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School of Graduate Studies

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Environmental Engineering Stream

Energy Potential of Municipal Solid Waste for Incineration:

Reppi Open Dump Site, Addis Ababa

By

Getachew Shiferaw

Advisor: Ato Teshome Worku

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfilment of the Requirement for the Degree of Master of Science in Environmental Engineering Stream

Advisor: Ato Teshome Worku

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Approved by Board of Examiners:

Chairman:

Department Graduate Committee	-------------------------	----------------
	Signature	Date
Ato Teshome	-------------------------	----------------
Advisor	Signature	Date
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(Internal examiner)	(Signature)	Date
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(External examiner)	(Signature)	Date

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LIST OF ABBREVIATIONS

AAU	Addis Ababa University
AACMA	Addis Ababa Cleansing Management Agency
MSW	Municipal Solid Waste
NYS	New York State
UN	United Nation
RDF	Refuse Derived Fuel
REF	Recovered Fuel
PDF	Packaging Derived Fuel
PPF	Paper and Plastic Fraction
PEF	Processed Engineered Fuel
WTE	Waste to Energy
ASTM	American Society of Testing and Materials
UNEP	United Nation Environmental Programme
WHO	World Health Organization
LHV	Lower Heating Value
HHV	High Heating Value
MBT	Mechanical and Biological Treatment
HCF	High Caloric Fraction
HOA-REC/N	Horn of Africa Regional Environmental Centre and Network
LFG	Landfill Gas
CDM	Clean Development Mechanism
NCV	Net Calorific Value
GCV	Gross Calorific Value
MC	Moisture Content
GHG	Green House Gas
GWP	Global Warming Potential
MSWM	Municipal Solid Waste Management
SWMS	Solid Waste Management System
EFW	Energy from Waste
CHP	Combined Heat and Power
IR	Integrated Research
VCM	Vinyl Chloride Monomer

PET	Polyethylene Terephthalate
CHP	Combined Heat and Power

Abstract

Solid waste handling and disposal are the pressing problems in Addis Ababa City. Millions of tons of municipal solid waste, hazardous/industrial wastes and commercial wastes are handled daily throughout municipal areas. Addis Ababa cleansing management agency confronted with great challenges in disposing of solid wastes in an efficient, cost effective and environmentally safe manner. The total quantity of MSW generated at the site was 3800m^3/day or 760 ton/day, annually 1,387,000 m^3.

Knowledge of the energy potential of MSW for incineration is necessity, in order to plan for energy recovery from MSW. Energy potential from municipal solid waste for incineration was done in an area called Reppi /Koshe, which is the only dumpsite in the city, with objective of evaluating energy potential (heating value) of municipal solid waste and feasibility for incineration.

Solid waste sampling and laboratory analysis were carried out according to the random sampling method based on American Society of Testing and Materials (ASTM) standards to determine the waste compositions and proximate analysis. The laboratory work undertaken at school of chemical and bioengineering and Arat kilo chemistry department.

According to the weekly analysis the main compositions of the generated MSW in the site were food waste, chat waste and fruit waste which accounted 65% by weight. In this work an average calorific value of 19.78 MJ/kg with variable high water content of 44-65% was determined. Based on the average calorific value, moisture content and MSW removed the net energy potential is 7.68 MJ/Kg with 84.5% energy efficiency.

Based on the results obtained, I recommended that the municipal solid waste at Reppi Dump Site is feasible for incineration as a strategy to reduce the amount of disposed waste and energy recovery.

1. Introduction

1.1 Background of the study

Municipal Solid Waste (MSW) includes commercial and residential wastes generated in municipal or notified areas in either solid or semi-solid form. It consists of household waste, construction and demolition debris, sanitation residue, waste from streets and so forth. The term MSW describes the stream of solid waste ("trash" or "garbage") generated by households and apartments, commercial establishments, industries and institutions. MSW composition is varies from different sources, seasons and living behaviours. MSW increases with the improvement of people's life, the increasing amount of MSW is becoming a problem baffling every government (sono-UN, 1999).Without effective handling and recovery; MSW may seriously threaten people's health, improvement of environment and man's sustainable development.

A limited supply of natural resources combined with an ever growing demand for energy and raw materials has promoted the evaluation of recovering latent energy resources from municipal solid waste (MSW) is important. In Addis Ababa, the per capita generation rate of MSW is 0.45 kg/c/day (Cleansing Management Agency document written in 2011). Land filling is the widely used method for solid waste disposal [(Sumiani *et al*, 2009)]. The existing dumping site in Addis Ababa is not properly engineered and managed. As a consequence, the solid waste management system (SWMS) needs to be updated to suit the waste quality, quantity and composition.

Incineration considered as option for waste reduction potential which can be 80-95% in terms of waste volume and only the final inert materials from incinerating being considered for land filling [(Rand, *et al* 2000)]. This method will reduce the quantity of incoming solid waste to landfills and also open opportunities for new technologies in treating MSW. The first step to understand the feasibility of design the incineration plan is to obtain the basic data regarding to quantity and quality of generated MSW.

Over the years, Reppi/Koshe dumpsite is open dumping, hauling the waste by truck, spreading and levelling and compacting by bulldozer. It has experienced an increase in the amount of municipal solid waste. Currently, this dumpsite receives 760 tones of municipal solid waste per day which is generated by residential, commercial, and industrial areas. It covers about 32 hectare and received waste from 1956. The dumpsite has lifespan around 49 years. However, due to industrialization, urbanization and population growth that lead to increase in waste generation, it is not equipped with plastic lining, leachate treatment and gas ventilation facilities. From the total area 19 hectares are in process to close for collection of methane gas to get CDM benefit by LFG-flaring system. The project is done by the horn of Africa regional environmental centre and network (HOA-REC/N).

The heating value of the organic component in MSW can be determined in various methods such as determined by using a full scale boiler as a calorimeter, by using oxygen bomb calorimeter, and by calculation (Tchobanoglous et al, 1993). However the present study highlights the high heating value result from the generated waste by using oxygen bomb calorimeter.

This study aim to determine the municipal solid waste compositions, characteristics and calorific value to know the net energy potential for incineration plan in Reppi /Koshe dumpsite located at Ayer tena, Addis Ababa. In order to achieve this, the study focused to evaluate the potential of seven waste category composite samples for energy recovery by excluding glass, metal and other waste type.

1.2 Statement of the problem

Municipal solid waste management (MSWM) is a major responsibility of local governments which typically consuming between 20 and 50 percent of municipal budgets in developing countries (Peter et al., 1996). According to cleansing management agency solid waste management is a major problem in Addis Ababa municipality. The waste segregation system at the source has not yet been strictly adapted by majorities of people. There is no sanitary landfill site. Collected wastes are dumped in the open dumpsite, which has a potential to cause serious health hazards.

In Addis Ababa, the solid waste generated at the household directly disposed in the dumpsite without sorting. This brings the need to manage and utilize the waste effectively and efficiently to reduce the cost of operation. There are strategies and procedures employed in the city, the problem lies in knowing the composition, physical and chemical properties, waste constituents, energy potential and utilizing as energy source. However, land filling needs to be limited, taking into account the hierarchy of waste management and other requirements. Furthermore, increasing costs and a lack of land suitable for landfills, disapproval of local communities to land filling their neighbourhood, very low customer satisfaction ,lack of environmentally sound, effective & efficient system makes it necessary to find a way to reduce the amount of land filled waste.

Understanding the energy potential of the waste in the dumpsite is the base for waste utilization for energy sector. Hence, this research is undertaken to evaluate the energy potential of municipal solid waste at Reppi /Koshe dumpsite.

The cost of waste management will be minimum, when the dumped municipal solid waste is utilized as a source of energy. In addition, this will reduce environmental pollution and land requirement for disposal.

Large quantity of the municipal solid waste (MSW) generated in Addis Ababa, disposed in controlled dumpsite, which result in high emission of methane and leachate production. Therefore, it would be of interest to study energy potential of municipal solid waste.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of the study is to evaluate the energy potential of Reppi/Koshe Dumpsite municipal solid waste as a strategy for further incineration to reduce its environmental effects.

1.3.2 Specific objective

The specific objectives of the study are:

- To determine the solid waste composition at Reppi /Koshe dumpsite using random truck sampling method for energy potential evaluation.
- To obtain the physical and chemical properties of the waste components at dumpsite (proximate analysis).
- To evaluate the energy content (heating value, net energy) of waste and its suitability for incineration.
- Assessing environmental aspect of municipal solid waste in reppi dumpsite and estimate emitted gases (pollutants) when they are combusted.
- To evaluate the collection and transportation cost of solid waste from the source to the dumpsite.

2. Literature Review

2.1 General condition of solid waste

Solid waste is material, which is not in liquid form, and has no value to the persons who is responsible for it (Chris Zurbrugg, 2003), from the days of primitive society, humans and animals have used the resources of the earth to support life and to dispose of waste .In early times, the disposal of human and other waste did not pose a significant problem, for the population was small and the amount of land available for the assimilation of waste was large. Problems with the disposal of waste can be traced from the time when humans first began to congregate in tribes, villages, and communities and the accumulation of waste become a consequence of life (Techobanaglous et al., 1993).

