored and maintained throughout the cycle of composting. This can be monitored by relatively simple handheld technologies, as opposed to complete monitoring systems situated throughout the composting pile, which are expensive and require specified engineers and technicians to install and maintain. The use of a hand-held moisture sensor is the most technologically feasible option for the facility, however does require a more labour intensive process. The moisture contents can be maintained by recirculating leachate into the pile. Events such as rainfall however, may require opened buildings to provide coverage to the piles or windrows, or leachate control measures, to prevent moisture levels exceeding 60%. This will increase the costs required to implement the facility, however is a critical component of ensuring the sustainability of the facility.

The mixing and turning of the pile has been mentioned within the previous few paragraphs. This component of a composting facility is able to be implemented with the use of front end loaders. As these are already in use within landfill sites, government cooperation with the implementing of a composting facility would mean minimal expenses would be required to obtain turning equipment.

The temperature of the pile is again able to be monitored with relatively cheap handheld instruments, as opposed to in-pile monitoring systems. This also increases the need for labour, but reduces expenses and the need for skilled personnel to install and maintain equipment. The methods for maintaining an adequate temperature are able to be maintained by the other composting factors, and therefore able to be conducted with suitable technologies.

The air requirements are also able to be maintained primarily via the turning and moisture content of the pile. As mentioned, this is achievable through available technologies within Indonesia. The pH level of the pile is also able to be monitored by handheld equipment, and able to be maintained by the other listed factors.

The need for an adequate area to implement the composting facility may be obtained by the use of existing landfill sites. This would require the cooperation of local governments, however would reduce costs for land acquisition, and provide an ideal location if current residents of the landfill were hired to operate the facility.

Based on the factors analysed, the optimal choice of composting facility would be a static pile or windrow composting facility and could be implemented by utilising mostly locally available technology and could be adapted well into to the local environment. As aerobic decomposition processes the biodegradable portion of the waste stream, it is therefore ideal that this process is combined with the use of a material recovery facility.

Anaerobic Digestion

Similarly to aerobic decomposition, anaerobic digestion can utilise various ranges of technologies to achieve a successful process. The most simplistic of these is a high solid single stage process, requiring a single reactor for digestion with no requirement for mixing within the reactor. The requirement for little pre-processing, minimal technological equipment and area requirements of an SSHS system allows for the system to be implemented with relative ease, utilising locally manufactured technologies and requiring minimal training to employ local residents. The other more technological intensive facilities would require a considerable amount of training and educating of personnel, and the fabrication and manufacture of parts would not be easily available within the local regions. This leads to the conclusion of a SSHS system being the most suitable aerobic digestion process within Indonesia.

The ability for an anaerobic facility to be implemented successfully is dependent on the ability of the factors which affect the digestion process to be maintained and monitored. These factors have been outlined in Table 7.8, as well as detailed within Chapter 5. The subsequent paragraphs detail the technological aspects of how these factors may be incorporated into the design, as well as how they may be maintained and monitored sustainably throughout the life of the facility.

Table 7.8: Various technological factors involved with aerobic digestion

Design Consideration	**Comment**
Solid Content	The solid content varies based on the type of digester selected, however typically a solid content of 4-8% is required for low solid digesters and 20-40% for high solid digesters.
Temperature	For an optimum digestion process, the reactor should be maintained at thermophilic temperatures (above 40°C).
	Continued on next page

Table 7.8 – continued from previous page

Design Consideration	Comment
C:N Ratio	Initial C:N ratios between 25 and 30 present optimum results. Lower ratios ammonia is released and biological activity is impeded. Higher ratios may reduce the production of biogas.
pH Control	To achieve an optimum digestion process, the pH levels should remain within the range of 6.4 to 7.2. To minimise the conversion of nitrogen to ammonia gas, the pH level should not rise about 8.5.
Mixing	The mixing of the components within the digesters increases the contact between the micro-organisms and substrate, improving the bacteriums ability to obtain nutrients.
Organic Loading Rate (OLR)	The organic loading rate (OLR) is the measure of the biological conversion capacity of the AD system and is measured in Chemical Oxygen Demand (COD) or Volatile Solids (VS) per cubic metre of the reactor. The use of a feed rate greater than the systems sustainable OLR, yields a low production of biogas due to the accumulation of constraining substances in the digestive.
Land Requirement	The land requirements for AD processes are dependent upon the type of digester used. Single stage digesters require significantly less areas than that of its multistage counterparts.

The solid content varies based on the type of digester selected, however typically a solid content of 4-8% is required for low solid digesters and 20-40% for high solid digesters. As previously explained, the optimum choice for implementation within Indonesia is the single stage high-solid digester. This type of processor reduces the need for preprocessing of the organic faction of MSW, and thus simplifying the process.

It is recommended that the temperature of the digestate be maintained at temperatures above 40°C, but within thermophilic ranges. The temperature of the digestate is able to be monitored with relatively cheap instruments. This increases the need for labour at the facility, however reduces the need for skilled personnel to install and maintain equipment. The methods for maintaining an adequate temperature within the reactor is primarily dependent upon the other factors involved with the digestion process.

Initial C:N ratios between 25 and 30 present optimum results for the digestion process. As concluded within section xx, the chemical composition of the organic fraction of the waste materials presents a carbon to nitrogen ratio of 30:1. This ratio falls within the required range for an optimum digestion process, allowing for the technical feasibility of the waste materials to be utilised within an anaerobic digestion process to be optimum.

To achieve an optimum digestion process, the pH levels should remain within the range of 6.4 to 7.2. The pH levels within the digestion process are primarily dependent upon the process itself and the initial composition of the waste materials. As explained, the waste materials present an optimum composition for the digestion process, and therefore the pH levels should be monitored throughout the process. This can be completed with relatively simplistic technologies, however again it does increase the need for labour.

The mixing of the components within the digesters increases the contact between the micro-organisms and substrate, improving the bacteriums ability to obtain nutrients. The formation of scum and the development of temperature gradients within the digester can also be prevented by the mixing of digestive materials. The mixing of the materials again can be utilised with a range of various technologies, from simple mechanised solutions to electronically dependent means.

The organic loading rate (OLR) is the measure of the biological conversion capacity of the AD system and is measured in Chemical Oxygen Demand (COD) or Volatile Solids (VS) per cubic metre of the reactor. This factor is primarily concerned with the specific reactor selected and therefore must be determined upon the design of the reactor.

Due to the obtainable energy source of biogas generated throughout the anaerobic digestion process, this aspect should also be analysed as part of the technical and operational principles. The calculations detailed within Appendix B concluded that a theoretical value approximately 1m^3 of gas can be generated from 1kg of organic waste. In comparison to the entire waste stream this pertains to approximately 0.3m^3 of gas per kg of commingled waste. The calculated biogas composition was estimated to be approximately 53% methane and 47% carbon dioxide. These values are well within accepted established values (Tchobanoglous et al. 1993).

7.4.3 Environmental Principles

The analysis of the environmental principles involved with a waste processing technology is a key consideration throughout the selection process. As developing nations often lack the funds and knowledge to adequately protect from environmental degradation, it is crucial that the selected process adequately minimises environmental impact as simply as possible. This section analyses the various environmental risks associated with aerobic and anaerobic methods of waste management, and the applicability at which these risks can be monitored and reduced within Indonesia.

Aerobic Digestion

Whilst aerobic digestion is a biological process, several environmental issues arise throughout the processing of MSW. These include the air quality from gaseous emissions, water pollution from leachate, as well as other potential hazards such as fire from poorly managed facilities. The selection of an appropriately integrated and sustainable waste processing technique also necessitates the analysis of energy uses and recovered throughout the process. These factors and their ability to be contained within Indonesia have been detailed in the following section.

Air Quality

The first environmental aspect of aerobic decomposition analysed, is air quality. Air quality is primarily related to the odour and particular matter released from the composting process, as well as the greenhouse impact. The greenhouse impact is primarily monitored by the emission of methane at composting facilities, as methane has 20 times more greenhouse warming potential than that of carbon dioxide. Well maintained and monitored aerobic decomposition facilities produce low quantities of methane; this adds the benefit of removing organic waste from landfills which usually contain poor oxygen concentrations, producing anaerobic conditions and large quantities of methane. The remaining problems associated with air quality are explained in the following paragraphs.

The odour problems associated with aerobic decomposition facilities can be linked to problems with either process control, containment of odorous areas, odour control technology or the siting of the facility. The highest peak of odour emissions commonly occur throughout the mixing and aeration procedures, such as the preparation of the feedstock, and during turning of the composting materials. The odour compounds released during the composting process vary slightly based on the chemical composition of the waste materials. Various odour compounds associated with compositing facilities are listed below within Table 7.9, however in many cases the various chemical components will not be released as odour during processing provided the process conditions are optimised. The facility will therefore require regular monitoring and control throughout the composting process to ensure an optimum process occurs.

