Characterization of Bio-Degradable Municipal Solid Waste (MSW) for WTE Technologies for Sri Lanka

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Degree of Master of Engineering

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

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Thesis/Dissertation submitted in partial fulfilment of the requirements for the degree
Master of Engineering

Department of Mechanical Engineering

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2. ....
   (Dr. H.K.G. Punchihewa)

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Abstract

Currently the mixed municipal waste as well as the source segregated household and commercial waste from eight local authorities is disposed at the Karadiyana waste-processing site. A small fraction of the source-segregated waste is processed as compost. All of the mixed waste is land filled. While the landfill is a managed landfill it does not meet the modern standards for a landfill by any measure. The environmental externalities due to open dumping caused by the site are palpable.

The main objective of the present study is ‘Selection of the waste to energy (WTE) conversion options based on composition of short-term bio-degradable portion of Municipal Solid Waste (MSW) available at dump sites under Municipal Councils of Sri Lanka’.

Data collection survey has been conducted at dump sites in, Kurunegala and Kandy Municipal Councils to find out the condition of Municipal Solid Waste, especially bio-degradable portion, dump data and waste data to propose suitable WTE conversion technology for each dump site. An analysis was conducted using Case Studies on physical and chemical composition of MSW in Sri Lanka and the results are presented in the report. Karadiyana W2E Project was considered as a case study to get real time data.

It is observed that the mixed waste collected in shopping (polythene) bags is causing many issues in both sites such as methane formation in bags, odour, leachate, landslides in the dump site. Composting of old dumps at the sites is practiced as a solution for waste reduction. Cleaning and sorting is done manually creating a lot of problems.

Gohagoda dump site is well managed separating plastics and polythene for recycling and bio-degradable for composting. Due to natural wind circulating through the dump odour is considerably reduced compared to Sundarapola site. In contrast to this, Sundarapola dump site shows negative operating conditions with insufficient and disorganized waste management practices.

The result revealed that the feasibility of the WTE conversion technology, in the form of a community owned power generation plant, bio-gas generating facility or composting facility operated on thermo-chemical and bio-chemical energy conversion of MSW. But it is an attractive option for Municipal Councils to reduce its long term stagnation of MSW at dump sites. In other words, if Municipal Councils implement this project, it would be an ideal solution where both the Municipal Council and the related community are benefited.

Sorting of waste at the source need to be established and collected separately. Waste Management Authority (WMA) needs monitoring all the dump sites in the country and regulates their operation. Waste auditing scheme is recommended for Waste Management Centers (WMC) while awarding ‘Star’ ratings for best waste sorting practices at the source.

Keywords: municipal solid waste, short-term bio-degradable waste, waste composition analysis, Karadiyana W2E Project, waste to energy, waste management centers, composting, anaerobic digestion, waste auditing scheme.

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LIST OF ABBREVIATIONS

Abbreviation	Description
$°C \cdot min^{-1}$	Centigrade per minute
3D	Three Dimensional
AD	Anaerobic Digestion
ASP	Aerated Static Pile
ASTM	American Society of Testing Materials
BM	Bio Methanization
BOD	Bio Chemical Oxygen Demand
CC	Chemical Conversion
CFL	Compact Fluorescent
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon dioxide
CRDF	Carbonized Refuse Derived Fuel
CSTR	Continually Stirred Tank Reactor
$dm^3 \cdot h^{-1}$	Cubic decimetre per hour
DTG	Degradation Thermo-gravimetric
EOL	End-of-Life
Eq.	Equation
EU	Europe
FAS	Free Air Supply
FBI	Fluidized Bed Incineration
Fe	Ferrous
FV	Fuel Value
GJ/t	Giga Joule per ton
H_2	Hydrogen
HCl	Hydrochloric
HDPE	High Density Polyethylene
HHV	Higher Heating Value
IWP	Integrated Waste Plant
JICA	Japanese International Corporation Agency
kcal/kg	kilo calories per kilogram
$kcal/Nm^3$	kilo calories per Newton percubic meter
KDU	Kotalawala Defence University
kJ/kg	kilo Joule per kilogram
kJ/m^3	kilo Joule per cubic meter
KMC	Kurunegala Municipal Council
kWh	kilowatt hour
L&YW	Leaf and Yard Waste
LCV	Lower Calorific Value
LTBD	Long Term Bio Degradable
MBI	Mass Bed Incineration
MC	Municipal Council/ Moisture Content
MJ/kg	Mega Joule per kilogram

LIST OF ABBREVIATIONS

Abbreviation	Description
MJ/Nm^3	Mega Joule per Newton per cubic meter
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
Mt	Metric ton
MW	Mega Watt
N_2	Nitrogen
NCV	Net Calorific Value
NO_x	Nitrous Oxide
NSWMSC	National Solid Waste Management Science Centre
O_2	Oxygen
PHI	Public Health Inspector
PM	Particulate Matter
R&D	Research and Development
RDF	Refused Derived Fuel
SD	Standard Deviation
SO_x	Sulphur Oxide
SSO	Source Separated Organics
STBD	Short Term Bio Degradable
SWM	Solid Waste Management
TGA	Thermo-gravimetric analysis
TPD	Tons per Day
TPY	Tons per year
TS	Total Solids
USEPA	United States Environmental Protection Agency
VS	Volatile Solids
WMA	Waste Management Authority
WMC	Waste Management Centre
WTE	Waste to Energy
WWTP	Waste Water Treatment Plant

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1. Introduction:

Food behavioural pattern of Sri Lankan community is to be considered to reduce food wastage. Attitudes towards change of food quantity consumed are a good starting point of domestic food waste reduction. To determine exact food quantity consumed it is needed to implement a proper domestic waste auditing scheme. Food saving in preparation is considered as the basic step for reducing the excess food waste segregation.

1.1. Background

When hearing the word “MSW”, it means creating adverse effect to health and environment such as odour, leachate and landslides etc.In the view point of energy MSW is a resource if it is properly managed.

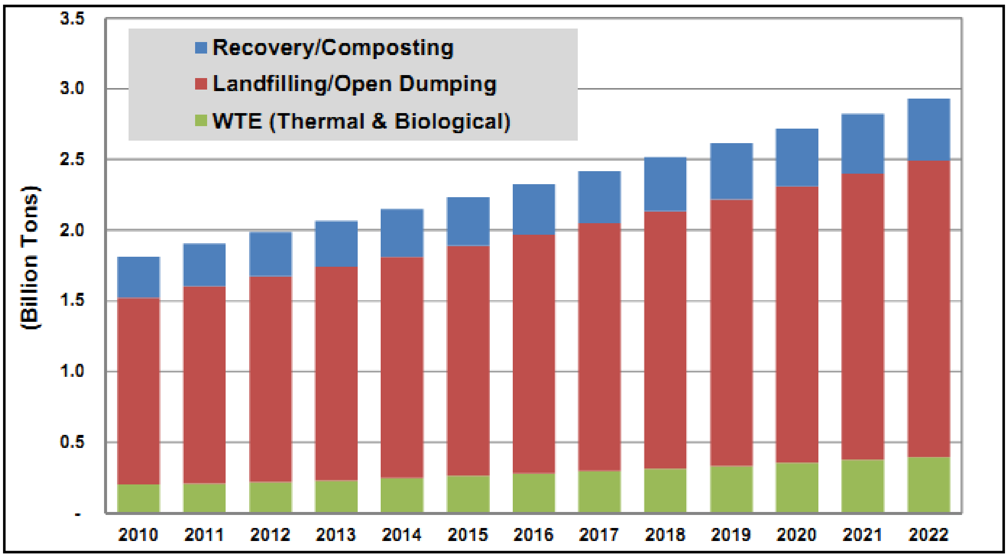


Figure.1.1: MSW Management by Disposal Method, World Markets: 2010-2022[5]

Heading into the next decade, policymakers are faced with the difficult choice of either expanding existing landfill capacity or investing in new WTE capacity[Figure.1.1]. The decision necessitates the consideration of long-term strategies, a luxury that slips further out of reach as jurisdictions face steadily increasing volumes of MSW. Illustrative of this point, China, which recently surpassed the United States as the leading generator of MSW, is at or near capacity for many of its estimated ~400 landfills. As an alternative to long-term landfill storage, WTE offers three key benefits: reduction of waste volumes by at least 90%, recovery of metals and other materials, and the generation of renewable base load energy. [5]

Waste management policies vary dramatically across regions – even among Member States within the EU and jurisdictions within the United States. Taking the long view, emerging policies in many developed countries embrace integrated waste management solutions, which aim to increase diversion rates away from landfills. Waste management infrastructure in developing countries is less mature, which suggests that integrated waste management solutions will be slower to advance. [5]

Despite these efforts, land filling remains the world's preferred method for managing and treating waste, despite its negative impact on the environment. In 2011, an estimated 1.4 billion tons of MSW was land filled or dumped in open pits worldwide. A shift away from this trend over the next decade will necessitate considerable economic and political will. Given the scale of the challenge, the preference for land filling is expected to remain mostly unchanged over the next decade, even under Pike Research's more optimistic WTE forecasts. [5]

Despite land filling's dominance, innovative waste management policies, coupled with changing economic conditions, are driving the growth of WTE capacity worldwide. This trend creates attractive business opportunities for providers of WTE technologies and related components. Although public opposition to incineration projects is still a major barrier to more widespread WTE deployment, today's mass burn facilities are far more advanced than the incinerators of old. Equipped with innovative emission control technology not possible just a decade ago, these facilities are getting a second look. [5]

MSW generation within Sri Lanka is 54% by biodegradable matter as depicted in Figure.1.2. [1] Generally waste stream contains both readily combustible components as well as non-combustible components and the composition of waste varies continuously with the economic development [1].

Sri Lankan waste significantly differs from developed countries' waste, and has considerably high moisture content [1]. It carries moisture content ranging 60% - 75% with low calorific value ranging 6,000 -9,000 KJ/kg on wet basis where as in developed countries the calorific value is typically around 10,000-12,000 KJ/ kg with 50 -55% moisture content [1]. Therefore, a careful study is needed when selecting appropriate technology to treat Sri Lankan MSW [1].

Figure.1.2: MSW Composition analysis [1]

1.2.Aim:

Characterization of bio degradable waste in Municipal Solid Waste (MSW) for waste to energy generation.

1.3.Objectives:

- To explore state of the art waste to energy technologies.
- To identify the composition in Municipal Solid Waste(MSW) of different localities in Sri Lanka.
- To match technologies with respect to MSW composition.
- To make recommendations on selecting waste to energy technologies.

1.4.Methodology

Phase-I: To explore state of the art waste to energy technologies

- Literature Survey on state of the art technology of waste to energy conversion
- MSW and its energy potential

Phase-II: Composition Survey for Bio-degradable portion (Data Collection)

- Survey on MSW in Sri Lanka
- Sample Analysis

Two different areas are selected. For each area a dump site location is selected. For each location nine samples are taken. That is 18 samples are taken for MSW composition survey for bio-degradable portion. Bio-degradable portion is then separated in the basis of short-term and long-term bio-degradable.

Short-term bio-degradable: e.g. food/kitchen waste, animal and plant matter etc.,
Long-term bio-degradable: e.g. coconut and king coconut shells, rice husks etc.,

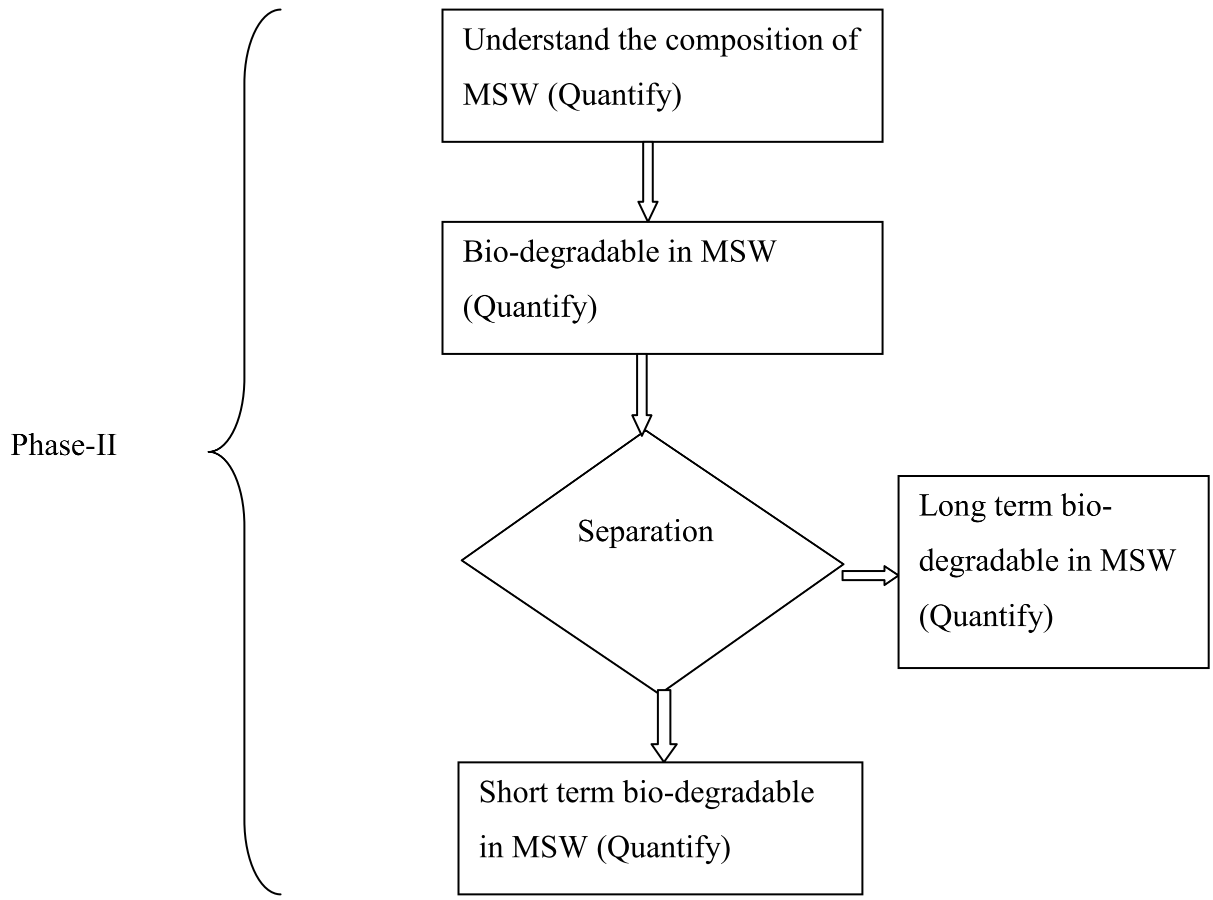


Figure.1.3: Composition Survey Methodology

MSW Composition Survey on Bio-degradable waste has to be carried out. "MSW Composition Survey Sheet" for each sample for each site has to be taken (Appendix I, Appendix II).

Phase-III: To match technologies with respect to MSW composition (Data Analysis)

Depending on ratio of short term to long term bio-degradable in each sample technologies are assigned from "Literature Review on Technology Selection".

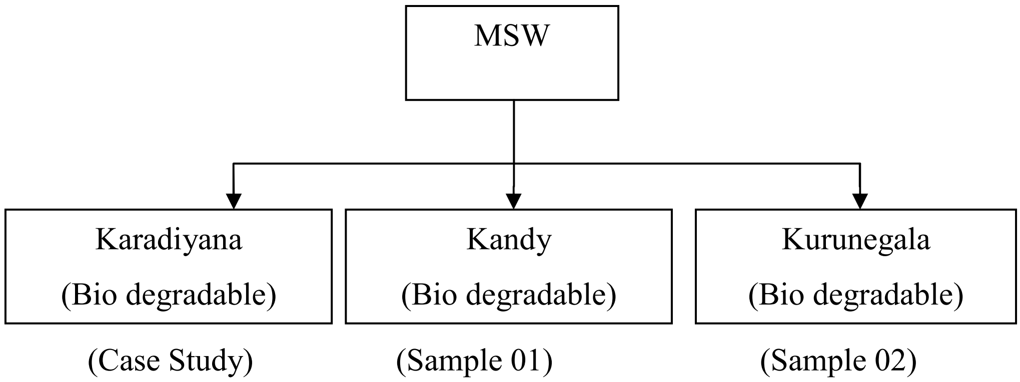


Figure.1.4: Selected waste dump sites for the study

Possible wastes to energy technologies for MSW are listed below;

1. Incineration
2. Gasification
3. Pyrolysis
4. Torrefaction
5. Recycling (Resource Recovery)
6. Composting
7. Anaerobic Digestion
8. RDF for direct combustion

Bio-degradable of MSW is further analysed for percentage of water content. Bio-degradable of MSW is collected into a PVC packing after weighing. Depending on this parameter technology may vary. (From literature review findings)

"MSW physical and chemical composition analysis result sheet" has to be filled for particular dump site/area/location (Appendix III, IV).

This MSW physical and chemical composition analysis result sheet is prepared based on Table-01: Determine the potential of recovery of energy, Table-02: Selection of best option for energy recovery and Table-14: Calorific values of available MSW in the Literature Review [4] [6]

Table.01: Determine the Potential of Recovery of Energy [4]

Quality	Parameters
Physical Parameters	• Particle size • density • moisture content
Chemical Parameters	• Volatile Solids • Fixed Carbon content • Inert • Calorific Value • C/N ratio (Carbon/Nitrogen ratio) • toxicity

Table.02: Selection of Best Option for Energy Recovery [4]

Waste Treatment Methods	Basic Principle	Important waste parkers	Desirable range
Thermo-chemical Conversation • Incineration • Pyrolysis • Gasification	Decomposition of organic matter by action of heat.	• Moisture content • Organic/ Volatile matter • Fixed Carbon • Total Inert • Calorific Value (NCV)	• < 45 % • >40 % • < 15 % • < 35 % • >1200 kcal/kg
Bio-chemical Conversion • Anaerobic digestion/ Bio-Methanization	Decomposition of organic matter by microbiological action	• Moisture content • Organic/Volatile matter • C/N ratio	• >50 % • >40 % • 25-30

Phase-IV: To propose pathways to manage MSW

Suitable technology is recommended for manage bio-degradable waste in MSW. For this, equations from section 2.2.2 could be used on net power generation potential from Waste to Energy [4]

Bio-Chemical Conversion (Enzymatic Decomposition) kW = 11.5 * W (Mt)[4]
Thermo-Chemical Conversion (Thermal Decomposition) kW = 14.4 * W (Mt)[4]

Therefore, MSW collection by Municipals has to be tabulated based on Table.14and Table.15.

Summary

Problem was introduced with scenario projection. Aims and Objectives were defined for the study being carried out. Methodology was illustrated with schematics. Criteria for selecting suitable WTE technology of respective conversion methodology for processing bio-degradable portion of MSW was defined by literature review findings. To carry out the research, project was divided into four phases.

2. Municipal Solid Waste(MSW) and Waste to Energy (WTE) conversion

2.1 Municipal Solid Waste (MSW)

"Municipal Solid Waste (MSW) more commonly known as trash or garbage consists of everyday items we use and then throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. This comes from our homes, schools, hospitals, and businesses. (U. S. Environmental Protection Agency)"

2.1.1 Constituents of Municipal Solid Waste (MSW)

The 2012 statistics of Municipal Solid Waste composition in Sri Lanka is illustrated by the Figure.2.1 below [2].

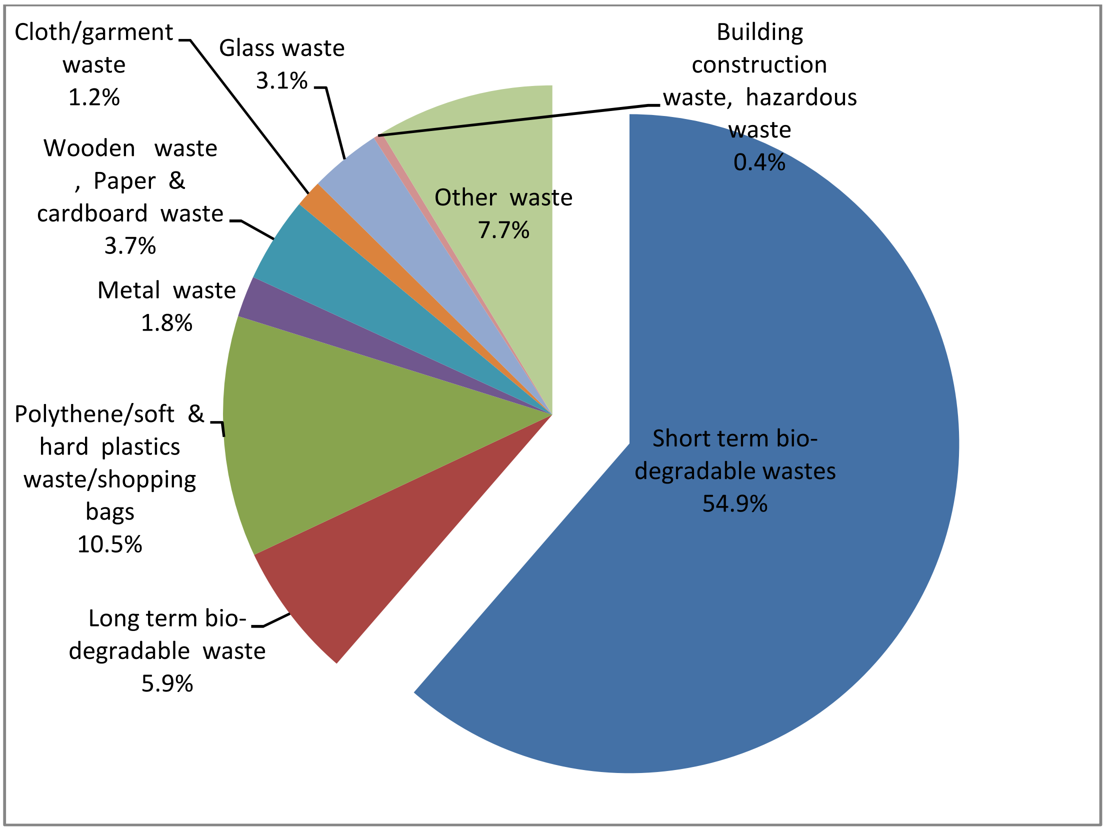


Figure.2.1: Compositions of MSW in Sri Lanka [2]

The Sri Lankan MSW mostly consists of Short term 54.5% bio-degradable waste (i.e. Food/Kitchen Waste, animal & plant matter…etc.), Long term bio-degradable waste (5.9%) (e.g. Coconut& king coconut shells, rice husks, slaughter house waste

(2.8%), leather …etc.) And Non-biodegradable as such; Polythene/soft & hard plastics waste/shopping bags (10.5%), Metal waste (1.8%) (e.g. aluminium cans steel containers…etc.), Wooden waste (e.g. Saw dust, tree cuttings…etc.) Paper & cardboard waste (3.7%), cloth/garment waste (1.2%), Glass waste (3.1%), Building construction waste, hazardous waste (0.4%) (Batteries, CFL bulb, paint bottles, e-waste…etc.) and other waste (7.7%) (e.g. Industrial waste etc.) [2].

2.1.2 Dumping of Municipal Solid Waste (MSW)

In Sri Lanka, the city of Colombo alone generates approximately 1200 tonnes of garbage per day [1]. Municipal solid wastes are generated in large quantities creating many social and environmental issues in Sri Lanka. The total waste generation is estimated at 6400 tons/day whereas waste collection is only about 3740 tons/day [1]. The Western Province accounts for more than 59% of the country's daily waste generation [1]. There are two major garbage dump sites in western province: Meethotamulla and Karadiyana. Daily average receiving to Meethotamulla dump site is around 750 – 800 tons/day while Karadiyana receive 400- 450 tons/day [1]. Around 250- 300 tons per day used for composting and the rest of the garbage in western provinces is dumped in unauthorized places [1].

2.2 Waste to Energy (WTE) conversion

Waste to Energy is the generic term given to a process by which the energy stored in waste (chemical energy) is extracted in the form of electricity, heat and/or a fuel for use in a de-centralized energy generation plant.

Thermal conversion processes can be divided into three different categories; combustion, gasification and pyrolysis with each process being dependent on the concentration of oxygen combustion takes place in an environment with an excess of oxygen, gasification is a partial oxidation process requiring an oxygen concentration slightly below the stoichiometric level. Pyrolysis occurs in the absence of oxygen [1].

Technology prioritization should be based on local waste characteristics especially high moisture content and biodegradable fraction. Thus, more appropriate technology options could be;

- Upstream waste management and resource recovery (Recycling)
- Composting
- Anaerobic digestion
- Prepare RDF and use direct combustion for energy generation [1]

Electricity can be generated on a small scale using biogas [Figure.2.2]. Biogas is exactly the same as methane, the fossil fuel extracted from underneath the rock, but it is produced by bacteria respiring animal wastes like manure [4].

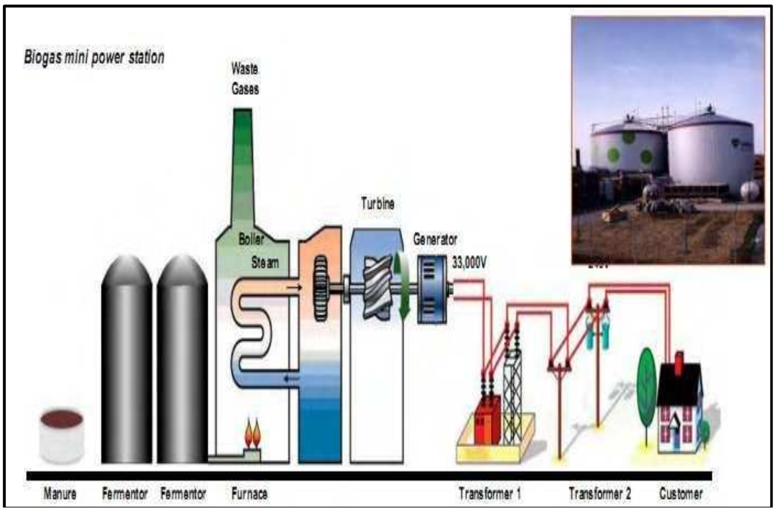


Figure.2.2: Generating electricity using biogas[4]

2.2.1 Parameters which Determine the Potential of Recovery of Energy

The basic factors are quantity and quality of waste. There are two parameters to measure the quality of waste that are physical and chemical parameters. [4]

2.2.2 Net Power Generation Potential from Waste to Energy

- Bio Chemical conversion (Enzymatic Decomposition) kW=11.5* W (Mt) [4]
- Thermo- Chemical conversion (Thermal Decomposition kW=14.4*W (Mt) [4]

2.2.3 What is Thermo- Chemical Conversion?

Conversion of MSW into either thermal or electrical energy through a process of combustion. Combustion is a product of several chemical reactions that are produced during the course of complete or partial oxidation of carbon and hydrogen of usual combustibles. In Sri Lanka high tariff for electricity (22.05Rupees per kWh for maximum 10 MW) [4].

2.2.4 Technical Options available for Thermo- Chemical Conversion

(a) Incineration

An MSW incineration power system generates electricity by driving turbines with high temperature steam produced by the incineration of MSW, as shown in Figure**.**2.3. After transportation in closed truck s, MSWs were poured into a storage pool to ferment for approximately three days. The characteristics of MSW in China are unsorted coupled with low calorific values (3000 – 5000 kJ/kg) and high moisture rates (45 – 65 %), which organic ingredients account for 40 – 60 % of dry weight.[12]

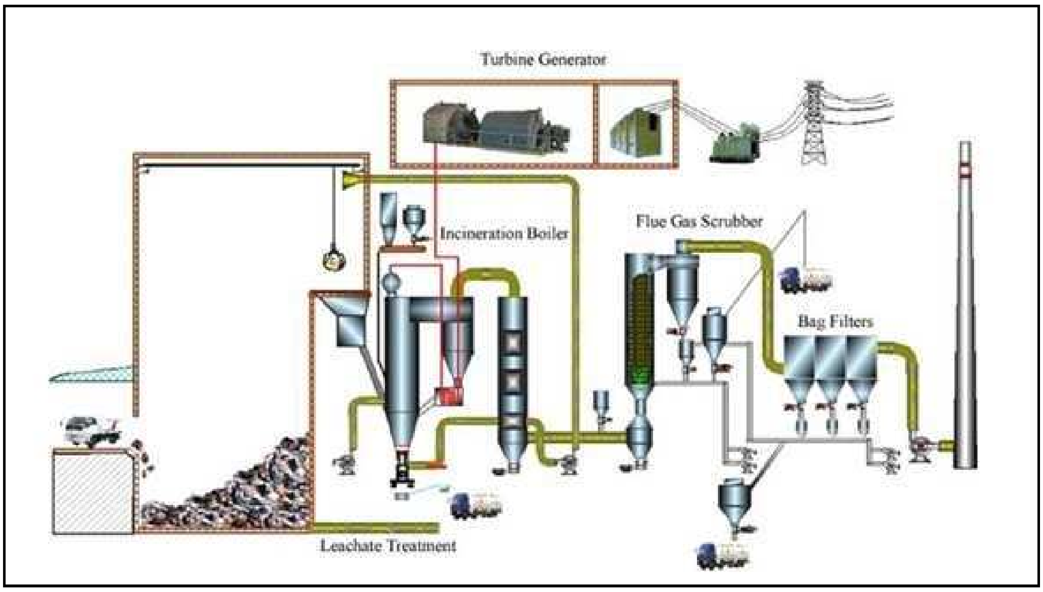


Figure.2.3: Schematic diagram of MSW incineration and power generation process [12]

This fermentation procedure could reduce the materials' humidity and increase their heating values MSWs were then burned in incineration boilers to heat water to generate steam, which is the driving force of turbine generators. The flue gases and solid residues generated during the MSW incineration process should be treated accordingly to avoid secondary environmental pollution, especially the flue gases which contain significant amounts of dioxins, particulate matters, heavy metals, sulphur dioxide, and hydrochloric acid. The flue gases are first sent into a flue gas scrubber to remove acidic material, after which bag filters are used to remove dust particles so that the gas can meet the final emission standards. Fly ash, one of the flue gas residues, is a hazardous substance and should be dealt with in accordance with hazardous material waste laws. [12]

Process flow of the Incineration is depicted by Figure.2.3. [4]

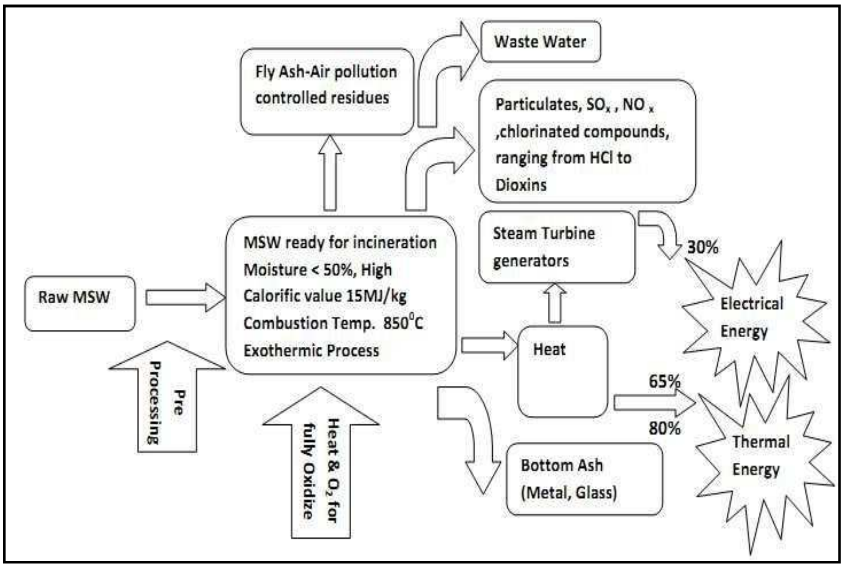


Figure.2.4: Incineration [4]

In addition to those emissions directly resulting from material combustion (also referred to as incineration or waste-to-energy [WTE]), the environmental burdens associated with material incineration include pre-processing that may occur prior to the combustion of the EOL(End-Of-Life) materials (depending on the incineration technology used); and the construction, operation and decommissioning of the incineration facility including air pollution control devices; and solid (e.g., ash), liquids (e.g., leachate from ash disposal in landfill), and gaseous emissions (e.g., CO_2, SO_x). A general life cycle flow diagram that identifies material, energy and emissions flows through a general WTE process is depicted in Figure 2.5. [25]

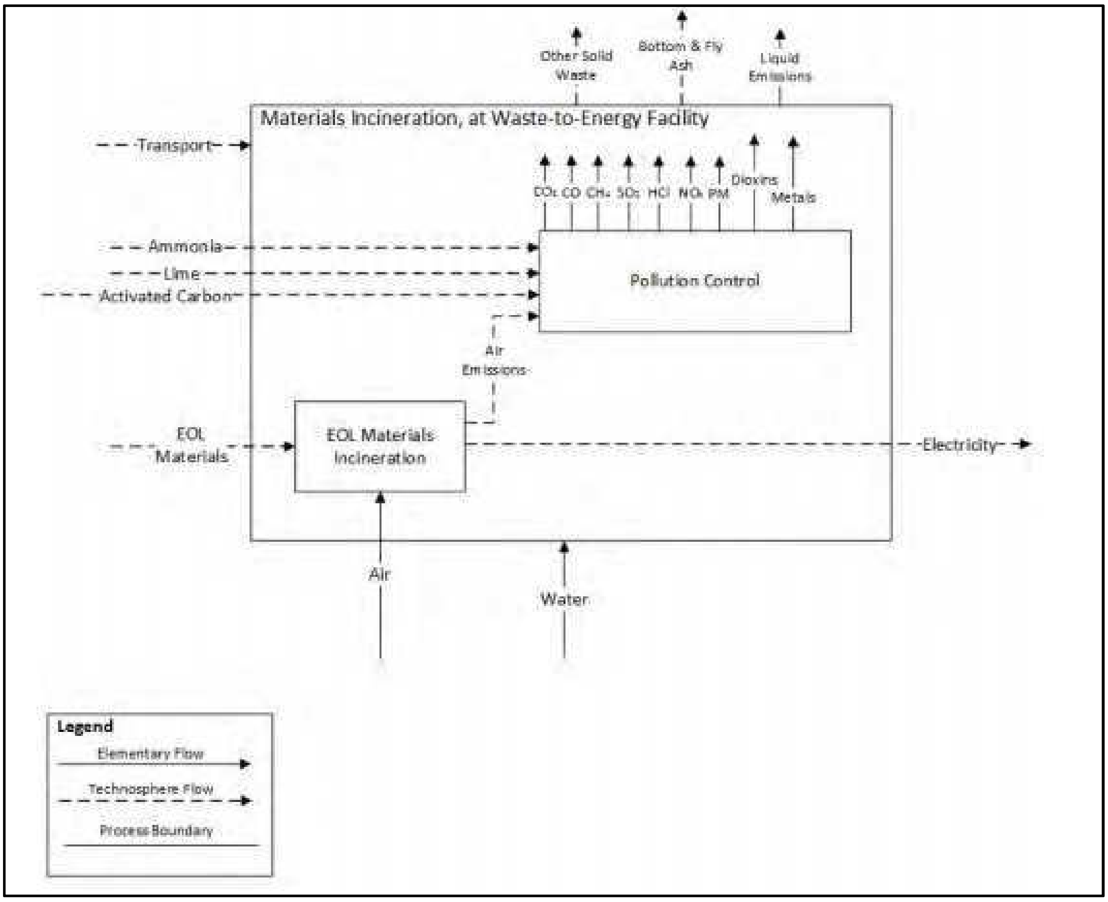


Figure.2.5: Example of Materials and Energy Inputs and Emissions Associated with Materials Incineration for Energy Recovery [25]

(b) Mass Burn

"Mass burn", where refuse is burned just as it is delivered to the plant without processing or separation is shown in Figure.2.6. [4]

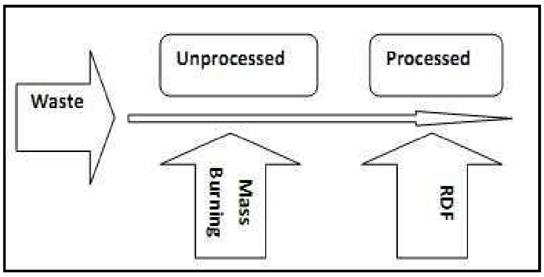


Figure.2.6: Waste Processing in Mass Burn and RDF Plant [4]

(c) Refuse Derive Fuel (RDF) for Direct Combustion

In an RDF plant, waste is processed before burning as shown in the Figure.2.6. Typically, the incombustible items are removed, separating glass and metals for recycling. The calorific value of RDF pellets can be around 4000 kcal/ kg. Apart from incineration it can be very effective method for preparing an enriched fuel feed for other thermo-chemical processes like Pyrolysis/ Gasification [4].