A material is discarded if it is abandoned by being disposed of; burned or incinerated, including being burned as a fuel for the purpose of recovering usable energy; or accumulated, stored or physically, chemically or biologically treated (other than burned or incinerated) instead of or before being disposed of. A material is disposed of if it is discharged, deposited, injected, dumped, spilled, leaked or placed into or on any land or water so that such material or any constituent thereof may enter the environment or be emitted into the air or discharged into groundwater or surface water.(NYS Dept. of Environmental Conservation). To a large extent ecological phenomena such as water and air pollution have also been attributed to improper management of solid waste (Techobanaglous et al., 1993).

According to waste management collection and disposal regulations of the Addis Ababa city government solid Waste means any solid or semi solid waste generated from different sources and discarded as unwanted or as useless.

2.2 Municipal solid waste

The term municipal solid waste (MSW) is normally assumed to include all of the waste generated in a community, with the exception of waste generated by municipal services, treatment plants, and industrial and agricultural processes (Tchnobanoglous, G and Kreith, F., 2002). MSW includes various wastes generated from people's daily and industrial process. With the improvement of people’s life, the increasing amount of MSW is becoming a problem baffling every government (sino-UN, 1999). Without effective handling, MSW may seriously threaten people’s health, improvement of environmental and man’s sustainable development. MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries.

There are several technologies for converting MSW to energy. Moreover Solid Recovered Fuel (Refuse Derived Fuel - RDF) offers significant environmental and market opportunities, is relatively clean and can be traded in the market for numerous energy applications replacing fossil fuels. Derived fuel such as recovered fuel (REF), packaging derived fuel (PDF), paper and plastic fraction (PPF) and process engineered fuel (PEF) (UNEP, 2005; Gendebien et al., 2003). With certain value as a resource, incineration for energy recovery (sheng, 1994) and low-temperature pyrolysis (Zhang, 1995) are considered effective measures preventing pollution. Incineration for energy recovery has been widely adopted in advanced countries (Zhang, 1997) and investigated with great effort in domestic scientific institutes (Jiang, 1998; sheng, 1997; Yang, 1998; Nie, 1999). The MSW industry has four components: recycling, composting, land filling and waste to energy (WTE) via incineration (Tchobanoglous *et al*., 1993).

According to ASTM standard (2006) that RDF is a shredded fuel derived from MSW which metal, glass and other inorganic materials have been removed and has particle size 95 weight % passes through a 2-in square mesh screen. MSW composition is varied from different sources, seasons and living behaviours. Raw MSW has high moisture content, low calorific value, wide range of particle size distribution and high ash content. These reasons make using raw MSW as fuel difficult and unattractive. RDF presents several advantages as a fuel over raw MSW. The main advantages are higher calorific value which also remains fairly constant, more uniformity of physical and chemical composition, ease of storage, handling and transportation, lower pollutant emissions and reduction of excess air requirement during combustion (Caputo and Pelagagge, 2002).

According to Addis Ababa city administration cleansing management agency "municipal solid waste" includes commercial and residential wastes generated in municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes. In simple words the municipal solid waste can be defined as the waste that is controlled and collected by local authority and municipality.

2.3 Source, composition and generation of municipal solid waste

Knowledge of the source and types of solid waste, along with data on the composition and rate of generation, is basic to the design and operation of the functional elements associated with the management of solid waste (Techobanaglousetal, 1993).

Three primary sources of MSW are classified as residential area, institutional and commercial waste (Tariq etal., 2007). The two main factors that effect on type and quantity of waste are culture and society consumption pattern. Generally MSW consist of around twenty different categories: food waste, paper (mixed), cardboard, plastic (rigid, film and foam), textile, wood waste, metals (ferrous or Non-ferrous), diapers, news print, high grade and fine paper, fruit waste, green waste, batteries, construction waste and glass, these categories can grouped into organic and inorganic (Marine, 2007).Solid waste can be categorized based on source as shown in Table 2.1.

Table 2.1 Solid Waste categories based on source

Source	Typical facilities, activities, or locations where wastes are generated	Types of Solid waste
Agricultural	Field and row crops, orchards, vineyards, diaries, feedlots, farms, etc	Spoiled food wastes, agricultural wastes, rubbish, and hazardous wastes
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power	Industrial process wastes, scrap materials, etc.; nonindustrial waste including food waste,

	plants, demolition, etc.	rubbish, ashes, demolition and construction wastes, special wastes, and hazardous waste.
Commercial and Institutional	Stores, restaurants, markets, office buildings, hotels, auto repair shops,	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes, etc.
Municipal solid waste	Includes residential, commercial and institutions	Special waste, rubbish, general waste, paper, plastics, metals, food waste, etc.

Source: (Hester, R. E and Harrison, R. M., 2002)

The municipal solid waste (MSW) is normally assumed to include all community waste with the exception of industrial process waste and agricultural waste. According to Addis Ababa city cleansing management agency, 2004 Sources of solid waste generated in Addis Ababa among others are household, institutional, commercial, factory, hotel and street sweeping. The solid waste types include Vegetable ,Paper ,rubber/plastics ,Wood , Bone ,Textiles ,Metals ,Glass ,combustible leaves ,Non-combustible stone and All fine. From the total waste removed 76% from household, 18% from institution and 6% from street sweeping. (Nor consult, 1982).

Composition is the term used to describe the individual components that make up a solid waste stream and their relative distribution, usually based on percent by weight (Gerald, 1997).The composition of municipal waste varies greatly from country to country and changes significantly with time. In countries which have a developed recycling culture, the waste stream consists mainly of intractable wastes such as plastic film, and un-recyclable packaging. In developed countries without significant recycling it predominantly includes food wastes, yard wastes, containers and product packaging, and other miscellaneousness wastes from residential, commercial, institutional, and industrial sources. Waste composition is influenced by factors such as culture, economic development, climate, and energy sources; composition impacts how often waste is collected and how it is disposed. Although waste composition is usually provided by weight, as a country's affluence increases, Waste volumes tend to be more important, especially with regard to collection: organics and inert generally decrease in relative terms, while increasing paper and plastic increases overall waste volumes.

The composition of the waste is a description of the contents of the waste. In addition to providing important information about the way to handle the waste, the composition tells us about the people who generated the waste. Table 2.2 shows the composition variation of household waste based on their income.

Table 2.2: Relative composition of household waste in low, medium and high-income countries

	Parameter	Low-income countries	Medium-income	High-income countries
Contents	Organic (putrecible), %	40 to 85	20 to 65	20 to 30
	Paper, %	1 to 10	15 to 30	15 to 40
	Plastics, %	1 to 5	2 to 6	2 to 10
	Metal, %	1 to 5	1 to 5	3 to 13
	Glass, %	1 to 10	1 to 10	4 to 10
	Rubber, leather, etc., %	1 to 5	1 to 5	2 to 10
	Other, %	15 to 60	15 to 50	2 to 10
Physical and chemical properties	Moisture content, %	40 to 80	40 to 60	5 to 20
	Specific weight, kg/m3	250 to 500	170 to 330	100 to 170
	Calorific value, kcal/kg	800 to 1100	1000 to 1300	1500 to 2700

Source: INTOSAI working group on environmental auditing, 2002

According to Addis Ababa City Cleansing Management Agency the City composition of Municipal Solid Waste is not done in recent years. Before 14 years in 1992 the physical compositions of Addis Ababa City solid waste are organic 60%, recyclables 15 % and others 25%. The individual waste type composition result showed in Table 2.3.

Table 2.3 solid waste composition of Addis Ababa City in year----??

Waste type	Percentage
Vegetable	4.2 %
Paper	2.5%
rubber/plastics	2.9%
Wood	2.3%
Bone	1.1%
Textiles	2.4 %
Metals	0.9%
Glass	0.5%
combustible leaves	15.1%
Non-combustible stone	2.5%
All fine	65%

Source: Tessema, 2010

Waste generation encompasses activities in which materials are identified as no longer being of value (in their present form) and are either thrown away or gathered together for disposal. Waste generation at present is not very controllable. However, reduction of waste at source is included in system evaluations as a method of limiting the quantity of waste generated. Generation rate of solid waste in low income, middle income and industrialized countries showed in Table 2.4.

Table 2.4 Waste generation rate

Solid waste	Countries		
	Low income	Middle income	Industrialized
Production Kg/cap/day	0.3-0.6	0.5-1.0	0.7-2.2
Ton/cap/year	0.2	0.3	0.6

Source: Urban Management Program – UNEP.

Different studies tried to estimate the quantity of waste daily generated from Addis Ababa city. Among these studies Gordon and nor consult are mentioned on their study at different time in the past. Accordingly Gordon tried to estimate municipal waste generated from the residential areas in 1994 and 1995, whereas Nor Consult forward his estimation of residential waste daily generation constant in 1982. Generation rate of solid waste in high income, middle income and low income group of Addis Ababa City population shows in Table 2.5.

Table 2.5 Waste generation rate of income group

Income Group	Different Studies		
	Nor consult, 1982	Gordon, June 1994	Gordon, Nov. 1995
High income			
g / capita / day	280	350	477
Liter / capita / day	1.0	1.08	2.226
Density, kg /m^3	280	322	220
Middle income			
g / capita / day	110	280	236
Liter / capita / day	0.28	0.70	1.246
Density, kg /m^3	390	395	196
Lower income			
g / capita / day	150	170	260
Liter / capita / day	0.4	0.55	1.316
Density, kg /m3	380	310	206
General population			
g / capita / day	150	221	252
Liter / capita / day	0.4	0.65	1.23
Density, kg /m^3	370	336	205

Source: From Addis Ababa City Cleansing Management Agency

Accordingly, the city administration solid waste management sector deploys the generation constant derived by these two studies for his solid waste management planning purpose. A long time 0.221 and 0.252 kg/capita/day constants has been used for planning at these sector. By taking different unpublished paper of professionals the city solid waste management agency takes 0.45 kg/capita/day as the daily per capita solid waste generation of Addis Ababa city.