The final factor pertaining to air quality is the release of particulate matter into the atmosphere. Particulate matter is classified by the particle shape or phase (such as fibres or aerosols), the chemical composition, the physical behaviour in the atmosphere (suspended in air or deposited from air), the biological activity (bio-aerosols) and the size of the particle. The greatest concentration of particulate matter released from aerobic decomposition occurs primarily during the pre-treatment of the waste materials, and the aeration (such as turning) of the waste within the pile or windrow. Particulate matter is also most present when sufficient moisture levels are not maintained within the pile or windrow. As the composting process relies on micro-organisms to break down the organic matter, the absence of control measures may allow for pathogens such as Legionella longbeachae, Aspergillus fumigatus, Mycobacterium tuberculosis and Hantavirus infections to be aerosol transmitted from the composting materials. These pathogens are capable of causing severe infections within humans, therefore requiring the composting process to be meticulously monitored and maintained. The problems

Table 7.9: Various odour compounds associated with smells (Recreated from (NSW, Environment & Heritage 2012)

Compound	**Description of smell**	**Detection limit**
Sulphur compounds		
Dimethyl disulphide	Rotten cabbage	0.1 μg/m^3
Dimethyl sulphide	Rotten cabbage	2.5 μg/m^3
Carbon disulphide	Rotten pumpkin	24 μg/m^3
Hydrogen sulphide	Rotten egg	0.7 μg/m^3
Methane thiol	Pungent sulphur	0.04 μg/m^3
Nitrogen compounds		
Ammonia gas	Medicinal	27 μg/m^3
Trimethyl amine	Fishy	0.11 μg/m^3
Volatile fatty acids		
Acetic acid	Sour (vinegar)	1019 μg/m^3
Propionic acid	Rancid	28 μg/m^3
Butyric acid	Putrid	0.3 μg/m^3

associated with the release of particulate matter enforce the need for the facility to be located in an area which will minimise effects on the surrounding community and environment, as well as the need for accurate monitoring and maintenance and personnel safety.

Water Pollution

The environmental factor relating to water pollution is primarily concerned with leachate from the organic materials. Leachate is any liquid which has extracted solutes, suspended solids or any other component of the material through which it has passed. In the application of waste management, it pertains to a liquid which has dissolved or entrained environmentally harmful substances from the waste material. Putrescible organics has a propensity to generate leachates which require careful management and monitoring. Food products typically contain sufficient quantities of moisture (evident in Chapter 5, pertaining to the moisture content of the waste stream) to generate leachate without the need for additional water. Other organics such as wood, garden and fibrous materials generally form leachates only with the addition of water. The leachates generated from the composting process can be acidic, and can contain metallic compounds present within the organic waste. Alkaline leachates can also be formed from organics with low C:N ratios. The organic compounds may cause the leachate to become high in nutrients, making it a favourable host for bacteria and other microorganisms. Leachates from composting facilities have the potential to pollute surface water bodies, as well as groundwater systems. The piles or windrows of raw organics may generate large quantities leachate when excessive moisture levels are obtained. Therefore leachate containment and monitoring must be implemented and regulated throughout the composting process.

Fire and other Potential Hazards

While aerobic digestion is primarily concerned with the generation of compost materials, avoiding anaerobic conditions, the generation of methane gases can occur. This poses potential risks of fire, as well as potential risks to humans from fire or suffocation. These risks can attract public and industry concern, while threatening damage or loss of facilities and equipment. Due to these potential risks, NSW, Environment & Heritage (2012) states that it is better to design facilities to avoid the release of these emissions, or at least collect them.

Energy Recovery

Whilst aerobic digestion does not specifically generate products for the utilisation of energy recovery, the process does however, recover the reusable resource of compost. This allows for energy to be saved from the transportation to landfill, whilst offsetting some of the processing costs. The specific market for compost within Indonesia is unknown; however the final compost product can be used in areas where unsanitary landfills have been implemented to aid in the land reclamation process.

Anaerobic Digestion

Similarly to aerobic digestion, the processing of MSW under anaerobic conditions presents various several environmental issues despite its use of biological processes. These issues also include the quality of air from gaseous emissions, water pollution from leachate, as well as hazards such as fire. These factors have been analysed and detailed within this section.

Air Quality

The primary concern with the air quality which may be induced by anaerobic digestion is the control of biogas generated by the process. The methane gas generated by anaerobic conditions is accompanied invariably by the generation of pungent odours. The odours are caused by the generation of ammonia, volatile amines, in high nitrogen content materials, hydrogen sulphide and volatile organic compounds. The odours associated with these chemical released are also outlined within Table 7.9. Whilst these odours are only produced throughout the AD process, the use of a well implemented and maintained AD facility will reduce or remove the odours released to the surrounding areas. As well as the generation of odours from the AD process, the digestion of commingled wastes in anaerobic conditions also presents numerous pollutant concerns. The primary pollutants of concern from the AD of commingled wastes include methane, nitrogen oxides (NO_2 and NO), sulphuric acid mists (H_2SO_4), sulphur oxides (SO_3 and SO_2), and non-methane volatile organic compounds. These pollutants present concern not only for being highly odorous, but can be toxic in low concentrations.

The odours released during anaerobic processing can be minimised by the use of flaring. Flaring also reduces the risk of explosions from the build-up of biogas. Energy recovery systems also present an alternative to reduce odours and reduce explosion risks, also providing a benefit of energy recovery from the biogas. The generation of biogas may also have environmental consequences due to the condensation of liquids from biogas. These liquids have the potential to pollute waters, and thus causing odour releases from such waters. The generation of condensed liquids from biogas should be avoided, where possible.

Water Pollution

As detailed within the environmental analysis of aerobic digestion, putrescible organics have a tendency to generate leachates which require careful management. Leachates have the potential to be acidic, particularly under anaerobic conditions. With the potential to pollute groundwater and surface water systems, these leachates require careful management and monitoring. Due to the use of sealed reactors, anaerobic digestions allows for the control of leachates to be achieved with greater ease.

Fire and other Potential Hazards

A key hazard involved with the operation of an anaerobic digestions facility is the fire risks involved with the production of methane gases. Uncontrolled biogas emissions may generate risks of fires, as well as potentially impose risks to humans from such fires or suffocation. Therefore as stated within the environmental analysis of aerobic digestion, the containment of these gases is crucial.

Energy Recovery

The process of anaerobic digestion is utilised primarily for the recovery of energy. The obtained biogas can be utilised within electricity generation, or directly for burning. As explained within Chapter 5, the use of biogas is a useful resource within developing nations, reducing the need for firewood to cook food. While the lobbing of trees for firewood may not be a pressing environmental problem, the use of use of biogas can yield tangible health benefits in terms of smoke reduction within the kitchen (Global Alliance for Clean Cookstoves 2012). Studies have also concluded that the installation of a biogas plant can significantly reduce respiratory diseases, including decreases in respiratory illness, eye infections, asthma and lung problems (Global Alliance for Clean Cookstoves 2012).

The production of biogas is also considered to be CO_2 neutral, and therefore does not emit additional greenhouse gases into the atmosphere. This is assuming that the biogas is properly recovered. The release of the methane gases into the atmosphere has a greater greenhouse gas impact than if the methane is simply combusted (Global Alliance for Clean Cookstoves 2012).

Conclusion

The analysis concluded that both aerobic and anaerobic methods of waste processing present similar potential risks for the environment. While these risks are more present and hazardous within anaerobic digestion, this form of biological processing allows for a greater ease of control over the containment and management of these problems. With the greatest issue within Indonesia being the ability to operate and manage these risks, allowing for minimal environmental impact, the process of anaerobic digestion can be concluded to present the greatest advantage to Indonesia. Based on the environmental principles involved with the implementation of an integrated and sustainable waste management system, the use of biogas within the developing nation, presents several benefits to the pressing environmental issues.

7.4.4 Financial Principles

In developing countries the financial principles involved with a waste management system play a primarily crucial role in the selection process, due to the limitation of funds. In many developing countries it makes financial and economic sense to opt for labour-intensive processes over capital intensive. The financial principles involved with the selection of an integrated sustainable waste management system include basing the technology on the all beneficiaries contribute principle, being geared towards the most efficient overall system, and ensuring highest productivity of labour and capital in the local situation.

Aerobic Digestion

The process of composting rarely generates profits individually. As a part of an integrated solid waste management system however, the aerobic decomposition of wastes can produce economic benefits on a much larger scale. The costs involved with the process of composting include the processing of the raw waste materials, the production of the compost, marketing and any environmental costs. This is counteracted by benefits such as the market values of the compost, savings from avoiding waste disposal costs, as well as the positive environmental impacts. In analysing the applicability of the all beneficiaries contribute principle to aerobic digestion, the application of the principle may be applied with relative ease due to the relatively low cost of implementation and operation. Aerobic digestion process presents the most budget-friendly approach to implementation. As well as this, the adaption of locally available equipment and labour intensive processes, aerobic digestion also adheres well to the minimisation of costs.