(d) Gasification

Energy of waste conversion technologies were in the past solely based on combustion process similar to solid fuels combustion technologies. The only plant additions were demanding flue gas treatment devices to clean up the emitting pollutants.[3]

Today, environmentally high efficient systems are based on multi stage thermal conversion process.

At first, two stage combustion systems have been designed for industrial, medical and hazardous waste incineration since in the past the legislation of developed countries had set higher environmental and technical standards for treating these wastes then treating the municipal solid waste. Those incinerators had small capacity and were mostly batch fired. The main intention for installing the second combustion chamber was to improve complete combustion of all organic components in gases leaving primary chamber. [3]

Multi stage incineration systems have made their first appearance some fifty years ago. All two (or multi) stage technologies share the common idea of two (or more) divided chambers (reactors). The two chamber combustion technology is in principle based on the air shortage in the primary chamber and excess air in the secondary chamber, what together assures good combustion conditions, low emissions and lower consumption of added fuel. [3]

The whole waste thermal treatment process is based on two groups of physical – chemical processes:

• warming, drying, semi-pyrolytic gasification of the waste in the primary chamber and

• mixing of the synthetic gases with air, ignition and complete combustion in the Secondary chamber. Two stage incineration system is in more technical detail presented in chapter Case study: presentation of small size waste – to – energy plant.

Gasification process emerged from combustion process as it is already present in every solid fuel combustor. Depending on the technology and waste (fuel) utilized can be updraft or downdraft system. These two terms define the movement of synthetic gas in co-flow (down draft) or contra-flow (updraft) compared to waste movement. Other types of gasification technology are even more comparable to pure combustion technologies (like fluidized bed, rotary kiln.).[3]

The schematic presentation of gasification reactor or primary chamber and combustion or secondary chamber is presented on Figure.2.7.[3]

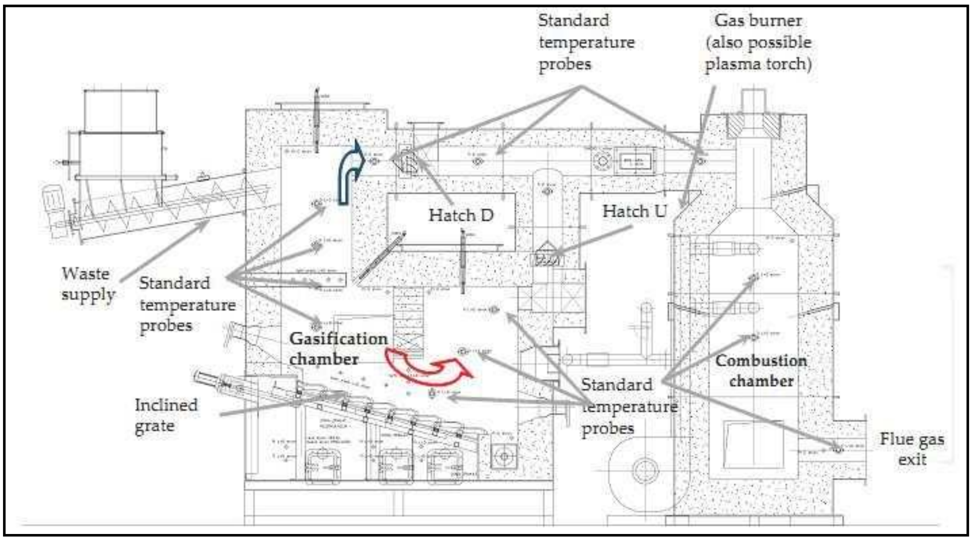


Figure.2.7: The schematic presentation of gasification and combustion chambers of Pilot scale waste gasification unit [3]

The gasification chambers on Figure 2.7 and implemented technology can be regarded as modular waste processing on the grate. Waste processing is conducted in two stages – the designed process enables to upgrade the investigated system with utilization of high calorific synthetic gas in gas turbine or internal combustion gas engine instead of burning it in secondary chamber. The system enables both updraft and downdraft operating regimes, depending on input waste characteristic and reactor operating conditions. The photo of the pilot plant in presented on Figure 2.8. [3]

In the primary chamber the gasification process is carefully managed with an exact air supply and temperature control. The system operates with air deficiency – compared to the theoretically required air for combustion, so pyrolytic gasification processes prevail. This is carefully controlled with under the grate air supply to ensure proper gasification process along the grate. The only possibility to overlook the gasification process along the grate in detail is to measure the temperature of the grate. As the upper side is covered with waste the only possibility is to measure the bottom side of the grate.[3]

This reactor design can in constant operation reach over 4 MJ/Nm^3 with average composition of RDF produced in Europe. Thus the system allows downdraft (hatch D on Figure 2.7 closed) or updraft (hatch U on Figure 2.7 closed) operation to be able to adjust the gasification to the properties of waste treated.[3]

Table.03: Calorific value of synthetic gas produced with air and various gasifier types[3]

Gasifier type	Calorific value of the product gas [MJ/Nm³]
downdraft	4 – 6
updraft	4 – 6
fluidized bed	4 – 6
fluidized bed - steam	12 – 18
circulating fluidized bed	5 – 6.5
cross flow	4 – 6
rotary kiln	4 – 6

This utilization of synthetic gas in gas engine or turbine is only possible if high calorific synthetic gas is produced. The literature shows that the gases with the calorific value of between 4 and 6 MJ/Nm^3 can be produced and the complete data is presented in Table 03. The gas turbine can run on gases with calorific values as low as 2.5 MJ/Nm^3. [3]

Figure.2.8: Pilot scale W-t-E gasification plant during experiments and investigations [3]

The whole process of gasification was controlled with the quantity of waste input into the chamber, the velocity of waste movement along the grate and quantity and distribution of air. The search for optimal operating conditions was based on the known composition of waste and operating experience.[3]

Generated synthetic gases are on the pilot scale system measured in the duct between primary and secondary chamber with Wobbe index analyser [12]. The temperature in primary chamber needs to be kept more or less constant just over 600 °C and the air supply must be carefully controlled.[3]

The pilot scale equipment tests have shown that this technology can offer production of synthetic gases of over 4 MJ/Nm^3. The generation of gas is highly dependent of the calorific value of the RDF. Test have shown that RDF with around 11 MJ/kg produces synthetic gases with around 2 MJ/Nm^3 and only RDF with calorific value of 15 MJ/kg or over enables the production of synthetic gas of 4 MJ/Nm^3 and over.[3]

Process flow of the gasification is depicted by Figure.2.9. [4]

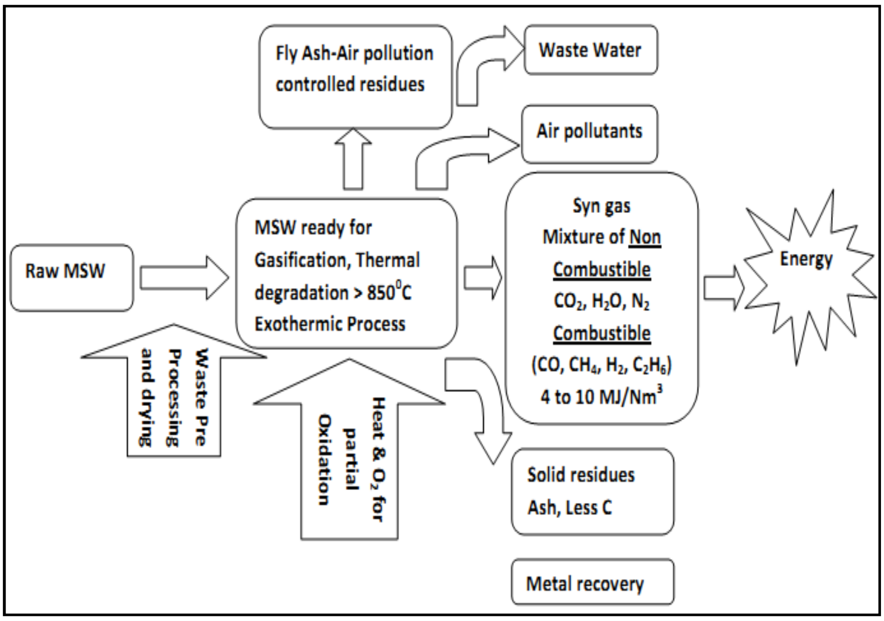


Figure.2.9: Gasification [4]

(e) Pyrolysis

Pyrolysis process is again being composed of thermal decomposition of organic matter which occurs in the absence of air. To reach decomposition conditions in reactor heat and sometimes steam need to be introduced to the reaction chamber.[3]

The pyrolysis gas has at least double the calorific value as gasification synthetic gas both produced from the same waste (fuel). But the overall energy efficiency is not always in favour of pyrolysis as there is pyrolysis gas partially utilized for heat and steam generation.[3]

To be able to compare all three thermal conversion processes in context of power production there are schematic presentations on Figure 2.10 to Figure 2.13.[3]

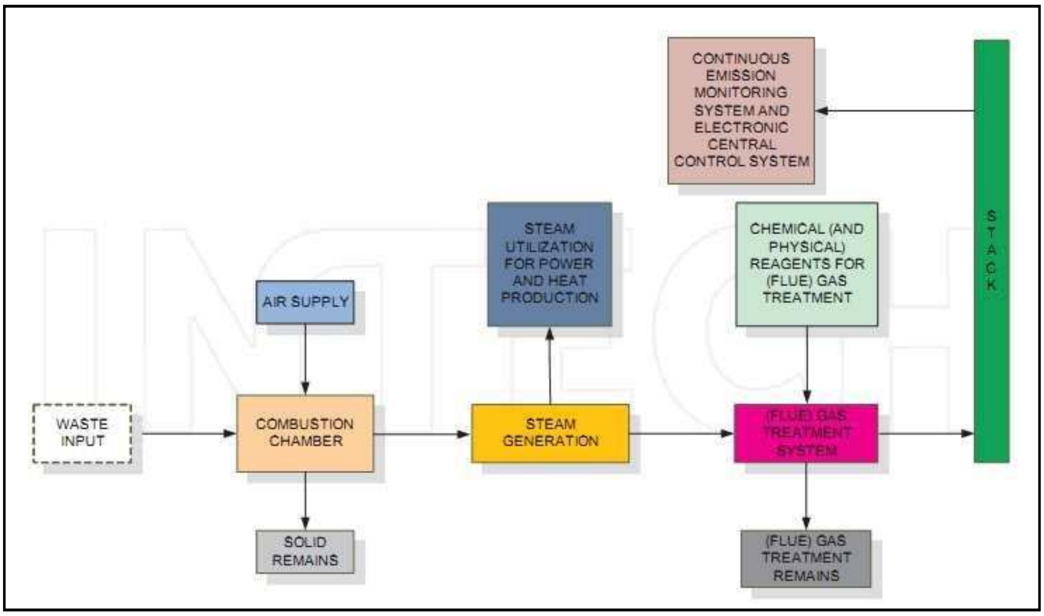


Figure.2.10: The schematic presentation of single stage combustion with steam generation and utilization[3]

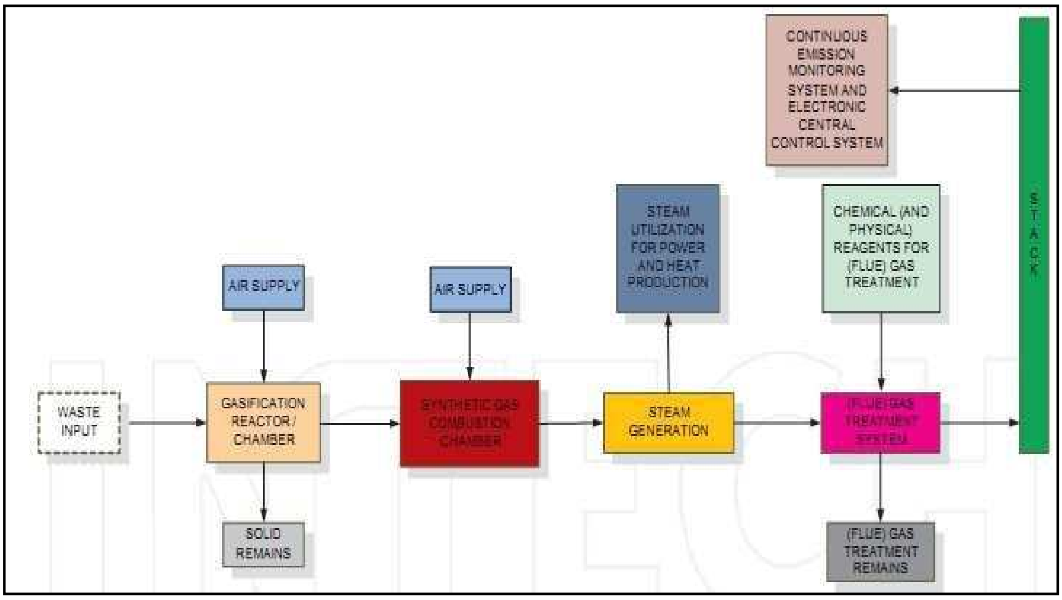


Figure.2.11: The schematic presentation of complete waste gasification system with immediate combustion of synthetic gas[3]

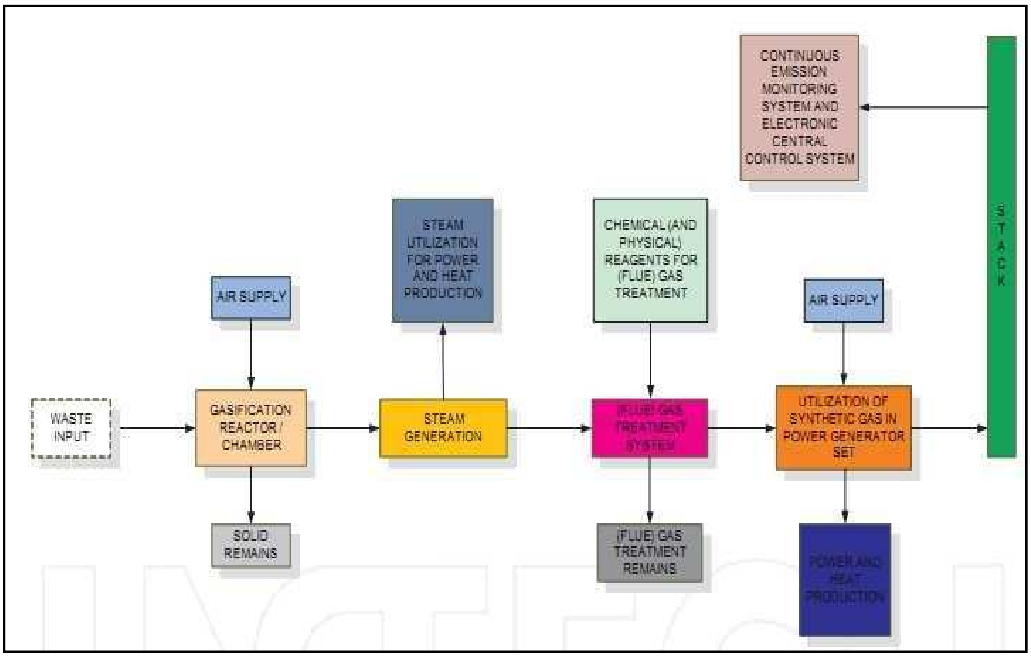


Figure.2.12: The schematic presentation of complete gasification system with high efficient electrical power production unit [3]

Thermal conversion of waste with combustion can produce only hot water, hot thermal oil or steam (Figure 2.10). The power production can only be achieved with Rankine cycle with clear limitations of overall efficiency. Even when combustion occurs in multiple stages (chambers) it does not improve power production efficiency. It only improves environmental performance of conversion process.[3]

On the other hand, can gasification or pyrolysis process lead to higher power efficiencies since part of energy transformation and utilization takes place in gas engine or turbine with higher overall efficiency. This two processes have also quite some drawbacks especially is questionable the durability and reliability of this technologies with RDF operation. Generally, these processes operate well with constant quality (properties) of waste (fuel) material without certain undesired materials that could cause problems along the conversion process.[3]

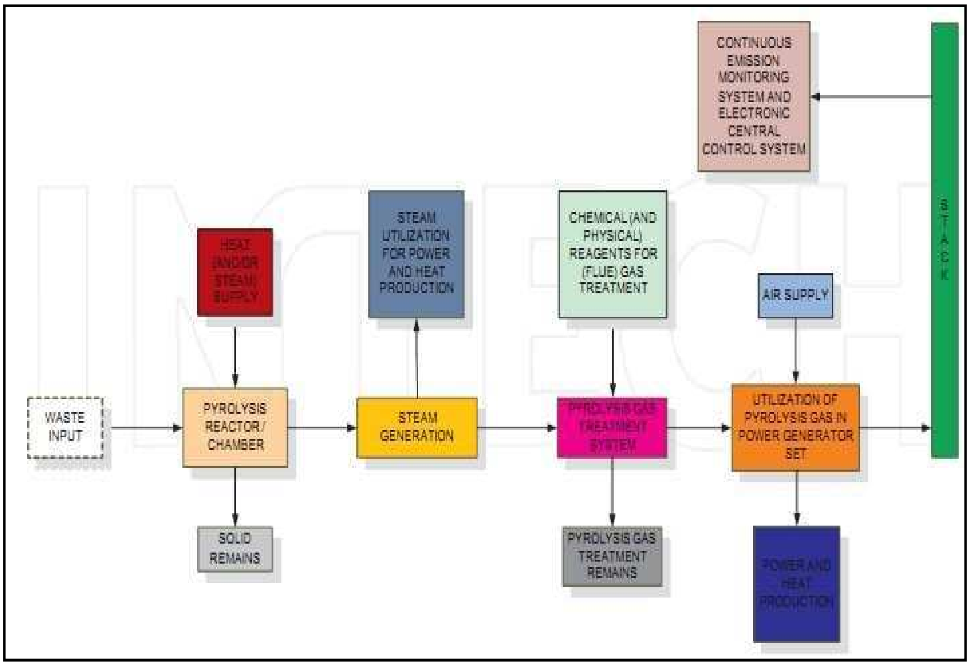


Figure.2.13: The schematic presentation of pyrolysis system with high efficient electrical power production unit [3]

Process flow of the Pyrolysis is depicted by Figure.2.14. [4]

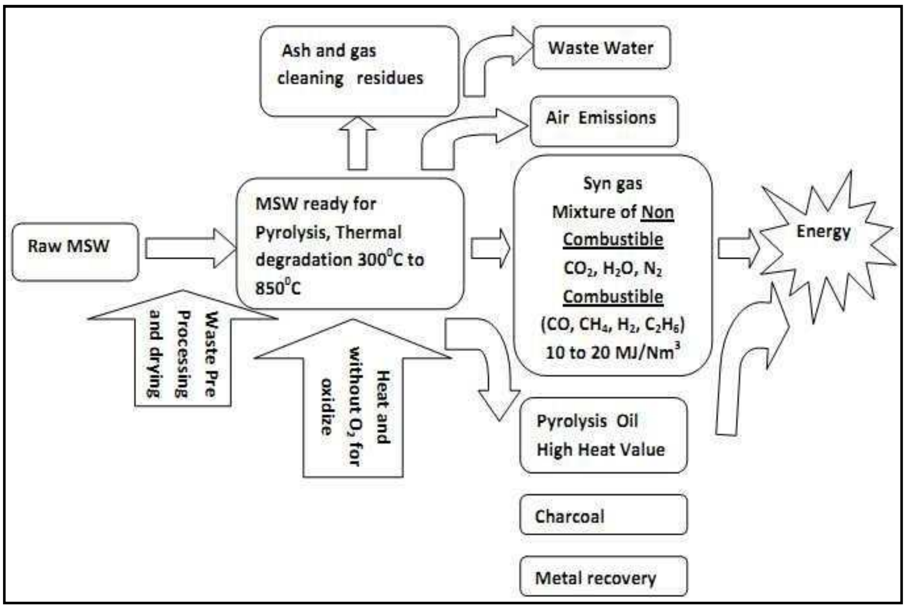


Figure.2.14: Pyrolysis [4]

(f) Plasma Pyrolysis Vitrification (PPV) / Plasma Arc Process

This is an emerging technology. The system basically uses a Plasma Reactor which houses one or more Plasma Arc Torches. Plasma Arc Torches is generated by application of high voltage between two electrodes and develop high heat zone 5000 to 14000° C. Organic materials are converted to Synthetic-gas composed of H_2, CO. Inorganic materials are converted to solid slag. Synthetic-gas can be utilized for energy production or proportions can be condensed to produce oils and waxes [4].

Process flow of the Plasma Pyrolysis Vitrification is depicted by Figure.2.15. [4]

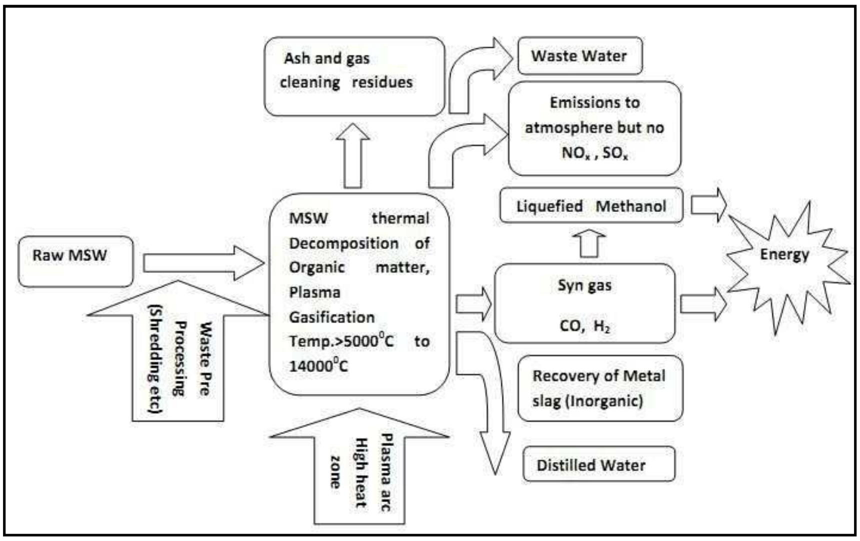


Figure.2.15: Plasma Pyrolysis Vitrification (PPV)[4]

(g) Organic Municipal Solid Waste Torrefaction

Torrefaction is also called roasting, high-temperature drying, low-temperature pyrolysis could be a helpful solution for overcoming problems with RDF qualitative requirements. Torrefaction is a thermo-chemical process, with following characteristics: temperature 200-300°C, heating rate <50°C·min^{-1}, residence time <60 minutes, no oxygen, atmospheric pressure (Tumuluru et al., 2011). [24]

Five process phases can be distinguished: pre-heat, pre-drying, drying and transient heating, torrefaction, cooling of the product (Bergman et al., 2005).[24]

As a result of the process, two products are obtained: bio char and torrefaction gas one with a mass balance of 70-80% and 23-30% respectively. The solid product is called bio carbon when agricultural or forestry biomass is used as a substrate. For other substrates, it is called carbonate or bio char (Malińska, 2015). The gas product is referred to as a tor-gas (Bergman et al., 2005).[24]

The solid product resulting from the processing of agricultural or forestry biomass is characterized by:

• *High energy density.* Processed biomass contains 70-80% of the initial mass and 80-90% of initial energy (Tumuluru et al., 2010);

• *Decrease in moisture content.* After the torrefaction process, the moisture content of the obtained product is approximately 1-2% mass (Tumuluru et al., 2010);

• *Hydrophobic properties.* Processed biomass manifests high hydrophobicity. Maximum water uptake is 1-6% (Tumuluru et al., 2010) (e.g. water content in unprocessed wood biomass ranges from 12 to 22%, bark from 45 to 55% (Kordylewski et al., 2008));

• *Increased carbon content.* The concentration of carbon in the structure of the compound results in increased bio carbon reduction properties (Bergman, 2005);

• *Reduction of oxygen and hydrogen.* The O/C and H/C ratios are reduced, resulting in an increase in the attractiveness of bio carbon as a substrate for the gasification process (Prins, 2005);

• *Better milling properties.* Due to the depolymerisation of cellulose fibres, lignin and hemi-cellulose bio char grinding requires less energy since the structure and form of the particulate matter is similar to carbon (Bergman et al., 2004).[24]

Due to the above, torrefaction process may be a good way to increase the fuel properties of RDF. However, this process has not been characterized or understood deeply.[24]

This paper presents the characteristics of the thermal decomposition of RDF using thermos-gravimetric analysis (TGA). Using the qualitative interpretation method of the TGA curve, changes in the mass decrease pattern of the sample under linear temperature increase were observed, whereby a comparison of the mass drop within temperature range with the values given in literature of the individual RDF components was conducted. The quantitative interpretation of the TGA allowed for the determination of kinetic parameters such as the reaction rate constant and activation energy. These parameters are indispensable in the torrefaction modelling process.[24]

RDF and produced carbonates are characterized in terms of fuel properties. The conducted analysis allowed to determine the suitability of the torrefaction as an alternative fuels valorisation process.[24]

a. RDF used in the study

The RDF used in the study was taken from a mechanical-biological waste treatment facility with the status of a regional waste treatment plant. The facility is located in the village of Gać, Poland (in the region of Lower Silesia). The process of production RDF from municipal solid waste is presented in Figure 2.16.[24]

A general 250 kg sample was taken from RDF's production line and then a laboratory sample of 5 kg was separated from the general sample by quartering (PN-Z-15006:1993). In order to homogenize the material (RDF and RDFs), it was ground to particle size ≤0.425 mm with the use of the LMN 100 knife mill. The material to be tested was prepared in the way presented below.[24]

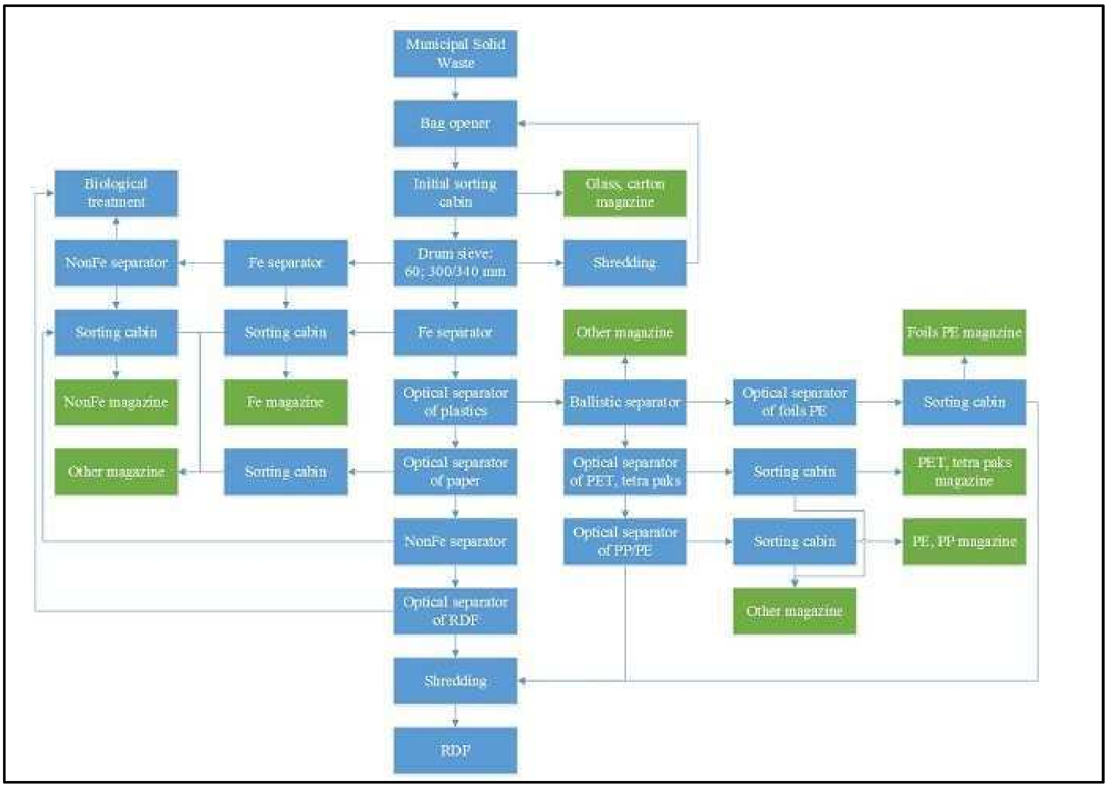


Figure.2.16: The configuration of RDF production lines at MBT plant in Gać [24]

b. Carbonized Refuse Derived Fuel production method

The bio char, previously referred to as Carbonized Refuse Derived Fuel (CRDF) (Białowiec et al., 2017) was obtained by means of the SNOL 8.1/1100 muffle furnace (Figure 2.17). CRDF samples were generated under the following conditions:

- Temperature range from 200 to 300°C (temperature interval of 20°C);
- Retention time: 20, 40, 60 minutes for each temperature;
- Temperature rise: 50°C·min^{-1} (maximum heating rate);
- Used gas: carbon dioxide;
- Gas flow: 10 dm^{3}·h^{-1}.

The heating of the reactor was commenced 5 minutes after gas introduction into the device began. Carbon dioxide was cut off when the temperature inside the reactor during the cooling phase reached 100°C (Madanayake et al., 2016).[24]

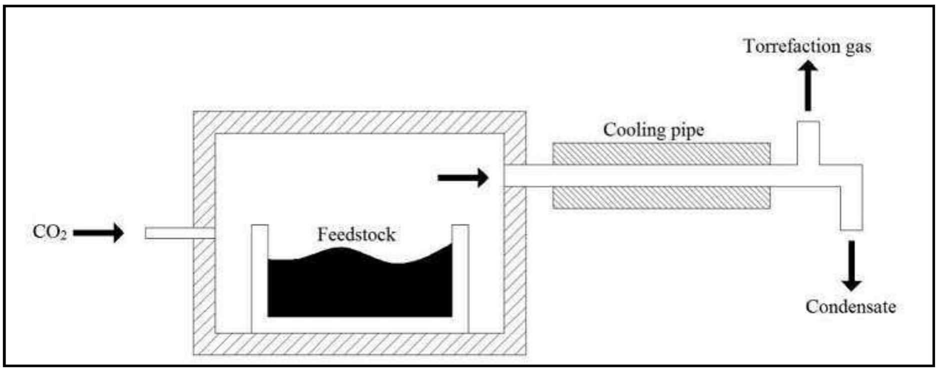


Figure.2.17: Schematic figure of the experimental set-up of CRDF generation [24]

c. Physical and chemical analysis of RDF and CRDF

The RDF and generated CRDF from torrefaction were tested for:

- Morphological composition (only RDF) in accordance with Malinowski and Wolny-Koładka (2012);
- Moisture content by means of the KBC65W laboratory dryer in accordance with the PN-EN 14346:2011 standard;
- Content of organic matter by means of the SNOL 8.1/1100 muffle furnace in accordance with the PN-EN 15169:2011 standard;
- Combustible and non-combustible content by means of the SNOL 8.1/1100 muffle furnace in accordance with the PN-Z-15008-04:1993 standard;
- Volatile content by means of the SNOL 8.1/1100 muffle furnace in accordance with the PN-G-04516:1998 standard;
- Higher heating value by means of the IKA C2000 Basic calorimeter in accordance with the PN-G-04513:1981 standard.

Each of the designations was repeated 3 times.[24]

d. Thermo-gravimetric analysis (TGA) of RDF

The thermos-gravimetric analysis was carried out by means of the Czylok RST 40·200/110P stand-mounted tubular furnace (Figure 2.18).[24]

The study used the method of qualitative and quantitative interpolation of the TGA curve. The qualitative method allows for determining the mass deviations of the sample to be tested at a set temperature. By this analysis, the distribution of particular chemical compounds that build up the sample may be observed. A quantitative method allows for determining the kinetic parameters of the process. The measurement is based on accurate determination of the mass change and its rate at particular temperatures. [24]

The first method was carried out under the following conditions:

- Temperature from 10 to 850°C;
- Temperature rise: $10°C \cdot min^{-1}$ (maximum heating rate);
- Used gas: carbon dioxide;
- Gas flow: $10\ dm^3 \cdot h^{-1}$.

The second method was carried out under the following conditions:

- Temperature range from 200 to 300°C (temperature interval of 20°C);
- Retention time: 60 minutes for each temperature;
- Used gas: carbon dioxide;
- Gas flow: $10\ dm^3 \cdot h^{-1}$.

Based on TGA results, the reaction rate and activation energy within the torrefaction temperature range was calculated by Statistica 13.1 software. The reaction constant rate of the thermal transformation of the material was calculated on the basis of a first-order reaction (Eq. 1, Eq. 2) (Bates et al., 2012):

$$M_S = M_S^0 \cdot e^{-k \cdot t} \quad (1)$$

$$\ln \frac{M_S^0}{M_S} = k \cdot t \quad (2)$$

Where: M_s is initial mass, g, M_s is mass per unit, g, k is reaction rate constant, $1 \cdot s^{-1}$,t is time, s.

The Arrhenius equation (Eq. 3) (Bates et al., 2012) represents the dependence of the reaction constant rate k on the temperature T:

$$k(T) = A \cdot \exp - \frac{E_a}{R \cdot T} \quad (3)$$

The logarithmic form of the equation (Eq. 3) is shown below:

$$\ln k(T) = \ln A - \frac{E_a}{R \cdot T} \quad (4)$$

Where: R is universal gas constant, 8.314 $J \cdot (mol \cdot K)^{-1}$, T is temperature, K, A is a pre-exponential factor, $1 \cdot s^{-1}$, E_a is activation energy, $J \cdot mol^{-1}$, k is reaction constant rate, $1 \cdot s^{-1}$.

Using the Arrhenius equation, activation energy can be calculated by means of the reaction constant rate. ln(k) is a linear function of $1 \cdot T^{-1}$ (Eq. 5) (Soria-Verdugo, 2015).

$$y = a \cdot x + b \quad (5)$$

where:

$y = \ln(k)$,

$b = \ln A$,

$a = \frac{E_a}{R}$,

$x = 1 \cdot T$.