2.4 Methods of municipal solid waste characterization

Physical and chemical analysis of the waste is important to characterize and classify the municipal solid waste for its proper management and for accurate estimation of the amount of landfill gas produced from the municipal solid waste. Physical and chemical characteristics indicate the composition of the MSW. They are directly influenced by the local aspects such as food habits, culture, socio-economic, seasonal, and climatic conditions [Bhoyar et al., 1996]. Four methods for estimating waste quantities and composition can be identified: direct sampling (also referred to as waste stream analysis and waste audits), material flow, surveying waste generators, and literature sources (Gerald, 1997).

Direct sampling: Direct sampling involves sampling, sorting, and weighing materials from the waste stream of a specific generator. This method has been used to estimate the composition of municipal waste streams. Representative sampling methods must be employed to achieve accurate results. When using the direct sampling method, the following questions must be addressed: How will representative samples of waste be obtained; and how many samples should be selected to achieve the desired level of accuracy in the results? The responses to these questions will influence the cost of conducting the study as well as the usefulness of the data.

Waste stream analysis: Waste stream analysis is another term used for characterizing the waste stream of a specific operation for a designated time period. Waste stream analysis is defined as a method for collecting, sorting, and measuring the amount and type of waste generated by an operation. Results of a waste stream analysis provide data about the amount and type of waste/residues in the waste stream. Data should be collected for a minimum of one week; the length of time depends on how the data are to be used and the accuracy required. The results are averaged to estimate the amount of waste that the facility generates for a period of time.

Waste audit: The basic objectives of a waste audit are similar to a waste stream analysis. A waste audit involves a more detailed assessment of waste. The waste audit assesses not only the output (waste), but also the input, such as food products, packaging materials, office supplies, mail, or any process that results in materials that must be discarded. The detailed and complicated analysis of material flow through an institution will enable the facility to find the amount purchased, used, recycled, and disposed of for different materials. A waste audit can involve all materials or focus on a specific material, such as cardboard or office paper that is generated by a facility or department.

Material flow: The material flow method applies the concept of conservation of mass to track quantities of materials as they move through a defined system or region. The material flow methodology in this instance is based on the production weight data for materials and products. Generation data are the result of making specific adjustments for imports, exports, and diversions to the production data by each material and product category. The method also considers the useful life of products. One of the problems with the material flow approach is that it is difficult to quantify product residues, such as food left in the container and detergent remaining in the package.

Surveying waste: Surveying industrial generators, such as food processors can provide useful data in quantifying waste generation. More accurate data can be obtained if the waste/residues are measured at the disposal site.

Literature sources: Data on waste/residues quantities and composition are available from a variety of sources including public agency documents, engineering reports, trade publications, and professional journals. These data may be helpful in assisting managers in identifying the type of residues/waste generated by a specific industry or activity. However, caution should be exercised when operational decisions are made based on data from the secondary sources. Waste characterization and generation rate studies are recommended for operational uses rather than relying on published data since each study site is unique.

Characterization of solid waste is important in evaluating alternative equipment needs, systems and management program and plans, especially with respect to the implementation of disposal and energy and resource recovery options. It depends on a number of factors such as food habits, cultural conditions, and socio-economic and climatic conditions. For composition of the incoming solid waste in reppi dumpsite done based on waste stream analysis method in the weekly basis.

2.5 components of municipal solid waste management

Solid waste management includes the process of generation, collection, storage, transport and disposal or reuse and re-circulation or incineration or any relevant method of disposal (WHO, 1971). These are done in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations. In its scope, it includes all administrative, financial, legal, planning and engineering functions involved in the whole spectrum of solutions to problems of solid wastes thrust upon the community by its inhabitants (Tchobanaglous, *et al*, 1997).

Municipal Solid Waste Management system affects the utilization of municipal solid waste for energy sources. In Addis Ababa SWM system affects to use waste to energy sources. But by evaluating the energy potential we can come to use the waste for energy source.

2.5.1 Waste Handling, Sorting, Storage, and Processing at the source

Waste handling and sorting involves activities associated with management of wastes until they are placed in storage containers for collection. Handling also encompasses the movement of loaded containers to the point of collection. Sorting is an important component of waste management and best-done onsite. However, there are various stages of sorting. These can be identified as the following: At the source or house hold level, at the community bin (municipal bin), at transfer station or centralised sorting facility, at waste processing site (pre-sorting and post sorting) and at the landfill site. Sorting Operations can be carried out in three ways: Manual sorting, Semi-mechanised sorting, and fully mechanised sorting.

The size of premises, nature (type) and generation rate of solid waste determines the type of storage to be used. Storage facilities must be animal and insect proof washable and robust enough to meet the exigencies in normal use. There is a limit to the duration that solid waste can be stored at source (in the premises) based on the type and source of solid waste. Solid waste should be collected and disposed of from temporary stores to final disposal site before breeding various disease-carrying vectors. Uncovered containers of waste are exposed to human and animal scavengers that litter waste around and create community health problems. Onsite storage is of primary importance because of public health concerns. Open ground storage, make shift containers should always be avoided and only closed containers should be used. Processing at the source involves backyard composting. Storage of wastes can be done at three levels: At source, at community level and at transfer stations. (Ramachandra, T. V. and Shruthi B.).

According to Addis Ababa city cleansing management agency waste handling is done by push cart containers to the point of collection. Solid waste is stored under plastic bags at the point of generation in residential area before it will be transported to the escape point. In the commercial and institutional areas, it will be stored in a 1.1 m3 standard container. Minor solid wastes along streets are temporarily stored in a dust bin. Sorting of waste takes place at various levels in the waste management process. The first level of source separation is at household: plastic materials, glass, bottles, are considered as valuable and usually sorted out for reuse. In the second level several collectors represent the second stage: Street boys, private sector enterprises, scavengers at municipal dumpsite, and the korales. Except these collectors almost all waste streams are not segregated from the source. In the assessment made wastes are not properly segregated and stored as normally in the city of Addis Ababa one can notice mixed waste transportation in the container. Municipal Solid Waste is commonly stored in rectangular concrete open bin. Sorting of waste at the source play a great role to utilize based on their characteristics for energy evaluation and also have an advantage to stop extra cost for sorting.

2.5.2 Collection and transportation/transfer

Collection is the component of waste management which comprises lifting and removal / Passage of a waste material from the source of production to either the point of treatment or final disposal. Collection of generated solid waste is the crucial part in MSW management. Efficiency in collecting solid waste & segregating it decides how well solid waste is managed and recovered for energy. Collection includes not only the gathering of solid waste, but also the transport of these materials, after collection, to the location where the collection vehicle is emptied. This location may be a material processing facility, a transfer station or a landfill disposal site. Now a day it is one of the most important issues in municipal administration, particularly in metro cities. Huge generation of MSW is one of the reasons behind the administrative Difficulty. The collection of municipal solid waste is a public service that has important impacts on public health and the appearance of towns and Cities.

Common Collection Types of municipal solid waste are Community bins, Door-to-Door collection, Block collection and Curb side collection (Tchobanolous, G et al 1993).The waste collection methods that are mainly adopted in Addis Ababa are Door to door collection by small and micro scale solid waste collecting enterprises. Here the worker uses a pushcart for the collection of waste without separating at the source and transfer station. In concept this activity includes collection of wastes by generators up to the temporary storage sites in their compound.

Transfer and transport involves two steps: The transfer of wastes from smaller collection vehicle to larger transport vehicle and, the subsequent transport of the wastes usually over long distances, to a processing or disposal site. The transfer usually takes place at a transfer station. The most common method for transfer is manual transfer from community bin to trucks. The transfer of waste directly from pushcarts to trucks by meeting at a specified time and place called synchronization points is suggested by which is a suitable option for the door to door collection method (Karadimas, 2004). In Addis Ababa city the collection and transportation task of solid waste categorized by two sub division. The first task is collection of wastes from institution, organization and higher commercial centre by private companies up to the disposal sites. The second task is collection and transportation of municipal wastes by governments deployed solid waste collection vehicles from the escape point. Whereas solid waste collection and transportation from organization, higher commercial institution, embassies, health care institution and large scale industries are conducted by private solid waste collection companies.

Table 2.6: Addis Ababa City solid waste collection history

Years/EC/	Solid waste collection capacity in m^3	Years/EC/	Solid waste collection capacity in m^3
1973	140,048	1990	317,377
1974	154,160	1991	362,797
1975	138,160	1992	393,927
1976	155,533	1993	0
1977	181,256	1994	472,722
1978	178,082	1995	452,192
1979	221,408	1996	547,327
1980	248,799	1997	623,624
1981	236,017	1998	540,266.91
1982	235,811	1999	615,335.65
1983	175,427	2000	573050
1984	168,588	2001	779645
1985	386,742	2002	1003742
1986	203,809	2003	1263342
1987	281,633	2004	1304340
1988	375,200	2005	1540391.61
1989	264,049		

Source: Addis Ababa City Cleansing Management Agency

2.5.3 Processing and transformation of Solid Waste

This functional unit encompasses the recovery of the sorted materials, processing of solid waste And transformation of solid waste that occurs primarily in locations away from the source of Waste generation. Sorting of the mixed waste usually occurs at a material recovery facility, transfer stations, combustion facilities and disposal sites. Waste processing and transformation solid waste processing reduces the amount of material requiring disposal and, in some cases produces a useful product. Examples of solid waste processing technologies include material recovery facilities, where recyclable materials are removed and/or sorted; composting facilities where organics in solid waste undergo controlled decomposition; and waste-to-energy facilities where waste becomes energy for electricity.