The second principle associated with the financial aspects of a waste processing facility is the efficiency of the overall system. The process should be gear towards the most efficient system, leading to the lowest cost per tonne to operate. The specific sale prices for compost materials were unable to be obtained and therefore a complete analysis of this principle was unable to be achieved. It can be established however, that the availability of cheap labour and the minimal need for advanced technological processes would greatly reduce the production costs. As well as labour costs, environmental control processes will also be a key component of the operational costs of the facility. This will primarily comprise of leachate control, as all other environmental factors can be relatively maintained based on the correct operational procedures of the facility.

The processing facility should also ensure the highest production of labour and capital in the local situation. In cooperation with the technical principles of the aerobic process, this aspect can be seen to be determined by the ability for employees to operate equipment. Aerobic digestion possibly poses the greatest opportunity for employment of local scavenger communities. With minimal needs for technologies, and the combined requirement of a material recovery facility, this would allow for great opportunities for employment to the local residents.

Anaerobic Digestion

Anaerobic digestion presents similar financial incentives and benefits to that of aerobic digestion, however is aided by the generation and possible sale of biogas. Anaerobic digestion is a somewhat a more technologically intensive process, requiring reactors to process the waste materials. This therefore leads to greater initial costs for the facility to be implemented. This factor may therefore influence the broader communitys willingness to contribute to the facility.

The second principle associated with the financial aspects of a waste processing facility is the efficiency of the overall system. The process should be gear towards the most efficient system, leading to the lowest cost per tonne to operate. The specific sale prices for biogas and anaerobic digestate were unable to be established and therefore a complete analysis of this criterion was unable to be established. Similarly to aerobic digestion, SSHS anaerobic decomposition facilities can be greatly dependent upon labour intensive processes, which would greatly reduce production costs. The efficiency of the system also includes the ability for environmental control procedures to be managed and the costing of these processes. As explained within the environmental analysis, the ability to contain environmental risks is simpler to control with anaerobic digestion facilities due to enclosed reactor facilities.

To obtain the environmental principles, the processing facility should ensure the highest production of labour and capital in the local situation. This aspect may be analysed in conjunction with the technical principles involved with an anaerobic facility, with the assessment of this aspect primarily based on the ability for employees to integrate with the processes and technologies. Anaerobic facilities do require some technologies which may not be based on indigenous technologies. This would therefore require greater training for employees in order for adequate integration to be achieved. The ability of this aspect may not be adequately examined until a design has been established; however this aspect may be incorporated into the design of the facility.

Conclusion

The analysis of the financial principles involved with aerobic and anaerobic digestion facilities was unable to be fully analysed due to lack of available data for these processes within Indonesia. The analysis did conclude reasonable similarities in the analysed financial principles of both processing methods. Aerobic digestion facilities do present a more budget-friendly approach to waste management, however this should be fully analysed with sale and benefits of the generated by-products. In conclusion it can be estimated that composting would present the cheapest option for implementation, however the complete cost-benefit analysis should be conducted prior to design.

7.4.5 Socio-Economic Principles

The socio-economic principles of an integrated and sustainable waste management system ensure that the system adequately integrates into the regions culture and economic surroundings and understandings. This principle is a key concern in the selection of an appropriately integrated and sustainable waste processing method, and therefore requires significant consideration throughout the selection process. This section presents the analysis of the socio-economic principles involved with the implementation of both aerobic and anaerobic digestion processes within Indonesia.

Aerobic Decomposition

The analysis of the socio-economic principles involved with the implementation of an aerobic digestion facility within Indonesia covers several key considerations. This section details the investigated principles and how the implementation of such facility would impact and adapt to the socio-economic culture within Indonesia.

As described within the socio-economic analysis of biological and thermal waste processing methods, the initial socio-economic principle of providing to all strata of the population, regardless of ethnic, cultural, religious or social background may not directly apply to the implementation of a waste processing technique, due to the specific location within the waste management system. It should be ensured however that the design and implementation of a facility should not adversely impact a particular stratum of the community in a deliberate manner, and the management of the facility ensures for equal employment opportunities. The primary concern related to this is the adverse effect that may be had on the local scavenger communities. The removal of this waste stream would consequentially remove the income of these residents. The process of composting is favourable within this criterion, due to the only processing the organic portion of the waste stream. It is required however, that the waste stream be processed to obtain an organic rich material, pertaining to all required factors of composting, prior to placement within the windrow or pile. This would require a combination of a MRF and composting facility, ideally located adjacent one another, for an optimum composting process to be achieved. The combination of a MRF and composting facility would require the residents of the scavenger communities be given priority for employment opportunities, to ensure adequate socio-economic principles are achieved. These employment opportunities should ensure that adequate and respectable pay rates are offered, to allow scavengers to see the potential benefits to relocating their employment to such a facility.

The second socio-economic principle analysed is the criterion to minimise public health risks. This is favourably achievable with the utilisation of a composting facility. An appropriately implemented and managed aerobic digestion facility controls and reduces the gaseous, particulate and leachate releases. This would reduce the unprocessed waste materials being transported to landfill, and thus reducing the current gaseous emissions and leachate seepage from uncontained and open dumpsites. The ability to implement and maintain the environmental control systems involved with the aerobic processing should also be accounted for as a consideration in the capability to minimise public health. Where applicable the implementation and maintenance of the control systems should ideally be capable of being operated and monitored by employees with minimal training, reducing the need for technical and skilled operators. The environmental considerations are detailed within section xx, and as seen, these control systems are relatively technologically basic. Thus reinforcing the previously analysed idea, an aerobic digestion facility would be minimalistic to public health risks.

The third socio-economic principle outlined within the ISWM concept report states that the system should be adapted to user demands and priorities, as well as the local willingness and ability to pay. A direct study of these criterions has not been conducted for the analysis of an aerobic digestion facilities, it has been concluded however, that due to the economic status of the Indonesian population, the willingness and ability to pay for expensive waste processing facilities is going to be considerably low. Further analyses of the financial aspects involved are detailed within the financial section of this chapter.

The selection of an integrated and sustainable waste processing technique should also improve the working conditions of system operators, and be great towards income and employment generation. These aspects of the socio-economic principles can again be primarily related to the improvement of the working conditions and employment of scavengers located on the dumpsites. As mentioned, the generation of jobs should primarily be focused towards the employment of scavengers. This would require a more labour intensive process over a technologically concentrated process. This criterion is able to be well adapted into a combination MRF and aerobic processing system. The means of a labour intensive MRF facility would utilise the employable skills of local scavengers, allowing for less training requirements than that of a technologically intensive facility. The utilisation of indigenous technologies for the composting facility would also greatly increase employment opportunities for the residents of scavenger communities. Such a facility would also improve the working conditions of the scavengers, with the utilisation of correct safety measures and equipment, as well as controlled waste processing methods to reduce the health problems currently associated in their working environment.

This analysis of the socio-economic affects associated with the implementation of an aerobic digestion facility indicates that the use of such a facility would favourably adhere to the socio-economic principles involved with the implementation of integrated and sustainable waste management technologies. The analysis concluded that a combined MRF and static pile aerobic system would be the most favourable option in achieving the socio-economic principles involved, thus confirming the previous analyses of this waste processing method.

Anaerobic Digestion

The analysis of the socio-economic principles involved with the implementation of an anaerobic digestion facility within Indonesia covers several key considerations. This section details the investigated principles and how the implementation of such facility would impact and adapt to the socio-economic culture within Indonesia.

Mentioned within the previous analyses of the socio-economic aspects of a sustainable and integrated waste management system; the initial socio-economic principle of providing to all strata of the population, regardless of ethnic, cultural, religious or social background may not directly apply to the implementation of a waste processing technique, due to the specific location within the waste management system. Despite this, it should be ensured that the design and implementation of such waste processing facility should not adversely affect a particular stratum of the community in a deliberate manner, and the management of such facility should ensure for equal employment opportunities. As previously describe, the primary concern related to these criterion, is the adverse effect that may be induced on the local scavenger communities due to the implementation of a new processing facility. The implementation of a waste processing facility would consequently remove or reduce the waste stream being transporting to the dumpsites, thus removing or reducing the income of the scavenger community residents. Similarly to aerobic decomposition, anaerobic digestion solely processes the organic fraction of the waste stream. As mentioned within previous anaerobic analyses, this process is optimised by the pre-processing of the waste and subsequent removal of non-organic materials. This requires that the anaerobic digestion facility ideally be combined with an MRF facility, optimally located adjacent to one another. This would require the residents of the scavenger communities be given priority for employment opportunities, to ensure adequate socio-economic principles are achieved. These employment opportunities should ensure that adequate and respectable pay rates are offered, to allow scavengers to see the potential benefits to relocating their employment to such a facility.