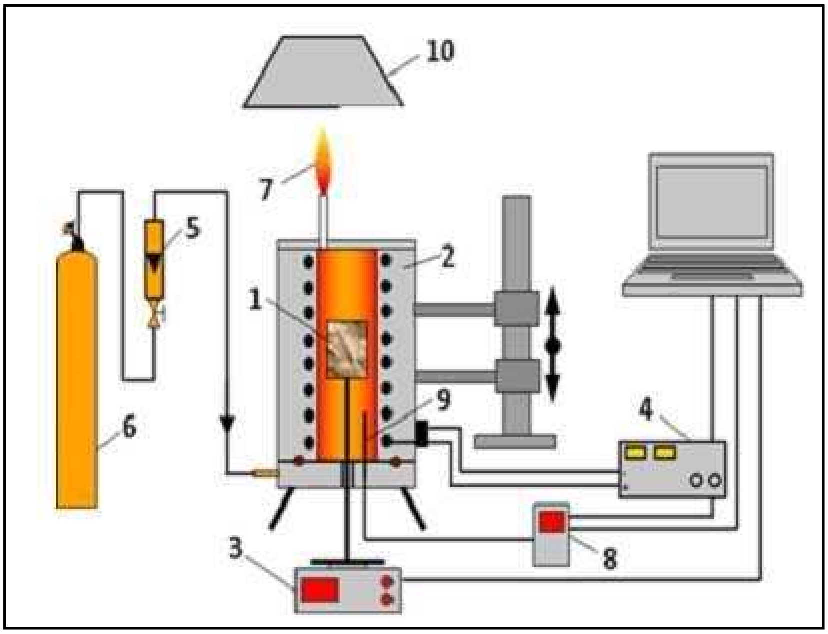


Figure.2.18: Reactor set-up

1 - A vessel filled with solid fuel sample

2 - Electrically heated reactor

3 - Electronic balance

4 - Electric power feeder (regulator),

5 - Rotameter

6 - Bottle with carbon dioxide

7 - Gaseous products of pyrolysis/ torrefaction process

8 - Temperature indicator

9 - Thermocouple

10 - Exhaust chimney

e. Results of the physical and chemical analysis of the substrate

RDF morphological composition is shown in Table 04.The percentage share of highly calorific waste (plastics, paper, wood, textiles) was 54.3%. This value is low, but lies within the lower range of values given in literature, where the proportion of highly calorific waste was from 53.2% to 100% (Seoi in. 2010;

Miskolczi i in., 2011; Kara, 2012; Kruger i in., 2014; Akdag i in., 2016; Çepolioğullar Ö i in., 2016).[24]

The average results of the physical and chemical analyses of RDF are presented in Table 05. Moisture content in the RDF was 17.31%. This value is within the upper limit of the moisture content in RDF. The moisture content reported in the literature ranges from 1.6% to 17.4% (Akdag et al., 2016; Edo et al., 2016; Manya et al., 2015; Seo et al., 2010; Singh et al., 2011). [24]

Analysing the results of the content of organic matter and the content of combustible components, it must be noted that RDF is mostly built of organic materials that break down to 550°C. This is reflected in the morphological composition of the alternative fuel, which consists mainly of materials (plastics and wood) that undergo decomposition at temperatures of 550°C (Robinson et al., 2016). The residual matter is ash, whose average value in the analysed material was 13.25%. The ash content in RDF ranges from 8.64% to 26.29% (Ahn et al., 2013; Akdag et al., 2015; Çepolioğullar et al., 2016; Miskolczi et al., 2011; Seo et al., 2010; Singh et al., 2012). The determined high calorific value was higher than usually given in the literature - from 17 to 22 MJ·kg-1 (Akdag et al., 2016; Çepolioğullar Ö et al., 2016; Whyte et al., 2015).[24]

f. Results of a thermo-gravimetric analysis

During the thermo-gravimetric analysis, two weight drops were observed. The mass decreases occurred between 210°C and 380°C, and between 380°C and 730°C. [24]

Material transformation followed one by one (Figure 2.19).The first thermal decomposition may be linked of hemi-cellulose and cellulose breakdown. The temperature ranges of the thermal decomposition of these two compounds are as follows: hemi-cellulose 220-315°C, cellulose 315-370°C (Akdeg et al. 2016; Carrier et al., 2011; Lu et al., 2012). [24]

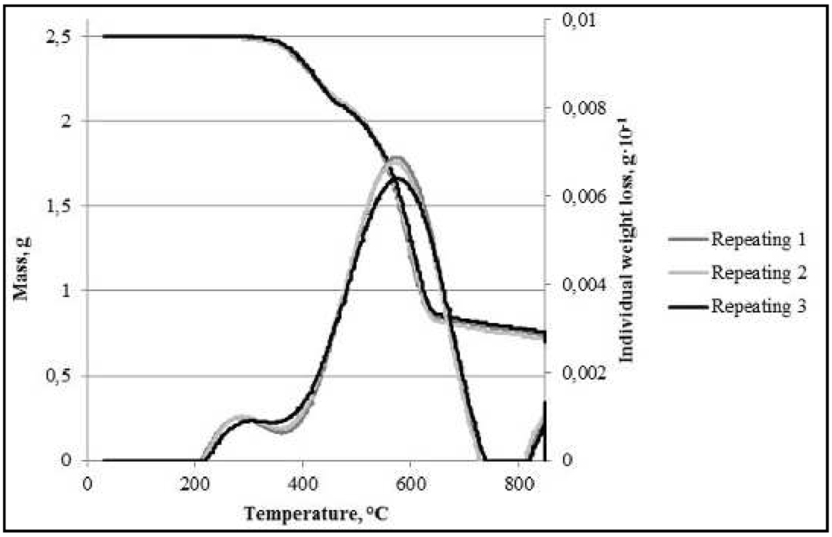


Figure.2.19: DTG and TGA characteristics of RDF [24]

The second peak may be linked to the decomposition of plastics. Degradation of these materials begins above 400°C (Robinson et al., 2016; Sanchez-Silva et al., 2012; Stępień et al., 2017). [24]

An equation (1) was used to calculate reaction constant rates and activation energies for temperatures within the range of 200-300°C (Table 06).The estimated activation energy was 3.71 $kJ \cdot mol^{-1}$. Literature review showed that activation energy for RDF depends on temperature ranges: between 240-380°C and between 250-370°C. The values obtained by Singh et al. (2012) and Grammelis et al. (2007) were much higher and were 97.8 and 121 $kJ \cdot mol^{-1}$, respectively.[24]

g. Results of the physical and chemical analysis of the CRDF

The average results of the physical and chemical analyses of carbonized refuse derived fuel are presented on 3D charts with spline interpolation (Figures 2.20-2.25).

Moisture content for untreated RDF was 17.31%. The residual water content in carbonates was the smallest at temperature 200°C and retention time 20 minutes. [24]

In that case, the moisture decreased to 0.13% (Figure 2.20). The moisture content increased to 1.27% along with the increase of the temperature and retention time of the torrefaction process. The studies conducted by Nobre et al., (2016), found that the torrefaction process had a positive effect on the moisture content reduction. They indicated that the content of water 6.02% in the raw material dropped to 2.23% during torrefaction at 300°C for 30 minutes. The contents of organic matter (Figure 2.21), combustible (Figure 2.22) and volatile components (Figure 2.23) were similar. This was correlated with characteristics of thermal de-composition of materials present in RDF, including plastic and lingo-cellulosic compounds. These materials undergo thermal degradation of up to 550°C. The higher content of combustible components in relation to the organic matter is associated with a high temperature distribution of volatiles (Lu et al., 2012, Robinson et al., 2016). The content of organic matter, combustible and volatile components in relation to unprocessed biomass were reduced by 6%, 7%, and 7%, respectively. These values are low compared to the results obtained by Nobre et al. (2016), where the decrease in the volatiles amounted to 22% at 300°C torrefaction with 30 minutes' residence time. Such a large difference may be due to the different morphological composition of the tested samples. The highest residual organic matter has been found for temperature range from 240 to 260°C, and residence time 40 minutes (Figure 2.23). The tendency of combustibles content decrease with the increase in torrefaction temperature, for all tested residence times, was observed (Figure 2.24). A similar relationship was found for volatiles content, with the highest value for a variant with temperature 200°C, and 60 minute of residence time (Figure 2.25). The ash content in CRDF is indirectly related to the increase in temperature and residence time that affects the sample gasification. It should be noted that ash content in carbonate increased to over 23% (Figure 2.25). The raw material was characterized by the ash content of 13%. The maximum ash content in torrefied materials was lower compared to RDF. The maximum value of the quoted parameter can be as high as 26%.The decrease in HHV is related to the ash content increase and the gasification of the volatile component. According to the principles of torrefaction, the substrate should have a low content of inert parts, because after the process, when partial degassing of the volatiles occurs, the mass ratio of the ash to the entire mass of the particle increases (Tumuluru et al., 2011). In the case of RDF torrefaction, the optimum value of the process was 260°C with 20 minutes of residence time. For this torrefaction parameters, the average value of HHV was 26.22 MJ·kg^{-1}.

Comparing this value with the average HHV of unprocessed material the obtained value was higher by 0.81 MJ·kg-1. The observed tendency of HHV decrease along with the increase in temperature and retention time was also reflected in the research carried out by Nobre et al. (2016), in which the HHV heat decreased from 17.68 to 15.70 MJ·kg^{-1}. Due to the low content of lingo-cellulosic compounds in the waste, they could have reacted completely at a temperature lower than 300°C. The main component of RDF were plastics, whose distribution starts at 400°C (Robin-son et al., 2016). The complete conversion of the lignocellulose parts caused a rise in the ash content, which had an impact on the ash presence in the sample. The final effect was that the higher ash content resulted in the decrease in HHV. Table 07 shows the comparison of raw material with the obtained CRDF's.[24]

Table.04: The average morphological composition (N=3)of the analysed RDF [24]

Waste group	Share of a waste group (%)
Plastics	30.3
Paper	11.3
Wood	10.5
Composite waste	8.3
Rubber	5.6
Textiles	2.2
Metal	0.1
Glass	0.1
Kitchen and garden waste	0.1
Other unidentified waste and mineral waste	31.6

Table.05: The average (±SD - standard deviation) values of physical and chemical properties of the analysed alternative fuel [24]

Sample	Alternative fuel
Moisture (%)	17.31 ± 4.48
Organic matter content (%)	85.80 ± 15.32
Volatile content (%)	85.13 ± 1.04
Combustible content (%)	86.75 ± 1.82
Ash (%)	13.25 ± 1.82
High calorific value (MJ·kg⁻¹)	25.41 ± 1.58

Table.06: Reaction constant rate and activation energy [24]

T, K	k, 1·s⁻¹	R^2	1·T⁻¹	ln(k), 1·s⁻¹	E, J·mol⁻¹	R^2
473	1.41E-05	0.89	2.11E-03	-1.12E+01	3.71E+03	0.55
493	1.44E-05	0.77	2.03E-03	-1.11E+01		
513	1.47E-05	0.78	1.95E-03	-1.11E+01		
533	1.37E-05	0.78	1.88E-03	-1.12E+01		
553	1.66E-05	0.80	1.81E-03	-1.10E+01		
573	1.66E-05	0.67	1.75E-03	-1.10E+01		

Table.07: The average (±SD - standard deviation) values of physical and chemical properties of the analysed alternative fuel and CRDF's [24]

Sample		Moisture (%)	Organic matter content (%)	Volatile content (%)	Combustible content (%)	Ash (%)	High calorific value (MJ·kg⁻¹)
Alternative fuel		17.31 ± 4.48	85.80 ± 15.32	85.13 ± 1.04	86.75 ± 1.82	13.25 ± 1.82	25.41 ± 1.58
200	20	0.08 ± 0.07	79.33 ± 0.30	79.29 ± 0.38	81.95 ± 0.30	18.04 ± 0.30	24.94 ± 0.31
	40	0.94 ±0.07	80.05 ± 0.89	77.50 ± 0.57	81.34 ± 1.00	18.65 ± 1.00	22.18 ± 0.49
	60	0.76 ± 0.10	80.83 ± 0.61	82.01 ± 0.85	82.65 ± 0.47	17.34 ± 0.47	25.15 ± 0.03
220	20	0.54 ± 0.05	79.93 ± 0.49	81.65 ± 1.10	81.70 ± 0.47	18.29 ± 0.7	26.53 ± 0.38
	40	1.63 ± 0.77	73.85 ± 0.47	80.60 ± 0.57	80.94 ± 3.08	24.25 ± 11.49	23.50 ± 0.19
	60	0.97 ± 0.03	78.42 ± 0.71	79.90 ± 0.31	79.69 ± 0.70	20.30 ± 0.70	24.64 ± 0.47
240	20	0.26 ± 0.02	77.41 ± 1.13	79.05 ± 0.76	78.85 ± 1.12	21.14 ± 1.12	23.10 ± 0.50
	40	0.80 ± 0.45	92.41 ± 0.85	80.84 ± 0.70	81.49 ± 0.39	19.01 ± 0.51	21.98 ± 0.32
	60	1.27 ± 0.08	76.10 ± 0.35	76.87 ± 0.67	77.82 ± 0.27	22.17 ± 0.27	25.34 ± 0.29
260	20	0.55 ± 0.05	80.45 ± 0.44	80.27 ± 0.44	81.79 ± 0.46	18.20 ± 0.46	26.22 ± 0.84
	40	1.77 ± 0.14	78.86 ± 0.60	80.11 ± 0.27	80.71 ± 0.60	19.28 ± 0.60	24.11 ± 0.31
	60	0.73 ± 0.02	76.55 ± 1.41	78.06 ± 0.88	78.49 ± 1.32	21.50 ± 1.32	22.65 ± 0.38
280	20	0.79 ± 0.01	78.31 ± 0.27	79.98 ± 1.07	80.11 ± 0.28	19.88 ± 0.28	23.74 ± 0.31
	40	0.73 ± 0.04	73.19 ± 0.11	75.13 ± 0.26	75.77 ± 0.14	24.22 ± 0.14	22.91 ± 0.44
	60	0.37 ± 0.06	70.62 ± 0.31	74.09 ± 0.70	73.30 ± 0.28	26.69 ± 0.28	22.26 ± 1.21
300	20	0.25 ± 0.023	74.40 ± 0.19	76.60 ± 0.23	76.38 ± 0.17	23.61 ± 0.17	22.91 ± 0.13
	40	1.23 ± 0.10	75.33 ± 1.06	76.73 ± 1.00	77.29 ± 0.94	22.70 ± 0.94	25.47 ± 0.82
	60	1.08 ± 0.07	76.27 ± 0.59	76.34 ± 1.04	78.52 ± 0.61	21.47 ± 0.61	24.12 ± 0.76

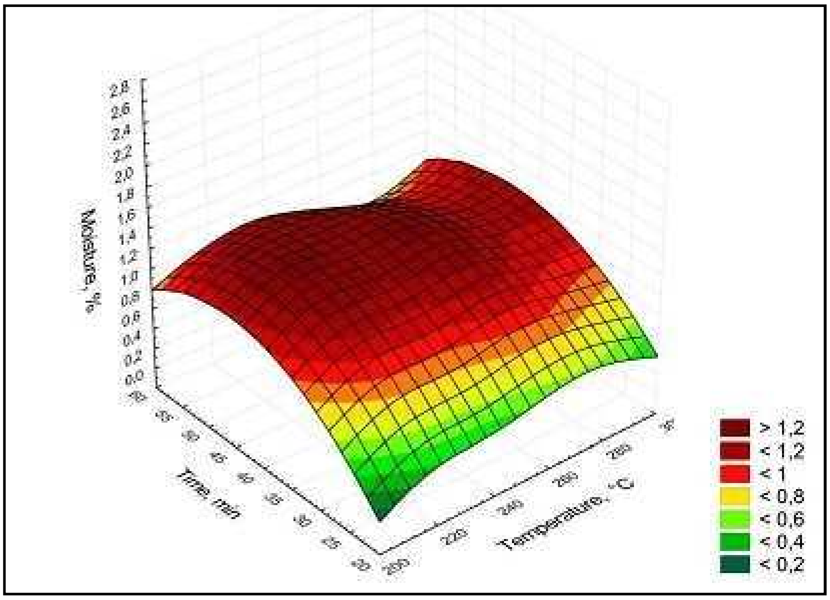


Figure.2.20: Effect of torrefaction temperature and retention time on the Moisture content in CRDF [24]

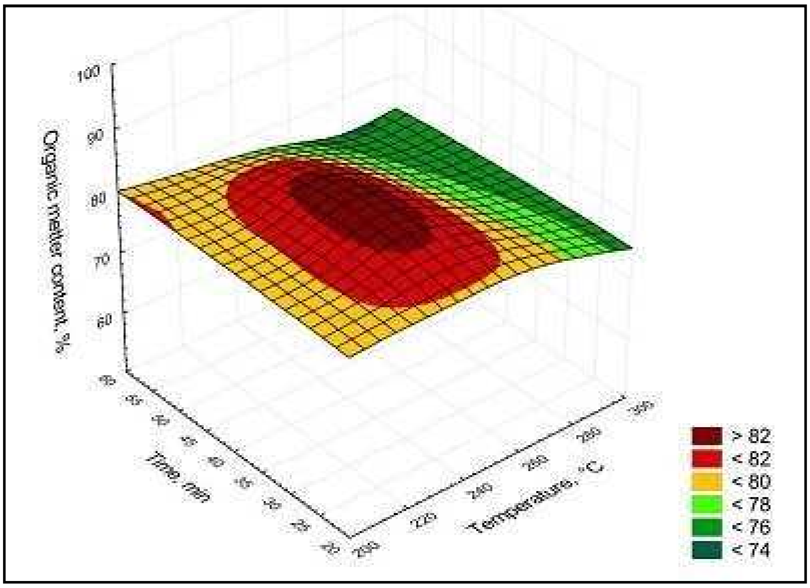


Figure.2.21: Effect of torrefaction temperature and retention time on the organic matter content in CRDF[24]

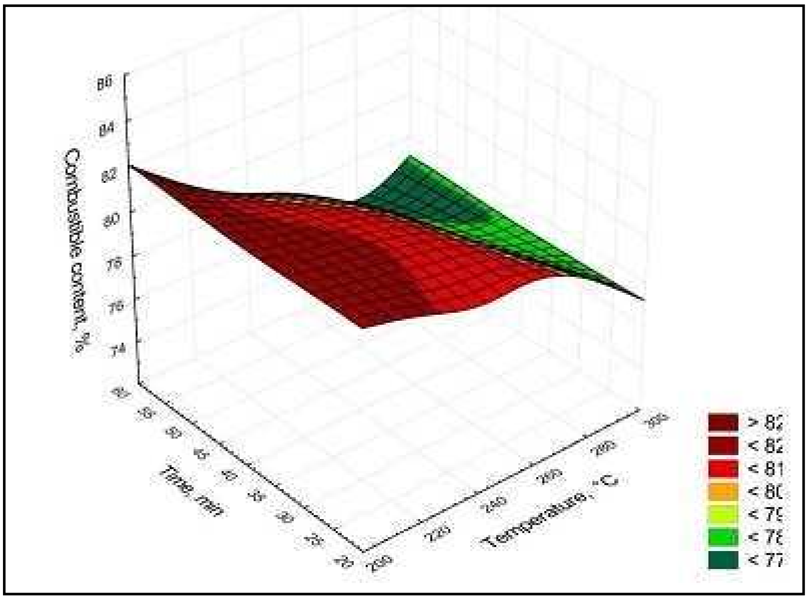


Figure.2.22: Effect of torrefaction temperature and retention time on the combustible content in CRDF[24]

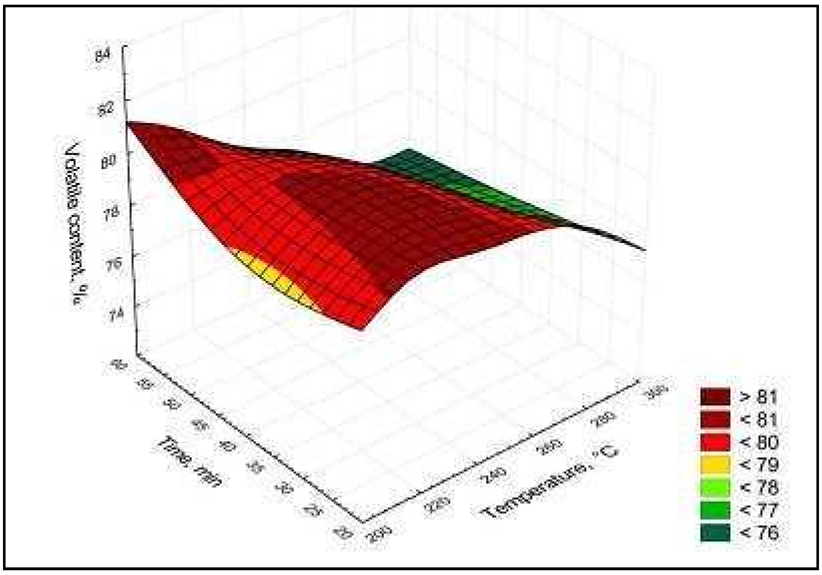


Figure.2.23: Effect of temperature and retention time on the volatile content in CRDF [24]

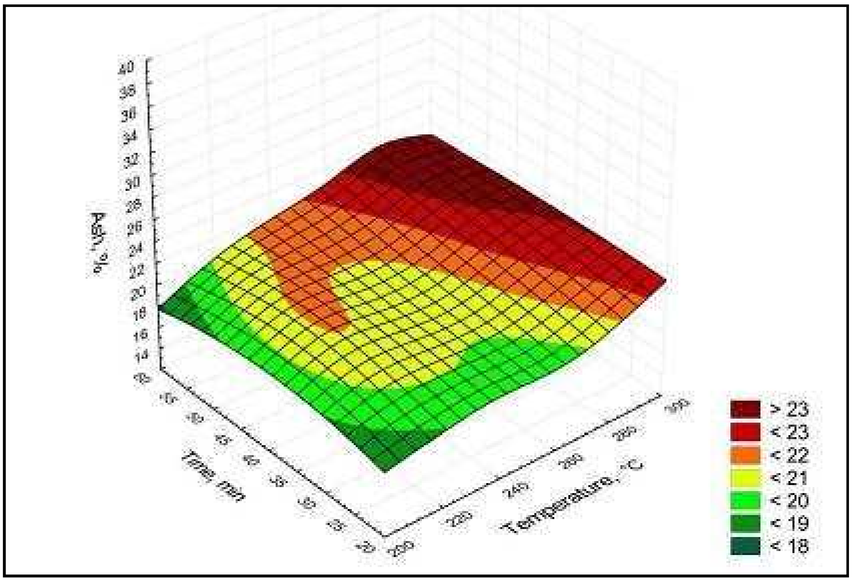


Figure.2.24: Effect of torrefaction temperature and retention time on the ash content of CRDF[24]

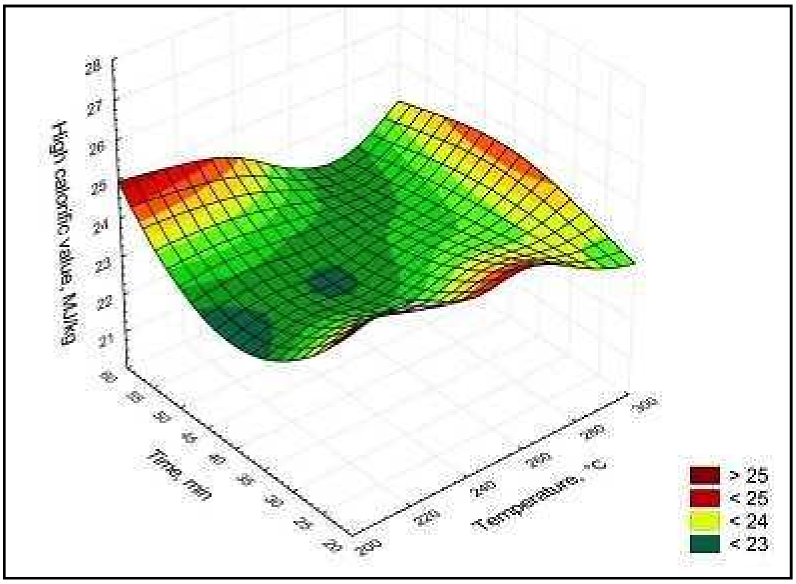


Figure.2.25: Effect of torrefaction temperature and retention time on the HHV of CRDF[24]

2.2.5 Bio Chemical Conversion of Waste

(a) Anaerobic Processing Technologies

Anaerobic digestion (AD) of source-separated organics (SSO) from the municipal solid waste (MSW) stream is relatively new, but has been used at a few sites in Europe for approximately 20 years. It is now being introduced into North America, while also becoming more widely adopted in Europe. Most digester technologies used for SSO were derived from earlier dairy manure and wastewater bio-solids digester technologies. Within the past few years, digesters specifically designed for SSO have been introduced. [17]

a. General Pre-treatment Requirements

Careful consideration must be given to pre-treating and mixing wastes for AD. SSO should be delivered to an enclosed, designated receiving area to keep vectors out and odours in. After receiving, loads should be inspected for unacceptable materials or materials that might damage processing equipment. Depending on collection program requirements and processing facility design, the inspection process may require mechanically removing materials from containers or bags.[17]

Once the feed stocks have been inspected and unacceptable materials removed, they may need to be physically or chemically altered (through grinding or shredding, or altering the pH) in order to provide optimal conditions for the digestion process, as particle size governs the surface area available for microbial action. The level and type of pre-processing and preparation required is dependent on the feedstock and also on the specific AD technology used. [17]

Feedstock pre-processing may involve removal of non-degradable waste that affects equipment or digesting quality. In some digestion systems, feed stocks are converted into a slurry form by adding water and agitating them. Light materials that float to the top of the slurry tank (e.g., film plastic) can then be skimmed or raked. Heavier materials (e.g., glass, rocks, and bottle caps) can be removed as grit from the bottom of the slurry tank.[17]

The preparation stage may involve a mixing step. In some digestion systems, feed stocks can be mixed with heated water or steam to increase the moisture content and the temperature of the waste to be processed. Mixing with warm water or steam also raises feedstock temperature, and increases the level of microbial activity and the extent of organic material degradation within the AD reactor. For dry digestion systems, feed stocks may be mixed with “bulking agents” or “structural” organic materials, such as ground-up leaf and yard waste (L&YW) or woodchips, to ensure water can percolate through the waste mass.[17]

Starter inoculums (e.g., recycled feedstock that has already gone through the digestion process or wastewater produced during digesting dewatering or percolation steps) might be added to initiate microbial activity at the mixing stage. The recycled material carries many microorganisms already adapted to the digester environment so they can inoculate the incoming waste, speeding up the start of digestion.[17]

b. Types of AD Technologies

There are two major categories of AD systems used for processing SSO: wet (low-solids) systems (Moisture content greater than 80%) and high-solids systems (moisture content less than 80%). There are subcategories within these categories based on specific moisture content ranges. Further subcategories involve staging sequential parts of the biological process in separate vessels, operating in different temperature ranges, and batch vs. continuous operation.[17]

i) High-Solids Versus Wet AD Systems

AD system general categories are based on the solids content (or conversely, the moisture content) of the materials being digested, since this is the most important factor governing equipment design. There is some inconsistency in the industry regarding the exact meaning of “dry” vs. “wet” and “low solids” vs. “high solids,” mainly because digester technology is evolving with time. In this document, and in keeping with the most recent usage in applying AD technologies to MSW organics, we use “high solids” and “wet” as the primary categories:

High Solids: Systems with typically less than 80%moisture content (greater than 20% solids). Using front-end loaders, feed stocks are typically stacked into the digester as solid materials, or pumped in as high-solids slurry.Wet: Systems with greater than 80% moisture content (less than 20% solids). Feed stocks are dissolved or suspended in a liquid form and are handled as a liquid.[17]

Table 08 presents a comparison of high-solids (slurry and stackable) vs. wet (low-solids) digestion systems, and provides a summary of differences in the basic types of digester based on moisture content.[17]

Table.08: Digester type by moisture content summary [17]

Digester type	Digester water content	Feedstock consistency	Net energy output[a]	Digestate treatment	Leachate production
High-solids stackable	Less than 60%	Stackable materials	Highest	Dewatering not required	Lowest
High-solids slurry	Between 60 and 80%	Wet but not liquid	Intermediate	Dewatering may be required	Intermediate
Wet (low solids)	Greater than 80%	Liquid	Lowest	Dewatering is required	Highest

Notes:
[a] Defined as energy generated less energy consumed per tonne of input feedstocks

ii) One Stage Versus Two Stage

Another means of classifying technologies is based on whether the digestion process occurs in a single vessel or two sequential stages. In two-stage AD systems, the first stage is generally operated at pH 5 to 6, which is near optimal for organisms that break down large organic molecules, but not for methane-forming bacteria that produce biogas. In the second stage, the pH is raised into the 6.5 to 7.2 range to optimize the system for methane formers. A single-stage system allows both stages to occur in one vessel, but is not optimal for either. [17]

iii) Thermophilic Versus Mesophilic

Both high-solids and wet (low-solids) systems can be configured as single- or multiple-stage digesters, and can be designed to operate in either thermophilic or mesophilic temperature ranges. Thermophilic digesters typically operate at temperatures of 50 to 60 degrees Celsius (°C). Mesophilic digesters typically operate at temperatures in the 30 to 38°C range. The main difference between these two ranges is the speed at which reactions occur. Digestion reactions occur faster in the high-energy thermophilic range, so provide higher throughput and a higher rate of biogas production than mesophilic, but at the cost of requiring external heat to maintain the higher temperature. [17]

Thermophilic and mesophilic processes can be established for both single- and multiple-stage digesters. [17]

iv) Technology Overview

Table 09 summarizes technology types; additional details are presented in the following subsections.

Table.09: AD technology summary [17]

Considerations	Digestion system type		
	High-solids stackable	High-solids slurry	Wet (low solids)
Waste pretreatment/ preparation	• Requires limited pretreatment: - Debagging, screening, and mixing - No aggressive size reduction - Needs bulking material (e.g., shredded or ground-up L&YW) to provide porosity - Particle size should be less than 20 cm	• Requires some pretreatment: - Debagging, aggressive size reduction (e.g., shredder) - No need for bulking material - Maximum particle size must be less than 5 cm to be pumpable	• Requires high level of pretreatment: - Debagging, aggressive size reduction (e.g., shredder) - Remove floatables and settleables - No need for bulking material - Particle size typically must be less than 5 cm to be pumpable
Moisture addition	• Most SSO wastes require no water addition • Requires moisture content to be less than 60% • Typically requires 0.05 m^3 water per t of waste	• Most SSO wastes require water addition • Requires moisture content to be 60% or greater • Typically requires 0.10 m^3 water per t of waste	• All SSO wastes require water addition • Requires moisture content 80% or greater • Typically requires 0.5 m^3 water per t of waste
Digester design	• Typical design ranges: - Configuration: concrete tunnels with tight doors - Operating capacity: 10 000 to 100 000 t SSO/year - Retention time: 14–30 days • Mode of operation: batch	• Typical design ranges: - Configuration: plug-flow or continuously stirred tank - Operating capacity: 3 000 to 250 000 t SSO/ year • Retention time: 14–30 days • Mode of operation: continuous or batch	• Typical design ranges: - Configuration: continuously stirred tank - Operating capacity: 3 000 to 250 000 t SSO/ year • Retention time: 14–40 days • Mode of operation: continuous

Table.09: AD technology summary [17] (cont'd)

Considerations	Digestion system type		
	High-solids stackable	High-solids slurry	Wet (low solids)
Digestate handling and characteristics (quantity and quality)	· Digestate (solid material) removed by front-end loaders · Typical moisture content of digestate between 50 and 60% by weight · Does not require dewatering before composting · Typically needs to be composted: – Can be added to other compost feedstocks, such as L&YW – Can be composted separately – Compost times typically reduced due to partial decomposition during digestion · Quantity: 0.85 t per t SSO processed	· Digestate pumped out of the digester · Typical moisture content of digestate prior to dewatering between 70 and 90% · Typically requires dewatering to a moisture content around 50% using filter/screw presses or other techniques commonly used in WWTPs for biosolids dewatering · Typically needs to be composted: – Can be composted to a humus-like condition – Compost times typically reduced due to partial decomposition during digestion – Can be dried and used as fertilizer if it contains adequate nutrients and does not contain substances harmful to plants carried over from feedstocks and not destroyed in the digestion process (see Chapter 16) · Quantity: 0.85 t dewatered digestate per t of SSO processed	
Effluent characteristics (quantity and quality)	Effluent consists of excess percolate water *Quantity: up to 0.1 m³ per t of SSO* · Almost all percolate from the digester is recirculated · With some wetter feedstocks, excess percolate may need to be disposed to a treatment facility	Effluent comes from dewatering of the digestate *Quantity: 0.1 to 0.3 m³ per t of SSO* · As much as 30% of the water fed into the digester may be discharged as effluent	Effluent comes from dewatering of the digestate *Quantity: 0.4 to 0.7 m³ per t of SSO* · As much as 45% of the water fed into the digester may be discharged as effluent
	Quality: · BOD_5: 2000 to 5000 mg/L · SS: 50 to 5000 mg/L · Ammonia as N: 1000 to 3000 mg/L	*Quality:* · BOD_5: 1 500 to 15 000 mg/L · SS: 50 to 5000 mg/L · Ammonia as N: 1000 to 3000 mg/L	*Quality:* · BOD_5: 1 500 to 15 000 mg/L · SS: 50 to 5000 mg/L · Ammonia as N: 1000 to 3000 mg/L
Unacceptable materials	· Contaminants, such as glass, metals, and plastics, present in feedstocks and removed before, during, or after digestion · Typically landfilled		
Net energy production (electrical)	· 170 to 250 kWh/t SSO	· 145 to 220 kWh/t SSO	· 110 to 160 kWh/t SSO

Notes:
** Net energy production is the electrical output minus the electrical and thermal energy consumed by the digester.*

BOD_5—5-day biochemical oxygen demand
cm—centimetre
kWh/t—kilowatt-hour per tonne
L—litre
N—nitrogen
m³—cubic metre
mg/L—milligrams per litre
SS—suspended solids
t—tonne
WWTP—wastewater treatment plant

c. High-Solids-Stackable Digestion Systems

High-solids-stackable AD systems that do not submerge the waste in a tank but rather recirculation percolating effluent water through the wastes are a relatively recent development in AD technology. In these systems, “stackable” materials with moisture content less than 60% are placed in tunnels using front-end loaders. After loading, a gas-tight door on the tunnel is closed, and water draining from the material is re-circulated to spray nozzles above the waste to carry microorganisms and nutrients through the waste mass. The material digests in the tunnel for typically 14 to 30 days, depending on the specifics of the process, and then the solid residual digesting is removed and processed.[17]

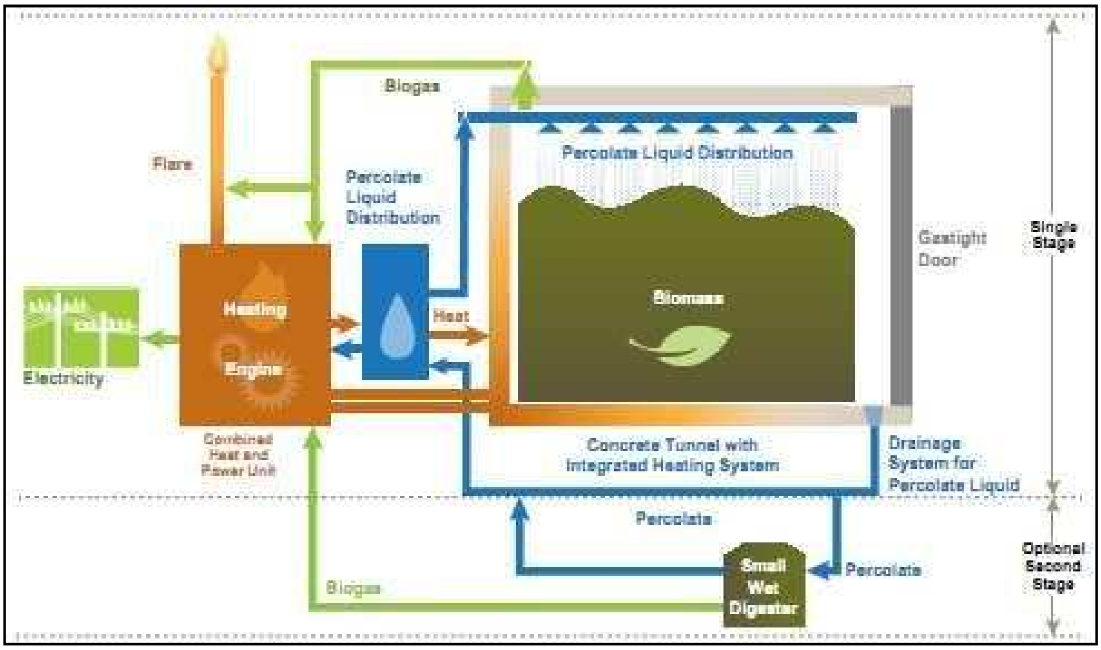


Figure.2.26: One-stage high-solids-stackable AD system flow diagram (with optional second stage)[17]

This AD process may be implemented as either a thermophilic or mesophilic process, and it may be implemented as a single- or two-stage process. As shown in Figure 2.26, percolate in a single-stage system is re-circulated directly back to the digesting wastes rather than through a second-stage digester. Biogas is collected directly from the tunnel that holds the feed stocks. The biogas in this system is being used as fuel in a combined heat and power unit, which generates electricity by burning the gas in an engine-generator set. Heat from the engine's cooling water jacket is used to heat the digester rather than being radiated to the air.[17]

This type of digester may be designed as either a one- or two-stage system. In a two-stage, high-solids-stackable AD process, the first stage occurs in the tunnel, which is operated to maintain the pH in a range of 5 to 6, below the methanogenic range. Hydrolytic organisms degrade the larger organic molecules to soluble sugars and fatty acids, which are then pumped with the percolate to a second-stage, small, wet digester before being re-circulated back to the tunnel. In two-stage systems, biogas is collected primarily from the second-stage digester.[17]

High-solids AD systems incorporating concrete tunnels can handle SSO waste flows of roughly 10 000 tonnes per year (TPY) and higher. A typical facility includes the concrete tunnels as well as liquid storage tanks, receiving and processing facilities, access roads, staff and administrative areas, and possibly a digesting composting area. [17]

Modular high-solids AD systems for stackable wastes, including tunnels built from materials other than concrete, are less expensive and may be cost-effective at capacities as low as 10 000 TPY of waste input and even lower, based on project specifics.[17]

The high-solids-stackable AD process is particularly appropriate for SSO commercial and residential food wastes. If materials arrive in bags, they must be debagged, and several techniques have been developed for debagging. Debagging knives can be placed in a rotating trammel screen, which also separates out materials too large for digestion. Organic waste maximum sizes should be in the 13- to 20-cm range. [17]

Aggressive size reduction should be avoided, as it can create liquid slurry. Screening and mixing are the primary feedstock pre-processing techniques appropriate for high-solids AD systems. Food wastes must be mixed with "structural" materials, such as shredded or ground L&YW, so that the mixture has enough permeability for uniform percolation. Fat, oil, and grease can be added in small quantities to increase biogas production. [17]

Table 10 provides an overview of high-solids-stackable AD systems.