Land filling continues to be required even if solid waste processing technologies are employed because all of these technologies produce some sort of residue or handle only a portion of the waste stream. For example, land filling is still required for ash and bypass Waste (waste that can't be burned) from waste-to energy facilities. Thus, solid waste processing technologies do not replace land filling; rather they are a part of an integrated system that reduces the amount of material that requires landfill disposal. (T. V. Ramachandra and Shruthi Bachamanda).

The different types of processing techniques are reuse/recycling and composting. Recycling is a process to change materials (waste) into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and water pollution (from land filling) by reducing the need for "conventional" waste disposal, and lower greenhouse gas emissions as compared to plastic production. Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, and Recycle" waste hierarchy.

Composting is a biological process of decomposition carried out under controlled conditions of ventilation, temperature, moisture and organisms in the waste themselves that convert waste into humus-like material by acting on the organic portion of the solid waste (Sathishkumar, et al 2002). It produces a sludge, which is high in nutrients and can be used as a fertilizer. This is one element of an integrated solid waste management strategy that can be applied to mixed municipal solid waste (MSW) or to separately collected leaves, yard waste or food waste. In Addis Ababa city cleansing management agency sorting, processing and transformation of solid waste is not worked except informal worker that collect for recycling like plastic and metal wastes.

2.5.4 Thermal treatment combustion/incineration

To reduce waste volume, local governments or private operators implement a controlled burning process called combustion or incineration. In addition to reducing volume, combustors, when properly equipped, can convert water into steam to fuel heating systems or generate electricity. Incineration facilities can also remove materials for recycling. A variety of pollution control technologies significantly reduce the gases emitted into the air, including: Scrubbers-devices that use a liquid spray to neutralize acid gases and Filters-remove tiny ash particles.

Burning waste at extremely high temperatures also destroys chemical compounds and disease causing bacteria. Regular testing ensures that residual ash is non-hazardous before being land filled (Chris Zurbrugg, 2003). For centuries, burning has been a popular method of reducing the volume of solid waste. The burning of waste was rampant and uncontrolled. While uncontrolled burning of solid waste can be detrimental to health and the environment, confined and controlled burning, known as combustion, can not only decrease the volume of solid waste destined for landfills, but can also recover energy from the waste-burning process. (Chris Zurbrugg, 2003).

Municipal solid waste (MSW) incineration is performed in large scale plants where the fumes and rest products such as bottom ash are handled in order to minimize the effect on the environment. In an incineration plant the combustible fraction of the MSW are oxidized so that energy can be recovered. The chemical reaction in combustion is occurring according to (Eq. 1) (Vallero, 2008).

$(CH)x + O_2 \rightarrow CO_2 + H_2O$-------------------------- (1)

Incineration of municipal solid waste in designed incineration plants with treatment of flue gases and waste water is a system chosen more and more often both in developing and developed countries. Incineration is often a profitable system even though the installation cost is high since production of heat, steam and electricity often leads to a large economic gain. An incineration plant in general consists of pre-treatment of waste, combustion, system for flue gas purification, water treatment and management of slag and ash. Pre-treatment is not always necessary, it depends on the type of incinerator since different types are more or less sensitive to the heterogeneity of the waste. Ash and slag are usually land filled (Sundqvist, 2005).

One important parameter influencing the energy potential in MSW is the heating value. The heating value is a measure of the energy which the waste contains and is determined by the chemical composition of the different fractions (Dong et al., 2003). The heating value regulates the combustion efficiency of the incinerator. It is therefore important to make sure the heating value is high enough so that no additional fuel is needed to fully combust the waste material. The lower heating value (LHV) is defined as the amount of heat produced when combusting a certain amount of fuel assuming all water is in the form of steam and is not condensed (Finet, 1987). The heating value is of great importance for the efficiency and management of the incineration plant. The minimum LHV required for the waste to combust without the addition of other fuel is 7000 kJ/kg MSW or 1.94 MWh/ton (Incineration Mauritius, 2007).

One of the advantages of incineration is that the waste residue is minimized; the waste is reduced to approximately 10 % of the volume and 25 % of the weight before combustion (Combes, 2008). The ash is sterilized by the high temperature in the furnace and the ash can be used as filling material if the content of metals and other toxic substances and metals is not too high. Another advantage of incineration is the possibility to sort and reuse metals. This saves both resourses and reduces emissions to the surrounding environment. The metal sorting is easier to perform prior to incineration than before landfilling by using a magnetic or electromagnetic separator (Meri, 2009). The incentive to sort metals is higher when incinerating MSW than in landfilling due to the fact that separation of inert material raises the energy output because of a higher LHV and a reduced risk of breakage. In both systems there is a motive in the gain in the market of reused metal. There is also an incentive for diverting concrete, drywall and glass from the waste stream prior to combustion since the presence of inert matter lowers the heating value, but also due to the limited recycling market for these products (Gilchrist, pers. comm).

The negative aspect of incineration is the air pollution and waste water problems. Emissions from combustion of waste depend on the substances in the waste and on the technology used; temperature and equipment for flue gas and water treatment. In incineration waste is combusted in a couple of seconds while waste deposited in a landfill takes decades to degrade. The fact that there is an inert residue, leads to a need of a landfill even in the incineration scenario. If there are metals in the ash and slag, toxic leakage from the landfill can lead to contamination of the surrounding environment. Incineration of waste produces a lot of energy. If there is a need for electricity and/or heat, the cost of building an incineration facility often has a short payback time. On the other hand, the cost of investment and operation is high.

However, incineration is only permissible after recyclables (such as secondary raw materials and biodegradable fractions) are separated from the MSW stream. Thus, it is important to consider various options, alternatives, or scenarios of MSW management options with respect to impact on the environment and energy systems. MBT consists of mechanical and biological processes and their combination depending on characteristic of waste. The mechanical stage includes separation of fractions for recycling, light fraction (high caloric fraction, HCF), and contaminants. The rest (low caloric fraction) is fed to the biological process (Diaz L.F., Savage G.M.). The resulting HCF, which mostly consists of paper, textiles, plastic, and wood, can be used as an additional energy source in either a cement kiln, power plants or in a waste incineration plant (Soyez K., Thrän D., Hermann T., Koller M., Plickert S.). Incineration provides the best way to eliminate methane gas emissions from waste management processes. Furthermore, energy from waste projects provides a substitute for fossil fuel combustion. These are two ways incineration helps reduce greenhouse gas emissions (*Decision* makers' guide to municipal solid waste incineration World Bank Washington, D.C.).

In Addis Ababa there is no thermal treatment of municipal solid waste by incineration for energy use but without energy recovery in Health care facilities like hospitals, clinics, health centers, pharmacies and other veterinary services, industries, electronic waste generators and few construction waste generators use incinerators in their compound for their disposal options. Most of their incinerator is brick single chamber incinerators. Only two incinerators in black lion and Pasteur hospitals have a capacity to generate temperature more than $1200^{o}{}_{C}$ for burning waste.

2.5.5 Solid waste disposal

Despite the effectiveness of source reduction, recycling, and combustion, there will always be waste that cannot be diverted from landfills. The safe and reliable long-term disposal of solid waste residue is an important component of integrated waste management. Solid waste residues are waste components that are not recycled, that remain after processing at a material recovery facility, or that remain after the recovery of conversion products and/or energy (Techobanaglous et al., 1993).

In many developed countries, burial in controlled landfills continues to be the most prevalent means of disposing of solid waste including hazardous waste. About 70% of the urban solid waste is disposed off in this way in the US and most European countries. On the other hand most of the municipal solid waste (MSW) in developing countries is dumped on land in a more or less uncontrolled manner. These dumps make very uneconomical use of the available space, allow free access to waste pickers, animals and flies and often produce unpleasant and hazardous smoke from slow burning fries (Chris Zurbrugg, 2003).

Landfill gas is produced in landfill sites due to the anaerobic degradation of biodegradable organic waste. The gas produced is typically about 60% of methane and 40% CO_2. Landfill gas, with high content of methane, is potentially explosive and, as such, needs to be controlled. In some means of controlling (extracting) the gas is not used, the gas can migrate off site, causing problem to the surrounding environment (Gerald, 1997). Non-engineered disposal is the most common method of disposal in low-income countries, which have no control, or with only slight or moderate controls. They tend to remain for longer time and environmental degradation could be high, include mosquito, rodent and water pollution, and degradation of the land (Ramachand).

Open dumps is the cheapest and the oldest easy method of MSW disposal is 'open dumping' where the Waste is dumped in low - lying areas on the city outskirts and levelled by bull - dozers from time to time. Open dumping is not a scientific way of waste disposal. Open dumps refer an uncovered site used for disposal of waste without environmental controls. The waste is untreated, uncovered, and not segregated. A WHO Expert Committee (1967) condemned dumping as “a most unsanitary method that creates public health hazards, a nuisance, and severe pollution of the environment. Dumping should be outlawed and replaced by sound procedures”.