The second socio-economic principle analysed is the criterion to minimise public health risks. Similarly to a composting facility, this may be favourably achieved with the utilisation of an appropriately implemented and maintain aerobic digestion facility. As described, anaerobic facilities utilised closed vessel units to cultivate the anaerobic process, thus practically eliminating the gaseous emissions generated by anaerobic conditions seem within uncontained landfill sites (A full analysis of these factors is detailed within the environmental section of this chapter). The analysis of the minimisation of public health risks should incorporate the ability to implement and maintain the environmental control procedures. These systems and procedures should, where applicable, be capable of being implemented and maintained by employees with minimal training, thus reducing the need for technical and skilled operators. As seen within the environmental analysis, these control systems are relatively technologically basic. Whilst some training may be required for the operational tasks of the biogas control and collection systems, it can be seen that an anaerobic facility would be relatively minimalistic to public health risks.

The socio-economic principles recommend that the system be adapted to user demands and priorities, as well as the local willingness and ability to pay. This principle requires a direct study of the criterion to be completed, which due to the limited resources on Indonesia, and the timeframe of this research, was unable to be obtained nor conducted. It can be assumed however, that due to the economic status of the Indonesian population, the willingness and ability to pay for expensive waste processing facilities is going to be considerably low. Further analyses of these aspects has been conducted and detailed within the analysis of financial principles, within this chapter.

The selection of an integrated and sustainable waste processing technique should also improve the working conditions of system operators, and be great towards income and employment generation. These aspects of the socio-economic principles can again be primarily related to the improvement of the working conditions and employment of scavengers located on the dumpsites. As mentioned, the generation of jobs should primarily be focused towards the employment of scavengers. This would require a more labour intensive process over a technologically concentrated process. This criterion is able to be well adapted into a combination MRF and anaerobic processing facility. The means of a labour intensive MRF facility would utilise the employable skills of local scavengers, allowing for less training requirements than that of a technologically intensive facility. The utilisation of indigenous technologies for the anaerobic digestion facility would also greatly increase employment opportunities for the residents of scavenger communities. Such a facility would also improve the working conditions of the scavengers, with the utilisation of correct safety measures and equipment, as well as controlled waste processing methods to reduce the health problems currently associated in their working environment.

The conducted analysis of the socio-economic principles associated with an anaerobic processing facility concludes that the criteria could be achieved with relative ease to achieve an integrated and sustainable waste management facility. The analysis again concluded than the combination with a MRF would be ideal for achieving these results.

7.4.6 Institutional and Administrative Principles

As explained within the institutional an administrative analysis of the biological and thermal processes, the majority of the criterions associated with these principles involved with an integrated and sustainable waste management system are primarily related to the business and management aspect of such system or facility. Due to this, the institutional and administrative principles were not completely analysed within the scope of this dissertation. Some of these aspects however, were directly related to the selection of an integrated and sustainable waste processing facility, and therefore have been included in the following analysis.

The primary concern related to the selection of an appropriately integrated and sustainable waste management process based on the institutional and administrative is the ability of the process to be geared towards capacity-building of operators and managers, specifically of local authorities. The aspects involved with this principle focus back to the technological perspectives of selection. The utilisation of a highly technologically intensive process would require specific training and education for the local authorities. This thus necessitates the need for skilled personnel to assist in the phasing of local authorities in operator and managerial positions, as the technologies stray from the culturally accepted Indigenous technologies. This criterion is primarily favourable to the selection of aerobic methods of decomposition due to its greater reliance on simple mechanisms to aid the digestion process. The anaerobic method does adhere feasibly to this criterion, however as the process is more technologically demanding than that of aerobic digestion, it is not the most favourable option for selection of this criteria.

The second key aspect which may be incorporated into the selection of a waste management system is the allowance for involvement of all stakeholders in the planning and implementation of the system, particularly weaker and underprivileged groups. This principle primarily relates to the socio-economic aspects of selection. The facility should principally allow for the involvement of the scavenger communities throughout the planning and implementation stages. This would allow for the residents to feel a part of the boarder community, allowing for the need of the facility and the benefits that the facility would provide to them to be clearly portrayed. In comparison of both aerobic and anaerobic processes, the implementation of an anaerobic facility would allow for greater involvement of the community in the planning and implementation of the facility due to the greater need for indigenous technologies and structures to operate the facility. Such activities have been well conducted previously within developing nations (Sacher et al. 2010). While this could be conducted on some level with an aerobic digestion facility, the lack of fixed structures and physically seen technologies for implementation, which may aid in the explanation of the process, the involvement of the community in such activities could be more challenging. The execution of the planning and implementation of an anaerobic digestion facility with the use of indigenous technologies would be the most preferable option for this criterion, allowing for the most active incorporation of the community throughout the development and implementation stages.

The remaining principles involved with the institution and administrative principles of an integrated and sustainable waste management system are primarily related to the managerial side of the planning and implementation. Therefore this aspect is beyond the scope of this report and has therefore been omitted. These aspects should be prioritised within the planning of such facilities, however do not play a key role in the selection of appropriate technologies. Based on the analysis conducted, it can be concluded that both aerobic and anaerobic methods of waste processing are feasible for implementation. Due to the greatest ethical consideration for the scavenger communities to be a key player in the design and implementation of such a facility, it is recommended that an aerobic digestion facility be implemented, based on the reliance on indigenous technologies and structures, as well as labour required for the construction of reactors.

7.4.7 Policy/Legal Principles

Similarly to the institutional and administrative principles, the legal principles involved with the implementation of an integrated and sustainable waste management system are primarily inclusive to the planning and development stages of the process. As stated, Indonesia is a signee of the Kyoto Protocol, requiring that countries meet their targets of greenhouse gas reduction annually and that actual emissions have to be monitored and precise records of trades are completed (United Nations 2012). To meet these standards, and reduce environmental degradation, Indonesia has several laws set out in relation to environment and waste management (as shown within Appendix D). The availability of these laws is limited and was therefore unable to be examined for the purpose of this dissertation. It should be however included within the design and implementation stages of the facility to ensure all requirements set out by law are achieved.

7.5 Conclusion

The analysis of the principles involved with the implementation an anaerobic and aerobic digestion facility concluded the two processes to be very similar in nature. Anaerobic digestion however did provide considerably more incentives in socio-economic principles, accommodating to the needs of local residents of scavenger communities in a greater way. This was primarily due to the generation of biogas which could provide for a great resource within these communities. The analysis concluded that a single stage high solid system to be the most beneficial to criteria, with the recommendation that a material recovery facility be implemented adjacent to the digestion facility. A MRF would allow for scavenger community residents to utilise their current knowledge, allowing for a greater transition into their new employment. The analysis also concluded that in areas where anaerobic digestion facilities may be limited considerably in size due to financial aspects, that it would be beneficial to run the facility in conjunction with a composting facility. This would increase the rate at which waste could be processed, also allowing for a greater quality of compost as the anaerobic digestate could then be mixed with the composting organic materials.

Chapter 8

Conclusions and Further Work

The analysis undertaken within Chapter 7 concluded similar results in the analysed principles between aerobic and anaerobic digestion as part of an integrated and sustainable waste management system. Anaerobic digestion did however present several key benefits over composting, primarily due to the production and application of biogas. It is therefore recommended that an anaerobic digestion facility take preference over an aerobic process. It was concluded that a single-stage high solid processing system would be the most applicable reactor for anaerobic processing, and a static pile or windrow system for a composting system. The implementation of an anaerobic digestion facility also requires the cooperation with a material recovery facility to aid the digestion process. This chapter presents several recommendations to the design considerations for the implementation of an appropriate processing facility.

8.1 Recommendations

The design of the system should primarily be focused on the implementation of an anaerobic facility in conjunction with a material recovery facility within an immediate distance from each other. The subsequent section details various considerations which should be taken into account throughout the design process.

The primarily technical considerations of design should focus on the utilisation of locally available equipment and indigenous technologies. This would be of primary concern with the construction of the digester, as well as the technologies utilised for the unit operations within the MRF. These processes should also be primarily focused on labour intensive methods over technologically intensive.

The rate at which a certain quantity of organic waste can be digested, will also be influenced by the technological processes. It should be ensured to the best ability as possible, that the rate at which MSW is processed is equal to the rate at which the waste is delivered to the landfill site. This factor will inevitably be influence by the technologies utilised within the facilities, such as the size of the reactors for anaerobic digestion, and the processes and labour capacity of the material recovery facility. Due the large capacity for employment at a MRF based on the population of scavenger communities, it would be reasonably possible to capacitate for the processing of waste at the rate at which the waste arrives at the landfill site within the MRF. Due to the capacity limitations of an anaerobic digestion facility, it may be possible to combine the facility with a composting facility to accommodate the rate at which the waste is processed within the MRF. This would operate in conjunction with the anaerobic digestion reactor, where the processed organic materials would be put into compost windrows when the capacity of the reactors has been reached. As explained within Chapter 5, the digestate produced via anaerobic digestion can be mixed with composting materials to increase the quality of the final product.