Table.10: High-solids-stackable AD system advantages and disadvantages [17]

Advantages	Disadvantages
• Can process waste with contaminant material (plastic, metals, rocks) • Handles solid stackable wastes with little pretreatment • Produces negligible effluents • More energy efficient than other AD systems • May require no water addition	• Requires mixing with shredded L&YW or other bulking materials • Must operate as a batch system, requiring purging and opening the digester between batches • Odour potential when door is opened

d. High-Solids-Slurry Digestion Systems

This type of digester is appropriate for a wider variety of materials than high-solids-stackable digestion. It can handle large volumes of wet materials, many types of food processing wastes, as well as residential and commercial food wastes. Some designs incorporate methods within the digester tank for removing large pieces of plastic and metals that sink or float. The feedstock quality may necessitate complex pre-treatment and conveyance equipment, including size reduction, mixing, and slurry pumping for feedstock handling. The feedstock receiving and separation/sorting areas need to be enclosed in a building equipped with air quality/odour control systems. The level of separation and cleaning of the feed stocks depend on the downstream product handling processes and requirements, but must be reduced to a pumpable slurry through size reduction and water addition (60% or greater moisture content).[17]

After debagging, the material is typically put through size-reduction machinery. Size reduction to 5 cm or less is generally considered necessary for this type of digester for pumping. Many package systems include recommended, specific size-reduction equipment for the particular digester.[17]

High-solids-slurry digesters are typically operated at a moisture content of 60 to 80% by weight. Although solids feed and conveyance equipment is generally more expensive than that used in wet (low-solids) systems, high-solids-slurry systems are more robust and flexible regarding acceptance of non-biodegradable material in the digester, such as rocks, glass, metals, and plastics.[17]

This type of digester may be either batch or continuous feed. Batch digesters are designed to be fairly simple, but because batch digesters have no continuous feed, the gas generation peaks at a certain point and decreases as the digestion progresses. Single-stage batch processes are typically used in very small applications (less than 5000 TPY) where energy recovery is not the major focus. Continuous-feed digesters are typically a better fit for larger AD systems that aim for energy recovery.[17]

Due to high solids content, material in high-solids-slurry reactors moves via plug-flow without using mechanical mixers. Biogas injection is sometimes used to assist mixing the reactor contents. However, complete mixing cannot be achieved with biogas injection, which reduces the ideal contact between microorganisms and substrate, thereby reducing overall system performance. Continuous-flow, high-solids-slurry systems are normally designed with an inoculums loop that recycles a fraction of the digesting from the end of the plug-flow digester vessel to the head end in order to distribute microorganisms rapidly into the incoming raw waste.[17]

Most high-solids-slurry digesters are designed to operate in the thermophilic range. See Figure 2.27 for a schematic of a typical high-solids-slurry digester.[17]

Within this category, vertical-silo-type slurry digester package systems use the available footprint efficiently, but may be limited by local height ordinances. The receiving and feed separation/sorting areas need to be enclosed in a building equipped with air quality/odour control. The system is continuously fed with continuous biogas generation and recovery. The biogas generated is piped to storage; from there, the biogas is delivered to the biogas handling system.[17]

Horizontal-reactor-type slurry digestion systems are also continuously fed. Typically; the horizontal digester is a cylinder with internal paddles or rotors that move the digesting material through the system. The biogas generated is piped to storage before being delivered to the biogas utilization system. Note that these processes typically contain a loop for recirculation of some digested material.[17]

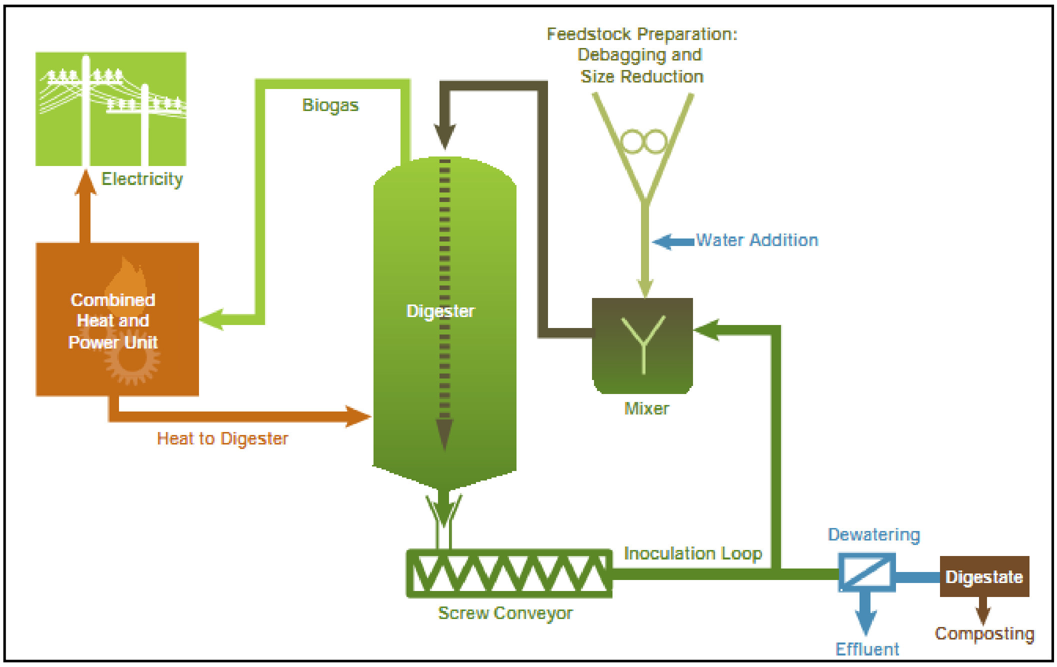


Figure.2.27: Vertical silo, one-stage, high-solids-slurry AD process flow[17]

Processing capacities for high-solids-slurry digesters that are operational range from 3 000 to greater than 250 000 TPY. The typical footprint for a large SSO facility includes receiving and pre-processing facilities, digester vessels, a dewatering facility, access roadways, and staff/administrative facilities, and may include a compost area for further processing digesting. Vertical silo digesters can be used to reduce the footprint of the facility (compared to horizontal digesters). [17]

Typical retention times are 14 to 30 days in the digester. Additional time for processing and composting digesting varies significantly, depending on the particular system used, the feed stocks, and end products. Very few high-solids-slurry systems are configured as two-stage systems.[17]

Table 11 provides an overview of high-solids-slurry AD systems.

Table.11: High-solids-slurry AD system advantages and disadvantages [17]

Advantages	Disadvantages
• Can process waste with contaminants (e.g., plastic, metals, and rocks) • Handles wastes that are in a liquid or slurry condition upon arrival • Produces less effluent than wet (low-solids) digestion • More energy-efficient than wet (low-solids) systems • Entirely contained system (high level of odour control)	• Slurry typically is not completely mixed, so can cause uneven digestion if not carefully managed • Produces more effluent than high-solids-stackable digestion • Less energy-efficient than high-solids-stackable digestion • May require water addition to make the feedstocks pumpable

e. Wet (Low-Solids) Digestion Systems

In wet (low-solids) systems, organic solid waste is diluted to 80% or more moisture content to allow continuous stirred operation and complete mixing. The designs of these systems are similar to WWTP bio-solids digesters and were some of the first designs used in treating MSW organics. Wet (low-solids) systems rely on pre-treatment more than their high-solids counterparts, and require various steps, depending on the feedstock. Wet (low-solids) systems can also be operated under mesophilic or thermophilic temperatures and be arranged as single-, dual-, or multistage digesters.[17]

Processing capacities for wet (low-solids) digesters that are operational range from 3 000 to greater than 250 000 TPY. A typical wet AD facility is similar to a high-solids-slurry facility in that it contains receiving and pre-processing facilities, digester vessels, a dewatering facility, access roadways, and staff/administrative facilities, and may include a compost area for further processing digesting.[17]

The footprint for a large facility, in the range of 150 000 to 200 000 TPY, is approximately 4 ha, including all process facilities, access roadways, and administrative facilities. [17]

Wet (low-solids) AD systems are most appropriate for very low-solids feed stocks, such as dairy manure and certain food processing wastes (e.g., juices, cheese whey, and spoiled milk). These wastes can be mixed with low- or high-solids materials as long as the moisture content does not drop below that required for good operation, typically in the 80 to 85% range. [17]

Feed stocks for continuously stirred systems must typically be processed to remove large, fibrous materials that can wrap around or otherwise interfere with the mixing and stirring mechanisms. [17]

Typical retention times are 14 to 40 days. Table 12 presents an overview of wet (low-solids) AD systems. [17]

Table.12: Wet (low-solids) AD system advantages and disadvantages [17]

Advantages	Disadvantages
• Handles wastes that are in a liquid or slurry condition upon arrival • Entirely contained system (high level of odour control)	• Cannot generally handle waste with contaminant material (e.g., plastic, metals, and rocks) • Requires significant pretreatment and operational care to avoid exceeding capacity or upsetting biosolids digestion • Produces more effluent than the other two digester types • Requires more energy consumption than high-solids digesters

The most common configuration of wet (low-solids) digesters used for processing food waste is the complete mix continually stirred tank reactor (CSTR) configuration shown in Figure 2.28.[17]

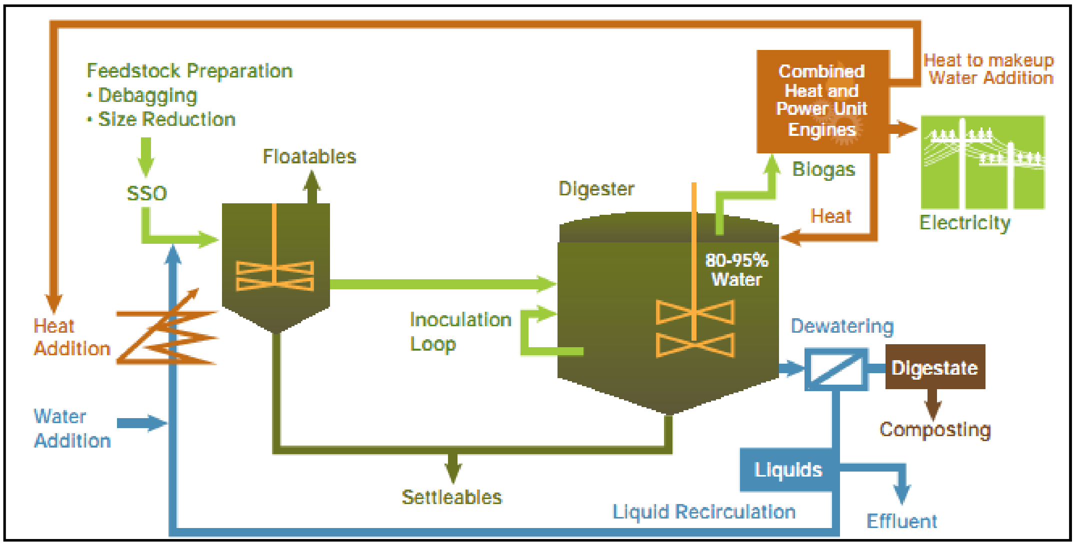


Figure.2.28: Typical complete mix CSTR wet (low-solids) AD process flow [17]

f. Co-digestion in Wastewater Treatment Plant Bio-solids Digesters

Co-digestion of food waste in WWTP sludge digesters may be an attractive option where capacity exists in these plants. Major modifications to the WWTP are generally not necessary, except to add receiving, pre-treatment, and feed equipment for the food wastes. [17]

Excess capacity in bio-solids digestion facilities is a prerequisite for co-digestion at WWTPs. Feed total solids (TS), carbon to nitrogen ratio, and operating conditions should be clearly determined to estimate how much feedstock can be added to the digester and to avoid process upsets. Without excess capacity, there may be a lack of sufficient drivers for co-digestion. [17]

Co-digestion at WWTPs requires training the WWTP operators to handle the SSO pre-treatment equipment. The objectives of pre-treatment are to:

- Separate unwanted impurities and inorganic material (e.g., grit, sand, and glass) not contributing to biogas production
- Provide more uniform and homogenous feedstock to the digesters

- Adjust feed TS content
- Protect downstream processes against damage
- Materials delivered must be sorted to remove large and harmful objects, shredded or ground to reduce their size, and then conveyed to the existing digester. Figure 2.29 shows a typical pre-treatment scheme. [17]

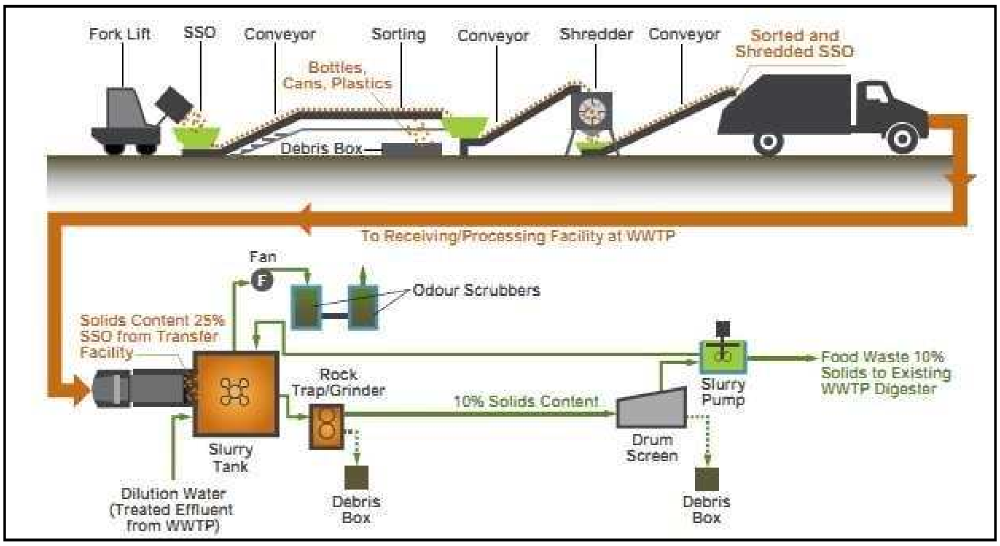


Figure.2.29: Pre-treatment scheme for food waste sent to WWTP digesters[17]

g. Biogas Technology in Sri Lanka

Biogas technology was introduced to Sri Lanka in 1970's. Biogas was produced by the breakdown of organic waste by bacteria without oxygen (anaerobic digestion or fermentation). Types of organic waste that could be turned in biogas are listed below [4].

- Leftover food from houses, shops, restaurants and factories
- Leftover straw and crops from farming
- Leftover meat and blood from slaughter houses
- Cow, sheep and chicken manure
- Sewage

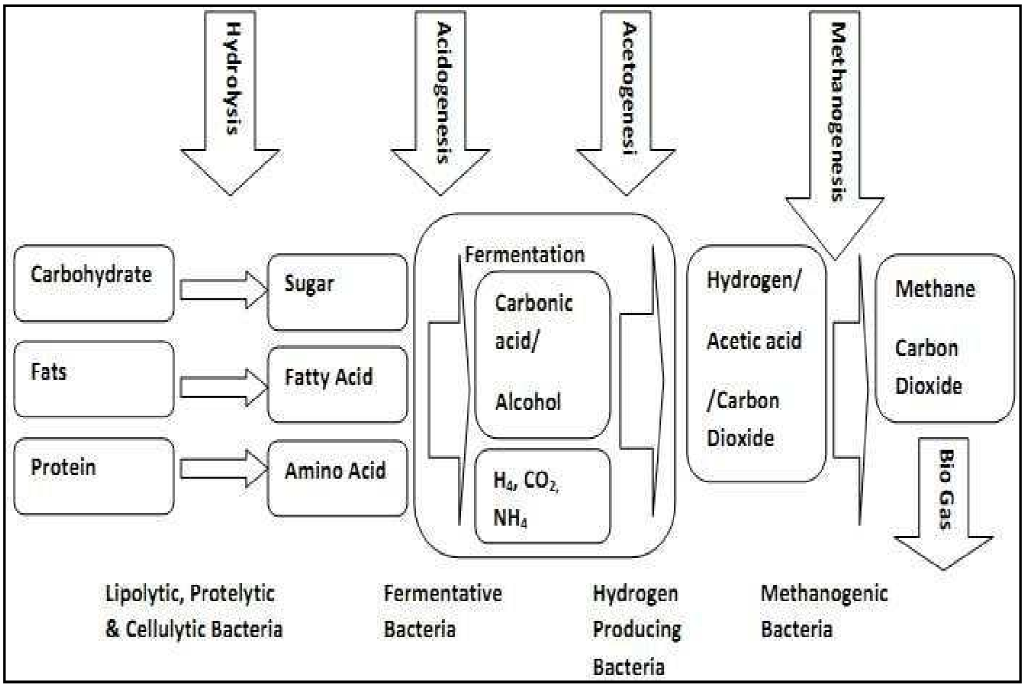


Figure.2.30: Anaerobic Digestion Process [4]

Biogas produced per tones of MSW (5000kcal/Nm^3) is 50-150m^3.Remaining 40-60% of feedstock was as soil conditioner (by weight basis) [4].

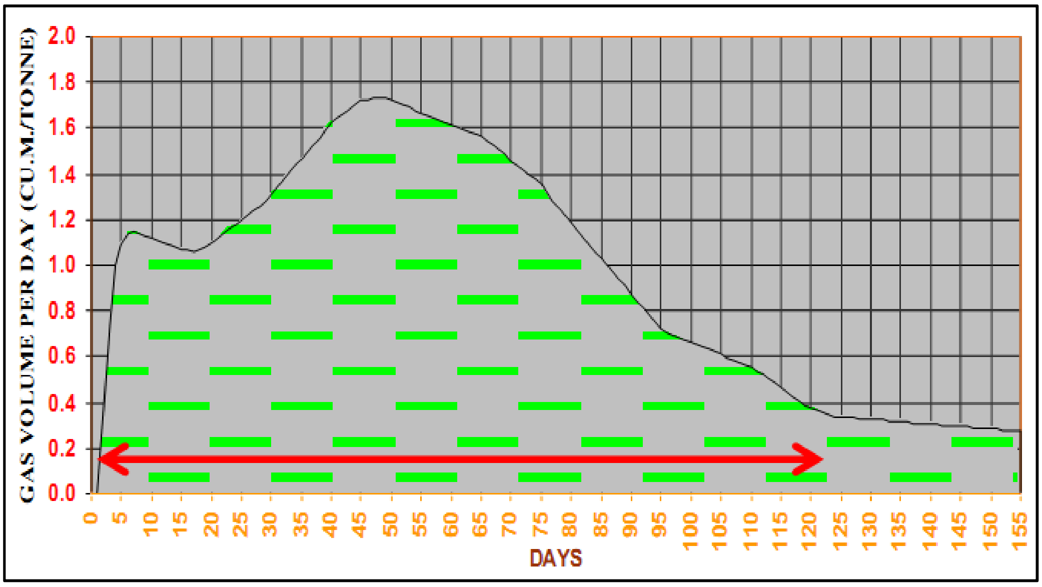


Figure.2.31: Biogas Production Rate from Market Garbage [4]

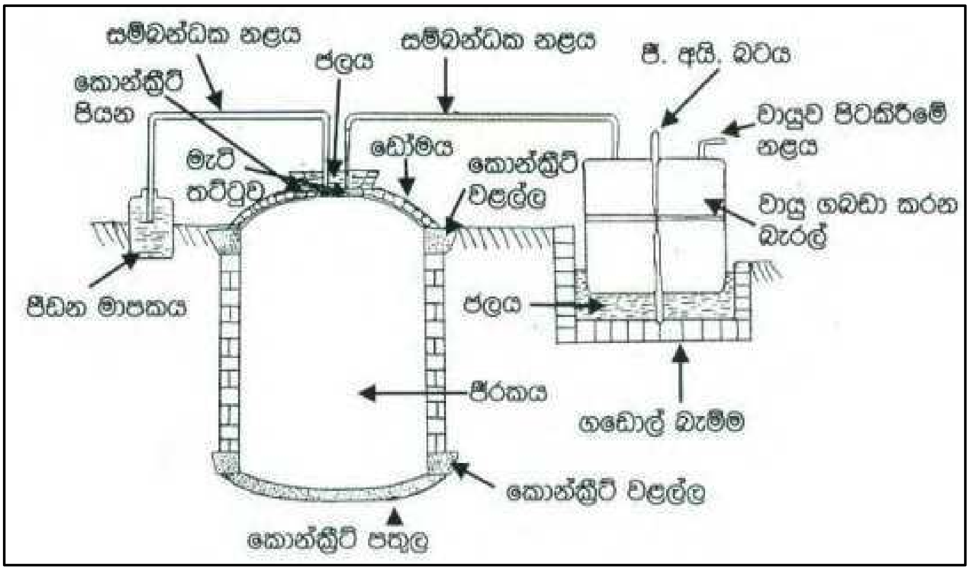


Figure.2.32: Sri Lankan Batch type [4]

(i) Bio-gas requirement &calculation size of the reactor

For Example: Requirement was 13kg of propane-equivalent per month. Biogas was 50-70% methane, 30-50% CO_2 and 5-15% N_2, H_2, etc. 13kg propane * 2.5 are 32.5 kg of methane. 32.5kg of methane / 60% is 54.1 kg of biogas/month. Per day requirement was 1.8 kg. Requirement of biogas per day was 2.1 m^3.Required size of the reactor was 10 m^3.How Much Energy was in Biogas? (FV methane =37258.9 kJ/m^3, FV propane = 93147.3 kJ/m^3, FV propane / FV methane = 2.5 and density of Bio gas 1.2 kg/Nm^3) [4]

Table.13: Capacity and Gas Generation Relationship [4]

No	Capacity(m^3)	Amount(kg)	Gas Generation(m^3/day)
01	06	15	1.5
02	08	25	2
03	10	50	2.5
04	12	80-100	3
05	15	150	3.75
06	22	500	5.5
07	35	650	8.75
08	44	750	11
09	65	1000	16.25

(b) Composting

a. General Feedstock Preparation Steps

Depending upon feedstock characteristics, size of the facility, and the composting technology employed, preparation steps may include particle size reduction, mixing and blending with other feed stocks and/or amendments, ferrous metal removal, and water or leachate addition. [17]

i. Particle Size Reduction

The size of individual feedstock and amendment particles affects the rate of decomposition. Smaller particles have a greater surface area relative to their volume, and more surface area means more of the material is exposed to microbial degradation, allowing the decomposition process to proceed more quickly. [17]

Figure.2.33: Shear shredders are commonly used to reduce particle size and further mix SSO feed stocks prior to composting [17]

ii. Mixing and Blending

The purpose of mixing equipment is to blend feed stocks, amendments and bulking agents, water, and other materials together into as homogeneous a mixture as possible. Providing a homogeneous mixture is an important step for providing optimal composting conditions and reducing the need for troubleshooting process-related problems. [17]

Figure.2.34: Vertical mixer used at a composting facility [17]

iii. Ferrous Metal Removal

Nails, bottle caps, and wire are examples of ferrous metal contaminants that can find their way into composting feed stocks. These materials may clog or damage processing and application equipment, or their sharp edges can result in injury to people using the finished compost. Magnet systems installed on the conveyor belts of screening, mixing, or grinding equipment are often used to remove ferrous metals during the preparation step. [17]

Figure.2.35: Water is best added to windrows when they are being turned [17]

iv. Water or Leachate Addition

If the moisture content of the materials being composted is less than 55%, the decomposition process is impaired. The moisture content of some feed stocks in the municipal solid waste (MSW) stream, such as leaves and dry grass, is normally too low (i.e., less than 55%) to sustain efficient active composting, so supplemental moisture must be added. Moisture can also be lost to heat generated during the active composting process, so it is also necessary to increase moisture during the preparation step to offset these losses, even with wetter feed stocks, such as food wastes. [17]

Figure.2.36: Water can be added to windrows and stockpiles using sprinklers [17]

The ability to add moisture during active composting has been engineered into many composting systems. Moisture can also be added during the preparation step. Stationary systems can be set up to allow water or leachate to be sprayed on materials coming out of grinding and shredding equipment discharge conveyors. Water or leachate can also be pumped directly into operating mixing equipment. [17]

Irrigate pile surfaces with caution, as watering may seal the available free air space (FAS) in the pile's wet layer, and water can quickly migrate to the bottom layer along small channels. When water migrates, the base of the pile can be over-wetted and can generate leachate, but can also leave dry sections throughout the pile. It is good practice to turn windrows as soon as possible after significant rain events or pile surface watering. [17]

v. Feedstock Preparation Considerations

Rather than a single preparation system that handles all of the materials delivered, consideration should be given to using two smaller systems in parallel. Although this approach is costlier, it provides internal redundancy within the facility in the event of scheduled maintenance or an equipment breakdown. Splitting processing systems into smaller, parallel lines also allows for operation of a single processing line when feedstock deliveries are lower than peak values, or for one line to be run on an evening or weekend shift to reprocess materials, if needed.[17]

b. Passively Aerated and Turned Composting Systems

i. Static Pile Composting

This method of composting is the simplest and least expensive option available. It is generally only appropriate for feed stocks with high C/N ratios (e.g., greater than 40:1), such as leaves and branches, and when there is an abundance of space and time available. [17]

The static pile method involves forming the organic feed stocks into large, outdoor windrows or piles, which are allowed to decompose for two to three years with little or no mixing or turning. Static piles are normally built using front-end loaders, skid-steers, farm tractors, or excavators. [17]

Once built, windrows or piles are passively aerated by convection and diffusion, so it is critically important that materials initially be mixed with amendment to provide sufficient FAS, allowing air flow within the pile. [17]

Although larger static piles are used at some facilities, they should ideally be limited to a height of 5 metres (m), as shown in Figure 2.33. There is a higher potential that anaerobic conditions and spontaneous combustion can occur in larger piles. The weight of materials in higher piles can also compress materials in the pile's base, which leads to further problems related to air flow and odours. [17]

Occasional remixing and reformation of the static pile is helpful in re-establishing porosity lost over time as the materials degrade. Without periodic mixing, areas within the pile will not attain the required temperatures for composting; thus, a proportion of the material will not be adequately composted, and the outer layer may not undergo composting at all. [17]

During pile remixing and rebuilding, the pile's dry areas should be remoistened to help speed up the composting process and reduce the likelihood of spontaneous combustion. [17]

When piles are too large or there is insufficient passive aeration, anaerobic conditions can develop within static piles, and odours can be generated that may affect the surrounding community. Odours are often released when piles are mixed or moved. The higher potential for odours increases the need for buffer zones between the static pile compost site and adjacent properties; which, in turn, increases land requirements. [17]

Static pile composting takes much longer to complete than other methods due to the lack of agitation and the resulting lower aeration rate. It is generally used at smaller facilities that process less than 1000 TPY. It is feasible to process larger quantities (e.g., up to 10 000 TPY), but the land requirements for such an operation are often a limiting factor because the longer composting time means that more space is required relative to other methods that compost materials more quickly.[17]

Leachate from static pile facilities is a mixture of higher-strength leachate from the piles themselves, and runoff from the working pad. Due to the larger working area footprint, the overall quantities of leachate from a static pile composting facility are higher than from a similarly sized facility using a different composting method. However, static piles have a lower surface area to volume ratio, which means that less rain and snow melt will infiltrate into the pile. [17]

Since static piles are built and moved using mobile equipment, there are no electrical or other utility requirements. [17]

Figure.2.37: Typical static pile method used to process L&YW [17]

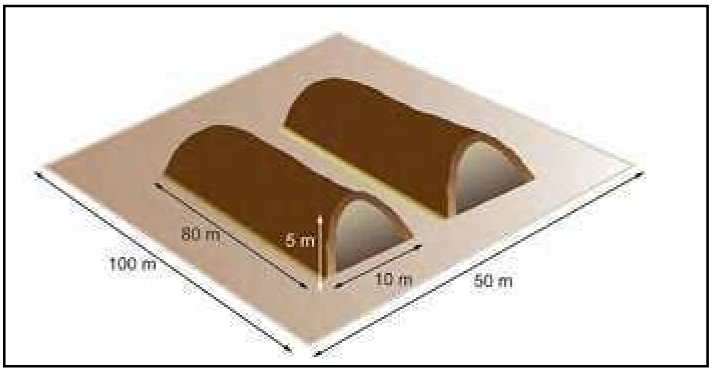


Figure.2.38: Typical footprint of a small scale (i.e., less than 1000-tpy) static pile composting facility[17]

ii. Bunker

Static piles built in small bunkers is a simple composting method well-suited to smaller feedstock quantities (i.e., less than 500 TPY). The bunkers can be constructed from cast-in-place concrete, concrete lock-blocks, modular concrete barriers (e.g., Jersey barriers), and even wood. Depending upon the installation location and climate, bunkers can be located outdoors, covered by a simple roof structure, or contained within a building. [17]

A typical installation consists of three separate bunkers. The first bunker is used for receiving fresh materials on a daily basis. When this bunker is filled (typically after one to two weeks), the third bunker is emptied and refilled with material from the second bunker. The material from the first bunker is then moved into the second bunker to make room for fresh materials. Active composting occurs in the second and third bunkers. The process of moving materials from bunker to bunker helps with mixing and re-establishing porosity lost as the materials degrade. [17]

Depending upon the size of the composting operation, materials can be moved from bunker to bunker using a skid-steer or small front-end loader. [17]

Due to their simplicity, bunker systems can be custom designed to match a specific application and rate of feedstock generation. Individual bunkers can range in size from 2 to 3 cubic metres (m^3), to as large as 20 m^3. Larger bunkers can also be equipped with aeration systems, as outlined later in this chapter, to provide better process and odour control. [17]

Figure.2.39: Small bunker composting system [17]

iii. Windrow

This method involves the feed stocks being formed into long, low piles known as windrows. The windrows are regularly moved or turned to re-establish porosity, break up, and blend material. The turning process also reintroduces oxygen into the windrow. However, since the oxygen can be rapidly consumed, aeration of windrows is still largely passive, and maintaining good FAS within the materials is important. [17]

The time required for active composting using this approach can be as low as 3 to 4 months if it is done in the summer and the site is aggressively managed, but 6 to 12 months is more common in colder climates. [17]

Turning regularly (e.g., one to three times per week during the active composting period), maintaining appropriate pile sizes (i.e., less than 3-m high), and ensuring sufficient FAS are important variables that must be controlled to accelerate processing times and reduce the potential for odour generation. [17]

Because composting times are reduced, the same quantity of material can be processed on a smaller footprint by using the windrow method rather than static piles. [17]

The area required for windrow composting is determined by windrow size and spacing, and these requirements are determined by the type of equipment used to turn the windrows. Windrows are typically 1.5- 3.5m high and 3- 6m wide. Spacing between windrows ranges from 1 to 5 m. Windrows are usually situated on a firm working surface, or pad, which is constructed to support the weight of delivery vehicles and turning equipment without rutting. The pad is normally sloped (0.5 to 2%) to direct drain runoff towards a collection ditch or detention pond. Composting pad surfaces are usually concrete, asphalt, cement-treated base, or compacted gravel. [17]

Sites that use large, self-propelled, straddle-type windrow turners can manage more material than sites that use front-end loaders or manure spreaders. Similarly, windrows created and turned with front-end loaders are larger than those turned with towed windrow turners. [17]

Windrow composting is almost always done outdoors where the pile is exposed to precipitation and can lead to runoff management problems. Any runoff created must be collected and treated, or added to a batch of incoming feedstock, increasing moisture content. To avoid problems with runoff, piles can be placed under a roof or in a building, although this adds to facility capital costs. [17]

Every time a windrow is turned, heat, water vapour, and gases trapped in the pore spaces are released into the atmosphere. If the facility is outdoors, there is little that can be done to capture the water vapour and gases; as a result, this composting method has the potential to affect adjacent neighbouring properties, so always turn windrows when odours will have the least impact on neighbours (e.g., mornings or when the wind is blowing away from neighbours).[17]

Leachate from windrow composting facilities is similar to that from static pile facilities: a mixture of higher-strength leachate from windrows and less contaminated runoff from the working pad. The quantity of leachate from a windrow composting facility is less than from a static pile facility of the same capacity due to the smaller footprint. [17]

Windrow composting is commonly used to process L&YW, brush, and wood residuals. Food waste and bio-solids can also be processed in this manner, but due to odour control, it is not generally recommended. Windrow composting is appropriate for facilities that process as little as 500 and as much as 50 000 TPY. [17]

Like static pile composting, there are no electrical or utility requirements for windrow composting, resulting in relatively low capital costs. Infrastructure generally includes an outdoor working pad, access roads, and accompanying drainage ditches and a detention pond. [17]

Figure.2.40: Straddle-style windrow turner [17]

Figure.2.41: Typical windrow operation with a towed windrow turner [17]

iv. Turned Mass Bed

Turned mass bed composting is a variation of the traditional windrow method. It is a continuous-flow system that relies on a specialized windrow turner and the use of windrows that are 15- 40m wide. [17]

To create a mass bed, the typical windrow turner is modified by adding a horizontal cross-conveyor behind the incline conveyor. As the modified unit travels down the length of the windrow, the material is still lifted up and thrown backwards by the incline conveyor. However, rather than falling back on the ground directly behind the turner, the horizontal conveyor catches the material and throws it to the side of the turner opposite the inclined conveyor.[17]
Due to the investment in the specialized turner, mass bed composting is generally appropriate for facilities processing between 15 000 and 50 000 TPY. [17]

Mass bed composting can be done indoors or outdoors. It can also be further improved by combining it with an in-floor forced-aeration system, as described later in this chapter. The time required for active composting using an un-aerated mass bed system is similar to that for windrow composting. [17]

The primary benefit of the mass bed approach is that it allows for a much larger quantity of material to be processed in a smaller footprint compared to windrow composting. Thus, even though the cost of the turning equipment is higher than large, straddle-type turners, the smaller working pad and reduced construction costs can make this approach very cost-effective. The smaller operating footprint also means there is a smaller quantity of leachate and runoff generated compared to a windrow facility with the same capacity. [17]

The downside to using mass beds is that there is less surface area and a lower level of passive aeration, driving the need for more frequent turning (e.g., every two to four days) and a higher level of monitoring. Because of the reduced amount of passive aeration, this approach is also less suitable for materials with a high oxygen demand, such as food waste and bio-solids. [17]

Figure.2.42: A self-propelled windrow turner used for turned mass bed Composting [17]