Sanitary landfills are an alternative to landfills or modern landfill which solves the problem of leaching to some extent is a sanitary landfill which is more hygienic and built in a methodical manner. Disposal of waste in landfills is the most common way to handle MSW trough out the world (Williams, 2005). A landfill is an engineered site where waste is being deposited. The aim of constructing a landfill is for disposal of waste, not to utilize the energy potential in MSW. The possibility to collect landfill gas for energy purposes is only a positive opportunity since it generates energy and lowers the environmental impact of the landfill. Usually, less than 50 % of the produced gas is captured in the collection system (Williams, 2005).

In Addis Ababa currently, there is one open dumpsite where a collected waste is disposed off. The site is getting full, surrounded by residential housing areas and public institutions and there is no daily soil cover. The site is becoming detrimental to the surrounding environment. The city government acknowledges the dangers to the environment and the public health derived from the uncontrolled waste dumping. Safe disposal of solid waste is important for safeguarding the public health, environment and wildlife as well. An efficient waste management system is the one that provides ecologically sound disposal option for waste that cannot be reduced, recycled, composted, combusted or processed further (Ali *etal*., 1999). In the site 5000 meter cube solid waste disposed per day. Currently by the coordinator of horn of Africa regional environmental centre and network (HOA-REC/N) 19 hectares of koshe dumpsite covered by soil to collect methane gas for the purpose of LFG-flaring system to get CDM benefit.

2.6 Municipal solid waste Properties

2.6.1 Physical properties

Important physical properties of MSW include Specific Weight (Density), Moisture Content, Particle Size and Distribution, Field Capacity, Permeability of Compacted Waste.

2.6.1.1 Specific Weight (Density)

Specific weight is defined as the weight of a material per unit volume (e.g. kg/m3, lb/ft3). Usually it refers to uncompacted waste. Density varies because of the large variety of waste constituents, the degree of compaction, the state of decomposition, and in landfills because of the amount of daily cover and the total depth of waste. Density is important because it is needed to assess the total mass and volume of waste, which must be managed. Density varies not only because of the type of treatment it gets (collection and compaction) but also because of geographic location, season of the year, and length of time in storage. Some typical density values of waste components are presented in Table 2.7.

Table 2.7 Typical Specific Weight Values

Component	Specific Weight (density), kg/m^3	
	Range	Typical
Food wastes	130-480	290
Paper	40-130	89
Plastics	40-130	64
Yard waste	65-225	100
Glass	160-480	194
Tin cans	50-160	89
Aluminium	65-240	160

Source: chapter 4 pdf, MSW properties

According to Louise Burger international, 1995 study the density of the Addis Ababa solid waste is estimated to vary from 205-370 kg/m^3 with the average being 333 kg/m^3.

2.6.1.2 Moisture Content

The most commonly used method of expressing moisture content is as a percentage of the wet Weight of material. Moisture content is important in regards to density, compaction, the role moisture plays in decomposition processes, the flushing of inorganic components, and the use of MSW in incinerators. Moisture increases the weight of the solid wastes and therefore the cost of collection and transport increases. Consequently waste should be insulated from rain or other extraneous water source. Also Moisture content is critical determinant in the economic feasibility of waste treatment by incineration. During incineration energy must be supplied for evaporation of water and raising the temperature of vapour.

The wet weight moisture content can be determined using the following equation:

M= (w-d /w) 100   Where M = moisture content (%)

w = initial weight of sample (kg)

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

Some typical moisture contents are shown in Table 2.8

Table 2.8 Typical Moisture Contents of Wastes

	Type of Waste	Moisture Content, %	
		Range	Typical
Residential	Food wastes (mixed)	50 - 80	70
	Paper	4 - 10	6
	Plastics	1 - 4	2
	Yard Wastes	30 - 80	60
	Glass	1 - 4	2
Commercial	Food wastes	50-80	70
	Rubbish(mixed)	10-25	15
Construction and demolition	Mixed demolition combustibles	4-15	8
	Mixed construction combustibles	4-15	8
Industrial	Chemical sludge(wet)	75-99	80
	Sawdust	10-40	20
	Wood(mixed)	30-60	35
agricultural	Mixed agricultural waste	40-80	50
	Manure(wet)	75-96	94

Source: Textbook, p. 70, Table 4-1

2.6.1.3 Particle Size and Distribution

The size and distribution of the components of wastes are important for the recovery of materials, especially when mechanical means are used, such as trommel screens and magnetic separators.

Particle size distribution, like the percentage of combustibles, is relevant to incineration and biological transformation methods. Particle size is also relevant for recycling and reuse and for equipment sizing for further treatment (Gerald, 1997). For example, ferrous items which are of a large size may be too heavy to be separated by a magnetic belt or drum system. The size of waste components can be determined using the following equations:

$Sc = L$ — Sc: size of component, mm

$Sc = (L+w)/2$ — L: length, mm

$Sc = (L+w+h)/3$ — W: width, mm

h: height, mm

2.6.2 Chemical properties

Chemical properties of MSW are very important in evaluating the alternative processing and recovery options. This is especially important where waste are burned for energy recovery, in which case the most important properties are Proximate analysis, fusing point of ash, Ultimate analysis (major elements), Energy content.

2.6.2.1 Proximate Analysis

Proximate analysis for the combustible components of MSW includes the following tests: Moisture (drying at 105^{o}C for 1 h), Volatile combustible matter (ignition at 950 ^{0}C in the absence of oxygen), fixed carbon (combustible residue left after Step 2) and ash (weight of residue after combustion in an open crucible). Fixed carbon is the carbon remaining on surface as charcoal. A waste with high fixed carbon requires a longer detention time on the surface of the furnace to achieve complete combustion than the waste with a low fixed carbon load. Typical proximate analysis values are showed in Table 2.9

Table 2.9 Typical Proximate Analysis Values (% by weight)

Type of Waste	Moisture	Volatiles	Carbon	Ash

Mixed food	70.0	21.4	3.6	5.0
Mixed paper	10.2	75.9	8.4	5.4
Mixed plastics	0.2	95.8	2.0	2.0
Yard wastes	60.0	42.3	7.3	0.4
Glass	2.0	-	-	96-99
Residential MSW	21.0	52.0	7.0	20.0

Source: Textbook, p.78, Table 4-2

2.6.2.2 Fusing Point of Ash

Fusing point of ash is the temperature at which the ash resulting from the burning of waste will form a solid (clinker) by fusion and agglomeration. Typical fusing temperatures: 1100 - 1200 ^{0}C.

Figure 2.1 Burning of waste and resulting ash agglomeration

2.6.2.3 Ultimate Analysis

Involves the percentage determination of C (carbon), H (hydrogen), O (oxygen), N (nitrogen), S (sulphur) and ash. The determination of halogens is often included in an ultimate analysis. The results are used to characterize the chemical composition of the organic matter in MSW, to define the proper mix of waste materials to achieve suitable C/N ratios for biological conversion processes, to determine heating value of MSW by modelling and to determine released gases when combustion takes place.

Table 2.10 Typical data on ultimate analysis of combustible materials found in SW

Percent by weight (dry basis)						
Type of waste	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food and food products						
Fats	73.0	11.5	14.8	0.4	0.1	0.2
Food wastes(mixed)	48.0	6.4	37.6	2.6	0.4	5.0
Fruit wastes	48.5	6.2	39.5	1.4	0.2	4.2
Meat wastes	59.6	9.4	24.7	1.2	0.2	4.9
Paper products						
Cardboard	43.0	5.9	44.8	0.3	0.2	5.0
Magazines	32.9	5.0	38.6	0.1	0.1	23.3
Newsprint	49.1	6.1	43.0	‹ 0.1	0.2	1.5
Paper(mixed)	43.4	5.8	44.3	0.3	0.2	6.0
Waxed cartons	59.2	9.3	30.1	0.1	0.1	1.2
Plastics						
Plastics(mixed)	60.0	7.2	22.8	-	-	10.0
polyethylene	85.2	14.2	-	‹0.1	‹0.1	0.4
Polystyrene	87.1	8.4	4.0	0.2	-	0.3
Polyurethane[b]	63.3	6.3	17.6	6.0	‹0.1	4.3
Polyvinyl chloride[b]	45.2	5.6	1.6	0.1	0.1	2.0
Textiles, rubber, leather						
Textiles	48.0	6.4	40.0	2.2	0.2	3.2
Rubber	69.7	8.7	-	-	1.6	20.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Wood,trees,etc						
Yard wastes	46.0	6.0	38.0	3.4	0.3	6.3
Wood(green timber)	50.1	6.4	42.3	0.1	0.1	1.0
Hardwood	49.6	6.1	43.2	0.1	‹0.1	0.9
Wood(mixed)	49.5	6.0	42.7	0.2	‹0.1	1.5

Wood chips(mixed)	48.1	5.8	45.5	0.1	‹0.1	0.4
Glass,metals,etc						
Glass and minerals[c]	0.5	0.1	0.4	‹0.1	-	98.9
Metals (mixed)[c]	4.5	0.6	4.3	‹0.1	-	90.5
Miscellaneous						
Office sweepings	24.3	3.0	4.0	0.5	0.2	68.0
Oils, paints	66.9	9.6	5.2	2.0	-	16.3
Refuse-derived fuel(RDF))	44.7	6.2	38.4	0.7	‹0.1	9.9

Source: chapter 4 pdf, MSW properties

2.6.2.4 Energy content

The energy content of the components of waste can be determined using a boiler system, laboratory bomb calorimeter, or by calculation using elemental composition (Techobanaglous et al., 1993) or by using mathematical models based on Kathiravale, 2003. It is important for feasibility study of municipal solid waste for incineration plan based on their energy value.