Further research into the benefit of the biogas should also be investigated. Such as whether the sale of this product is viable or is offered as an incentive to the employees. The effects of the gaseous compounds released through the burning of the biogas should also be examined prior to the use of the biogas for household applications. The possible fire risks and hazards associated with the use of biogas within the slum communities should also be examined and these risks associated into the design of how the biogas is distributed.

The design should also incorporate considerations to ensure minimal impact on the surrounding environment. This will primarily be inclusive of the treatment of leachate and gaseous emissions from the digestion facilities. The design should ensure minimal impact on soil, air and water on a local, regional and global level. As well as follow the waste management hierarchy where applicable, which would primarily involve greater importance on the recovery of materials over the degradation and landfilling of them. The facility should also be adapted to allow processing as close to the source as possible. With the ethical considerations involved with the facility, it is primarily recommended that the facility be located as close to the scavenger communities as possible.

The various financial considerations involved with the design of the facilities should accommodate for the application of the all beneficiaries contribute principles, thus requiring the adaptation of relatively cheap technologies. The financial allocation to the implementation of a system will have a direct affect upon the rate at which a certain quantity of organic waste can be digested, due to the influence on the number and size of reactors implemented. This aspect will then subsequently influence the amount of waste which can be processed by the facility. The digestion of organic materials in anaerobic conditions is limited to the size and amount of digesters, the process may be inclusive of an aerobic digestion facility to increase processing rates.

The primarily ethical issue associated with the implementation of a waste processing facility is the impact which the facility would have on the local residents of scavenger communities. It is recommended that the residents of these communities be given primary preference for employment at these facilities. The employment of the residents within the material recovery facility would also allow for their current knowledge to be utilised throughout the treatment process. This would allow for greater integration of workers into the new facility from their previous employment. It is also recommended that the facility be located within the vicinity of the scavenger communities to allow for the greatest potential for employment.

The implementation stages of the process should ensure minimal set up times to allow for a quick transition from unsanitary landfills. Due to the ability for composting facilities to be implemented in versatile areas, and relatively quickly in comparison to anaerobic methods, this may involve the implementation of a MRF and composting facility whilst an anaerobic facility is developed. These design considerations whilst not an exhaustive list, should be incorporated throughout the stages of design to ensure the system is adequately and appropriately integrated into the culture and current processes. It should also be ensured the principles outlined within Chapter 7 be included to achieve an integrated and sustainable system. In conclusion the design considerations outlined the following recommendations:

- Priority given to the implementation of an anaerobic digestion facility in conjunction with an MRF.
- Focus given to the generation of biogas for use within slum communities.
- An aerobic digestion process is implemented to reduce the cost of a solely anaerobic intensive facility.
- The anaerobic digestate is mixed with the composting materials to improve quality.
- An aerobic composting facility is initially constructed to reduce the environmental impacts associated with the landfilling of waste during the construction of anaerobic digesters.
- Residents of local should be given priority for employment opportunities to offset the ethical impacts of an MRF.
- Scavenger community residents are incorporated into the design and implementation processes.
- Employees of the facilities are given respectable pay wages, which provide incentives for them to see the benefits of a sanitary processing system.
- Education initiatives are utilised to promote public awareness of the plans and to allow greater understanding of the benefits of a sanitary system.

8.2 Further Work

Further research must be conducted into several areas prior to the design of a facility. This should initially include research into the market and requirements for the sale of recyclable goods. The technologies required within the material recovery facility will be dependent upon the requirements (size, density, etc.) for the sale of recyclable goods, and therefore this data should first be acquired prior to the selection of equipment. Further investigations should be undertaken in the field of biogas use. This research should include the health and environmental impacts of the combustion of the gas, as well as the best approach to deliver or sell the by-product. Design and implementation stages could then be undertaken if these studies supported the established conclusions for an appropriately integrated and sustainable waste processing facility.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
Project Specification

FOR: **Matthew BATES**

TOPIC: THE SELECTION OF INTEGRATED AND SUSTAINABLE WASTE PROCESSING TECHNIQUES FOR APPLICATION WITHIN INDONESIA

SUPERVISORS: Mr. Steven Goh

ENROLMENT: ENG 4111 – S1, E, 2012
ENG 4112 – S2, E, 2012

PROJECT AIM: This project seeks to research technologies that could be used to process waste within Indonesia, as well as investigate and contain the implications of current practices.

SPONSORSHIP: World Relief Australia Inc.

PROGRAMME: **Issue A, 21st March 2012**

1. Research current practices of waste management, as well as the environmental, economical and human impact of the practices in Indonesia and Cambodia.
2. Establish a list of the problems associated with the current practices.
3. Research the current methods of waste management used throughout other parts of the world.
4. Compare these other practices to how they may be used to overcome the current problems, and how culturally applicable they are to the underdeveloped countries.
5. Evaluate the various methods, and how they may be altered to be utilised within these countries.
6. Establish a suitable solution to be applied within these countries, which will eliminate or reduce the problems with the current methods.

AGREED:

___________________ (Student) ___________________ (Supervisor)

___ / ___ / ___ ___ / ___ / ___

Appendix B

Calculations

B.1 Estimation of the Chemical Composition of Indonesian Waste

This section outlines the calculations in determining the chemical composition of the commigled waste stream. Based on table B.19 and B.20 and the characteristics of the Indonesian waste stream (see 6), the chemical compositions for each waste component was established based on the dry weight of each waste component (shown in table B.1 and B.2). The dry mass for each waste component was calculated using equation B.1.

$$M = \left(\frac{w-d}{w}\right)100 \tag{B.1}$$

where M = moisture content (%)

w = initial mass of sample as delivered (kg)

d = mass of sample after drying at 105°C (kg)

Based on the calculated dry mass of the waste components, the chemical mass composition of each waste component was calculated for a 1000kg sample (as shown within table B.3).

The mass of the water within the waste was then calculated to determine the individual hydrogen and oxygen content within the waste (as shown within equation B.2 to B.4, and table B.4.

$$\text{Mass of water} = \text{Total mass of waste sample} - \text{Dry mass of waste} \tag{B.2}$$

$$\text{Mass of water} = 1000 - 563.4 = 436.6\text{kg}$$

$$\text{Mass of H in H}_2\text{O} = \left(\frac{\text{mass of water}}{\text{molecular mass of H}_2\text{O}}\right) \times \text{atomic mass of H} \tag{B.3}$$

$$\text{Mass of H in H}_2\text{O} = \left(\frac{436.6}{2 \times 1 + 16}\right) \times 2 \times 1 = 48.5\text{kg}$$

Table B.1: Molar composition of waste elements.

Component	**Amount ($x10^6$ tonnes/year)**	**Composition (%)**	**Moisture Content, by mass**	**Dry Mass ($x10^6$ tonnes)**
Food Wastes	22.4	58	70	6.72
Plastics	5.4	14	2	5.292
Paper	3.6	9	6	3.384
Wood	1.4	4	20	1.12
Glass	0.7	2	2	0.686
Leather	0.7	2	8	0.644
Fabric	0.7	2	10	0.63
Metals	0.7	2	3	0.679
Inert Material (dust, dirt)	0.5	1	8	0.46
Other (assumed oils, paints)	2.3	6	15	1.955

Table B.2: The estimated chemical percentage compositions, based on table B.20.

Component	**Carbon (%)**	**Hydrogen (%)**	**Oxygen (%)**	**Nitrogen (%)**	**Sulfur (%)**	**Ash (%)**
Food Wastes	48	6.4	37.6	2.6	0.4	5
Plastics	60	7.2	22.8	0	0	10
Paper	43.5	6	44	0.3	0.2	6
Wood	49.5	6	42.7	0.2	0.1	1.5
Glass	0.5	0.1	0.4	0.1	0	98.9
Leather	60	8	11.6	10	0.4	10
Fabric	55	6.6	31.2	4.6	0.1	2.5
Metals	4.5	0.6	4.3	0.1	0	90.5
Inert Material (dust, dirt)	26.3	3	2	0.5	0.2	68
Other (assumed oils, paints)	66.9	9.6	5.2	2	0	16.3

Table B.3: The estimated chemical mass compositions.

Component	**Amount per 1000kg (kg)**	**Dry Mass per 1000kg (kg)**	**Carbon (kg)**	**Hydrogen (kg)**	**Oxygen (kg)**	**Nitrogen (kg)**	**Sulfur (kg)**	**Ash (kg)**
Food Wastes	580	174	83.5	11.1	65.4	4.5	0.7	8.7
Plastics	140	137.2	82.3	9.9	31.3	0.0	0.0	13.7
Paper	90	84.6	36.8	5.1	37.2	0.3	0.2	5.1
Wood	40	32	15.8	1.9	13.7	0.1	0.0	0.5
Glass	20	19.6	0.1	0.0	0.1	0.0	0.0	19.4
Leather	20	18.4	11.0	1.5	2.1	1.8	0.1	1.8
Fabric	20	18	9.9	1.2	5.6	0.8	0.0	0.5
Metals	20	19.4	0.9	0.1	0.8	0.0	0.0	17.6
Inert Material (dust, dirt)	10.0	9.2	2.4	0.3	0.2	0.0	0.0	6.3
Other (assumed oils, paints)	60.0	51.0	34.1	4.9	2.7	1.0	0.0	8.3
Total	1000	563.4	276.9	36.0	159.1	8.6	1.0	81.8

Table B.4: Mass distribution of elements.