Figure.2.43: A mass bed system in the process of being turned; note turner location at bottom left of the pile and aisle created behind the turner[17]

v. Passively Aerated Windrow

This composting method is a cross between the static pile and ASP methods discussed in the following section. The mixture of materials to be composted is placed in long, low windrows, which are constructed over a network of 100-millimetre (mm)-diameter perforated pipes, as shown in Figure 2.34. The pipes are placed every 30 to 45 centimetres (cm) along the length of the windrow, and are covered with a 15-25cm layer of compost or peat moss. The pipes extend laterally to the outside of the windrow and are open-ended so that air can enter and naturally diffuse through the windrow without the use of aeration fans. A layer of compost or peat moss is placed overtop the windrow's surface to help discourage insects, to assist with moisture retention, and to manage odours. [17]

The increased level of passive aeration relative to the traditional static pile method should theoretically allow for quicker composting times, which are generally estimated to be between one and two years.[17]

As with static piles and ASP systems, particular attention must be given to the moisture and porosity of the material when constructing the windrow so that adequate aeration can be maintained. [17]

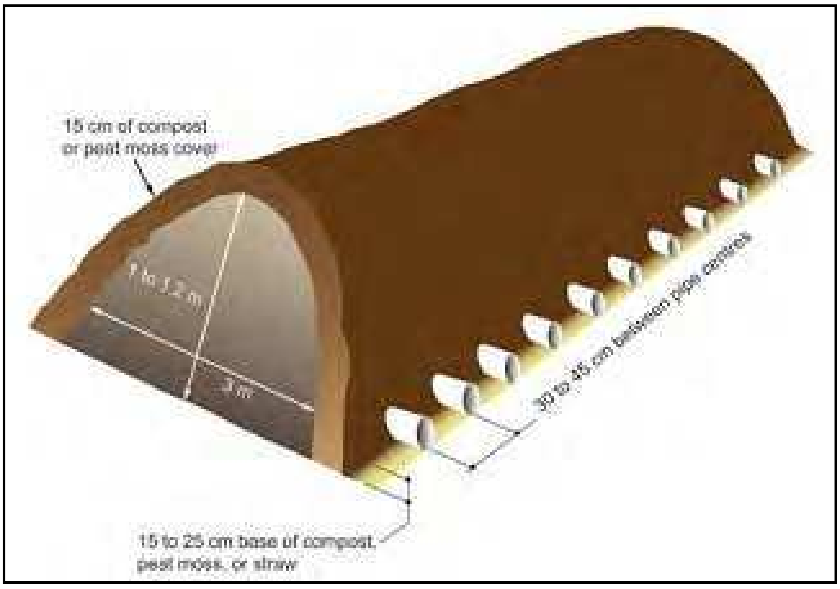


Figure.2.44: Typical passively aerated windrow system [17]

c. Actively Aerated Composting Systems

Active aeration is a common feature in all of these technologies. There are many subtle variations in the design of composting aeration systems, and many system designers and vendors use these variations to provide a balance between processing efficiency and capital costs. [17]

In an actively aerated composting system, the air is distributed through the composting pile by a network of air pipes underneath the composting pile. The simplest method is a pipe-on-grade system using a set of perforated pipes that are laid out on the ground, with the compost pile built on top of the pipe system. The perforated pipe is often covered by a porous layer of woodchips or straw before the compost pile is built to improve air distribution. The perforated pipes and the porous base layer should typically be at least 2 m from the edges of the pile to prevent air from short-circuiting out the ends and sides of the pile, and to force air to pass through the material being composted, as shown in Figure 2.37.[17]

The aeration pipes can be installed in or underneath the floor of the composting vessel or pad. There are several variations of in-floor systems, including covered trenches, pipe and spigot arrangements, and elevated plenums. These systems are costlier to construct but allow for quicker pile construction and tear-down, since there are no exposed pipes. They also eliminate the risk of damaging aeration piping and the need to replace pipes. Often, below-grade systems provide more efficient air delivery, which translates to reduced electrical consumption by aeration fans. [17]

Aeration systems generally fall into three categories: positive, negative, and bidirectional. In a positive aeration system, airflow is introduced at the base of the composting pile, and air flows up and out of the pile's surface, as shown in Figure 2.38. The sides and top of positively aerated compost piles are sometimes

covered with a layer of coarse compost or screening over to help manage odours and retain heat and moisture in the pile. [17]
A negative aeration system is designed to pull air down through the composting pile and into the aeration pipes. This allows the odorous compounds in the air to be captured and directed to some form of odour treatment system. [17]

A bidirectional aeration system requires a higher degree of engineering and hardware, but it allows switching between positive and negative aeration through the use of additional air ducting and manually or automated dampers, providing better control of temperatures in the compost pile. [17]

With these aeration systems, air can be forced through the composting pile on a continuous or intermittent basis. Continuous operation allows for lower air flow rates, but excessive cooling may result if the system is not carefully designed and managed. Over-cooled piles will not reach the temperatures needed for pathogen destruction and can increase the time required to stabilize materials. [17]

Intermittent fan operation is more common. Aeration fans are typically controlled by a timer or by a system that measures temperatures in the piles and turns the fans on and off, much like a home thermostat. [17]

Fans are usually of the centrifugal-axial-blade type. The size of the fan depends on a number of factors, including: the type and porosity of material in the pile, the size of the pile, and air flow characteristics of the air distribution system. It is recommended that an experienced designer size and select the fan. [17]

Figure.2.45: Typical passively aerated windrow system [17]

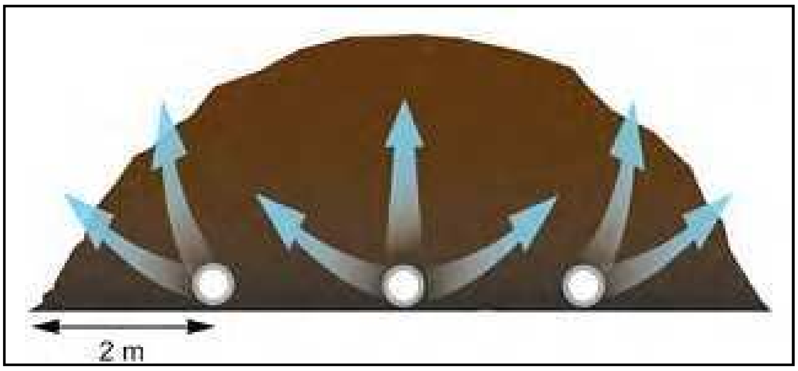


Figure.2.46: Aeration pipes must be installed away from the edges of the Compost pile to prevent short-circuiting of air [17]

Figure.2.47: In-floor aeration with pipe and spigot system; inset photo shows system prior to concrete floor being poured[17]

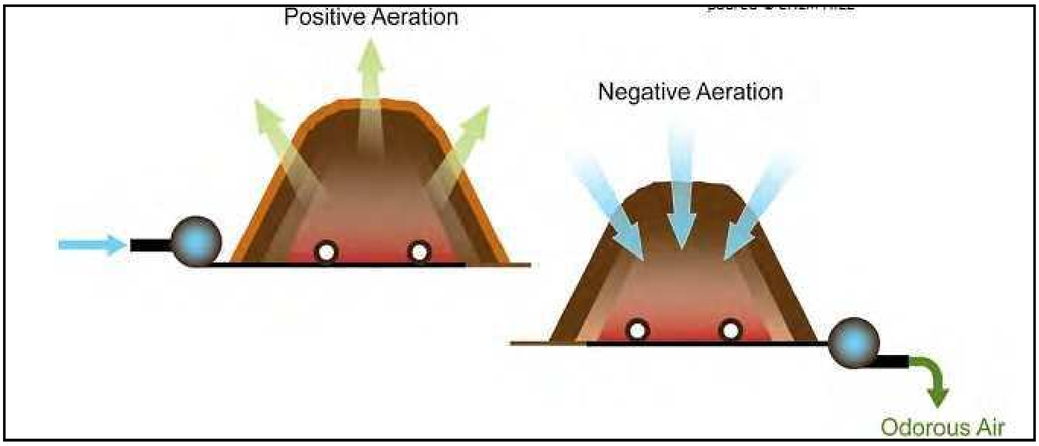


Figure.2.48: Aeration systems are designed to operate in positive or negative mode and can be designed to switch back and forth between these two modes[17]

i. Aerated Static Pile

This method of composting was developed in the early 1970s and has since been used successfully for L&YW, food waste, animal mortalities, animal manures, bio-solids, and industrial composting. ASP composting offers less exposed pile surface, requires less agitation, and generally allows for a higher level of odour control than static pile and windrow composting, particularly if negative aeration is used. [17]

ASP systems are very versatile in that they can be used at small facilities processing less than 1 000 TPY and at large facilities processing in excess of 100 000 TPY. [17]

Feed stocks are mixed and piled to depths of between 1.5 and 3.5 m, depending upon the feedstock characteristics and site design. In more extensively engineered systems, pile heights of up to 8 m are possible. There is no standard width or length for ASPs, as size is often dependent on site-specific requirements and land availability. [17]

ASP composting facilities are normally designed around a composting time of two to six weeks. After being removed from the ASP system, materials are usually further cured in outdoor windrows. At some facilities, the composting piles are remixed halfway through the active composting period to re-establish porosity in the materials and/or to ensure that all materials are exposed to the higher temperatures needed for pathogen and weed seed destruction in the pile core. As necessary, the materials are also remoistened during this remixing step. [17]

Since ASPs are not turned regularly, care must be taken during the blending of feed stocks with structural amendments so that adequate porosity is maintained throughout the composting period. It is important to achieve a homogeneous mixture and not compact the material with machinery while constructing the pile so that air distribution is even and no anaerobic areas develop causing sections of un-composted material. [17]

Figure.2.49: Typical ASP system with aboveground piping; block walls separate batches to better utilize available space[17]

The concept of using covers overtop ASP composting systems was a natural progression that has evolved over the past several decades. There are many tarp variations that use woven and nonwoven fabrics. The tarp covers generally protect the pile from infiltration of precipitation, reduce evaporative loss of water from the compost pile, contain litter that may be in the compost pile, reduce vector attraction, and in some cases help to control odours and volatile organic compound emissions. Covered ASP systems are usually designed with an active composting time of three to eight weeks. [17]

One early covered ASP system used silage bags that are made from polyethylene film, and vary in lengths up to 60m long. The bags have either a 1.5-3m diameter and are perforated to allow air movement and leachate drainage. Feed stocks are injected into tubes as they are unrolled using a special piece of equipment that also places one or two flexible plastic aeration pipes in the bottom of tubes. When the pods are filled, the ends are sealed, and the pipe(s) in the base are connected to a positive aeration system. When the composting is complete, the plastic tubes are cut open, and the materials are removed. [17]

Covered ASP systems that use tarps containing a semi-permeable membrane are also available. These systems typically use positive aeration, and depending upon the installation, in-ground aeration trenches or aboveground aeration piping. Aeration fans are controlled by an oxygen or temperature sensor and a control computer. The membrane within the tarp helps to treat odorous process air as it diffuses through the tarp. [17]

Although covers on these various systems can be placed manually, mechanical winders are available. Weights (e.g., sandbags or water-filled hoses) are typically used around the perimeter of the piles to seal the edges of the tarp on the ground and prevent process air from short-circuiting. Straps are often placed overtop the tarps to secure them in the wind. [17]

Figure.2.50: Composting system using polyethylene covers [17]

Figure.2.51: Covered, positively aerated composting system [17]

Figure.2.52: Mobile unit used to place and remove covers [17]

ii. Enclosed Aerated Static Pile (Tunnel)

Fully enclosed ASP composting is a further improvement on bunker-style ASP composting systems. This system uses a positively aerated composting system with below-floor aeration. The aeration floor and the composting pile are housed completely within a long and narrow, cast-in-place concrete enclosure (hence, the tunnel). These enclosures are typically 3-6m wide, 6-10m high, and upwards of 50m long. The enclosures are designed to allow large front-end loaders to drive in and out to load and remove materials. [17]

A custom-designed door system is used to seal the front of the enclosure during active composting. These doors manually slide on tracks (similar to a barn door) or are hinged at the top and opened using hydraulics. Locking mechanisms and rubber door gaskets are used to keep an airtight seal on the tunnels when the doors are closed. [17]

The active composting time is two to four weeks, and the system can be sized and designed to allow for materials to be removed and remixed halfway through this period. [17]

During operation, process air is exhausted from the headspace area of the tunnel, above the composting pile. The sealed door system and tightly controlled air exhausting allow for a very high degree of process air containment. This generally leads to improved odour control and less building corrosion compared to unenclosed composting systems. However, the design of the aeration system in tunnel systems is typically more complicated than in a typical ASP system. [17]

The larger quantity of concrete involved in constructing the tunnels also adds to construction costs. However, since the tunnel is completely sealed, it is not necessary that it be situated inside a building. In a typical tunnel composting facility design, only the loading/unloading end of the tunnel, and the aeration fans at the opposite end, are indoors; tunnel bays are often outdoors. [17]

Tunnel system space requirements are similar to bunker-style ASP systems. Like bunker systems, the tunnel walls allow for the sides and back of the composting pile to be vertical, which optimizes space: a 6m-wide by 30mlong tunnel can hold approximately 430 m3 of material, which corresponds to roughly 215 tonnes (t) of organic waste feedstock and amendment material.[17]

Based on the magnitude of the investment, tunnel composting systems are usually more appropriate for facilities processing more than 25 000 TPY; however, they may be used to process smaller quantities (as low as 10 000 TPY) when a higher degree of odour control is required. Larger facilities that use this technology are in the range of 100 000 TPY. [17]

One issue that has been encountered with tunnel composting systems is related to worker health and safety, and whether the tunnel meets the criteria of a confined space under the various provincial occupational health and safety regulations. Designation as a confined space may necessitate facility operators to implement specific operating protocols and use personal protective equipment (PPE) and alarm systems. [17]

Figure.2.53: Close up of tunnel door system [17]

Figure.2.54: Aerated static pile composting inside an enclosed concrete Tunnel [17]

iii. Static Container

Static containerized systems are a type of in-vessel composting system that relies on a number of discrete composting vessels. These containers are very similar to 40-cubic-yard (yd^3) roll-off containers used in North America for handling commercial solid wastes. The size of the individual containers makes them portable, and they can be moved around the facility. They are also modular, and additional containers can be added as more capacity is required.

The containers are filled through sealable doors in the rear or roof of the container. Once filled, the containers are moved to an outdoor concrete or asphalt pad and connected to a stationary aeration system capable of providing air to multiple containers. Air is fed into the base of the filled composting container and removed from the top. The odorous exhaust air is then passed through a bio-filter for treatment. [17]

After two to four weeks of active composting, the containers are emptied by hoisting them on a truck with a specialized lifting system, and material is tipped out of the rear doors, much like a dump truck. This same truck is used to move empty and full containers around the site. Discharged material needs to be further cured and matured before being used as a soil amendment. [17]

Footprint requirements for each composting container are relatively small, but the space required for multiple containers can quickly add up. [17]

The capacity of these systems depends on the composting time, but is generally between 200 and 900 TPY per container. Facilities using this technology are generally smaller and have fewer than 15 containers. [17]

Figure.2.55: Static container composting system [17]

Figure.2.56: Composting system that uses multiple static containers [17]

Figure.2.57: Each static container is attached to a central air system using flexible hoses[17]

iv. Agitated Container

Agitated container systems are generally stationary and operate on a continuous-flow basis. Like static container systems, agitated container and vessel systems tend to have smaller capacities and are modular. This makes them well-suited to facilities with smaller quantities of feedstock (e.g., less than 10 tonnes per day [TPD]) and facilities that will be developed and expanded over time. [17]

These composting systems tend to have integrated control systems that monitor temperature and other control parameters, and manage water addition. A mixing and loading hopper and a bio-filter for treating exhaust air are also usually included. [17]

Material handling is also generally automated. In some units, a moving floor system slowly walks materials from the unit's inlet end to its discharge end. One or more sets of spinners may also be located along the length of the unit to agitate materials and break up clumps. [17]

Other systems use an auger that runs along the length of the vessel to move materials towards the unit's discharge end. The auger is driven by a motor and gear box situated outside of the processing chamber so it is readily accessible for maintenance. [17]

Systems are available in a wide range of sizes, from 300 kilograms (kg) per day, to 12 TPD. Additional processing capacity can be achieved by using multiple units in parallel. [17]

The size of these units vary based on their capacity; smaller units can fit inside a single parking stall, while larger units are typically 3-5m wide and have lengths exceeding 7 m. Installations are commonly designed with a composting time of 2 weeks; however, 4-week composting times are possible by lengthening the unit.[17]

Figure.2.58: Agitated container composting system installed at a University Campus[17]

Figure.2.59: Agitated container system [17]

v. Channel

Channel systems are essentially turned windrow piles placed inside of buildings. The windrow is situated between two long, parallel, concrete walls that are 1.8-2.4m high and spaced between 3- 6m apart.[17]

The raw materials are loaded into one end of the channel and are moved down its length over a period of two to four weeks by a turning machine that rides along the tops of the concrete walls. The turning machine has a conveyor or rotating drum that hangs below it and physically lifts and throws the compost backwards, agitating it in the process. As the turning mechanism makes repeated passes down the channel over time, it moves the mass of material from the feed end of the channel to its discharge end. Oxygen and temperature control within each channel is provided by an aeration system in the floor of the channel. [17]

Several channels are used simultaneously to obtain the necessary daily or weekly processing capacity. The length of time material spends in the channels is a function of the channel length and how often material is turned. Channel systems are normally designed with a composting time of 2 to 4 weeks. With a turning schedule of every 1 to 3 days, channels are generally 30- 75m long. Buildings enclosing the channels are typically 15- 30m longer to accommodate equipment access to each end of the channels. Building widths depend on the number and width of individual channels. [17]

Figure.2.60: Channel composting system [17]

Feed stocks can only be added to the channel system at the in-feed end; consequently, there is only one opportunity to achieve the proper blend of feed stocks and amendments, requiring skilled operators to work with different loads and types of wastes so that the proper blend is achieved. [17]

The aeration system used in most channel composting systems is positive; air is blown upwards through the pile and escapes from the top surface. This approach results in large quantities of steam and poor visibility, particularly in un-insulated buildings. In some cases, it is possible to construct a secondary enclosure overtop the channels to contain and collect this air, improving indoor air quality. [17]

Channel systems are very efficient from a materials handling perspective, since materials are moved as they are turned. This reduces the quantity of material handling required with front-end loaders. Improved efficiencies can be realized by installing a conveyor belt system at the tail end of the channels to automatically collect and move materials as they are discharged from the channel. [17]

vi. Agitated Bed

An agitated bed composting system is similar to a turned mass bed system, with a much higher degree of automation. These types of systems are well-suited for installations handling large volumes of material (e.g., more than 50 000 TPY). [17]

The system consists of a large bed of composting material enclosed within perimeter walls. The walls around the bays allow for material depths between 2 to 3 m. The bays are equipped with an aeration system in the floor, similar to that used with ASP and tunnel systems. Both positive and negative aeration can be used, but negative aeration is more common. [17]

Material in each bay is turned every one to three days using an automated system. Composting time of materials in the bays is typically around three to four weeks and is governed by the length of the bed and the turner design (i.e., how far the material is moved with each pass). The turner consists of an auger or flail, which is suspended from a bridge crane that spans the bay. The movement of the turner along the bridge crane, combined with the bridge crane’s ability to travel up and down the length of the bay, enables the turning device to access all areas of the bay. [17]

Operationally, materials are placed along the receiving side of the bay using front-end loaders or conveyor systems. The materials are subsequently moved across the bay by the turner, which follows a serpentine path from the bay’s discharge end to its receiving end. As the turner makes a lateral pass across the bay, the augers or flails physically lift material and move it towards the discharge end. Over time, as the turner makes repeated passes through the bay, the fresh material moves completely across the bay and is discharged onto the floor or a conveyor belt. [17]

The capacity of the bed is a function of the depth of material and the bed width. Dimensions range from 25-50m long and 10-75m wide. Higher capacities can be achieved by installing several agitated beds in parallel. [17]

Agitated bed systems are well-suited for processing SSO feed stocks with high proportions of food waste. Facilities that use this technology typically have capacities ranging from 15 000 to greater than 100 000 TPY. [17]

Figure.2.61: Agitated bed system viewed from discharge end of bay [17]

Figure.2.62: Bridge crane and suspended auger turning mechanism viewed from discharge side of Bay[17]

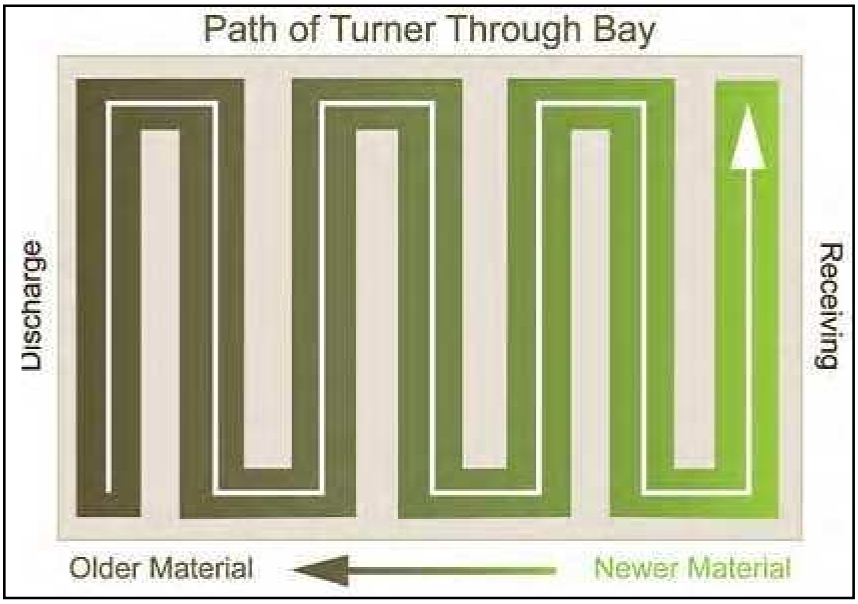


Figure.2.63: Agitated bay turner movement and material flow [17]

vii. Rotating Drum

Several small-scale, horizontal, rotating drum systems have been developed during the past decade, modelled on large-scale drum systems that were popular in the 1990s for composting MSW. [17]

Drum systems typically consist of a steel drum with a diameter between 1.5 and 5 m. In small-scale systems, the drums have a length of up to 10 m. By comparison, large-scale systems use drums that are significantly longer (i.e., 30 to 80 m). [17]

The drums are positioned on a slight incline (less than 5%) and rotate at between 0.5 and 5 rotations per minute (rpm). The combination of the drum's rotation and incline, with gravity, results in materials tumbling down the drum in a corkscrew manner from the upper in-feed end to the lower discharge end. [17]

Air is typically injected into the drums, usually at the discharge end, to meet process air requirements. Depending on the size of the drums, they are driven by large ring-gears, rubber trunnions, or sprockets and chains. The loading and unloading doors and the drive mechanisms introduce a higher degree of mechanical complexity and maintenance requirements relative to other in-vessel composting systems. [17]

Drum capacities for smaller-scale systems range from 5 to 50 m^3; generally, the drums are loaded to between 65 to 80% of their total volume. Loading more material into the drum prevents materials inside from tumbling and reduces processing efficiency. [17]

A drum's annual capacity is determined by how much is unloaded from the drum and how often. For example, if a drum has 50% of its contents unloaded each day, it will have twice the annual capacity of a drum the same size that only has 25% of its contents unloaded each day. [17]

Rotating drums are usually designed with a composting time of one to seven days. With composting times this short, the material emerges without having completed the active composting step and needs further treatment. [17]

Figure.2.64: Small-scale rotating drum system [17]

Composting is becoming an increasingly popular method of managing organic materials. The overall environmental impact resulting from a specific composting operation would depend on its size (e.g., small-scale home composting versus industrial-sized yard waste composting) the type of materials being composted, the methods of managing the compost at the facility, and emissions released (e.g., biogas and leachate) as the compost is processed and matures over time. A composting process should include materials and energy inputs and emissions associated with constructing, operating, maintaining, and decommissioning the infrastructure and mobile equipment used at composting facility. Figure 2.64 presents, as an example, materials and energy inputs and emissions. [25]

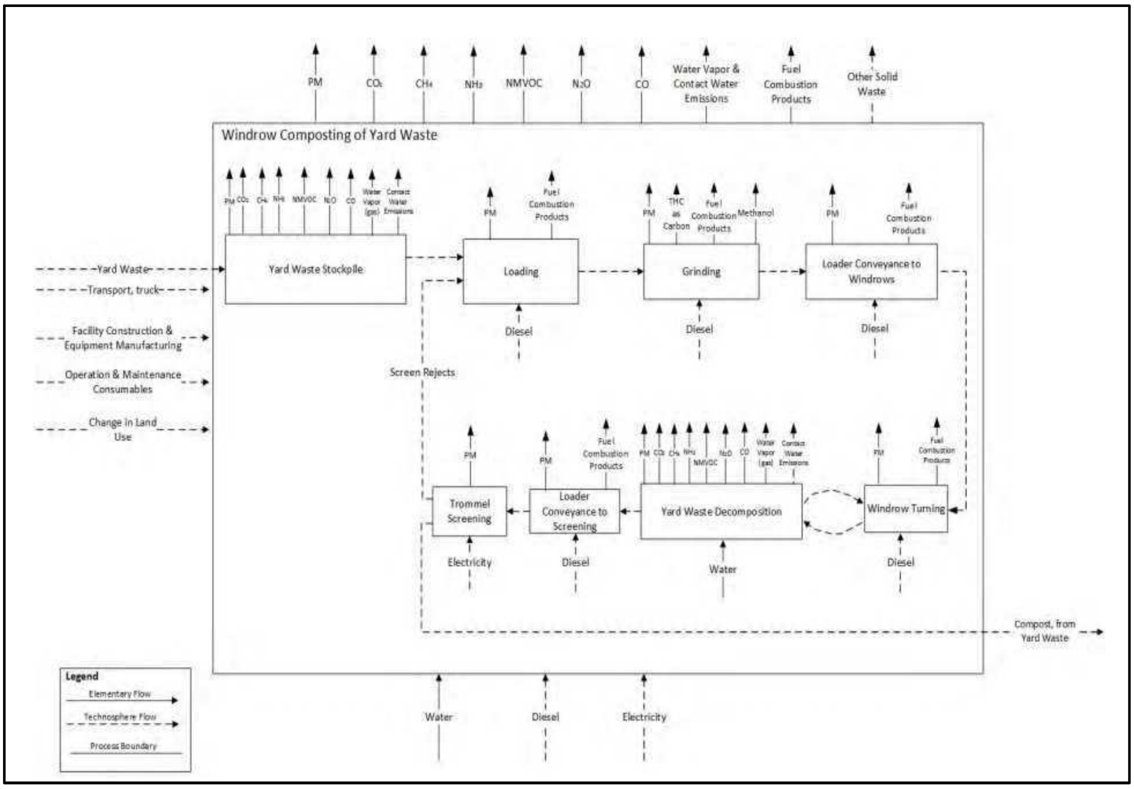


Figure.2.65: Example of Materials and Energy Inputs and Emissions Associated with Composting of Yard Waste [25]

(c) Recycling(Resource Recovery)

MRFs are used to recover and process recyclable EOL materials or recyclable material streams and generally serve as an intermediate point between material collection and material re-use. MRFs can be designed around a variety of configurations, which in the US are typically based on the type of materials received at the facility (e.g., single-stream recyclables, dual-stream recyclables, mixed EOL materials). [25]

MRFs typically include a covered area for tipping and loading materials, sorting equipment, equipment to move and load materials, storage space for material stockpiles, and offices. Emissions attributable to MRFs include those associated with manufacturing (including natural resources extraction) of construction materials and energy used for facility construction; production of energy (electricity and fuels) resources (including water) used for facility operation; emissions (e.g., leachate, dust) from materials processing operations; and EOL management of materials generated from facility maintenance and decommissioning. [25]

Factors that impact emissions from a MRF include the facility's level of mechanization (manual sorting would require less fuel than mechanized sorting), process efficiency, the distance from the MRF to a disposal facility (for residuals), the distance from the recovered materials end user(s), and the end-use application of the recovered recyclables (e.g., producing refuse derived fuel (RDF) from recyclables to replace combustion fuel may offset different emissions than using the recyclables as a raw feedstock replacement for virgin materials). Figure.2.65 presents an example of the material and energy inputs and emissions associated with the recovery of a specific recyclable (e.g., corrugated containers) at an MRF. [25]

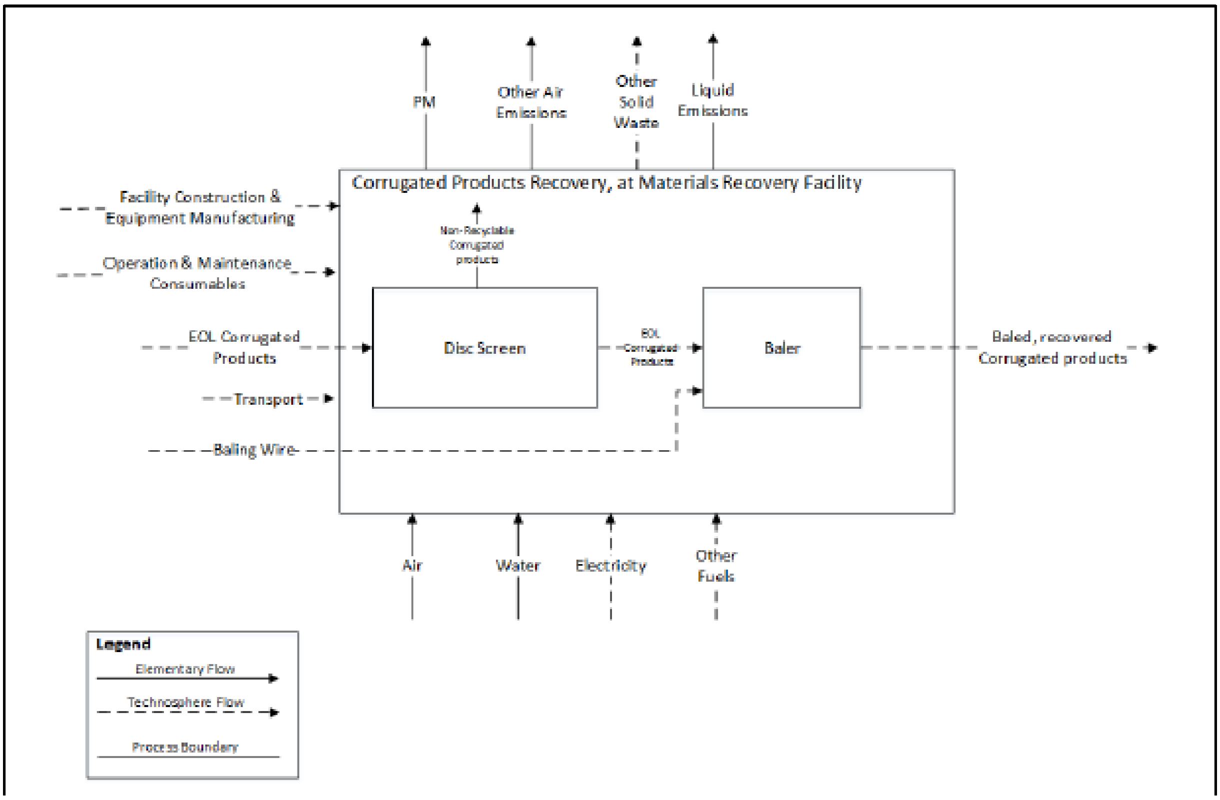


Figure.2.66: Example of Materials and Energy Inputs and Emissions Associated with Recovery of a Specific MSW Constituent [17]

2.3 Researches on MSW Composition

Western Province total MSW collection was around 1700Mt/day and out of this amount Colombo District account for 1300 Mt/day. That showed that 44% of all MSW collection Sri Lanka (2838 Mt/day) was collected from Colombo district [6].

Table.14: MSW Collection by Municipals in each district in Sri Lanka [6]

Province	**District**	**Daily Collection (Mt./day)**	**District Percentage**	**Province Total**	**Province Percentage**
Western	Colombo	1256.5	44.27%	1662.7	58.58%
	Gampaha	313.2	11.03%		
	Kaluthara	93	3.28%		
Southern	Galle	102.5	3.61%	198.46	6.99%
	Matara	68	2.40%		
	Hambantota	27.96	0.99%		
Central	Kandy	145.04	5.11%	229.22	8.08%
	Matale	32.78	1.15%		
	NuwaraEliya	51.4	1.81%		
Wayamba	Kurunagala	73.48	2.59%	170.19	6.00%
	Puttalam	96.71	3.41%		
Sabaragamuwa	Rathnapura	49.06	1.73%	91.86	3.24%
	Kegalle	42.8	1.51%		
Uva	Badulla	57.38	2.02%	85.66	3.02%
	Monaragala	28.28	1.00%		
North Central	Anuradhapura	52.41	1.85%	74.14	2.61%
	Polonnnaruwa	21.73	0.77%		
Eastern	Ampara	57.04	2.01%	232.81	8.20%
	Baticaloa	119.33	4.20%		
	TrincoMalee	56.44	1.99%		
North	Jaffna	71.37	2.50%	93.43	3.28%
	Mannar	3.5	0.12%		
	Kilinochchi	0.92	0.03%		
	Mulathivu	8.74	0.31%		
	Vavniya	8.9	0.31%		
Total		2838.47	100.00%	2838.47	100.00%

2.3.1 Technology selection for a proposing MSW based power plant

Characteristics of available MSW were first analysed and then heating (Calorific) value of available MSW was arrived at. Appropriate technology was then selected. It was important to calculate average heat value of available waste in each Municipal Council (MC) which would give an initial idea about whether those available wastes could burn directly or not. Table.15 details the calculation results, where calorific value of Colombo MC Waste was arrived at 6431.01 kJ/kg. [6]

Table.15: Calorific values of available MSW in local authorities in Colombo district [6]

No	**Name**	**Daily Garbage amount(Mt./day)**	**Polythene /Plastic**	**Bio Degradable**	**Long Term Degradable**	**Metal**	**Wood**	**Glass**	**Paper**	**Construction Waste**	**Meat, Fish Shop Waste**	**Wood Waste & Cloths**	**Other**	**Average Calorific Value (kJ/Kg)**
			32799	**4180**	**6050**	**0**	**15445**	**195**	**15814**	**0**	**4180**	**15445**	**0**	
1	Colombo MC	700	5.6	83.4	0	2	0	0.6	7	0	0	0	1.4	**6431.01**
2	Dehiwala-Mt. MC	150	7	64	1	2	10	1	6	0	0	9	0	**8457.78**
3	Moratuwa MC	150	3.82	37.09	0	1.09	0	0.55	3.27	3.27	0	49.27	1.64	**10931.23**
4	Sri Jpura MC	65	10	42	5	2	2	5	12	13	5	2	2	**8072.23**
5	Kolonnawa UC	30	5	67	4	0	10	9	5	0	0	0	0	**7035.30**
6	Maharagama UC	60	7.98	60.9	0.51	8.44	6.96	3.9	2.2	0	3.99	5.12	0	**7581.89**
7	Sithawakapura UC	7.5	5	80	2	1	1	1	6.9	1	0.1	2	0	**6665.60**
8	Homagama PS	15	3.65	82.03	3.28	0.04	1.82	1.82	3.65	1.82	0.06	1.83	0	**5971.47**
9	Kaduwela PS	34	3.57	57.14	0	7.14	4	2	7.16	6	5	7.99	0	**6756.41**
10	Kesbawa PS	15	6.67	50	6.67	3.33	13.33	1.67	6.67	6.67	1.66	3.33	0	**8381.80**
11	Koti/Mullariyawa PS	25	5.56	58.33	2.22	2.22	6.67	2.22	6.67	0	0.56	8.89	6.66	**7881.90**
12	Sithawakapura PS	5	6	40	40	0	4	0	4	6	0	0	0	**7310.30**
	Simple Average of (%)		**5.82**	**60.16**	**5.39**	**2.44**	**4.98**	**2.40**	**5.88**	**3.15**	**1.36**	**7.45**	**0.98**	**7661.34**
	Average (%) based on total weight		**5.81**	**70.13**	**0.83**	**2.27**	**2.31**	**1.32**	**6.36**	**1.36**	**0.62**	**7.77**	**1.21**	**7479.68**

2.3.2 Technology Selection

MSW to Energy/Power technologies have been developing gradually from traditional ones to advanced ones in the following order: Landfill gas capture, Mass bed incineration (MBI), Fluidized bed incineration (FBI), Gasification, Pyrolysis, anaerobic digestion and Plasma. Relative advantages and disadvantages of Technology are noted in Table 16 [6].