An evaluation of the potential of the waste material for use as a fuel in the incinerator requires the determination of its heating value, expressed as kilo joules/ kilo grams (kJ/kg). The heating value is determined experimentally using bomb calorimeter test in which the heat is generated at a constant temperature of 25 ^{o}C from the combustion of dry sample. The heating values are important in the evaluation of incineration process as a means of energy recovery or disposal.

2.7 Energy recovery from municipal solid waste

Municipal Solid Waste (MSW) contains organic as well as inorganic matter. The latent energy present in its organic fraction can be recovered for gainful utilisation through adoption of suitable Waste Processing and Treatment technologies.

The recovery of energy from wastes also offers a few additional benefits as follows: The total quantity of waste gets reduced by nearly 60% to over 90%, depending upon the waste composition and the adopted technology; Demand for land, which is already scarce in cities, for land filling is reduced; The cost of transportation of waste to faraway landfill sites also gets reduced Proportionately; and Net reduction in environmental pollution.

It is, therefore, only logical that, while every effort should be made in the first place to minimise generation of waste materials, recycle and reuse them to the extent feasible, the option of Energy Recovery from Wastes be also duly examined. Wherever feasible, this option should be incorporated in the over-all Scheme of Waste Management. Study energy potential of municipal solid waste is important for the recovery of energy. Building of transfer station near the source for energy recovery to separate the waste is based on their classification and energy potential value.

2.7.1 Basic Techniques of Energy Recovery

Energy can be recovered from the organic fraction of waste (biodegradable as Well as non-biodegradable) basically through two methods as follows: Thermo-chemical conversion: This process entails thermal de-composition of organic matter to produce either heat energy or fuel oil or gas; and Bio-chemical conversion: This process is based on enzymatic decomposition of organic matter by microbial action to produce methane gas or alcohol.

The Thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content. The main technological options under this category include Incineration and Pyrolysis/ Gasification. The bio-chemical conversion processes, on the other hand, are preferred for wastes having high percentage of organic bio-degradable (putrescible) matter and high level of moisture/ water content, which aids microbial activity. The main technological options under this category are Anaerobic Digestion also referred to as Biomethanation.

2.7.2 Parameters affecting Energy Recovery

The main parameters which determine the potential of recovery of energy from Wastes (including MSW), are: Quantity of waste, and Physical and chemical characteristics (quality) of the waste. The actual production of energy will depend upon specific treatment process Employed, the selection of which is also critically dependent upon (apart from certain other factors described below) the above two parameters. Accurate Information on the same, including percentage variations thereof with time (daily/ seasonal) is, therefore, of utmost importance.

The physical parameters requiring consideration include: size of constituents, density, and moisture content smaller size of the constituents' aids in faster decomposition of the waste. Wastes of the high density reflect a high proportion of biodegradable organic matter and moisture. Low density wastes, on the other hand, indicate a high proportion of paper, plastics and other combustibles. High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions. It also makes the waste rather unsuitable for thermo-chemical conversion (incineration, pyrolysis/ gasification) for energy recovery as heat must first be supplied to remove moisture.

The important chemical parameters to be considered for determining the energy recovery potential and the suitability of waste treatment through bio chemical or thermo-chemical conversion technologies includes Volatile Solids, Fixed Carbon content, Inert, Calorific Value, C/N ratio (Carbon/Nitrogen ratio), Toxicity. The desirable range of important waste parameters for technical viability of energy recovery through different treatment routes is given in the Table 2.11 The parameter values indicated therein only denote the desirable requirements for adoption of particular waste treatment method and do not necessarily pertain to wastes generated / collected and delivered at the waste treatment facility. In most cases the waste may need to be suitably segregated/ processed/ mixed with suitable additives at site before actual treatment to make it more compatible with the specific treatment method. This has to be assessed and ensured beforehand.

Table 2.11 Desirable range of important waste parameters for technical Viability of energy recovery

Waste treatment method	Basic principle	Important waste parameters	Desirable range
Thermo-chemical conversion	Decomposition of organic matter by	Moisture content	< 45%
		Organic/volatile	> 40%

▪ Incineration ▪ Pyrolysis ▪ Gasification	action of heat	mater	
		Fixed carbon	< 15%
		Total Inert	< 35%
		Calorific value (Net calorific value)	> 1200k-cal/kg
Biochemical conversion Anaerobic digestion/ Bio-methanisation	Decomposition of organic matter by microbial action	Moisture content	> 50%
		Organic volatile matter	> 40%
		C/N ratio	25-30

Source: The Expert Committee of India, 2000

Indicated values pertain to suitably segregated/ processed / mixed wastes and do not necessarily correspond to wastes as received at the treatment facility.

2.7.3 Assessment of Energy Recovery Potential

A rough assessment of the potential of recovery of energy from MSW through different treatment methods can be made from knowledge of its calorific value and organic fraction, as under: In thermo-chemical conversion all of the organic matter, biodegradable as Well as non-biodegradable, contributes to the energy output:

Total waste quantity: W tonnes

Net Calorific Value: NCV k-cal/kg.

Energy recovery potential (kWh) = NCV x W x 1000/860 = 1.16 x NCV x W

Power generation potential (kW) = 1.16 x NCV x W/ 24 = 0.048 x NCV x W

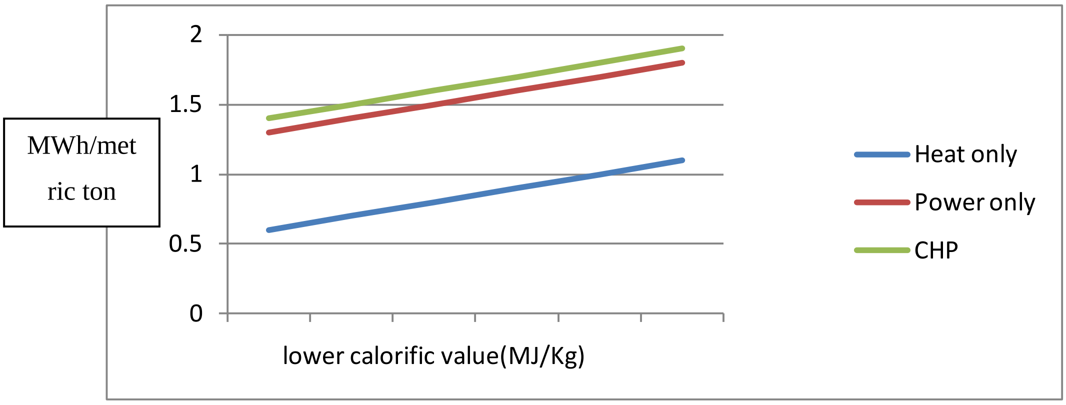
Conversion Efficiency = 25%

Net power generation potential (kW) = 0.012 x NCV x W

If NCV = 1200 k-cal/kg., then

Net power generation potential (kW) = 14.4 x W

Figure 2.2 Energy recovery from MSW based on their source



Source: World Bank 1818 H Street, N.W. Washington, D.C. 20433, U.S.A.

2.8 Wastes as Fuel and criteria for incineration

A most crucial factor in the feasibility of an MSW incineration plant is the nature of the waste and its calorific value. If the mandatory criteria for waste combustibility are not fulfilled, the project should be terminated. As a result of the socio-economic situation in many low to middle income countries or areas, only limited amounts of useful resources are wasted. Organized and informal recycling activities in the waste handling system tend to reduce the amount of paper, cardboard, and certain types of plastic in the waste. Additionally, the waste may have high ash and moisture content. Municipal solid waste in such areas therefore often ends up with a low calorific value and its ability to burn without auxiliary fuel is questionable either year round or in certain seasons.

In areas with heavy precipitation, closed containers for collection and transportation should be used to avoid a significant increase of the water content of the waste. Industrial, commercial, and institutional wastes (except from market waste) tend to have a significantly higher calorific value than domestic waste. Mixing different types of wastes may therefore make incineration possible. However, the collection system must be managed well to maintain segregated collection under these circumstances.

2.8.1 Key Criteria for Waste as Fuel

A preliminary feasibility assessment of using a particular waste as fuel can be made on the basis of the content of ash, combustible matter (ignition loss of dry sample), and moisture. The average annual lower calorific value must be at least 7 MJ/kg, and must never fall below 6 MJ/kg in any season; Forecasts of waste generation and composition are established on the basis of waste surveys in the catchment area of the planned incineration plant; Assumptions regarding the delivery of combustible industrial and commercial waste to an incineration plant should be founded on an assessment of positive and negative incentives for the various stakeholders to dispose of their waste at the incineration facility; The annual amount of waste for incineration should not be less than 50,000 tons, and the weekly variations in the waste supply to the waste incineration plant should not exceed 20 percent. Moisture contents (MC) greater than 50% are generally not suitable for combustion since the energy required to evaporate the water reduces the efficiency. Typically the combustion process will produce about 25% bottom ash by weight of the input.

The maximum amount of energy recoverable through MSW incineration depends primarily on the lower calorific value of the waste, but also on the system applied for energy recovery. It is most efficient when both electricity and steam/heat are produced, and the yield is lowest when only electricity is generated and the surplus heat is cooled away. Energy prices vary greatly from place to place, even within the same country. Electricity is a high-value energy form, so a low energy yield is, to some extent, compensated for through price differences.