	Mass (kg)	
Component	**Without H_2O**	**With H_2O**
Carbon	276.93	276.93
Hydrogen	35.98	84.48
Oxygen	159.1	547.20
Nitrogen	8.61	8.61
Sulfur	1	1
Ash	81.78	81.78

Table B.5: Molar composition of waste elements.

		Moles	
Component	Atomic Mass	Without H_2O	With H_2O
Carbon	12.01	23.058	23.058
Hydrogen	1.01	35.624	83.644
Oxygen	16.00	9.944	34.200
Nitrogen	14.01	0.615	0.615
Sulphur	32.07	0.031	0.031

$$\text{Mass of O in } H_2O = \left(\frac{\text{mass of water}}{\text{molecular mass of } H_2O}\right) \times \text{atomic mass of O} \quad (B.4)$$

$$\text{Mass of O in } H_2O = \left(\frac{436.6}{2 \times 1 + 16}\right) \times 16 = 388.1\text{kg}$$

The molar composition of the elements (neglecting the ash content) was then calculated (as shown within Table B.5). The approximate chemical formula was then determined with and without sulphur and with and without water. This is outlined within table

Without sulphur:

Without H_2O: $C_{38}H_{58}O_{16}N$

With H_2O: $C_{38}H_{136}O_{56}N$

B.6 and shown below:

With suphur:

Without H_2O: $C_{739}H_{1142}O_{319}N_{20}S$

With H_2O: $C_{739}H_{2682}O_{1097}N_{20}S$

Table B.6: Chemical composition of waste sample.

	Mole Ratio (Nitrogen = 1)		**Mole Ratio (Sulphur = 1)**	
Component	**Without H_2O**	**With H_2O**	**Without H_2O**	**With H_2O**
Carbon	38	38	739	739
Hydrogen	58	136	1142	2682
Oxygen	16	56	319	1097
Nitrogen	1	1	20	20
Sulphur	0.1	0.1	1	1

B.2 Estimation of Chemical Composition of Organic Fraction

This section details the calculations in determining the chemical composition of the organic waste stream. Based on table B.19 and B.20 and the characteristics of the Indonesian waste stream (see Chapter 6), the chemical compositions for each waste component was established based on the dry weight of each component (shown in Table B.7 and B.8). The dry mass for each waste component was calculated using Equation B.1.

Based on the calculated dry mass of the waste components, the chemical mass composition of each waste component was calculated for a 1000kg sample (as shown within Table B.9).

The mass of the water within the waste was then calculated to determine the individual hydrogen and oxygen content within the waste (as shown within Equation B.5 to B.7,

Table B.7: Molar composition of waste elements.

Component	**Amount ($x10^6$ tonnes/year)**	**Composition (%)**	**Moisture Content, by mass**	**Dry Mass ($x10^6$ tonnes)**
Food Wastes	22.4	58	70	6.72
Paper	3.6	9	6	3.38
Wood	1.4	4	20	1.12
Fabric	0.7	2	10	0.63

Table B.8: The estimated chemical percentage compositions, based on Table B.20.

Component	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulfur (%)	Ash (%)
Food Wastes	48	6.4	37.6	2.6	0.4	5
Paper	43.5	6	44	0.3	0.2	6
Wood	49.5	6	42.7	0.2	0.1	1.5
Fabric	55	6.6	31.2	4.6	0.1	2.5

Table B.9: The estimated chemical mass compositions of organic waste.

Component	**Amount per 1000kg (kg)**	**Dry Mass per 1000kg (kg)**	**Carbon (kg)**	**Hydrogen (kg)**	**Oxygen (kg)**	**Nitrogen (kg)**	**Sulfur (kg)**	**Ash (kg)**
Food Wastes	580	174	83.5	11.1	65.4	4.5	0.7	8.7
Paper	90	84.6	36.8	5.1	37.2	0.3	0.2	5.1
Wood	40	32	15.8	1.9	13.7	0.1	0.0	0.5
Fabric	20	18	9.9	1.2	5.6	0.8	0.0	0.5
Total	730	308.6	146.1	19.3	121.9	5.7	0.9	14.7

Table B.10: Mass distribution of elements.

Component	Mass (kg)	
	Without H_2O	**With H_2O**
Carbon	146.1	146.1
Hydrogen	19.3	66.1
Oxygen	121.9	496.5
Nitrogen	5.7	5.7
Sulfur	0.9	0.9
Ash	14.7	14.7

and Table B.10.

$$\text{Mass of water} = \text{Total mass of waste sample} - \text{Dry mass of waste} \tag{B.5}$$
$$\text{Mass of water} = 730 - 308.6 = 421.4\text{kg}$$

$$\text{Mass of H in } H_2O = \left(\frac{\text{mass of water}}{\text{molecular mass of } H_2O}\right) \times \text{atomic mass of H} \tag{B.6}$$
$$\text{Mass of H in } H_2O = \left(\frac{421.4}{2 \times 1 + 16}\right) \times 2 \times 1 = 46.8\text{kg}$$

$$\text{Mass of O in } H_2O = \left(\frac{\text{mass of water}}{\text{molecular mass of } H_2O}\right) \times \text{atomic mass of O} \tag{B.7}$$
$$\text{Mass of O in } H_2O = \left(\frac{421.4}{2 \times 1 + 16}\right) \times 16 = 374.6\text{kg}$$

The molar composition of the elements (neglecting the ash content) was then calculated (as shown within Table B.11). The approximate chemical formula was then determined with and without sulphur and with and without water. This is outlined within Table

Table B.11: Molar composition of waste elements.

		Moles	
Component	Atomic Mass	Without H_2O	With H_2O
Carbon	12.01	12.162	12.162
Hydrogen	1.01	19.129	65.487
Oxygen	16.00	7.621	31.032
Nitrogen	14.01	0.405	0.405
Sulphur	32.07	0.029	0.029

Without sulphur:

Without H_2O: $C_{30}H_{47}O_{19}N$

With H_2O: $C_{30}H_{162}O_{77}N$

B.12 and shown below:

With suphur:

Without H_2O: $C_{426}H_{670}O_{267}N_{14}S$

With H_2O: $C_{426}H_{2295}O_{1087}N_{14}S$

Table B.12: Chemical composition of organic waste sample.

	Mole Ratio (Nitrogen = 1)		**Mole Ratio (Sulphur = 1)**	
Component	**Without H_2O**	**With H_2O**	**Without H_2O**	**With H_2O**
Carbon	30	30	426	426
Hydrogen	47	162	670	2295
Oxygen	19	77	267	1087
Nitrogen	1	1	14	14
Sulphur	0	0	1	1

B.3 Estimation of Amount of Gas Produced from Anaerobic Conditions

This section explains the calculations involved in the estimation of the gas produced through the anaerobic processing of the organic fraction of the waste. Within section B.2, the chemical composition of the organic waste materials was found to be $C_{30}H_{47}O_{19}N$.

The total mass of the organic material within a 1000kg sample was determined to be 730kg, including moisture, and 308.6kg, excluding moisture (see section B.2). For the purpose of these calculations, it has been assumed that 5 percent of the decomposable material will remain as inert materials (Tchobanoglous et al. 1993).

$$\text{Decomposable organic wastes (dry basis), kg} = 308.6 \times 0.95 = 293.2\text{kg} \qquad \text{(B.8)}$$

The standard chemical balance equation for the anaerobic process is shown by equation B.9.

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3 \qquad \text{(B.9)}$$

Where: $a = 30$ $b = 47$ $c = 19$ $d = 1$

The resulting equation is:

$$C_{30}H_{47}O_{19}N + 9.5H_2O \rightarrow 15.75CH_4 + 14.25CO_2 + NH_3 \qquad \text{(B.10)}$$

The mass of the methane and carbon dioxide produced was then determined from equation B.10. The molecular masses involved with the balancing of this equation are shown within Table B.13.