Table.16: Technology analysis of different MSW to Power Technologies [6]

Technology	Advantages	Disadvantages	Final Conclusions
Pyrolysis	Energy conversion efficiency is high when compared with other technologies. Can work with mixed waste after initial separation of metals and bulky wastes	High Tech nature and need technology transfer from patented technology owners which increase the capital cost.	Possible solution for Sri Lanka if financing for project is feasible.
Anaerobic digestion:	As large biodegradable part contain in available Solid waste in Colombo , this method is more suitable	Need to separate bio degradable part and other part from waste Separation of MSW will increases cost of Electricity generation	Suitable for Sri Lanka (as high bio degradable portion of available MSW) but required separation of bio degradable part from incoming mixed MSW. There is a failure experience in Sri Lanka with this method as difficulty in sorting bio degradable part from mixed MSW.
Plasma Technology	Required to separate only inert materials (metal and building waste) all others can be applied to this process.	This is new technology and stile in R&D Stage Need time to establish the technology	This could not suitable for case of Western Province Sri Lanka

Table.16: Technology analysis of different MSW to Power Technologies [6]

Technology	Advantages	Disadvantages	Final Conclusions
Landfill gas capture	Suitable for available waste in Colombo as high biodegradable contents	Environmental Problems with Landfills Need high environmental standards if we apply for carbon credit which will more expensive Low Energy capture efficiency Need More lands for land filling Need to wait several years to generate bio gas	Not suitable for case of Western Province Sri Lanka as this required more lands for landfills which are not possible in Colombo urban.
Mass Burn incineration	Easy to implement plant is waste is burnable. Waste volume reduction up to 90% will reduce the land requirement for landfills.	Marginal heating values of available waste cause it is difficult to burn waste without additional fuel High environmental impact due to fluid gases emitting to atmosphere	Not suitable for case of Western Province Sri Lanka as marginal heating values of burning without additional fuel.
Fluidized Bed Incineration with RDF	Most common practices in similar countries such as India, china, Thailand etc.	High cost associate with RDF processing Environmental impact and high cost with flue gas control system	Suitable for Sri Lanka
MSW Gasification:	Energy conversion efficiency is greater that other methods(incineration, anaerobic digestion) etc.	Plant need more control in gasification process according to various waste types and which will increase the cost and difficulty in operation	Possible solution for Sri Lanka. There are advanced high tech solutions to overcome the drawback of this method but the cost will be very high.

2.3.3 Criteria for selection of Waste Processing Technology

For planning and designing of a waste management plan, some preliminary survey is required to be obtained from the city/town and accordingly selection of waste processing technologies can be done for the city/town. In case of waste quantity is

found less than requirement, a regional plan may be prepared for clusters of towns to achieve the desired quantity of waste. In case of excessive generation of waste, the waste can be reduced by adopting decentralized treatment process (vermin-composting/Biogas) in pockets – within garden premises, large residential complex, etc. However, Integrated waste processing plants are capable of processing both organic and incinerable wastes.[7]
The primary criteria for selection of waste processing technologies are as under;

1. Quantity of waste generation
2. Characteristics of waste (Physical and chemical property)
3. Based on land availability
4. Prevailing environmental conditions
5. Climatic condition and terrain
6. Social acceptance
7. Market for the products
8. Capital investment
9. Sitting criteria
10. Environmental norms

The quantity of waste generation plays vital role in selection of waste processing technologies. Vermi-composting and Biogas plants are capable of handling effectively up to 30 Tonne/per day and suitable for small towns. Aerobic composting plants are found operational up to 500 Tonnes/day. The waste-to-Energy plants are found cost-effective for processing waste 500 Tonnes/day and above. [7]

Waste characteristics such as C/N ratio, moisture content, calorific value, etc. indicate the treatment technology to be adopted. The desirable C/N ratio for composting is 30:1 with moisture content 50-60%.; otherwise, these parameters are maintained by addition of some selected wastes. The desirable calorific value of waste considered for incineration should not be less than 1500 kcal/kg (SWM Rules, 2016). The desired calorific value of waste can be achieved practicing effective segregation of wastes. However, multiple technologies can be selected for a city for processing solid wastes in an integrated way depending upon the quantity and characteristics of wastes as under (Table-17).[7]

Table.17: Options for Integrated Technologies as per waste quantity generation [7]

Sno.	Population range	Waste Gen.TPD	Composition	Technological options
1	Above 2 Million	>1100 TPD	Biodegradables 35 to 50 %	IWP comprising -BM +CC+ RDF. W to E plant for power, based on: gasification, pyrolysis, incineration and mass burning. RDF to cement industry Plastic to fuel oil
2	1 M to 2 Million	550 to 1100 TPD	Biodegradables 40 to 55 %	IWP comprising -BM +CC+ RDF. W to E plant for power, where wastes exceeds 500 TPD based on: gasification , pyrolysis, incineration and mass burning. RDF to cement industry Plastic to fuel oil
3	1 Lakh to 10 Lakh	30 to 550 TPD	Biodegradables 40 to 55 %	IWP-BM, CC + RDF as feed stock to power plant / cement industry. Plastic to fuel oil
4	50,000 to 1 Lakh	10 to 30 TPD	Biodegradables 45 to 60 %	BM, VC or CC RDF
5	Less than 50,000	Less than 10	Biodegradables 45 to 65 %	BM,VC / CC and RDF
6	Hill towns	State capitals	Biodegradables 30 to 50 %	BM, CC / RDF as feed stock. Plastic to fuel oil

*IWP- Integrated Waste Plant, BM- Bio-methanization, VC- Vermicomposting,CC- Chemical Conversion, RDF- Refused Derived Fuel

From the above table, cities having population 1 lakh to above 2 million can adopt the most common technology to treat waste 500TPD to above 1100 TPD in an integrated way comprising waste treatment plants of bio-methanization, Chemical Conversion and Refused Derived Fuel. For treating the waste the composition of biodegradable waste should be varies from 30 to 60 % depending upon the generation of waste and the technologies those are in practice. For population less than 50,000 technologies like vermin-compositing and bio-methanization can be used as they are more effective. The Hilly areas having land crisis, the technologies like bio-methanization, vessel composting, static pile composting, RDF, etc. can be used. The desired characteristics of waste for various technologies are given at Table-18. [7]

Table.18: Specifications for Various Type of Waste Processing Technologies [7]

S.No.	Method	MSW characteristics	C/N ratio	pH Control	Temperature required	Moisture Content
1	**Compositing**	Sorted organic fraction of MSW, preferable with same rate of decomposition	Between 25 – 50 initially. Release of ammonia and impeding of biological activity at lower ratios	7 – 7.5 (optimum). Not above 8.5 to minimize nitrogen loss in the form of ammonia gas	50-55°C for first few days and 55-60°C for the reminder composting period. Biological activity reduces significantly at higher temperature	55% (optimum)
2	**Incineration**	MSW with calorific value as high as possible; Volatile matter >40%; Fixed carbon <15%; Total inert <35%	Calorific Value-As high as possible; >1200 kcal/kg	–	850°C to 1400°C	As minimum as possible; <45%
4	**Pyrolysis**	–	–	6.5-8.5 (optimum)	elevated temperatures 700°C-900°C	–
5	**Gasification**	–	–	–	Temperature greater than 1000°C	–
6	**Biomethanation**	Sorted organic fraction only; Higher the putrescibility, better is the gas yield; Fibrous organic matter is undesirable as the anaerobic microorganisms do not break down woody molecules such as lignin	25-30 (preferable)	Acidogenic bacteria through the production of acids reduce the pH of the tank. Methanogenic bacteria operates in a stable pH range and temperature	Mesophilic bacteria act optimally around 37°-41°C or at ambient temperatures between 20°-45°C. Thermophilic bacteria act optimally around 50°-52° and at elevated temperatures up to 70°C. Mesophiles are more tolerant to changes in environmental conditions and hence more stable, but thermophiles act faster.	>50%; Implications on feed, gas production, system type, system efficiency
	Vermi composting	Any organic waste which are not appreciably oily, spicy, salty or hard and that do not have excessive acidity and alkalinity	30:1 (preferred). Brown matter (wood products, saw dust, paper etc) is rich in carbon and green matter (food scraps, leaves etc) in nitrogen.	Slightly alkaline state preferable. Correction by adding small dose of calcium carbonate	20 – 30oC	40-55% preferable; cover the tank with wet sack and sprinkle water as required

(b) Key Criteria for Solid Waste Incineration

MSW incineration projects are appropriate only if the following overall criteria are fulfilled:

- A mature and well-functioning waste management system has been in place for a number of years.
- Incineration is especially relevant for the dry bin content in a 2-Bin system. For un-segregated waste, pre-treatment is necessary.
- The lower calorific value (LCV) of waste must be at least 1450 kcal/kg (6MJ/kg) throughout all seasons. The annual average LCV must not be less than 1700 kcal/kg (7 MJ/ kg).
- The furnace must be designed in line with best available technologies to ensure stable and continuous operation and complete burn out of the waste and flue gases.
- The supply of combustible waste should be stable and amount to at least 500 tons/ day.

- Produced electricity and/ or stream can be sold at a sustainable basis (e.g. feeding into the general grid at adequate tariffs). It is possible to absorb the increased treatment cost through management charges, tipping fees
- Skilled staff can be recruited and maintained.
- Since the capital investment is very high, the planning framework of the community should be stable enough to allow a planning horizon of 25 years or more.
- Pre-feasibility study for the technology led to positive conclusions for the respective community.
- Strict monitoring systems are proposed and monitored.

(c) Key Considerations for operation of Incinerators

Incineration of municipal solid waste should meet with the following criteria:

- Minimum gas phase combustion temperature of 850 °C and a minimum residence time of the flue-gases, of two seconds after the last incineration air supply.
- Optimum oxygen content (~lower than 6%) should be maintained in order to minimize corrosion and ensure complete combustion. The carbon monoxide content of the flue gas is a key indicator of the quality of combustion
- Fly ash acts as a catalyst for de-novo synthesis (at 200-450°C) of dioxins and furans. In order to reduce formation of dioxins and furans, it is imperative that maximum fly ash is removed before gases cool down to 200-450°C.
- The flue gases produced in the boilers should be treated by an elaborate flue gas treatment system.

2.4 How to classify STBD/LTBD waste in MSW

A few studies had been done in the country to find the composition of the MSW stream in Sri Lanka. Table 19 gives the composition of MSW in some selected cities in Sri Lanka. Here, the organic waste is categorized as **long term biodegradable (taking 2-3 months for degradation)** and **short term biodegradable (degrades within 2 months).**[8]

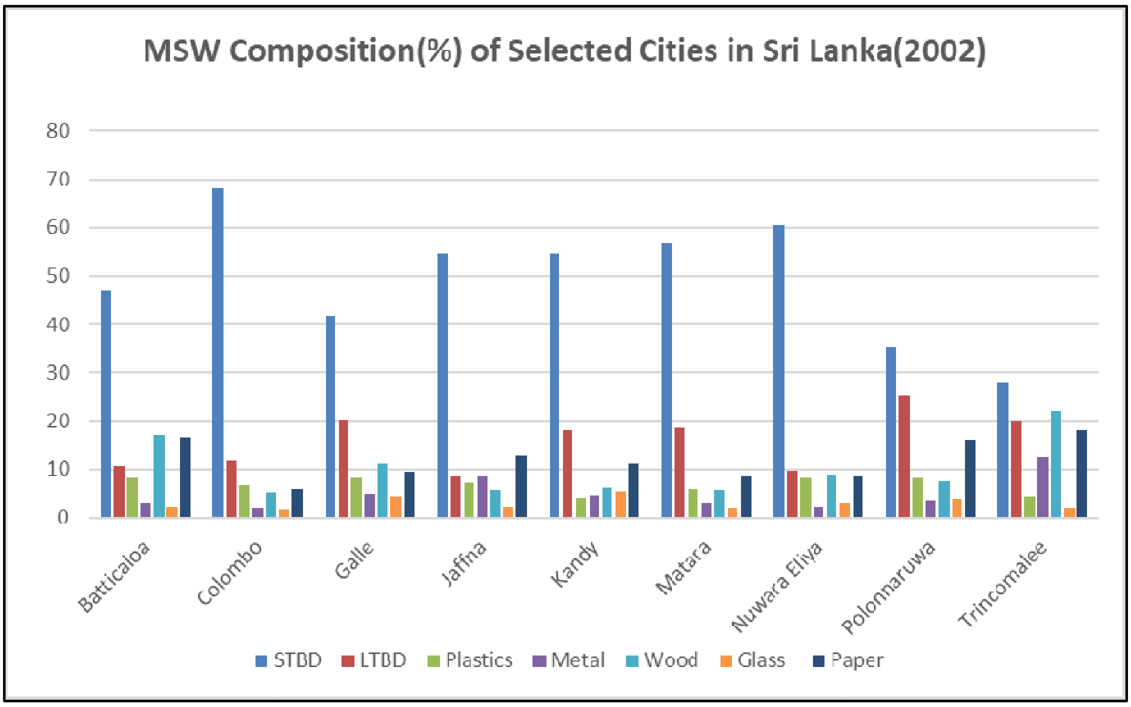


Figure.2.67: MSW composition in some selected cities of Sri Lanka [8]

Biodegradable waste includes any organic matter in waste which can be broken down into carbon dioxide, water, methane or simple organic molecules by micro-organisms and other living things by composting, aerobic digestion, anaerobic digestion or similar processes. In waste management, it also includes some inorganic materials which can be decomposed by bacteria. Such materials include gypsum and its products such as plasterboard and other simple organic sulphates which can decompose to yield hydrogen sulphide in anaerobic land-fill conditions.

(Table 19&Table 20)[9]

Table.19: Approximated time for compounds to biodegrade in a marine Environment [9]

Product	**Time to Biodegrade**
Paper towel	2–4 weeks
Newspaper	6 weeks
Apple core	2 months
Cardboard box	2 months
Wax coated milk carton	3 months
Cotton gloves	1–5 months
Wool gloves	1 year
Plywood	1–3 years
Painted wooden sticks	13 years
Plastic bags	10–20 years
Tin cans	50 years
Disposable diapers	50–100 years
Plastic bottle	100 years
Glass bottles	200 years
Aluminium cans	Undetermined

Table 20: Time-frame for common items to break down in a terrestrial Environment [9]

Product	Time to Biodegrade
Vegetables	5 days – 1 month
Paper	2–5 months
Cotton T-shirt	6 months
Orange peels	6 months
Tree leaves	1 year
Wool socks	1–5 years
Plastic-coated paper milk cartons	5 years
Leather shoes	25–40 years
Nylon fabric	30–40 years
Tin cans	50–100 years
Aluminium cans	80–100 years
Glass bottles	1 million years
Styrofoam cup	500 years to forever
Plastic bags	500 years to forever

2.4.1 Factors affecting bio-degradation rate [9]

In practice, almost all chemical compounds and materials are subject to biodegradation processes. The significance, however, is in the relative rates of such processes, such as days, weeks, years or centuries. A number of factors determine the rate at which this degradation of organic compounds occurs. Factors include light, water, oxygen and temperature. The degradation rate of many organic compounds is limited by their bioavailability, which is the rate at which a substance is absorbed into a system or made available at the site of physiological activity, as compounds must be released into solution before organisms can degrade them. [9]

The rate of biodegradation can be measured in a number of ways.

Respirometry tests can be used for aerobic microbes. First one places a solid waste sample in a container with microorganisms and soil, and then aerates the mixture. Over the course of several days, microorganisms digest the sample bit by bit and produce carbon dioxide, the resulting amount of CO_2 serves as an indicator of degradation. Aerobic bio-degradation equation is given below.[9]

$$C_{polymer} + O_2 \longrightarrow C_{residue} + C_{biomass} + CO_2 + H_2O$$ --------- (6)[9]

Biodegradability can also be measured by anaerobic microbes and the amount of methane or alloy that they are able to produce. Anaerobic degradation formula is given below.[9]

$$C_{polymer} \longrightarrow C_{residue} + C_{biomass} + CO_2 + CH_4 + H_2O$$ --------- (7) [9]

It's important to note factors that affect biodegradation rates during product testing to ensure that the results produced are accurate and reliable. Several materials will test as being biodegradable under optimal conditions in a lab for approval but these results may not reflect real world outcomes where factors are more variable. For example, a material may have tested as biodegrading at a high rate in the lab may not degrade at a high rate in a landfill because landfills often lack light, water, and microbial activity that are necessary for degradation to occur. Thus, it is very important that there are standards for plastic biodegradable products, which have a large impact on the environment. The development and use of accurate standard test methods can help ensure that all plastics that are being produced and commercialized will actually biodegrade in natural environments.[9]

2.5 Researches on MSW quality analysis for WTE conversion

2.5.1 Physical, Chemical and Biological Characteristics

The major physical characteristics measured in waste are:

a) Density,
b) Size distribution of components, and
c) Moisture content.

Other characteristics which may be used in making decision about solid waste management are:

a) Colour,
b) Voids,
c) Shape of components,
d) Optical property,
e) Magnetic properties, and
f) Electric properties.

Optical property can be used to segregate opaque materials from transparent substances which would predominately contain glass and plastic. Magnetic separators are designed based on the magnetic characteristics of the waste. Moisture content is essential for leachate calculation and composting. Density is used to assess volume of transportation vehicle and size of the disposal facility. Shape can be used for segregation as flaky substance will behave differently compared tonon-flaky substance. [11]

Important chemical properties measured for solid waste are:

- Moisture (water content can change chemical and physical properties),
- Volatile matter,
- Ash,
- Fixed carbon,
- Fusing point of ash,
- Calorific value,
- Percent of carbon, hydrogen, oxygen, sulphur and ash.

Proximate analysis of waste aims to determine moisture, volatile matter, ash and fixed carbon. Ultimate analysis of waste aims to analyse percent of carbon, hydrogen, oxygen, sulphur and ash. [11]

The collective waste density depends on the fraction of the waste and density of individual waste. Table.21 gives proximate analysis and ultimate analysis of various components of waste along with physical properties of the waste. [11]

Table.21: Proximate and ultimate analysis of waste components [11]

Waste material	Waste density (kg/m^3)	Moisture content (%)	Inert residue (%)	Calorific value (kj/Kg)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
Asphalt	680	6–12		17100–18400	83–87	9.9–11	0.2–0.8	0.3–1.1	1.0–5.4
Cardboard, corrugated paper box	30–80	4–10	3–6	16375	44.0	5.9	44.6	0.3	0.2
Brick/Concrete/Tile/dirt	800–1500	6–12	99						
Electronic equipments	105		0–50.8	14116.27–45358.28	38.85–83.10	3.56–14.22	7.46–51.50	0.03–9.95	–
Food waste	120–480	50–80	2–8		48.0	6.4	37.6	2.6	0.4
Garden trimmings	60–225	30–80	2–6	4785–18563	47.8	6.0	38.0	3.4	0.3
Glass	90–260	1–4	99						
Leather	90–450	8–12	8–20		60.0	8.0	11.6	10.0	0.4
Metal–Ferrous	120–1200	2–6	99						
Metal–Non Ferrous	60–240	2–4	99						
Municipal solid waste/ biomedical waste	8 7–348	15–40							
Paper	30–130	4–10	6–20	12216–18540	43.5	6.0	44.0	0.3	0.2
Plastic	30–156	1–4	6–20		60.0	7.2	22.8		
Rubber	90–200	1–4	8–20		78.0	10.0		2.0	
Sawdust	250–350			20510	49.0	6.0			0.10
Textile	30–100	6–15	2–4		55.0	6.6	31.2	4.6	0.15
Wood	156–900	15–40	1–2	14,400–17,400	49.5	6.0	42.7	0.2	0.1

Source Tchobanoglaus (1977); Integrated publishing, NAa, b; Engineering tool box, NA; University of technology Vienna, NA; USEPA, NA; Wesset al.(2004); Othman (2008)

Summary

Municipal Solid Waste (MSW) was defined according to USEPA classification. Waste composition was defined for Sri Lankan MSW from literature findings. It was found that Short-Term-Bio-Degradable portion for Sri Lanka was 54.5%.The basis of sorting STBD/LTBD was clearly sorted with degradation time period using literature review findings. Waste characteristics (physical and chemical) were studied.

3. Data Collection & Analysis

3.1 Case studies

3.1.1 Karadiyana WTE Project Case Study

The Colombo South Waste Processing Facility, also known as Karadiyana W2E project is located at the existing government run waste site located Karadiyana Landfill, approximately 2 km from Ratmalana Airport and 15 km central Colombo.[18]

At present the Karadiyana landfill receives waste from as many as 8 local authorities and some of this waste is used to produce compost while the majority is disposed in the open dump. The site though well managed is an environmental hazard to the nearby communities, waterways and air. [18]

Figure.3.1: Waste management Project at Karadiyana [18]

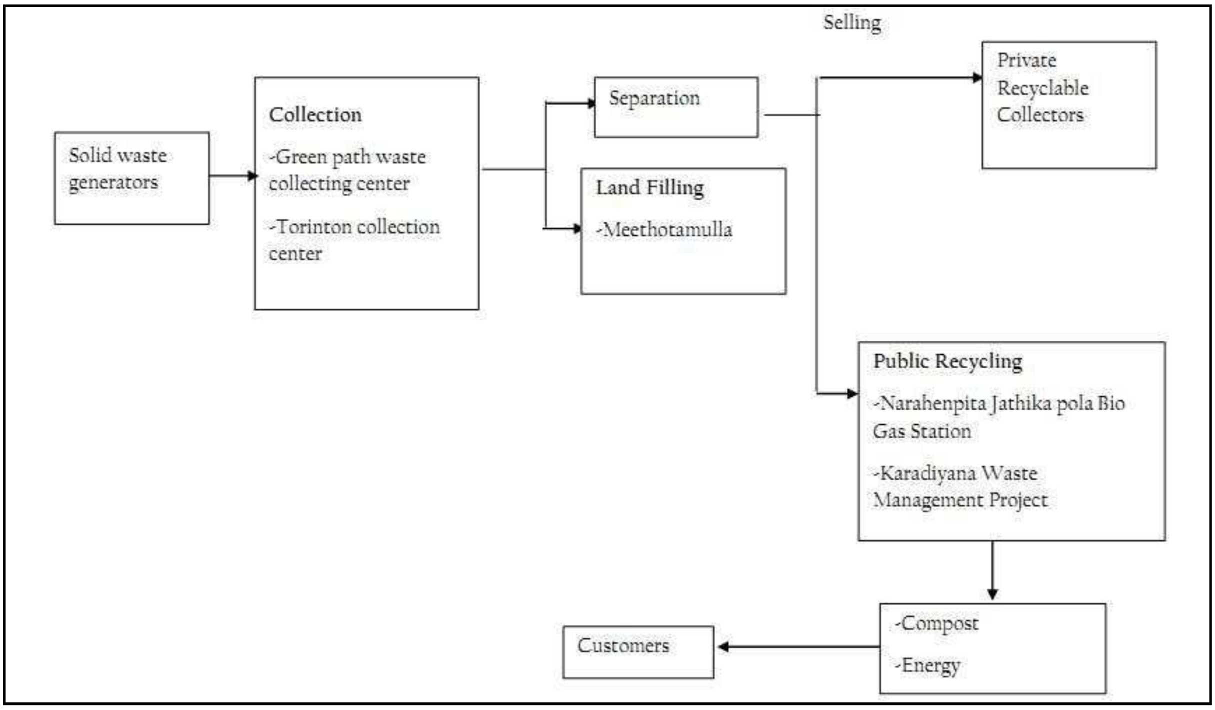


Figure.3.2: SWM process model based on SWM practices in Sri Lanka[9]

A solid waste processing facility is developed to address the roughly 500+ Tons Per Day (TPD) of waste received at the site. This will be an integrated waste processing facility to process fresh municipal solid waste received at the site. The facility is designed to maximize energy production while having minimum environmental impact by optimizing the recovery of energy and nutrients in the waste stream. The processing facility will reduce the amount of waste diverted to landfills by as much as 80% by mass and 90% by volume, whilst the fraction, which will be disposed in a suitably prepared landfill is mostly inert with no ill effects on the environment. [18]

The design consists of a biological treatment plant that will process the fast degradable, high moisture content organic waste in a wet fermentation anaerobic digestion system. This system will treat a maximum of 140 TPD of degradable organic waste per day. The remaining waste will be diverted to an incinerator facility having a capacity of 500 TPD. [18]

- The project will generate a total of 83,000,000 kWh of electricity per year. This is sufficient to supply the demands of 40,000 households (World Bank per capita energy use in Sri Lanka).[18]
- The plant will generate liquid and solid fertilizer from the biological treatment of the organic fraction of the waste. 40,000 tons/year of liquid

fertilizer, which will be processed to a high quality bio-fertilizer for the local market.[18]

- The incinerator bottom ash generated in the incineration process can be used as a secondary amendment to the rapidly expanding construction industry in thecountry.[18]

(a) Mass burn Incineration

Mass burn incineration is the most widely used and the oldest end-of-the-pipe waste disposal method in the world. Mass burn incineration today an environmentally friendly (in comparison to open dumping), widely accepted waste treatment method presently. Similar plants are found in every major city in the world, London, Paris, Copenhagen, Tokyo, Beijing, Shanghai Singapore etc. where it is difficult or impossible to transport waste a great distance from the source. [19]

The technology consists of a mass burn incineration with energy recovery boiler and an advanced flue gas cleaning system meeting European Union emission standards. The incinerator is a moving grate type with a four-stage heat recovery boiler. The flue gas cleaning system will assure that the emissions exceed the standards required in the country and will meet EU2010 emission standards. The plant will be designed taking to consideration the recommendations and guidelines of the Waste Incineration Directive used in the European union. International consultants, COWI of Denmark and Deltaway Energy BV of Netherlands are used in designing the plant. [19]

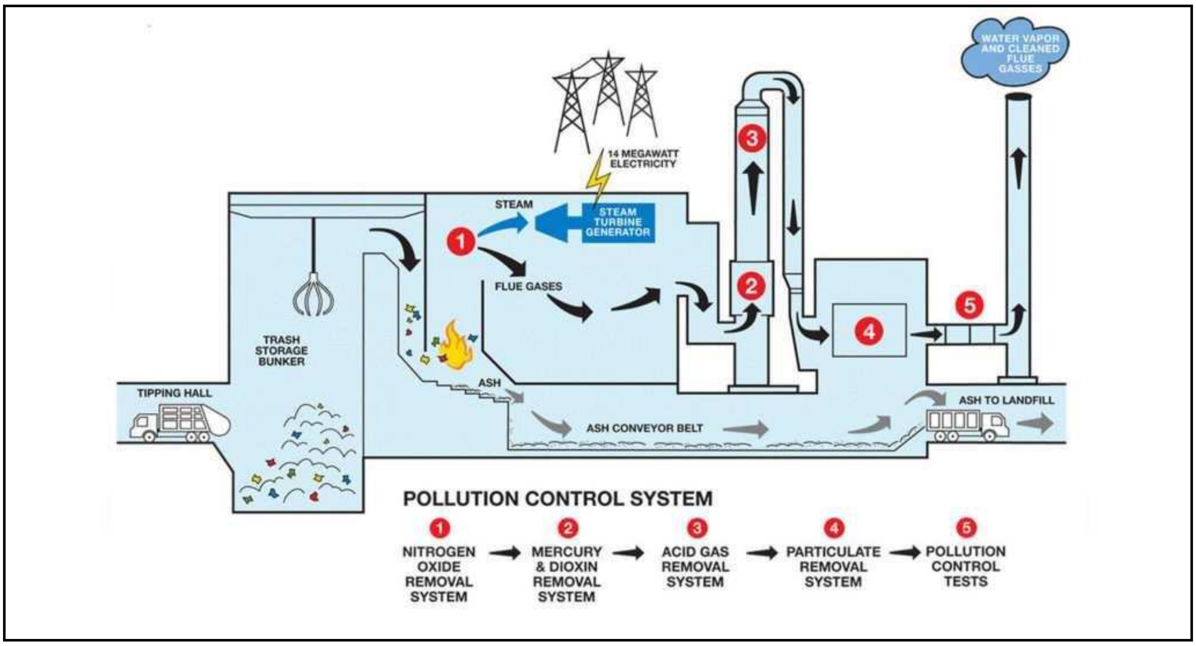


Figure.3.3: Proposed Mass Burn Incineration Plant[19]

(b) Biological Processing

Biological process has been incorporated to treat the organic fraction of waste that is separated at the households (at source). This process allows for the recovery of not only energy but also nutrients in the waste stream. [20]

The decomposition of organic matter in the absence of oxygen is called anaerobic digestion. Anaerobic decomposition is a naturally occurring process that produces biogas-containing methane (natural gas) as a by-product. In fact, anaerobic decomposition is an ongoing process deep in the Karadiyana landfill, which produces biogas. Biogas consists of methane, CO_2 and water vapour. Methane is also known as natural gas that escapes in to the atmosphere where it acts as a potent greenhouse gas. However, if the process is controlled and the biogas is collected it can be combusted to produce electricity. The largest and most advanced anaerobic digestion system will be installed in Karadiyana to treat as much as 40,000 tons of organic waste per year. It will produce approximately11000000kWh electricity per year. Additionally, as a by-product, the plant will produce 40,000 tons/year of liquid fertilizer and 7500 tons/year of solid fertilizer. [20]

The plant will be built by Xergi of Denmark, which is currently the largest biogas producer in the world. [20]

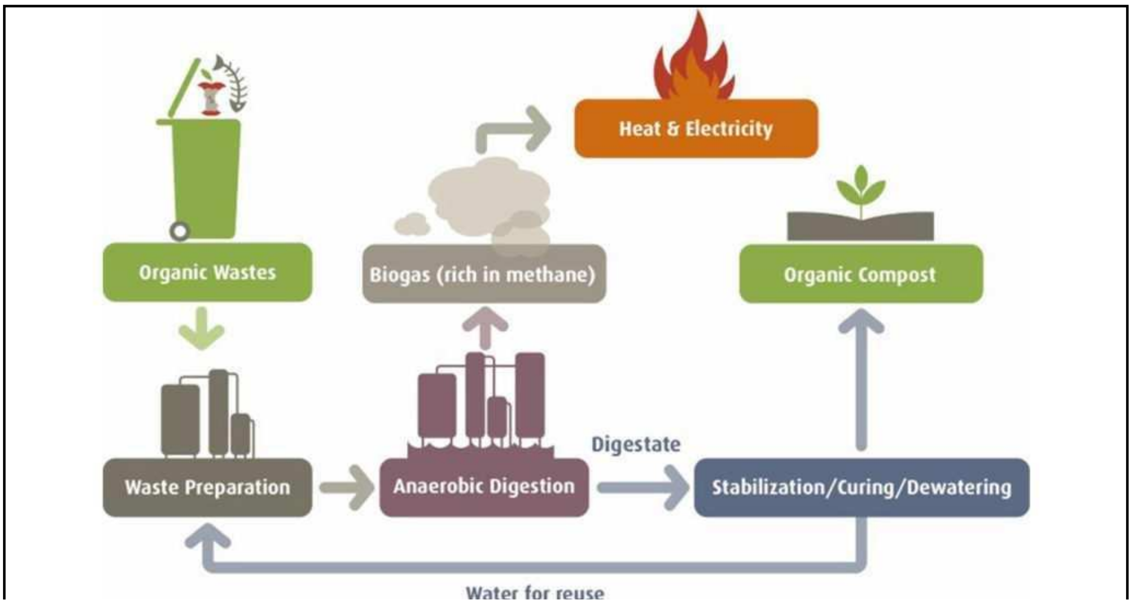


Figure.3.4: Proposed Biological Waste Processing Plant [20]

3.1.2 Kandy MC Case Study

Kandy municipal council was selected as representative case-study for the country. The composition of MSW in the Kandy municipality is quite similar to that of the average MSW in Sri Lanka. Also, the collection, transportation and final disposal practices are quite similar all over Sri Lanka. Furthermore, as a deep dumpsite, the Gohagoda dumpsite in Kandy can be considered representative of most of the legal dumpsites found in major cities of Sri Lanka. With 110,000 persons living within municipal limits, Kandy is the second largest city of Sri Lanka, and is located in the Central province of the country. At present, 110 tons/day of MSW are collected and dumped at the Gohagoda dumpsite, which is located three km away from Kandy's City Centre. Kandy is one of the main commercial and developed cities, and waste generation has been increasing rapidly within the Kandy Municipality. For instance, in just three years, MSW generation rose rapidly from 100 tons/day in the years 2006–2007to110 ton/day. The biodegradable fraction represents the largest share of the waste and is an important contributor to methane emissions under tropical climatic conditions. [14]

(a) Composition analysis of municipal solid waste

Around two tonnes (3.4 m^3) of MSW was collected from different waste streams based on actual quantities from the Kandy Municipality and composition was analysed. MSW was separated as combustibles and non-combustibles. Weights of different types of waste such as food waste, garden waste, wood, polythene, cardboard, paper, glass, plastic, rubber, metal, textile and leather were measured. [15]

MSW composition could vary from place to place according to the location, population density, income level and social background (Wang and Nie, 2001). The composition of MSW collected in the Kandy Municipality is shown in Figure 3.5.