2.9 Emissions from municipal Solid waste incineration

The incineration of municipal waste involves the generation of climate-relevant emissions. These are mainly emissions of CO_2 (carbon dioxide) as well as N_2O (nitrous oxide), NOx (oxides of nitrogen) NH_3 (ammonia) and organic C, measured as total carbon. CH_4 (methane) is not generated in waste incineration during normal operation.

The emissions from incineration highly depend on the composition of the incoming waste, but also on the combustion efficiency of the incinerator and the technology used for flue gas treatment Depending on the fuel composition and operational circumstances nitrogen oxides, sulphur dioxide, carbon monoxide, hydrogen chloride, dioxins and furans, hydrogen fluoride, volatile organic carbon and heavy metals are emitted (Williams, 2005).

For the reference waste, the amounts of energy and GHG emissions from landfill or thermal conversion into energy were estimated using various factors reported in the literature. When landfilled, the biodegradable portion of the waste releases CH_4 and carbon dioxide (CO_2). Part of the LFG is recovered, but the remainder diffuses into the atmosphere. Because of its high global warming potential (GWP), CH_4 can significantly contribute to GHG emissions. When waste is burned for energy by incineration or other thermal conversion, fossil carbon in the waste is released as CO_2 together with a small amount of other GHGs such as nitrous oxide (N_2O) and CH_4. However, energy production indirectly reduces GHG emissions by displacing the use of fossil fuels. The amount of displaced fossil fuel depends on the LHV of the waste and the fuel efficiencies for heat and electricity. The emission factors established for landfilling and combustion are then applied to various cases of waste management and fuel efficiencies to identify the potential for energy and reduction of GHG emissions.

Incinerator is a container for burning refuse, or plant designed for large-scale refuse combustion. Thus, incineration is one of the best known methods of managing municipal solid waste disposal. Nevertheless, the environmental consideration must be done before setting up a recuperative energy incinerator.

3. Materials and Methods

3.1 Description of Study Area

The study area, Reppi /Koshe dumpsite, is situated in the South West part of the city, which is the only dumpsite in Addis Ababa. It has a total area of 32 hectares. From this 19 hectares are in process to close for collection of methane gas. About 70% of the work is completed by covering soil and installing pipe. The purpose of collecting methane gas from this dumpsite is for CDM benefit by LFG-flaring system. The project is done by the horn of Africa regional environmental centre and network. The dumpsite location is not centre for all sub cities of Addis Ababa. Due to population increase and urbanization the site is surrounded by housing areas and institutions, these affect people living near to the dumpsite. All the city solid wastes are dumped in this site over 49 years and the site is getting full.

Figure 3.1 Reppi /Koshe dumpsite

Figure 3.2 Methane gas collection site in reppi/koshe dumpsite.

3.2 Methodology

The methodology followed for this study involves review of related literatures; establishment and training of crews for the random truck sampling, sorting and measurement of municipal solid waste in the dumpsite for composition determination; proximate analysis; heating value evaluation; net energy potential calculation based on calorific value and moisture content; ultimate analysis; environmental aspect and collection and transport cost analysis of municipal solid waste.

The followings are the major methodological steps followed during the study.

3.2.1 Method of Random Truck Sampling

Generally there are two formal types of sampling and analysis methods based on ASTM D 5231-5292 namely, random truck sampling and quartering. The sampling plan for this project used both sampling technique to identify the fresh waste characteristics and composition of fresh garbage waste (incoming waste to dumpsite/day). In this part both type of MSW trucks (lift and compacter truck) were considered to take the samples and the procedure is applicable for collecting the representative municipal solid waste. For my work hazardous and hospital medical waste are not included in the sampling.

The first steps in random sampling method was a random selection of arrival waste loads (trucks) by considering all sub-cities and unload a truckload of wastes in a controlled area near to the site then quarter the waste load. After these select one of the quarters, mixed well, picked up 10 kg sample of waste and separate all of the individual components of the waste into preselected components. Typically, 100 kg of waste sorted for each day and these processes repeated for 6 days and for one day a total of 10 trucks were selected. Finally place separated components in a balance and determine the percentage distribution of each components by mass. The sampling processes were done between February and March, a period of dry season in Addis Ababa City. Individual waste component and composite samples recorded and the fresh waste samples taken back to laboratory for chemical analysis. Figure 3.3 shows the flow of municipal solid waste random truck sampling method.

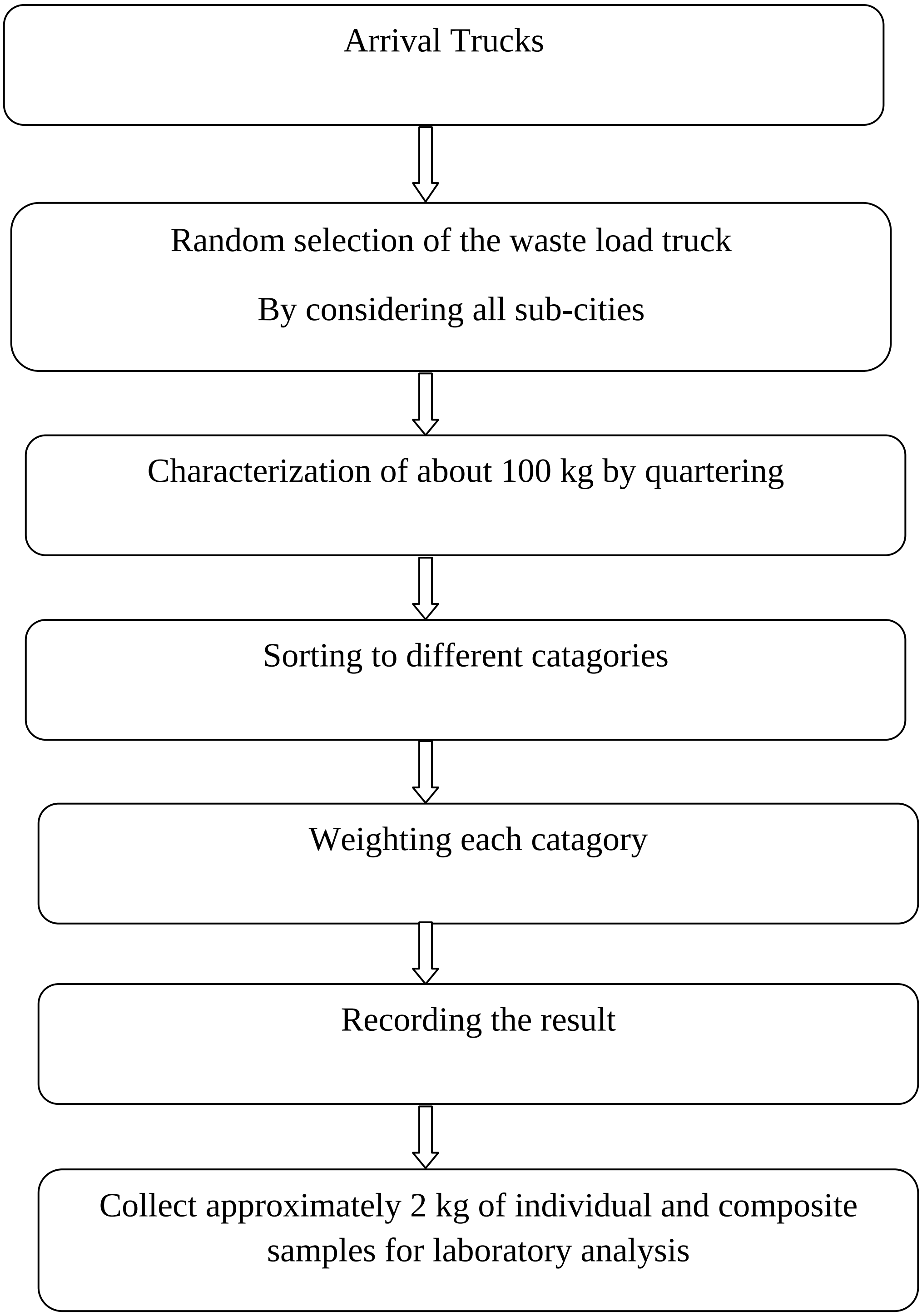


Figure 3.3 Flow of municipal solid waste random truck sampling

3.2.2 Sorting of Waste

The characterization of the solid waste into different categories is depending on region and waste sources. The solid waste dumping in the landfill usually categorize between 15 to 24 different categories: food waste, paper (mixed),news print, plastic(film), plastic(rigid), plastic(foam), textile, rubber/leather, wood waste, yard waste, high grade paper, corrugated paper, glass(clear), glass(coloured), metal(aluminium), batteries/ hazardous, diaper, fruit waste, metal(ferrous), metal (non-ferrous), inorganic organics, others, fine [(Kathirvale et al, 2003)].

Manual sorting was performed by four sorters during six to eight hours; all sorting personnel worked in the dumpsite for money years; they had a know how to identifying the type of waste and technical requirements of the sorting process. The collected solid waste sample after sorting process would divide to 10 related categories, prepared and sealed in plastic bags before transporting to laboratory. Next, the waste separated according to the selected classification such as wood, paper, plastic, food, fruit, textile, chat, glass, metal and other waste, each category was weighted for percentage distribution of each waste components.