The calculation of the mass of the methane and carbon dioxide generated are shown below:

Table B.13: Molecular mass of chemical components

Compound	**Total Molecular Mass**
$C_{30}\ H_{47}O_{19}N$	725
H_2O	171
CH_4	252
CO_2	627
NH_3	17

$$\begin{aligned} \text{Methane} &= \frac{252}{725} \times 293.2\text{kg} \\ &= 101.9\text{kg} \\ \text{CarbonDioxide} &= \frac{627}{725} \times 293.2\text{kg} \\ &= 253.6\text{kg} \end{aligned}$$

The mass of the gases was then converted to volume. The density of methane and carbon dioxide were assumed to be 0.668 and 1.842kg/m^3 respectively. The volume for each gas was calculated, as shown below:

$$\begin{aligned} \text{Methane} &= \frac{101.9}{0.668} \\ &= 152.5\text{m}^3 \\ \text{CarbonDioxide} &= \frac{253.6}{1.842} \\ &= 137.7\text{m}^3 \end{aligned}$$

Determining the percentage composition of the resulting gas mixture:

$$\begin{aligned} \text{Methane (\%)} &= \left(\frac{152.5}{152.5 + 137.7}\right) \\ &= 52.6\% \\ \text{Carbon Dioxide (\%)} &= \left(\frac{137.7}{137.5 + 152.5}\right) \\ &= 47.4\% \end{aligned}$$

From this the theoretical amount of gas generated per unit mass of solid waste was calculated:

Based on the dry weight of organic material:

$$\frac{152.5 + 137.7}{293.2} = 0.99\text{m}^3/\text{kg} \tag{B.11}$$

Based on a 1000kg commingled waste sample:

$$\frac{152.5 + 137.7}{1000} = 0.29\text{m}^3/\text{kg} \tag{B.12}$$

B.4 Thermal Efficiency of Waste Combustion

Table B.14 and B.16 outline the various factors involved with the composition required for calculation.

Table B.14: Components of the waste stream

Component	% of Total	Amount/1000kg
Combustible	52.44%	524.4
Non-combustilbe	4%	40
Water	43.56%	435.6

Table B.15: Mass composition of combustible waste

Element	%
Carbon	27.60
Hydrogen	3.58
Oxygen	15.82
Nitrogen	0.86
Sulphur	0.10
Water	43.56
Inerts	8.48

Assumptions for calculation:

- The heating value of the solid wastes is 11,800 kJ/kg.
- The grate residue contains 5% unburned carbon.
- The entering air is at 25°C.
- The grate residue is at 425°C.
- The specific heat of the residue is 1.05kJ/kg°C.
- The latent heat of water is 2400kJ/kg.
- Radiation loss is 0.005 of gross heat input.
- All oxygen is bound in water.
- The theoretical air requirements are:

$$\text{Carbon :}(C + O_2 \rightarrow CO_2) = 11.52\text{kg/kg} \quad \text{(B.13)}$$

$$\text{Hydrogen :}(2H_2 + O_2 \rightarrow 2H_2O) = 34.56\text{kg/kg} \quad \text{(B.14)}$$

$$\text{Sulphur :}(S + O_2 \rightarrow SO_2) = 4.31\text{kg/kg} \quad \text{(B.15)}$$

- The net hydrogen available for combustion is equal to percent hydrogen minus 1/8th the percent oxygen. This accounts for the "bound water" in the dry combustible material.
- The heating value of carbon is 32,600kJ/kg.
- The moisture in the combustion air is 1%.

Calculating the amount of residue:

$$\text{Total Residue :}\frac{84.8}{0.95} = 89.26\text{kg}$$

$$\text{Carbon in Residue :}89.26 - 84.8 = 4.46\text{kg}$$

Available hydrogen in bound water:

$$\text{Net Available Hydrogen :}3.58 - \frac{15.82}{8} = 1.6025\% = 16.025\text{kg}$$

Table B.16: Composition of combustible waste

Element	%
Carbon	27.60
Hydrogen	3.58
Oxygen	15.82
Nitrogen	0.86
Sulphur	0.10
Water	43.56
Inerts	8.48

$$\text{Hydrogen in bound water} : 3.58 - 1.6025 = 1.98\% = 19.8\text{kg}$$

$$\begin{aligned} \text{Bound water} &= \text{oxygen} + \text{hydrogen in bound water} \\ &= 158.2 + 19.8 = 178\text{kg} \end{aligned}$$

Table B.17: Air requirements

Element	Air Requirement (kg)
Carbon	3128.14
Hydrogen	553.83
Sulphur	4.31
Total dry air	3686.27
Moisture	8.48

Table B.18: Total combustion efficiency

Item	**Value (kJ/kg)**
Gross heat input	11781190
Heat lost in unburned carbon	145235
Radiation loss	58906
Inherent moisture	1053734
Moisture in bound water	430589
Moisture generated	348886
Sensible heat in residue	37489
Total losses	2074839
Net heat available	9706351
Combustion efficiency	82%

B.5 Standard Values

Table B.19: Standard moisture contents for waste components. Redrawn from Tchobanoglous et al. (1993))

Type of Waste	Moisture Content, by mass (%)	
	Range	Typical
Residential		
Food wastes (mixed)	50-80	70
Cardboard	4-10	6
Paper	4-8	5
Plastics	1-4	2
Textiles	6-15	10
Rubber	1-4	2
Leather	8-12	10
Yard wastes	30-80	60
Wood	15-40	20
Glass	1-4	2
Tin cans	2-4	3
Aluminium	2-4	2
Other metals	2-4	3
Dirt, ashes, etc.	6-12	8
Ashes	6-12	6
Rubbish	5-20	15
Residential yard wastes		
Leaves (loose and dry)	20-40	30
Green grass (loose and moist)	40-80	60
Green grass (wet and compacted)	50-90	80
Yard waste (shredded)	20-70	50
Yard waste (composted)	40-60	50
Municipal		
In compactor truck	15-40	20
In landfill		

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Table B.19 – continued from previous page

Type of Waste	Moisture Content, by mass (%)	
	Range	**Typical**
Normally compacted	15-40	25
Well compacted	15-40	25
Commercial		
Food wastes (wet)	50-80	70
Applicances	0-2	1
Wooden crates	10-30	20
Tree trimmings	20-80	5
Rubbish (combustible)	10-30	15
Rubbish (noncombustible)	5-15	10
Rubbish (mixed)	10-25	15
Construction and demolition		
Mixed demolition (noncombustible)	2-10	4
Mixed demolition (combustible)	4-15	8
Mixed construction (combustible)	4-15	8
Broken concrete	0-5	-
Industrial		
Chemical sludges (wet)	75-99	80
Fly ash	2-10	4
Leather scraps	6-15	10
Metal scrap (heavy)	0-5	-
Metal scrap (light)	0-5	-
Metal scrap (mixed)	0-5	-
Oils, tars, asphalts	0-5	2
Sawdust	10-40	20
Textile wastes	6-15	10
Wood (mixed)	30-60	25
Agricultural		
Agricultural (mixed)	40-80	50

Continued on next page

Table B.19 – continued from previous page

Type of Waste	Moisture Content, by mass (%)	
	Range	Typical
Dead animals	-	-
Fruit wastes (mixed)	60-90	75
Manure (wet)	75-96	94
Vegetable wastes (mixed)	60-90	75

Table B.20: Standard chemical compositions for waste components. Redrawn from Tchobanoglous et al. (1993))

Type of Waste	Moisture Content, by mass (%)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food and food products						
Fats	73.0	11.5	14.8	0.4	0.1	0.2
Food wastes (mixed)	48.0	6.4	37.6	2.6	0.4	5.0
Fruit wastes	48.5	6.2	39.5	1.4	0.2	4.2
Meat wastes	59.6	9.4	34.7	1.2	0.2	4.9
Paper products						
Cardboard	43.0	5.9	44.8	0.3	0.2	5.0
Magazines	32.9	5.0	38.6	0.1	0.1	23.3
Newsprint	49.1	6.1	43.0	<0.1	0.2	1.5
Paper (mixed)	43.4	5.8	44.3	0.3	0.2	6.0
Waxed cartons	49.2	9.3	30.1	0.1	0.1	1.2
Plastics						
Plastics (mixed)	60.0	7.2	22.8	-	-	10.0
Polyethylene	85.2	14.2	-	<0.1	<0.1	0.4
Ploystyrene	87.1	8.4	4.0	0.2	-	0.3
Polyurethane	63.3	6.3	17.6	6.0	<0.1	4.3
Polyvinyl chloride	45.2	5.6	1.6	0.1	0.1	2.0

Continued on next page

Table B.20 – continued from previous page

Type of Waste	Percentage by mass (dry basis)					
	Carbon	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulphur**	**Ash**
Textile, rubber, leather						
Textiles	48.0	6.4	40.0	2.2	0.2	3.2
Rubber	69.7	8.7	-	-	1.6	20.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Wood, tree, etc.						
Yard wastes	46.0	6.0	38.0	3.4	0.3	6.3
Wood (green timber)	50.1	6.4	42.3	0.1	0.1	1.0
Hardwood	49.6	6.1	43.2	0.1	<0.1	0.9
Wood (mixed)	49.5	6.0	42.7	0.2	<0.1	1.5
Wood chips (mixed)	48.1	5.8	45.5	0.1	<0.1	0.4
Glass, metals, etc.						
Glass and mineral	0.5	0.1	0.4	<0.1	-	98.9
Metals (mixed)	4.5	0.6	4.3	<0.1	-	90.5
Miscellaneous						
Office sweepings	24.3	3.0	4.0	0.5	0.2	68.0
Oils, paints	66.9	9.6	5.2	2.0	-	16.3
Refuse-derived fuel (RDF)	44.7	6.2	38.4	0.7	<0.1	9.9