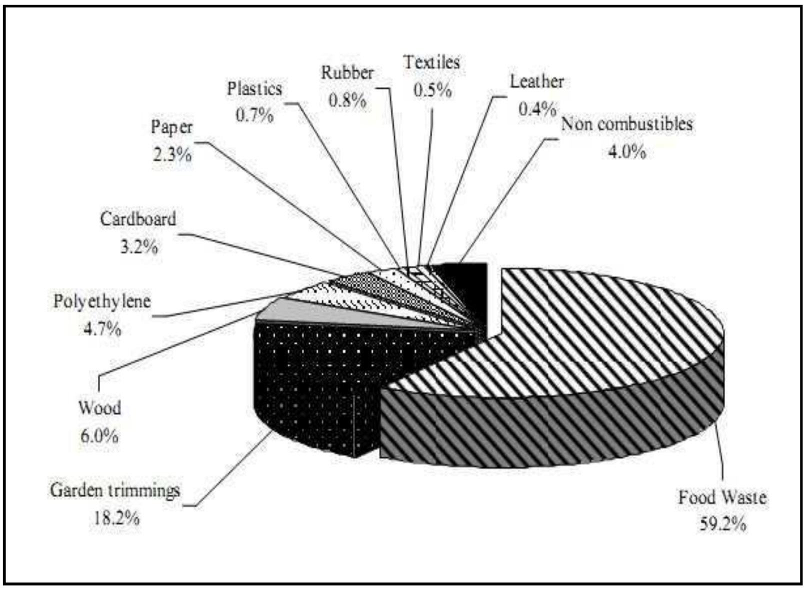


Figure.3.5: Composition variation of municipal solid waste in Kandy municipality. [15]

The results indicate that WTE technology has very high potential as the waste streams consists more than 95% of combustible materials and it could be one of the best options to avoid large quantities, especially organic wastes ending up in landfills and open dumps (Chee et al., 2005). According to the composition, food waste was the highest fraction and contained more than 60% of water in weight basis, which is the core factor for variations in calorific values. [15]

Modified Dulongmodel:It can be applied to all types of wastes and modified Dulong (Eqs. 8 and 9) has been used by Tchobanoglous*et al.* (1993) for finding High Heating Values (HHV) of solid waste. [15]

Calorific Value Superior (CVS) (kJ/kg) =337C+1428(H-O/8) +95S …… (8)

Calorific Value Inferior (CVI) (kJ/kg) = CVS-2465(W+9H) …………… (9)

Where, C: Carbon %, H: Hydrogen %, O: Oxygen % S: Sulphur %,
W: Mass of water

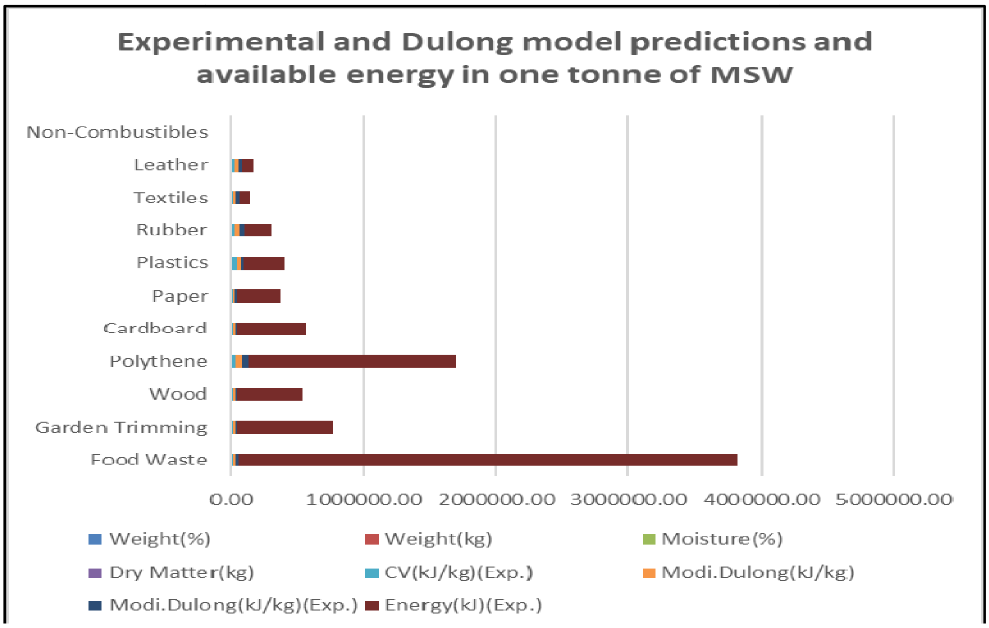


Figure.3.6: Experimental and Dulong model predictions and available energy in one tonne of Municipal Solid Waste. [15]

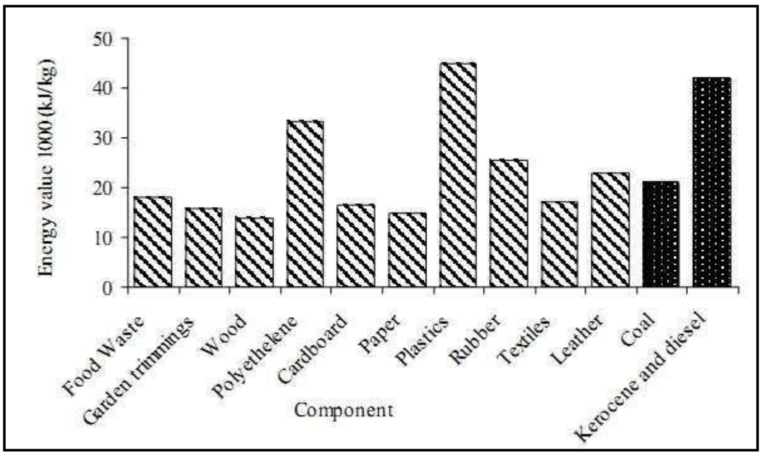


Figure.3.7: Calorific values of some fossil fuels and different types of municipal solid waste. Note: Source: for energy value of Coal and Kerosene; Kandpal.et al. 1994.[15]

Elemental ratios for different waste types were obtained from Tchobanoglous*et al.* (1993) and applied directly to obtain the calorific values. Carbon content of MSW was found to be approximately equal to the Volatile Solid (VS) content/1.8. It could be validated with similar ratios for VS and Carbon percentages that have been reported in literature for MSW (Themelis*et al.*, 2002). [15]

Safizadeh model:Similar to the application of modified Dulong model, two sets of carbon values were obtained from reported values (Tchobanoglous *et al.,* 1993) and deduced values based on VS/1.8 (Eq. 10). [15]

Heat of Combustion at 298K in kJ/kg = (94.19 x C%+55.01) 4.187 …… (10)

Modified Safizadeh model:Both of the models with four sets of values differed with the experimental calorific values. Thus, the model developed by Safizadeh (1981) was modified.

It was derived by regressing experimental values of carbon percentages with the bomb calorimeter values. It could also be expressed in terms of VS% of wastes.

Heat of Combustion at 298K in kJ/kg = 202.02 x C% + 9197.3 ……… (11)

Even though Modified Shafizadeh equation (Eq. 11) predicted best for naturally built biodegradable wastes, notable differences were identified in plotting with structurally modified biodegradable wastes like paper and card board. These deviations were similar to once encountered in analysing non-biodegradable wastes. Therefore, predictions were difficult and inaccurate with the existing and the modified models. [15]

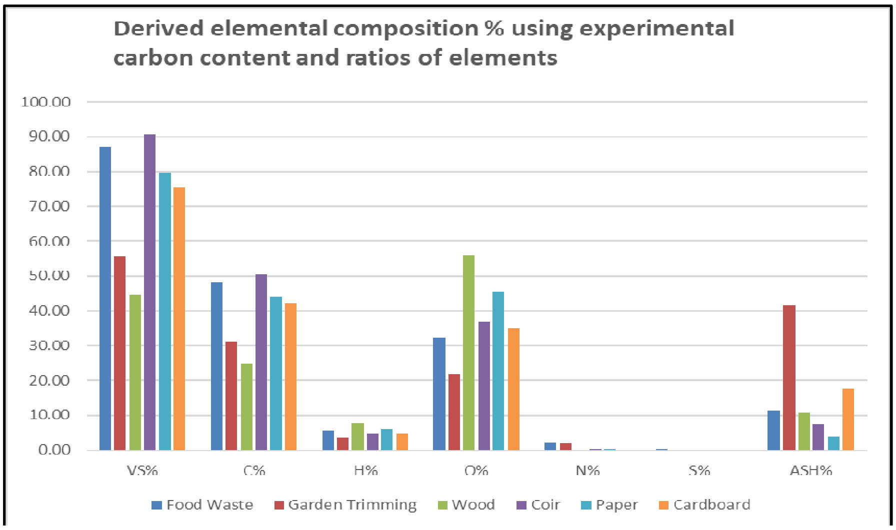


Figure.3.8: The derived elemental composition percentages using experimental carbon content and ratios of elements given by Tchobanoglous et al (1993). [15]

(b) Calculation of energy potential

According to the composition of MSW, energy components of different wastes were determined using dry matter amounts and the calorific values. Energy values for each type of waste were summed up to obtain the total (gross) energy in one tonne of MSW. The annual energy production potential was estimated based on daily waste generation and the value was compared with annual energy consumption level at present. [15]

(c) Gross energy content in municipal solid waste from Kandy municipal council

Apart from the usefulness of comparing models, the experimental values were used to deduce the gross energy content of one tonne of MSW. The individual energy contents of different types of wastes and the gross energy contents are given in Table 25. It is apparent that the moisture contents of waste played a crucial role in reducing the energy values. It is noteworthy that although food waste retained the highest moisture content of 65%, amounted to 59% of composition that produced 41% of the total energy. In comparison, 4.7% of polyethylene, relatively a very small quantity released under experimental conditions 17% of the total energy. A considerable energy content of the gross value of 9.12 GJ/t of MSW will be lost if the water will be allowed to evaporate in a thermal power plant without it being condensed. Thus the gross value will be reduced to an inferior calorific value by an amount of 2465 (9H+W) where H: Hydrogen% and W: Moisture%. Further 25% will likely to be ravaged as system losses in most power generation plants, including biochemical processes of WTE. However, biogas production systems in integration with Residual Derived Fuels (RDF) can reduce the expected initial losses in dehydrating the wastes for thermal systems, unless the thermal systems are closed looped (Chee et al., 2005). Therefore, energy potential for consumption is 6.84 GJ/t of MSW. [15]

(d) Energy potential and consumption in Kandy

In analysing further this numerical value, the total energy potential would be 684 GJ/day in Kandy municipal limits. Thus total usable energy generation possibility is 69.3 GWh/yr. It will satisfy 15% of the present energy demand of the 110,000 persons living within the Municipality. The reported maximum per capita energy consumption rate is 5000 kWh/yr. (EEDRB. 2005), leading to annual total of 440 GWh. On the other hand, per capita maximum electricity consumption rate in Sri Lanka is 300kWh/yr. (EEDRB. 2005). Based on that, 33 GWh of power is required per year and it is half of the energy production potential from MSW. Therefore, application of WTE concept is an appropriate and cost-effective method for supplementing energy requirements in Kandy. [15]

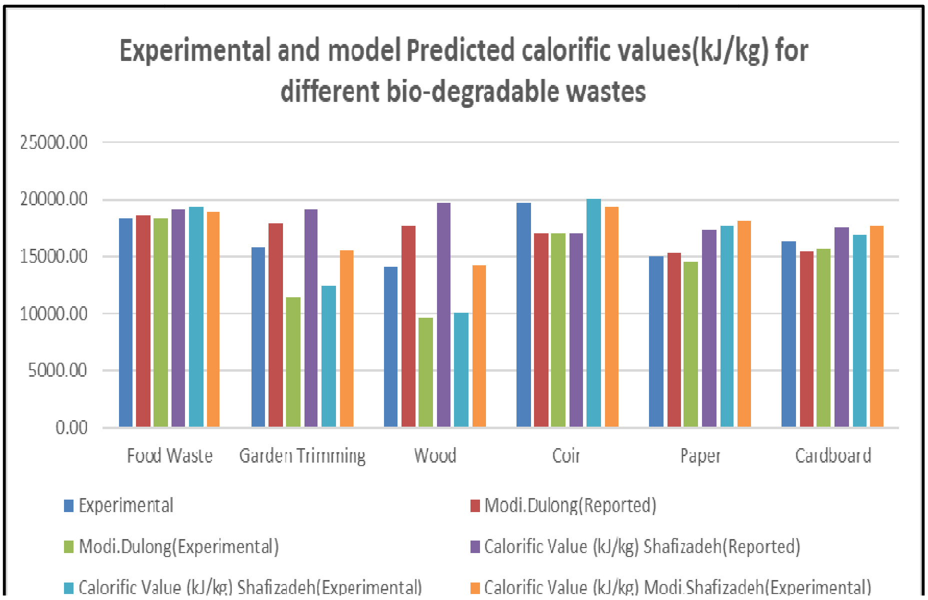


Figure.3.9: Experimental and model predicted calorific values (kJ/kg) for different type of biodegradable wastes. [15]

3.1.3 Kurunegala MC Case Study

(a) Waste amount and Waste composition

The waste amount in the Kurunegala MC is calculated by the waste generation unit of each source mentioned in the SWM Action Plan (2008) by the NSWMSC and the waste generation number of each source collected by the local survey in this project. As a result, the total waste generation unit in the Kurunegala MC is 1.84kg/person/day.[10]

Table.22: SW generation amount in the Kurunegala MC [10]

Source		Generation rate		Generation sources	Generation (ton/day)
Residential	Collection	0.25	Kg/person/day	25,571	6.49
	Non-collection	0.25	Kg/person/day	522	0.13
Commercial	Hotels (large)	51.90	Kg/(hotel)	0	0.00
	Hotels (middle)	25.95	Kg/(hotel)	10	0.26
	Hotels (small)	9.65	Kg/(hotel)	38	0.37
	Restaurants (large)	69.20	Kg/(restaurant)	0	0.00
	Restaurants (middle)	43.25	Kg/(restaurant)	14	0.61
	Restaurants (small)	9.65	Kg/(restaurant)	126	1.22
	Organic-shops (large)	207.60	Kg/(shop)	1	0.21
	Organic-shops (middle)	25.95	Kg/(shop)	18	0.47
	Organic-shops (small)	9.65	Kg/(shop)	71	0.69
	Non-organic shops (large)	43.25	Kg/(shop)	8	0.35
	Non-organic shops (small)	9.65	Kg/(shop)	762	7.35
Institutions	Schools	70.28	Kg/(school)	55	3.87
	Hospitals	202.85	Kg/(hospital)	27	5.48
	Public office	9.65	Kg/(institution)	280	2.70
	Bank/Private office	19.04	Kg/(institution)	20	0.38
	Buddhist temples	17.30	Kg/(temple)	13	0.22
	Hindu temples	17.30	Kg/(temple)	6	0.10
	Mosques	17.30	Kg/(mosque)	5	0.09
	Churches	17.30	Kg/(church)	10	0.17
Industries	Large	1,490.8	Kg/(industry)	3	4.47
	Domestic	8.65	Kg/(industry)	302	2.61
Market		649.30	Kg/market	3	1.95
Port		-	Kg/port	0	0.00
Drainage		745.40	Kg	7	5.22
Recyclables		382.43	Kg	7	2.68
Total					48.07
Population					26,093 person
Total waste generation unit					1.84 kg/person/day

Source: SWM Action Plan (2008), NSWMSC

Waste composition in the Kurunegala MC is referred to in the survey results in the SWM Action Plan (2008) by the NSWMSC. The result revealed the ratio of organic waste composed of kitchen waste and grass & wood occupies less than 70%, on the other hand, the ratio of recyclable waste composed of paper, textiles, plastic, metal and glass & bottles occupies close to 30%, which is the urbanized waste composition. [10]

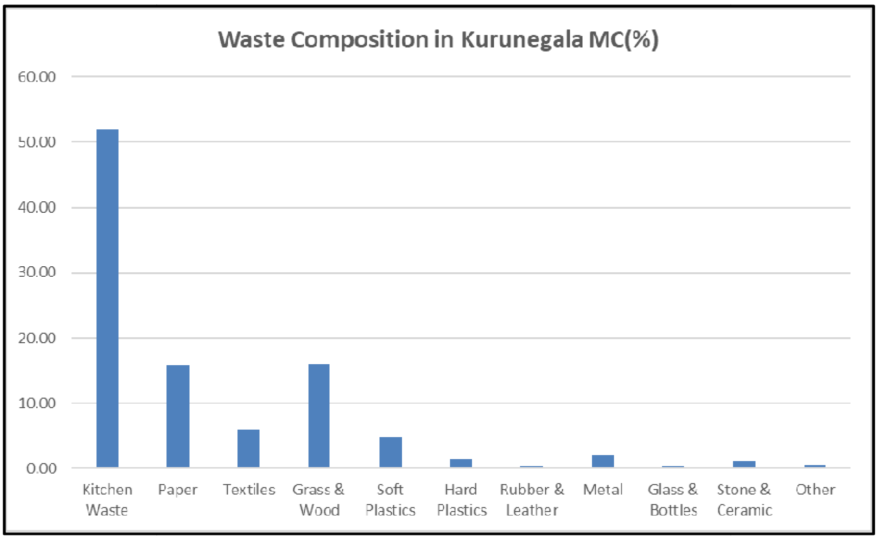


Figure.3.10: Waste composition in Kurunegala MC [10]

3.2 Composition Survey at Karadiyana opendumping site

The composting plant operates at Karadiyana is not capable of using use all the categories of wastes. And also some sides of elevated dumping areas slip and crack. Hazardous and poisonous elements leach down to the ground water and contaminate the water bodies around. Ultimately, a little portion of waste is recycled at Karadiyana dumping site which won't be sufficient of preventing the site is been unusable. Open dumping method become unsuccessful when there are no any measures to reduce waste. [23]

Following are some waste reduction methods used in the fields of waste management.

3.2.1 Burned in open pits

In this method, municipal solid waste disposal has been conducted by disposal on low-value lands where the wastes were burned in open pits. [23]

3.2.2 Sanitary landfills

Sanitary landfills differed from the open-pit burning and disposal since burning was no longer allowed and each day's waste was covered with a thin layer of soil. This soil layer was designed to reduce, but not necessarily eliminate releases of odour and prevent vermin from entering into the waste.[23]

3.2.3 Development of the Sanitary Landfill

Burning was stopped and a few inches of soil was placed over the waste at the close of each day. When the landfill became full, some additional soil was placed over the landfill to grade the landfill surface. Sometimes these closed landfills were then used for parks, industrial/commercial development and other purposes. [23]

3.2.4 High pressure (>7 kg/cm^2compaction)

Compact systems with a capacity 7 kg/cm^2 up to 351.5 kg/cm^2 or 5000 lb/in2 come under this category. In such systems, specialized compaction equipment is used to compress solid wastes into blocks or bales of various sizes. When wastes are compressed, their volume is reduced, which is normally expressed in percentage and computed by equation (Ramachandra, 2009)[23]

Volume of waste before compaction, m3 $=V_i$

Volume of waste after compaction m3 $= V_f$

Volume reduction % ` $= (V_i-V_f)/ V_i *100$

The compaction ration of the waste is given as,

Compaction ratio $=V_i/V_f$

After having a comprehensive interview with the professional related with the Karadiyana dump site, the history of dumping site, present waste management method and previous researches related to the Karadiyana dumpsite were discovered. After the initial survey, twenty-five samples were collected from the selected area in the dumping site. There in the dumpsite a particular place had been allocated for dumping of Easily Bio degradable waste and other places contained mixed MSW. These mixed wastes contained, long term Biodegradable, Cotton, Nylon, Plastic, Polythene, PVC, Rubber, News Paper, Cardboards, Sponge /Regiform, Construction Demolitions, Glass and Easily Bio degradable. With the survey of the previous researches done in the field it was realize that more than 7 kg/cm^2 compaction effort is required for the compaction test. And also, the compaction ratio of the samples was measured. [23]

By using the laboratory condition for compaction, compaction ratio was measured. The tensile testing machine was prepared for testing (Figure 3.11). The tensile testing machine, concrete mould and mechanical attachment were used for this compaction test. MSW Samples were collected from May to September in 2015. Twenty-five samples were collected during that period. These collected samples were brought into Civil Engineering laboratory, KDU for testing. Compaction test was done for mix sample as well as sample separated by categories. Laboratory testing was done using the method below. [23]

Figure.3.11: Tensile testing machine, concrete mould and mechanical attachment [23]

- Mould was fixed accordingly.
- Initial weight of sample was recorded.
- Mould was filled with sample and compressed by tensile testing machine.
- Compressed height and load were recorded. This compression work was done
- until the mould fill with compressed sample
- Mould was removed and sample cube was collected as shown in Figure 3.7.
- Volume and weight of cube were recorded.
- Moisture content (%) and compaction ratio were calculated.
- The same process was followed for all samples.

Figure.3.12: Compacted MSW Sample[23]

After the laboratory testing, graph content compaction ratio variations with waste type, moisture content and soil content were plotted. Variation of compaction ratio was recognized with waste type, moisture content and soil content by using graphs. According to the recognition of compaction ratio, the optimum one was found. [23]

These optimum compaction ratios are able to be used for the calculation of volume reduction in Karadiyana dumping site. Volume of the landfill after the compaction and the volume reduction of total dumping site after the compaction will have to be calculated using compaction ratio and approximate volume of the dumpsite.[23]

(a) Composition of the sample

Samples were separated into categories and weighed. The total average weight of each category was calculated using those weights. According to the results, the normal composition of a sample is shown in the Table 28. [23]

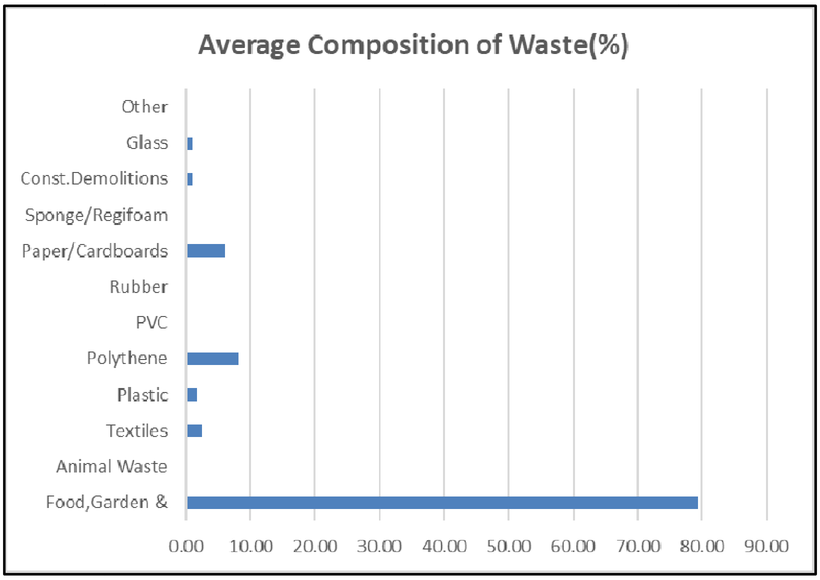


Figure.3.13: Average composition of Waste [23]

(b) Mixed sample test results

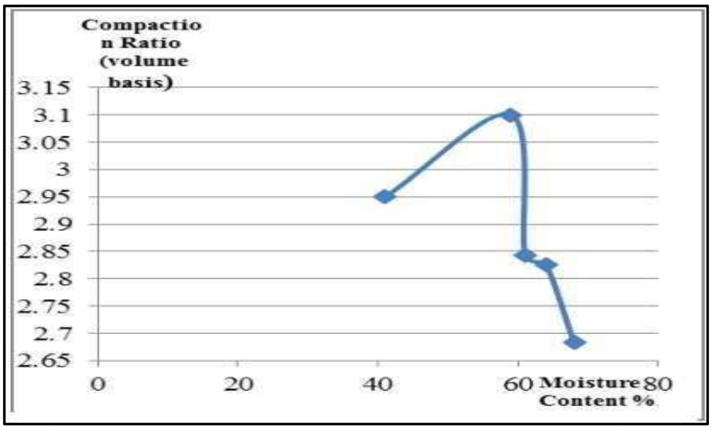


Figure.3.14: Compaction ratio variation moisture content in Mix sample[23]

Other than moisture content, particle size distribution of the collected samples directly affected to the variation of the compaction ratio. Normally, the compaction ratios varied in between 3.1 to 2.68. Moisture content in mix sample varied in between 41% to 68%. Percentage of Food, Garden and Animal waste affected to the moisture content stay in this range. [23]

According to the figure;

- Optimum moisture content is 59%.
- Maximum compaction ratio is 3.1.

(c) Paper, cardboards test results

According to the composition of the sample, Paper, Cardboards percentage is 6.07%. Moisture content is varied in between 4.5% to 11%. Other than moisture content, type of paper directly affected to this high variation of the compaction ratio. Optimum moisture content is 7.7%.Maximum compaction ratio is 5.7. [23]

(d) Textile sample test results

According to the composition of the sample, textiles percentage is 2.55%. Textile contents nylon and cotton. Compaction ratio changes according to the percentage of nylon and cotton in the textile, other than the variations in moisture content. Content of nylon and cotton affected to the compaction ratio changes, Optimum moisture content is 29%. Maximum compaction ratio is 4.19. [23]

(e) Plastic test results

According to the composition of the sample, plastic percentage is 1.59% and small amount of moisture content is in plastics. Other than, the moisture content, hardness of plastic is affected to compaction ratio. Plastic in dumping site have various type of hardness as examples PVC pipes needs a higher compaction compared with a plastic bottle. So the compaction rate changes in a larger range.

It affects this sudden reduction of the compaction ratio. Optimum moisture content is 3.1%. Maximum compaction ratio is 4.8 [23]

(f) Food, Garden & Animal waste

According to the composition of the sample, the maximum percentage of the sample is Food, Garden and Animal waste. The variations of the compaction ratio after mixing soil with the samples in different ratios, compaction ratio varied in between 3.6 to 4.6 and soil content varied 10% to 50%.Optimum soil content is 19%. Maximum compaction ratio is 4.6. [23]

(g) Comparison of mixed waste and the individual waste

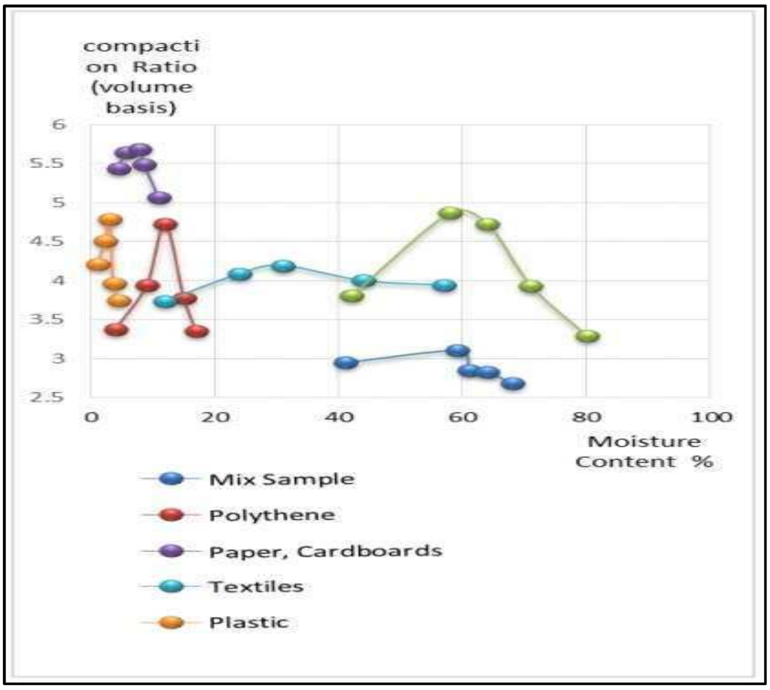


Figure.3.15: Comparison of the mixed & individual MSW[23]

(h) Existing volume at the open dumpsite Karadiyana

The volume of dump has been increased by 156678 m^3 according to volume calculation of Karadiyana management during last five years. Considering both values, the approximate volume is 686179 m^3.[23]

1) Karadiyana dumpsite compacted as mix sample,

- Approx. volume in Karadiyana dumpsite = 686179 m3
- Maximum compaction ratio in mix sample = 3.1
- Compacted volume = 686179/3.1 = 221348 m3
- Volume reduction = 686179-221348 = 464831 m3

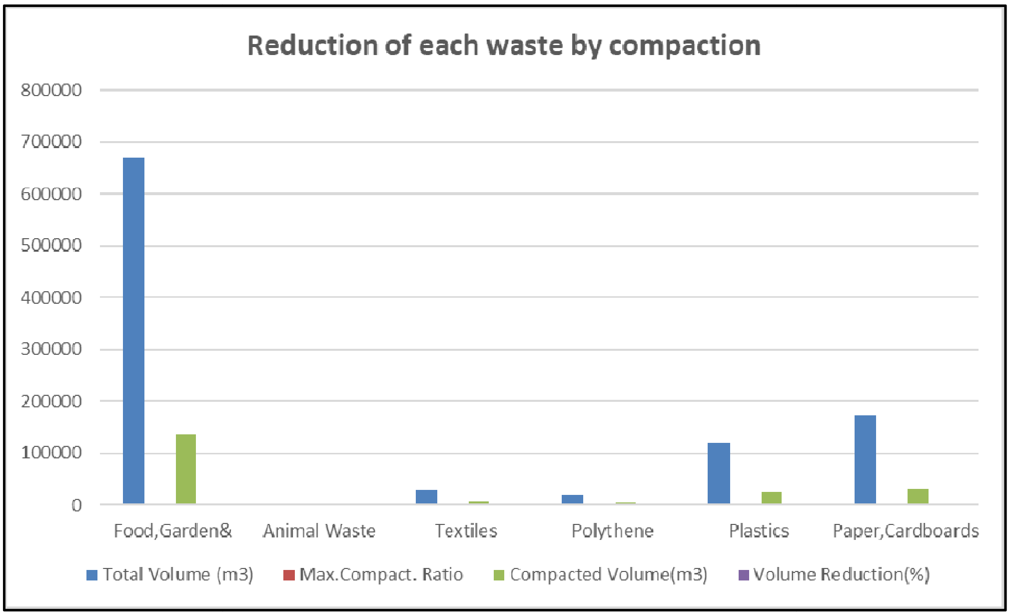


Figure.3.16: Reduction of each waste by compaction [23]

Among the two methods above, maximum reduction in the compacted volume can be achieved by separating samples into categories before compaction, but there is not a big difference in both results. [23]

- Compacted volume in mix sample is 221348 m^3
- Compacted volume in sample separating category is 203292 m^3 -Volume difference is about 18056 m^3.

Considering Karadiyana dumping site, this volume is not large. Therefore, both methods are acceptable but sample separation is rather a difficult task in a site like this. High technology and labour force are needed. When considering that factor into the account, compaction of the mixed waste rather than separating into categories is suitable. [23]

There is ability to compact dump after separating them into categories. And also there is ability to separate the waste as polythene, plastic, paper, glass and metal and those categories can be used for recycling process. 79.25% of Food, Garden and Animal waste in Karadiyana dump site can be used as materials for compost production in this research study maximum compaction ratio range 3.1 to 1 through 5.7 to 1. Compaction effect will be increased maximum compaction ratio come to this range. [23]

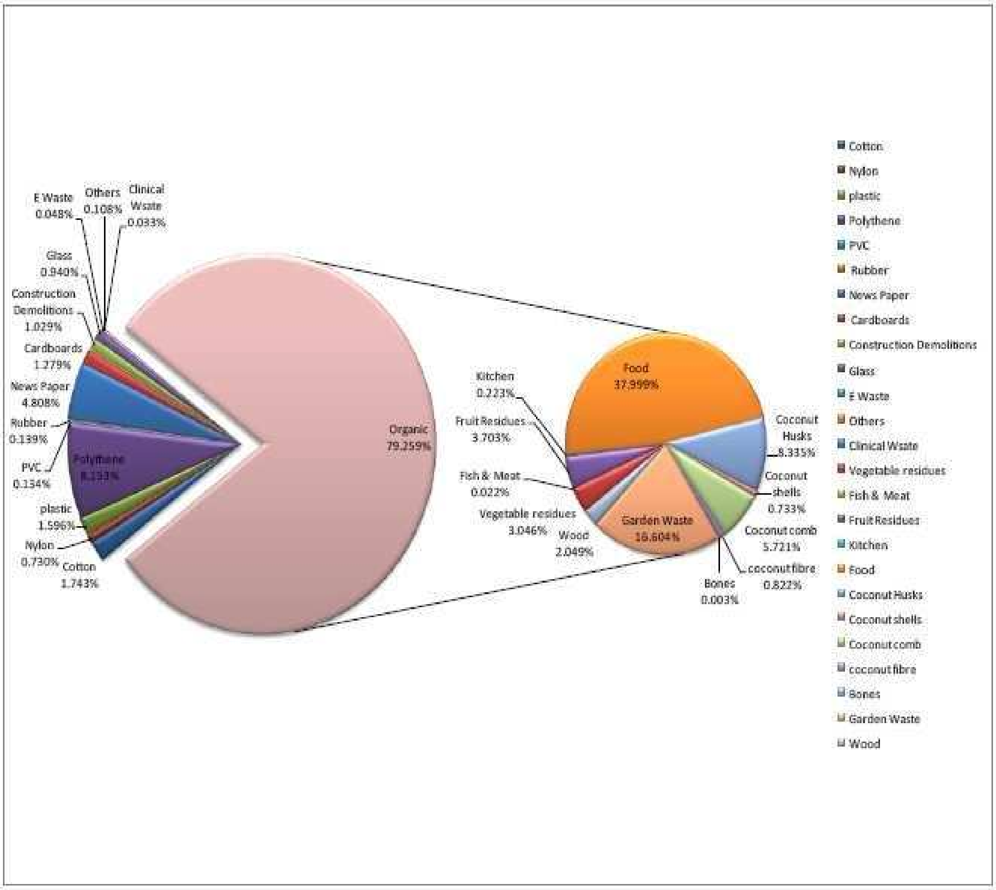


Figure.3.17: Composition of MSW arriving at Karadiyana open dumping

3.3 Composition Survey at Gohagoda dump site under Kandy Municipal Council

Site Location: 1km from Katugastota- Gohagoda road.

Size of the dump surveyed: 120m x 60m x12 ft

Age of the dump: 03 years

Daily MSW Collection: 130tons/day

Total sample size: 0.5625m^3

Samples were taken from the dump covering three different location levels and three samples from each level. The sample measuring box with dimensions 50cm x 50cm x 25cm was used.

Figure.3.18: Sample Box

Samples were collected to normal garbage bags. Weight of the empty sample box and sample weight with sample box was measured. Observations were recorded. Following queries were made with site officials;

- Are there any lands to start Waste to Energy plant near to dump site location? If No, what are the next nearer land locations available?***Yes. 05 acres land***
- How do you collect man power around the location mentioned above?***FromMahaiawa area***
- Is there any machinery available for preparing the land to start the new plant? If Yes, give the nearer locations. ***Yes, 02 Excavators. Kurunegalafeasible.***
- Are there any natural environmental resources / live beings affected by starting WTE plant? If yes, what are they? ***No, 36 acres no living.(Boundary is Mahaweliriver)***

- How about the health facilities available in this area/location? Mention few places of important. ***Katugastota, Gohagoda, Peradeniya Hospitals & KPH***

Figure.3.19: Sample Collection at Gohagoda dump site

According to the information provided by PHI and site officers, following observations were made;

(i) There are three gulley browsers owned to the site having capacity of 13000L.

(ii) The waste from sewerage is 13000L/day. They are treated and disposed to the Mahaweli river with acceptable quality.

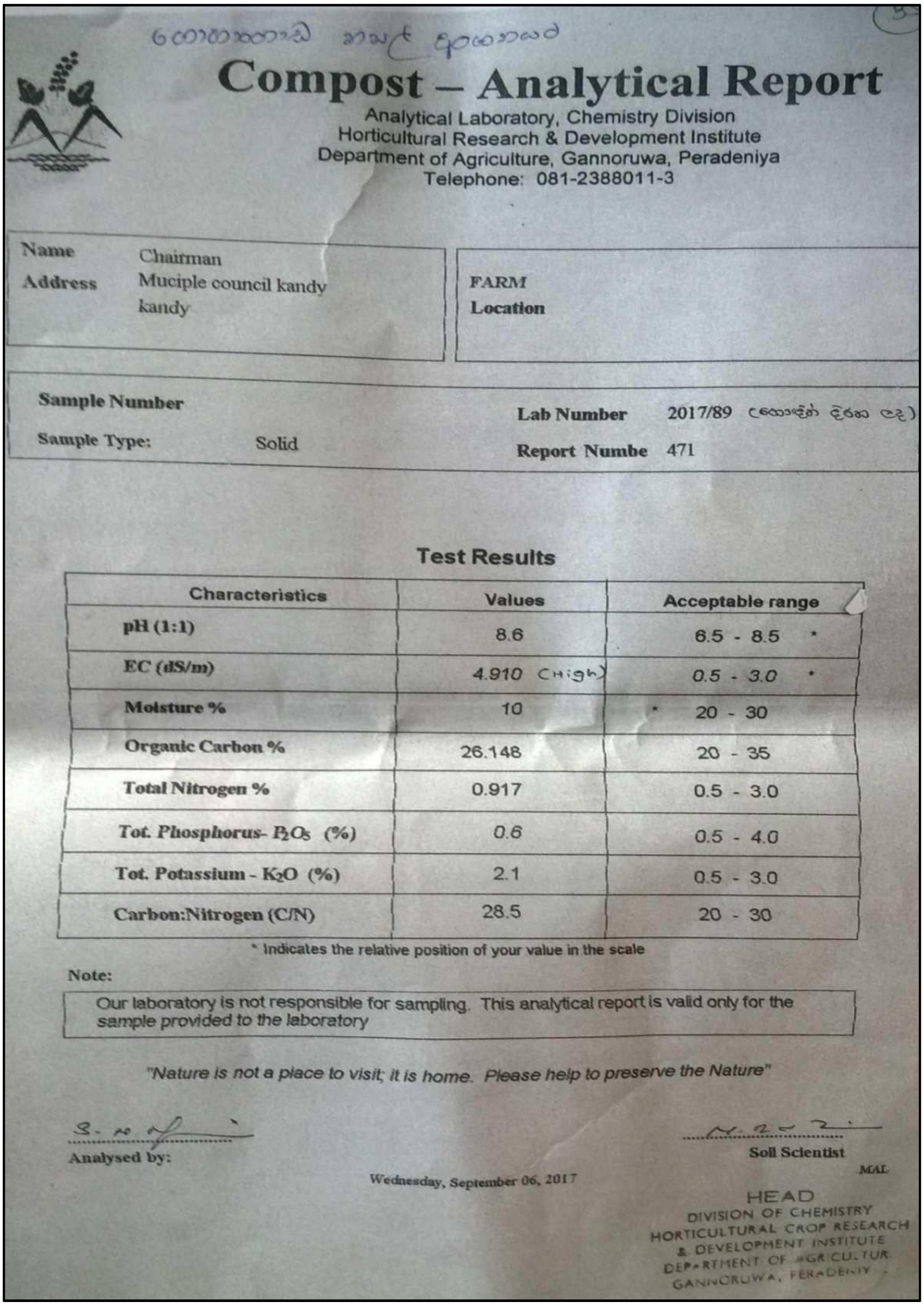
(iii) Separated waste is transported from tractors under Kandy Municipal Council. Separated polythene/plastic is used in recycling plant at the site.