Appendix C

Summary of Indonesian Waste and Environmental Laws

Table C.1: Summary of Indonesian Waste and Environmental Laws (Sourced from Meidiana & Gamse (2010))

Field	**Law/Policy**		
	Prior to 1999	1999 - 2004	2005 - 2012
Environment	Regulation 24/1992 Act 23/1997	Regulation 27/1999 Ministerial Decree 86/2002	Ministerial Decree 45/2005
Waste Management	-	-	Waste Law 18/2008
Recycling	-	-	Ministerial Decree
Air and Water Pollution	-	Regulation 41/1999 Regulation 82/2001	-
Health and Sanitation	-	Law 7/2004 Ministerial Decree 288/2003 Law 32/2004	Ministerial Decree 852/2008 Regulation 16/2005
Imported Waste	Ministerial Decree 230/1997 Regulation 18/1999	Ministerial Decree 41/2008	-
Economic Instrument	Regulation 18/1997	-	-

Appendix D

Summary of EPA Standards

Table D.1: Summary of EPA standards. Redrawn from Tchobanoglous et al. (1993))

Applicability	
The New Source Performance Standards (NSPS) apply to municipal waste combustors (MWC) with unit capacities above 250ton/day that combust residential, commercial, and/or institutional discards. Industrial discards are not covered by the NSPS.	
Good Combustion Practices (GCP)	
Maximum load level demonstrated during dioxin/furan performance test cannot exceed 110 percent of maximum demonstrated load. 4-hour average Maximum particulate matter (PM) control device inlet temperature cannot exceed 17°C above maximum demonstrated temperature during dioxin/furan performance test.	
CO level (block averaging time) as follows:	
Modular starved and excess-air MWCs	50 ppmv (4 hours)
Mass burn waterwall and refractory MWCs	100 ppmv (4 hours)
MWCs using fluidized bed combustion	100 ppmv (4 hours)
Mass burn rotary waterwall MWCs	100 ppmv (24 hours)
RDF stokers 150 ppmv (24 hours)	
Coal/RDF mixed fuel-fired MWCs	150 ppmv (4 hours)

Continued on next page

Table D.1 – continued from previous page

State certification for MWC supervisors. Operator training and training manual for other MCW personnel.	
MWC organic emissions (measured as dioxins/furans)	
Dioxins/furans	30ng/dscm
Best Demonstrated Technology (BDT)	Good Combustion Practices (GCP) spray dryer and fabric filter.
MWC metal emissions (measured as PM)	
Particulate matter	34 mg/dscm
Opacity	10% (6 minute average)
BDT	Fabric filter
MWC acid gas emissions (measured as SO_2 and HCl)	
SO_2	80% or 30ppmv (24 hours)
HCl	95% reduction or 25ppmv
BDT	Spray dryer and fabric filter
Nitrogen oxides emissions	
NO_x 180ppmv	(24 hour daily block)
BDT	Selective noncatalytic reduction
Monitoring requirements	
SO_2	Continuous emission-monitoring system (CEMS), 24 hour mean.
NO_x	CEMS, 24 hour arithmetic average
Opacity	CEMS, 6 minute average
CO, load, temperature	CEMS, 4 or 24 hour average
PM, dioxins/furans and HCl	Annual stack test

Appendix E

Risk Assessment

As part of any engineering project all preventative action must be taken to maximise the safety of all personnel involved. A risk assessment is designed to minimise risk by recognising, evaluating and controlling hazards prior to the activity. As the content of this dissertation is primarily researched based, the presence of hazards was minimal with the majority of research conducted through textual literatures. However as the focus of the dissertation is on a region and subject which contains many hazards, there are many precautions to be taken into consideration if a site visit was conducted by any personnel.

The open dumpsites currently used within Indonesia contain several present hazards. The following table lists potential hazards, as well as the safety precaution that should be implemented.

Table E.1: Assessment of Risks

Hazard	**Safety Precaution**
Injury from sharp or contaminated object on ground.	Closed in shoes and safety gloves to be worn on dumpsite.
Illness from inhaling gases from dumpsite.	Gas or dust mask to be worn on dumpsite.
Injury or death from collision with vehicle on dumpsite.	High visibility vest to be worn on dumpsite.
Injury or death from collapse of dumpsite mounds.	The sites should not be visited in periods of severe weather, and visitors should always be escorted by an employee or local of the dumpsite.

Appendix F

Assessment of Consequential Effects

As the area of research has an implication on the lives of many people, as well as the environment, the effects of the implementation of any development and research must be considered. This is to ensure the sustainability of the solution and surrounding environment, as well as any safety or ethical issues that may be associated with any development or tasks. As the area of research takes place outside of Australia, it will be ensured that any health, safety and ethical issues abide or exceed the local laws and legislation.

F.1 Sustainability

The implication of a new process for the management and engineering of waste has a large risk of environmental consequences. As the countries of focus have little or no frameworks in place for sustainable development, the project will follow the frameworks set in place by the Institution of Engineers Australia. This framework, set out within the document, Towards sustainable engineering practice: engineering frameworks for sustainability, published by the Institution of Engineers, Canberra, Australia, 1997, shall be followed and referenced as a guideline of sustainability for the project. The document outlines ten aspects of sustainability to be used as a benchmark to measure the sustainability of any engineering project. The aspects of this document are listed below, along with the relevant methodology to ensure that these aspects are integrated into the development of this project.

1. Development today should not undermine the development and environmental needs of future generations.

    - The improvement of the current dumping methods within the developing countries of South East Asia will have an effect into the future. The focus shall be shifted onto sustainable methods in waste management, ensuring a healthy environment and development for future generations.

2. Environment protection shall constitute an integral part of the development process.

    - As one of the problems with the current waste management practices is the detrimental effects on the surrounding environment, it shall be ensured throughout research and development of a possible solution that this problem is not increased in any way for any period of time.
    - The open dumping grounds present a possible problem of more leachate from the dumpsite being released into the surrounding environment or waterways, if the movement of large volumes of garbage is required for processing or construction. This will be examined throughout the course of research, and monitored throughout the process of any development.

3. Engineering people should take into consideration the global environmental impacts of local actions and policies.

    - With such a large proportion of the worlds population living within Asia, the overall effect of the environmental practices in place within this region takes effect on a global scale.
    - A particularly evident problem within the area of waste management is the methane released as the waste degrades. Methane is 23 times more effective at trapping heat within the atmosphere than that of carbon dioxide

(NOVA 2009). The project will seek to ensure that there is a minimal release of methane gas into the atmosphere in the development of a sustainable waste management process.

4. The precautionary approach should be taken scientific uncertainty should not be used to postpone measures to prevent environmental degradation.

    - All measures will be taken to ensure minimal environmental impact occurs with the development of a solution to current waste practices.

5. Environmental issues should be handled with the participation of all concerned citizens.

    - Within the culture in the regions surrounding the dumpsites, few locals know of the environmental impacts of the current waste practices. It shall be ensured that locals are well informed of the reasons for change and any questions they may have are answered and available for the whole community to access.

6. The community has a right of access to, and an understanding of, environmental information.

    - An environmental discussion will be clearly described and reported on in the dissertation.

7. The polluter should bear the cost of pollution and so environmental costs should be internalised by adding them to the cost of production.

    - The dissertation investigates methods to solve the current environmental problems from the dumpsites, and steps of action shall be documented within the dissertation.

8. The eradication of poverty, the reduction in differences in living standards and the full participation of women, youth and indigenous people are essential to achieve sustainability.

    - The issue of poverty is coherently evident in the open dumpsites of South East Asia.

- Methods for reducing poverty in these regions in the development of new sustainable waste management process will be reviewed and all appropriate action will be assessed in reducing the difference in living standards.

9. People in developed countries bear a special responsibility to assist in the achievement of sustainability.

    - The focus of research is solely within locations of developing countries. The sustainability framework utilised throughout the dissertation have been obtained from pre-existing frameworks in use within developed countries.

10. Warfare is inherently destructive of sustainability, and, in contrast, peace, development and environmental protection are interdependent and indivisible.

    - Improved waste management practices improve the economy, surrounding environment and living standards for residents of these regions.

(Greene 1997)

F.2 Ethics

The ethical responsibility involved with this topic comprises of several issues which may not be recognised as areas of concern, and instead a part of daily life within these developing countries. As the development of an ethical framework has not been established by any engineering institution within these countries, the Code of Ethics set forth by the Institution of Engineers Australia shall be followed for all concerning ethical matters of the project. The Code of Ethics outlines and defines values and principles, as well as provides the Guidelines on Professional Conduct for engineers to use as a framework in exercising judgement in the practice of engineering. The main points outlined within the Code of Ethics are to demonstrate integrity, practise competently, exercise leadership and promote sustainability. These ethics shall be followed throughout the project and quoted where relevant throughout the report. (Engineers Australia 2010)