(iv) Food and organic waste (bio-degradable) is dumped on the open dump mentioned above.

(v) Due to high wind blow through the above open dump odour is reasonably reduced.

(vi) Leachate from the dump is sent to the gulley waste collection tank, treated and disposed to the Mahaweli river with accepted quality.

(vii) There is an old open dump converted into Compost Generation Plant as it consists of more bio-degradable fraction.



Compost – Analytical Report

Analytical Laboratory, Chemistry Division
Horticultural Research & Development Institute
Department of Agriculture, Gannoruwa, Peradeniya
Telephone: 081-2388011-3

Name: Chairman
Address: Muciple council kandy kandy

FARM
Location

Sample Number
Sample Type: Solid

Lab Number: 2017/89
Report Numbe: 471

Test Results

Characteristics	Values	Acceptable range
pH (1:1)	8.6	6.5 - 8.5 *
EC (dS/m)	4.910 (High)	0.5 - 3.0 *
Moisture %	10	* 20 - 30
Organic Carbon %	26.148	20 - 35
Total Nitrogen %	0.917	0.5 - 3.0
Tot. Phosphorus- P_2O_5 (%)	0.6	0.5 - 4.0
Tot. Potassium - K_2O (%)	2.1	0.5 - 3.0
Carbon:Nitrogen (C/N)	28.5	20 - 30

* Indicates the relative position of your value in the scale

Note:

Our laboratory is not responsible for sampling. This analytical report is valid only for the sample provided to the laboratory

"Nature is not a place to visit; it is home. Please help to preserve the Nature"

Analysed by:

Wednesday, September 06, 2017

Soil Scientist

MAL

HEAD
DIVISION OF CHEMISTRY
HORTICULTURAL CROP RESEARCH & DEVELOPMENT INSTITUTE
DEPARTMENT OF AGRICULTURE
GANNORUWA, PERADENIYA

Figure.3.20: Compost Analytical Report at Gohagoda Composting Plant

(viii) Polythene /Plastic recycling plant generate different size granules according to the colour of parts to be recycled.

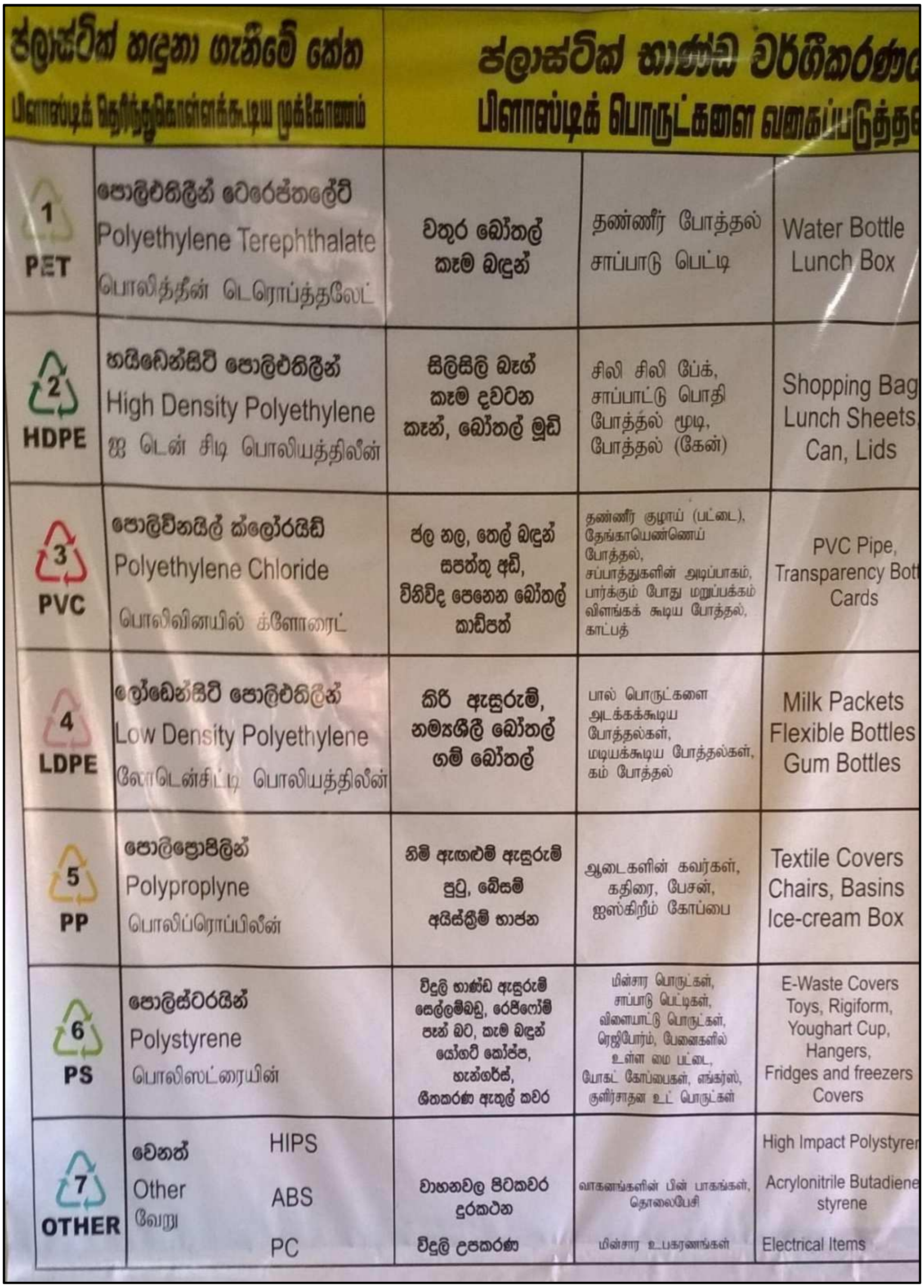


Figure.3.21: Plastic Classification at Gohagoda Recycling Plant

3.4 Composition Survey at Sundarapola dump site under Kurunegala Municipal Council

The Sundarapola dump site is located in Yanthampalawa- Sundarapola road 1.5km from Yanthampalawa junction. This open dump is spread over 12.5 acres. Daily MSW collection is 45-50 Mt/day. Total sample size is 0.5625m^3.Similarly, nine samples were taken from different locations of the open dump. Observations were recorded.

Following queries were made with site officials;

- Are there any lands to start Waste to Energy plant near to dump site location? If No, what are the next nearer land locations available? ***No, No any other lands Nearby rather than dump site (12.5 acres)***
- How do you collect man power around the location mentioned above? ***Inapplicable. But it is possible to collect man power.***
- Is there any machinery available for preparing the land to start the new plant? If Yes, give the nearer locations. ***Yes, Yanthampalawa area.***
- Are there any natural environmental resources / live beings affected by starting WTE plant? If yes, what are they? ***No, Leachate is pumped to gulley tank converting into fertilizer. (20-30m from the dump site living exists)***
- How about the health facilities available in this area/location? Mention few places of important. ***Kurunegala Hospital, Dispensaries and Nursing Homes.***

Figure.3.22: Sample Collection at Sundarapola dump site

According to the information provided by site officers following observations were made.

(i) There is an old open dump converted into Compost Generation Plant as it consists of more bio-degradable fraction.

(ii) Leachate is pumped into the gulley waste tank and converted into fertilizer.

(iii) Therefore, no disposal to the surrounding environment.

(iv) Community is living 20m away from this dump site.

3.5 Analysis the MSW samples for %STBD and %MC

Samples collected to garbage bags (09 each) were sorted for composition analysis. Then separated %STBD fraction (09 each), that was 18 samples of STBD were dried in the hot sunlight for two days. Hence %MC was estimated. The results were tabulated as followed.

Figure.3.23: MSW sorting and drying

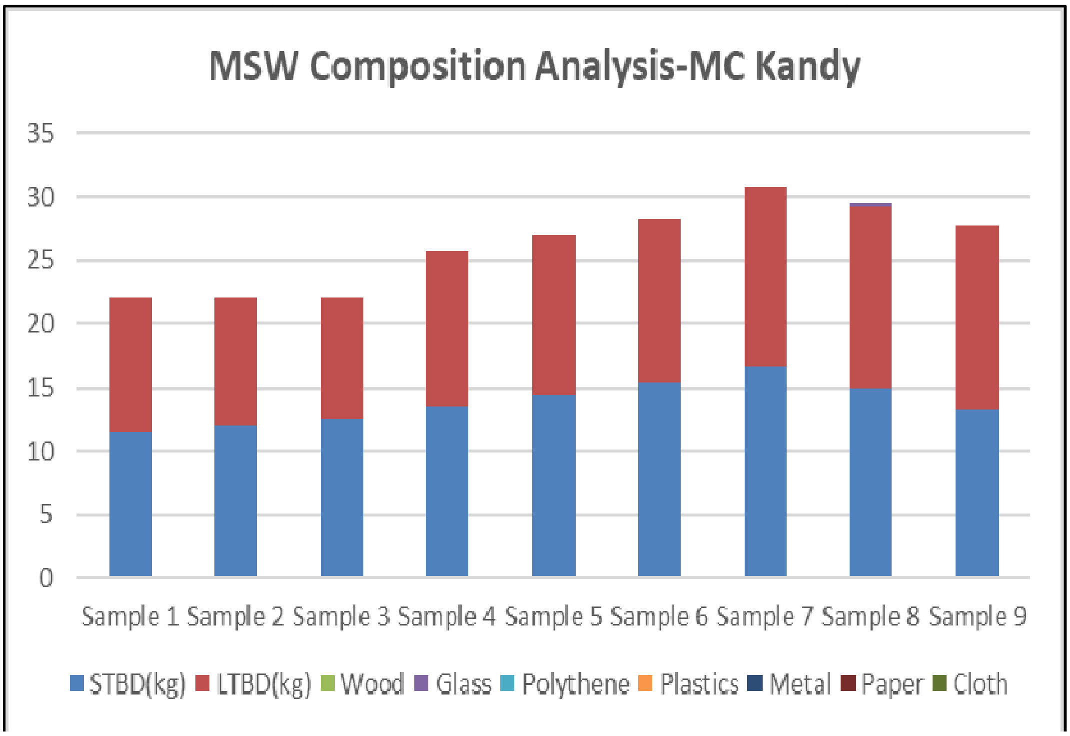


Figure.3.24: MSW Composition Analysis-MC Kandy

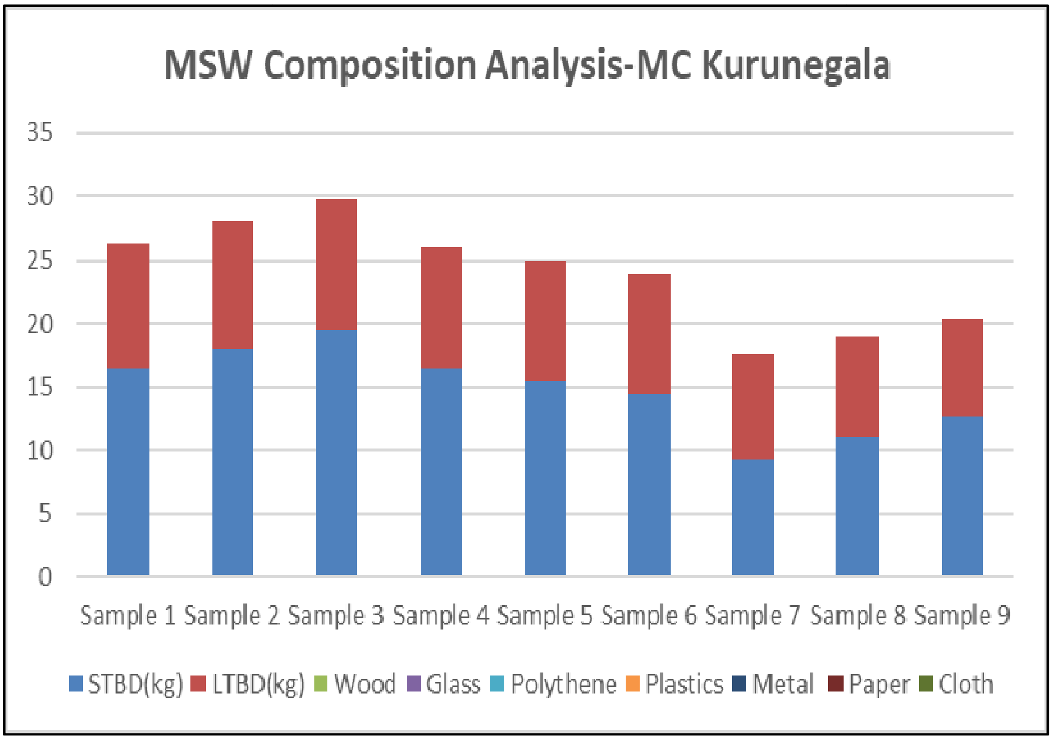


Figure.3.25: MSW Composition Analysis-MC Kurunegala

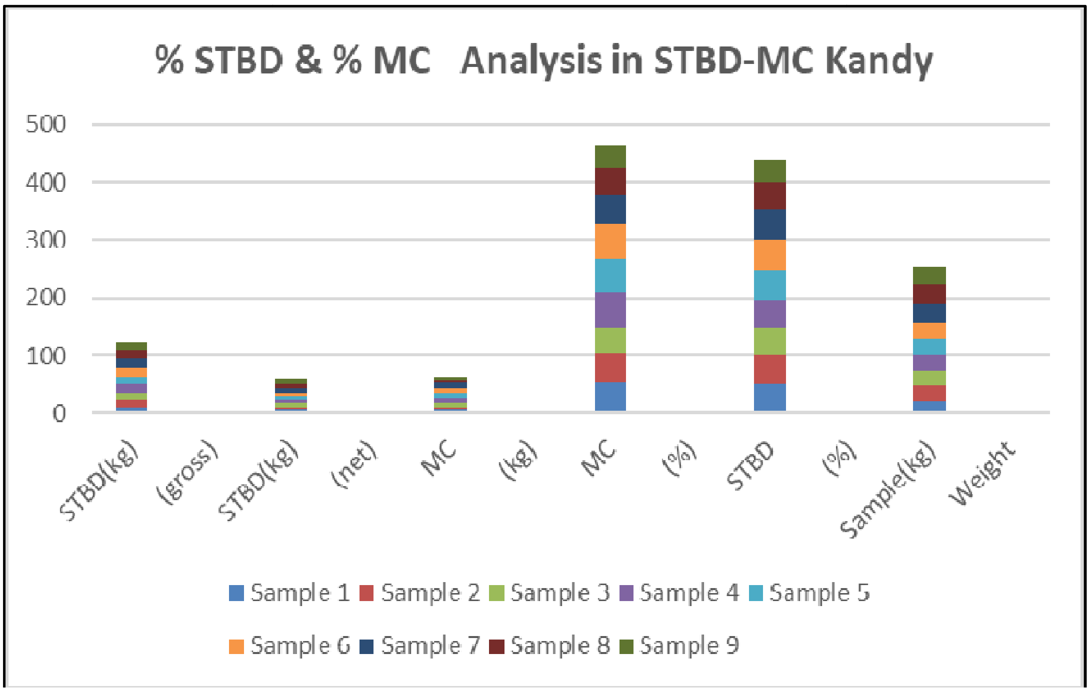


Figure.3.26: % STBD & % MC Analysis in STBD-MC Kandy

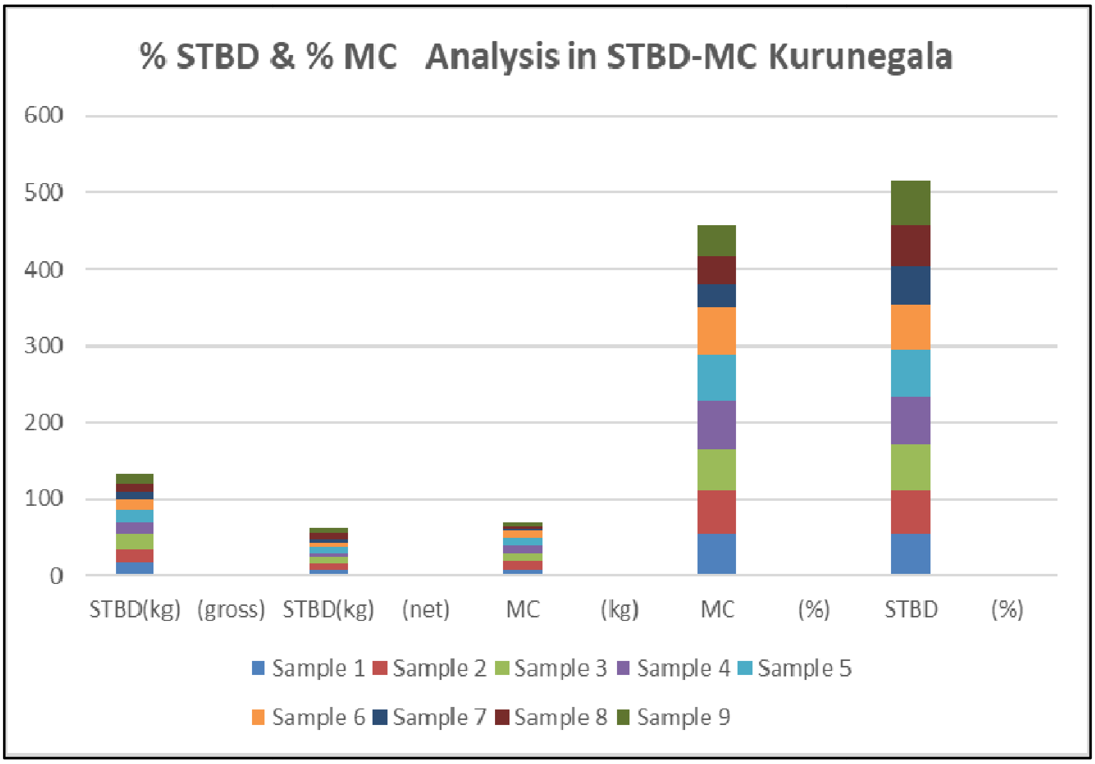


Figure.3.27:% STBD & % MC Analysis in STBD-MC Kurunegala

3.6 Proximate Analysis

Proximate analysis of the waste was carried according to ASTM 3173-3175 Standard methods. It involved the determination of moisture content, volatile matter, ash content and fixed carbon of the solid waste samples from the four dumpsites. 2 kg samples of solid wastes were collected from each dumpsite and taken to Laboratory for analysis. [16]

3.6.1 Moisture content

The moisture contents of the collected solid waste samples were determined using ASTM 3173 method. 1kg of the solid waste sample was placed in a pre-weighted dish and placed in an oven at 105 ^{0}C to a constant weight. [16]

The moisture content was calculated as a percentage as shown in (12):

% moisture content = [(Wet weight – Dry weight)/ Wet weight] x 100………. (12)

3.6.2 Volatile matter content

Volatile matter content was determined by weighting 5g of the dried waste samples and placed in a muffle furnace for 7 minutes at 950^{0}C (ASTM 3175). After combustion, the samples were weighted to determine the ash dry weight, with the volatile matter being the difference between the dried sample and the ash as shown in (13) [16]

% Volatile matter=[(Dry sample weight–Ash weight)/Dry sample weight]x 100%-----------------------(13)

3.6.3 Ash and fixed Carbon content

Ash content of the samples waste was determined by heating the samples in an oven at 750 ^{0}C (ASTM 3174). The residue left after combustion represents the ash content. Fixed carbon was determined by the following (14):

Fixed Carbon (% weight) =100–weight (% moisture content+%Ash + % volatile Matter)... (14)

3.6.4 Calorific Value

The calorific value or lower heat value (LHV) of the municipal waste was determined using proximate analysis models. Proximate analysis models were created based on the weight percentage of volatile matter and fixed carbon. The advantage of using proximate analysis data is that it gives result based on sample sizes and the models do give an accurate estimation of the calorific values (Amin et al, 2011). The model equations for predicting the calorific value of MSW based on proximate analysis are as follows: [16]

$$LHV = 45V - 6W$$ …………….. (15)

Where, LHV: lower calorific value (kcal/kg)

V: combustible volatile matter (%),

W: moisture content (%)

ii. Bento's model

$$LHV = 44.75VM - 5.85W + 21.2$$ ……………………. (16)

Where LHV: lower heating value (kcal/kg)

VM: Volatile matter (%)

4 Results & discussion

4.1 Chemical Composition of STBD fraction

The results obtained from Composition Analysis were tabulated as follows.

Table.23: Result of Composition Analysis (Physical Composition)

Dump Site	% STBD	%MC	Waste Density(kg/m^3)
Gohagoda (MC-Kandy)	48.97	51.6	221.3
Sundarapola (MC-Kurunegala)	57.25	50.86	237.3

Referring Table 24: Physical and chemical composition of Food waste & Garden waste of MSW in Sri Lanka was tabulated below.

Table.24: Physical and chemical composition of MSW in Sri Lanka [14]

Component	MSW composition (%)	Moisture content (%)	Chemical composition (dry basis)						
			C (%)	H (%)	O (%)	N (%)	S (%)	Ash	Chemical formulae
Food waste	59.20	65.00	49.12	5.35	31.43	2.17	0.33	11.59	$C_6H_{7.8}O_{2.88}N_{0.23}S_{0.02}$
Garden waste	18.20	40.00	44.11	4.44	28.11	2.52	0.22	20.60	$C_6H_{7.2}O_{2.87}N_{0.29}S_{0.01}$
Wood	6.00	40.00	43.85	4.30	30.57	0.14	0.07	21.06	$C_6H_{7.1}O_{3.14}N_{0.02}$
Plastics	5.40	0.00	60.00	7.20	22.80	0.00	0.00	10.00	$C_6H_{8.6}O_{1.7}$
Paper	2.30	3.00	47.99	4.56	33.45	0.23	0.15	13.62	$C_6H_{6.8}O_{3.13}N_{0.02}S_{0.01}$
Cardboard	3.20	0.00	45.03	4.17	31.49	0.21	0.14	18.96	$C_6H_{6.66}O_{3.14}N_{0.02}S_{0.01}$
Rubber	0.80	0.00	78.00	10.00	0.00	2.00	0.00	10.00	$C_6H_{9.2}N_{0.13}$
Textile	0.50	0.00	55.00	6.60	31.20	4.60	0.15	2.50	$C_6H_{8.6}O_{2.6}N_{0.43}S_{0.01}$
Leather	0.40	0.00	60.00	8.00	11.60	10.00	0.40	10.00	$C_6H_{9.6}O_{0.87}N_{0.86}S_{0.02}$
Other	4.00								
Total	100.00								

Table.25: Chemical Composition bio-degradable waste

MSW Component	MSW Composition (%)	%MC	Chemical Composition (Dry basis)					
			Ash	%C	%H	%O	%N	%S
Food Waste	59.2	65.0	11.59	49.12	5.35	31.43	2.17	0.33
Garden waste	18.20	40.0	20.10	44.11	4.44	28.11	2.52	0.22

As Gohagoda and Sundarapola dump site %MC is lie between 40%-65%, it is possible to interpolate to find corresponding chemical composition.

Referring Table18: Proximate and ultimate analysis of waste components for Food Waste following standard values could be used to check the experimental values.

Waste density =120-480 kg/m^3

Moisture Content = 50-80%

Inert Residue =2-8%

Calorific Value = N/A

<u>Chemical Composition</u>

C=48.0%, H=6.4%, O=37.6%, N=2.6% and S=0.45.

According to Proximate analysis of the waste according to ASTM 3173-3175 Standard methods explained in equations (1) to (5) of the above study following results could be tabulated.

Table.26: Chemical Composition STBD waste Analysed

Dump site	STBD (%)	%MC	%VS	Chemical Composition (Dry basis)					
				Ash	%C	%H	%O	%N	%S
Gohagoda	48.97	51.6	83.85	16.15	46.43	4.86	29.65	2.36	0.27
Sundarapola	57.25	50.86	83.60	16.40	46.30	4.84	29.55	2.37	0.27

According to Table 07 & Table 02 for both dump sites % STBD satisfy MC>50% Bio-chemical conversion could be selected. But still two parameters are to be checked. That is % Volatile Matter and C/N ratio.

Table.27: Selection of Best Option for Energy Recovery on STBD

Dump Site	% MC	%VM	C/N ratio	Conversion Methods
Gohagoda	51.6	83.85	19.67≈ 20.0	Bio-chemical: Composting Bio-Methanization
Sundarapola	50.86	83.60	19.53≈ 20.0	Bio-chemical: Composting Bio-Methanization

C/N=20 is the best for composting.

Net Power Generation Potential (N.P.G.P) from WTE

Bio-Chemical Conversion [Enzymatic Decomposition] =11.5 * W (metric ton) …kW

For Gohagoda dump site (%STBD: 51.6)

N.P.G.P = 11.5 * 130 Mt/day * 25days/month * 12months * 51.6/100

=231,426kW/year

=231.4MW/year

For Sundarapola dump site (%STBD: 50.86)

N.P.G.P = 11.5 * 45 Mt/day * 25days/month * 12months * 50.86/100

=78,960.15kW/year

=78.96MW/year

From Table 17, according to following also technology option could be selected.

Population range : 100,000-1,000,000

Waste generation : 30-550 TPD

Composition : Bio-degradable (40-55%)

Technology Option : IWP-BM, CC+RDF as feed stock to power plant/Cement Factory

From Table 18, according to specifications for various types of waste processing technologies option could be selected.

Table.28: WTE technology Selection criteria on STBD

Method	**MSW Characteristics**	**C/N ratio**	**Moisture Content**
Composting	Sorted organic fraction of MSW ,preferable with same rate of decomposition	Between25-30 initially. Release of ammonia and impeding of biological activity at lower ratios	55% (optimum)
Bio-methanization	Sorted organic fraction only; Higher the putrescibility, better is the gas yield; fibrous organic matter is undesirable as the anaerobic microorganism do not break down woody molecules such as lignin.	25-30 (preferable)	>50% ; implication on feed, gas production, system type, system efficiency

5 Conclusions & recommendations

In Gohagoda dump site by considering socio-environmental concerns on selected two technologies composting is recommended as there are more old dumps of bio-degradable fraction. But for fresh waste Anaerobic Digestion (AD) is recommended for STBD fraction as there is more moisture content.

In Sundarapola dump site by considering socio-environmental concerns on selected two technologies composting is recommended as there are few dumps of bio-degradable fraction. It has fresh waste dump, Anaerobic Digestion (AD) can be recommended as there is community living nearby to get the benefit of WTE plant (Specially Bio-Gas Utility).

As the country being considered, from different surveys revealed that the short term bio-degradable waste is more (54.5%) and moisture in this portion is more (>50%). As there is no way to treat mixed waste collected in shopping bags an auditing scheme for MSW Processing Centres are recommended.

Therefore, with case studies concerned and country specific considerations Anaerobic Digestion (WTE Plant) with Composting Yard is recommended for processing STBD fraction of MSW.

Sorting of waste at the source need to be established and collected separately. Waste Management Authority (WMA) needs monitoring all the dump sites in the country and regulates their operation. Waste auditing scheme is recommended for Waste Management Centers (WMC) while awarding 'Star' ratings for best waste sorting practices at the source.

It is suggested that the Municipality need identifying urban area, business profile or type of domestic units. For residential units with sufficient land area, self-composting need to be made compulsory allowing benefits to be returned to the community.

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Appendix-I

MSW Composition Survey Sheet

Area: Kandy Date: 08-02-2019

Municipal Council: Kandy

Dump Site Location: Gohagoda-Katugastota

Weight of the empty sample box (y) = 9.4 kg

Volume of the empty sample box = 50x50x25 cm^3= 0.0625m^3

Sample 01

Weight of the sample with box (x_1) = 32.0 kg
Standard sample weight (x_1 - y) = 22.6.kg

Weight of Bio-degradable(Sample 01)

S.T.B.D (Gross)(a) = 184 kg/m^3
L.T.B.D (Gross)(b) = 168 kg/m^3

Sample 02

Weight of the sample with box (x_2) = 33.8 kg
Standard sample weight (x_2 - y) = 24.4 kg

Weight of Bio-degradable(Sample 2)

S.T.B.D (Gross)(a) = 192 kg/m^3
L.T.B.D (Gross)(b) = 160 kg/m^3

Sample 03

Weight of the sample with box (x_3) = 35.6 kg
Standard sample weight (x_3 - y) = 26.2 kg

Weight of Bio-degradable(Sample 03)

S.T.B.D (Gross)(a) = 200 kg/m^3
L.T.B.D (Gross)(b) = 152 kg/m^3

Sample 04

Weight of the sample with box (x_4) = 36.5 kg
Standard sample weight (x_4 - y) = 27.1 kg

Weight of Bio-degradable(Sample 04)

S.T.B.D (Gross)(a) = 216 kg/m^3
L.T.B.D (Gross)(b) = 196 kg/m^3

Sample 05

Weight of the sample with box (x_5) = 37.6 kg
Standard sample weight $(x_5 - y)$ = 28.2 kg

Weight of Bio-degradable(Sample 5)

S.T.B.D (Gross)(a) = 232 kg/m^3
L.T.B.D (Gross)(b) = 200 kg/m^3

Sample 06

Weight of the sample with box (x_6) = 38.7 kg
Standard sample weight $(x_6 - y)$ = 29.3 kg

Weight of Bio-degradable(Sample 06)

S.T.B.D (Gross)(a) = 248 kg/m^3
L.T.B.D (Gross)(b) = 204 kg/m^3

Sample 07

Weight of the sample with box (x_7) = 41.1 kg
Standard sample weight $(x_7 - y)$ = 31.7 kg

Weight of Bio-degradable(Sample 07)

S.T.B.D (Gross)(a) = 268 kg/m^3
L.T.B.D (Gross)(b) = 224 kg/m^3

Sample 08

Weight of the sample with box (x_8) = 41.9 kg
Standard sample weight $(x_8 - y)$ = 32.5 kg

Weight of Bio-degradable(Sample 8)

S.T.B.D (Gross)(a) = 240 kg/m^3
L.T.B.D (Gross)(b) = 228 kg/m^3

Sample 09

Weight of the sample with box (x_9) = 42.7 kg
Standard sample weight $(x_9 - y)$ = 33.3 kg

Weight of Bio-degradable(Sample 09)

S.T.B.D (Gross)(a) = 212 kg/m^3
L.T.B.D (Gross)(b) = 232 kg/m^3

Appendix-II

MSW Composition Survey Sheet

Area: Kurunegala Date: 08-02-2019

Municipal Council: Kurunegala

Dump Site Location: Sundarapola-Yanthampalawa

Weight of the empty sample box (y) = 9.4 kg

Volume of the empty sample box = 50x50x25 cm^3= $0.0625m^3$

Sample 01

Weight of the sample with box (x_1) = 40.5 kg
Standard sample weight (x_1 - y) = 31.1 kg

Weight of Bio-degradable(Sample 01)

S.T.B.D (Gross)(a) = 264 kg/m^3
L.T.B.D (Gross)(b) = 156.8 kg/m^3

Sample 02

Weight of the sample with box (x_2) = 41.05 kg
Standard sample weight (x_2 - y) = 31.65 kg

Weight of Bio-degradable(Sample 2)

S.T.B.D (Gross)(a) = 288 kg/m^3
L.T.B.D (Gross)(b) = 160 kg/m^3

Sample 03

Weight of the sample with box (x_3) = 41.6 kg
Standard sample weight (x_3 - y) = 32.2 kg

Weight of Bio-degradable(Sample 03)

S.T.B.D (Gross)(a) = 312 kg/m^3
L.T.B.D (Gross)(b) = 163.2 kg/m^3

Sample 04

Weight of the sample with box (x_4) = 35.6 kg
Standard sample weight (x_4 - y) = 26.2 kg

Weight of Bio-degradable(Sample 04)

S.T.B.D (Gross)(a) = 264 kg/m^3
L.T.B.D (Gross)(b) = 153.6 kg/m^3

Sample 05

Weight of the sample with box (x_5) = 34.6 kg
Standard sample weight $(x_5 - y)$ = 25.2 kg

Weight of Bio-degradable(Sample 5)

S.T.B.D (Gross)(a) = 248 kg/m^3
L.T.B.D (Gross)(b) = 152 kg/m^3

Sample 06

Weight of the sample with box (x_6) = 33.6 kg
Standard sample weight $(x_6 - y)$ = 24.2 kg

Weight of Bio-degradable(Sample 06)

S.T.B.D (Gross)(a) = 232 kg/m^3
L.T.B.D (Gross)(b) = 150.4 kg/m^3

Sample 07

Weight of the sample with box (x_7) = 28.65 kg
Standard sample weight $(x_7 - y)$ = 19.25 kg

Weight of Bio-degradable(Sample 07)

S.T.B.D (Gross)(a) = 148 kg/m^3
L.T.B.D (Gross)(b) = 134.4 kg/m^3

Sample 08

Weight of the sample with box (x_8) = 29.90 kg
Standard sample weight $(x_8 - y)$ = 20.50 kg

Weight of Bio-degradable(Sample 8)

S.T.B.D (Gross)(a) = 176 kg/m^3
L.T.B.D (Gross)(b) = 128 kg/m^3

Sample 09

Weight of the sample with box (x_9) = 31.15 kg
Standard sample weight $(x_9 - y)$ = 21.75 kg

Weight of Bio-degradable(Sample 09)

S.T.B.D (Gross)(a) = 204 kg/m^3
L.T.B.D (Gross)(b) = 121.6 kg/m^3

Appendix-III

MSW Physical and Chemical Composition Analysis Sheet

Area: Kandy Date: 08-02-2019

Municipal Council: Kandy

Dump Site Location: Gohagoda-Katugastota

MSW Sample Analysis

Sample	% S.T.B.D	% L.T.B.D	MC(%) in STBD	Organic/Volatile matter(%)	Calorific Value(CV) (kCal/kg)	C/N Ratio
Mix 1	49.2	41.0	50.12	83.85	3471.63	19.67
Mix 2						
Mix 3						
Mix 4	51.4	44.3	58.65			
Mix 5						
Mix 6						
Mix 7	46.2	43.8	46.04			
Mix 8						
Mix 9						
Average	48.9	43.1	51.6			

S.T.B.D: Short Term Bio-Degradable

L.T.B.D: Long Term Bio-Degradable

MC: Moisture Content

Appendix-IV

MSW Physical and Chemical Composition Analysis Sheet

Area: Kurunegala Date: 08-02-2019

Municipal Council: Kurunegala

Dump Site Location: Sundarapola-Yanthampalawa

MSW Sample Analysis

Sample	% S.T.B.D	% L.T.B.D	MC(%) in STBD	Organic/Volatile matter(%)	Calorific Value(CV) (kCal/kg)	C/N Ratio
Mix 1	56.9	31.6	55.5	83.60	3464.77	19.53
Mix 2						
Mix 3						
Mix 4	61.5	37.7	61.32			
Mix 5						
Mix 6						
Mix 7	53.7	39.0	35.76			
Mix 8						
Mix 9						
Average	57.3	36.1	50.86			

S.T.B.D: Short Term Bio-Degradable

L.T.B.D: Long Term Bio-Degradable

MC: Moisture Content

Appendix-V

MSW Collection by Municipals

Province/District	Dump Site Location	Daily Collection (Mt /day)	Average S.T.B.D(%)
North Western (Kurunegala)	**Sundarapola**	***45-50***	***57.25***
	Sample 1		
	Sample2		
	Sample3		
	Sample4		
	Sample5		
	Sample6		
	Sample7		
	Sample8		
	Sample9		
Central (Kandy)	**Gohagoda**	***130***	***48.97***
	Sample 1		
	Sample2		
	Sample3		
	Sample4		
	Sample5		
	Sample6		
	Sample7		
	Sample8		
	Sample9		

S.T.B.D: Short Term Bio-Degradable

Mt: Metric Ton(1000kg)