For laboratory work take seven related waste category by excluding metal, glass and other waste type from ten waste categories. Based on literature information these waste types are not suitable for recovery of energy by combustion because they needs excess heating and release high emission gases when they are combusted. For laboratory analysis the samples taken from dumpsite and from the source based on the composition result. From the dumpsite only dry waste type were taken the rest moist waste collected at source before 2 or 3 hours interval to move laboratory.

3.2.3 Proximate analysis

Proximate analysis consist of moisture content, ash content, volatile matter and fixed carbon determined by putting the selected sample to different range of the temperature, between 100°C to 950°C. In order to reduce the magnitude of error arising from the moisture change and from decomposition the analysis of the sample was started with in two to three hours after collection. Care was also taken to make the samples are well mixed and each waste component were taken and chopped manually to reduce the size. The well mixed sample finally taken for laboratory analysis.

The laboratory methods for measuring the proximate analysis of samples in this research were carried out based on ASTM standard. This standard determines the condition of laboratory analysis such as moisture, volatile and ash content. The percent moisture of the MSW samples was determined by weighing the samples `into a pre weighed dish and drying the samples in an oven at 105°C to a constant weight (ASTMD 3173). The percent moisture content (MC) was calculated as a percentage loss in weight before and after drying. The composite samples of MSW material used in the moisture content determination were weighed and placed in a furnace for 7 minutes at 925°C (ASTMD3175). After combustion, the samples were weighed to determine the ash dry weight, with volatile solids being the difference between the dried solids and the ash.

High volatile matter content indicates easy ignition of fuel. Ash content of waste is the non-combustible residue left after waste is burnt, which is represents the natural substances after carbon, oxygen, sulphur and water. Analysis include of dried the samples at 750°C for 1 hour (ASTMD 3174). The ash content is important in the design of the furnace grate, combustion volume, pollution control equipment and ash handling systems of a furnace.

Fixed carbon defined by carbon found in the material which is left after volatile test. Fixed carbon is determined by removing the mass of volatile from the original mass of the sample. The fixed carbon determined based on dry basis by the equation:
Fixed carbon (Wt% dry basis) =100-(Wt% Ash +Wt% volatile matter).
Fixed carbon acts as a main heat generator during burning.

3.2.4 Elemental (ultimate) analysis

The carbon (C), hydrogen (H), oxygen (O), sulphur(S) and nitrogen (N) determination in biomass represents the so called elementary analysis. These elements are detected by flash EA1112 thermo flash gas analyser except oxygen. Oxygen is determined by difference based on other element determination. About 10 mg of sample are burned at 900°C in an oxygen atmosphere, so the C is converted into CO_2, H in H_2O, S into SO_2 and the N in N_2. The first three compounds are detected quantitatively by an IR detector, while N_2 is determined by a thermal conductivity detector. The sample was taken from two days of the week (Friday and Wednesday), which have minimum and maximum heating value based on their composition result. The elemental analysis of waste components was done at Arat kilo chemistry department laboratory.

3.2.5 Calorific Value

The heating value of the organic component in MSW can be determined in various methods by using a full scale boiler as a calorimeter, by using the oxygen bomb calorimeter, and by calculation (Tchobanoglous et al, 1993). Experimental determination by using a bomb calorimeter utilizes a sample of 1g. In this research oxygen bomb calorimeter is used to determine the heating value. To prepare the sample first known dry weights of MSW sample were chopped, well mixed manually and fed into a bomb calorimeter. The samples were then ignited in excess oxygen at 30 bars using an electric arc where the rise in temperature due to combustion of the sample was noted and the calorific values of MSW determined.

Low Heating Value (LHV) is also known as net calorific value of a fuel. It is defined as the amount of heat released by combusting a specified quantity and the final temperature of the combustion products is above the boiling point of water (100^oC). The LHV assumes the latent heat of vaporization of water in the fuel and the reaction products is not recovered. Lower heating value (LHV), doesn't include the water condensation heat. The high heating value can be determined experimentally in the laboratory with bomb calorimeter. The lower heating value is calculated net of fuel moisture and water that forms in the combustion reaction. Therefore, to calculate a LHV of a fuel from a HHV or vice versa, the moles of water produced when a mole of fuel is burned must be determined. Hence HHV = LHV + nHv (H_2O, 25^oC). The heat of vaporization of water at 25 ^0C is; Hv (H_2O, 25 ^0C) = 44.013 kJ/mol or 2.445MJ/kg.

3.2.6 Net energy potential

Net energy potential of municipal solid waste determined in the laboratory or by theoretical calculation. But for this study due to the absence of incinerator the net energy potential was determined by calculation based on the result of moisture content, calorific value and mass of sample waste. Also the power generation potential determined by calculation by considering other factors like oxygen supply and furnace efficiency and the incineration plant work 24 hour are satisfied.

Theoretically net energy potential of municipal solid waste determined by using the equation adapted from Fobil et al. (2002):

Net energy (N_e) = gross total annual energy (G_{te}) – energy required in drying the waste (E_d).

$N\text{e} = G_{te} - E_d$

3.3 Materials and Instruments

The following materials and instruments were used during the study:

A. Hand protective plastic gloves: To protect hand from direct contact with waste

B. Mouth & Nose Mask: To protect from bad smells and inhalation of any fumes

C. Balance scale: For weight measurement

D. Plastic sheets: To ensure no loss of waste during sorting

E. Small Garbage: For the collection of fresh solid waste from the source for laboratory Work

F. plastic bags: For handling the sorted waste for measurement

G. Digital Camera: For capturing pictures of the working process

H. Oven: To dry the waste for moisture content determination

I. Crucibles: Used to handle during the determination of ash and VCM

J. Furnace: For determination of volatile matter and ash content

K. Bomb calorimeter: For the determination of high heating value

L. Gas analyser: To determine carbon, hydrogen, nitrogen, oxygen and sulphur

M. Electric grinder: For size reduction

4. Results and Discussion

The quantity, nature and characteristics of the waste fluctuate with respect to time, region and condition prevailing there. Similarity is the solid waste which showed wide variation in the present study. Waste from different categories can have different chemical and physical characteristics which is directly depend on the type of wastes source.

4.1 Result of random truck sampling

Solid waste characterization from random truck sampling method was done for a period of one week starting from Monday until Saturday which would cover the characteristics for whole week. The total amount of the waste to be sorted in a day was approximately 100 kg. This amount was equally distributed among the number of trucks which Selected to collect the sample of that day. Table 4.1 shows the number of trucks and the waste sorted for each one.

Table 4.1 Number of trucks and the waste sorted per trucks

Days	Number of selected Trucks	Amount of waste Sorted per truck, Kg	Total amount of waste sorted per day ,kg
Monday	10	10	99.1
Tuesday	10	10	99.8
Wednesday	10	10	99.9
Thursday	10	10	99.8
Friday	10	10	99.4
Saturday	10	10	100

4.2 Solid waste compositions

Obtained result from sorting process and quantity of each individual component of the municipal solid waste at Reppi dump site is given Table 4.3**.** An average between 15 to 20 different categories of solid waste was found at dumpsite waste stream during one week. The composition was then categorized into ten major categories: food, fruit, chat, paper, plastic, textile, wood, metal, glass and other waste. The waste type included under each category listed in Table 4.2.

Table 4.2 Waste composition category

Waste category	Waste components
Food waste	Injera, bread, cake, meat, packed food, mixed food
Fruit waste	Vegetables,banana,onion,avocado,mango,Papaya,orange,tomato,potato
Chat waste	Chat
Plastic waste	Film, rigid and foam plastic composed mainly of packaging, plastic products, hard and flexible plastic household items, PET bottles, Jerry can, highland, etc
Textile waste	Included both organic based (such as cotton, jute, etc.) and synthetic based (synthetic clothes, wrappers, bags).
Wood waste	Pieces of wood, sawdust
Metal waste	Tin can, aluminium and other metal type
Glass waste	Cleared and coloured type it included beer bottles, liquor bottles, and other beverage and juice bottles.
Paper waste	Included all paper products (printed or plain paper, newspapers and magazines, notebooks), all types of corrugated and non-corrugated carton boxes and packages, etc.
Other waste	Soil, dirt, ash, house sweeping dust, hair, grass, dust, ceramics, sand and gravels, household potential hazardous wastes such as dry batteries, household chemicals, or any other wastes that cannot be distinctly classified under any of the above nine categories were all classified as others.

Table 4.3 Average quantity of solid waste composition

Categories of municipal solid waste	Monday (%)	Tuesday (%)	Wednesday (%)	Thursday (%)	Friday (%)	Saturday (%)	Average (%)	Standard deviation
Food waste	17.28	8.4	15	7.09	17.88	23.55	14.87	±6.2
Fruit waste	30	40	28	34.8	32.61	13.25	29.77	±9
Chat waste	13.5	27.5	21	12.41	11.35	27.94	18.95	±8
Plastic waste	3.4	3.2	4	6.2	2.4	3.14	3.72	±1
Textile waste	5	3	3	2.65	1.86	2.46	3	±1.1
Wood waste	1.5	0	2.86	4.43	5.63	1.95	2.73	±2.1
Metal waste	0.9	2	1.8	4.21	1.4	3	2.22	±1.2
Glass waste	3.8	2	3	4	2.2	3.5	3.08	±1
Paper waste	3	3.2	5	4.21	5.08	4.22	4.12	±1
Other waste	20.72	10.5	16.3	21.5	19	17	17.5	±4

The main purpose of this method was to estimate the quantity of solid waste component which generate at Reppi dump site, for proximate; heating value and elemental analysis determination in the laboratory based on the composition result. Figure 4.1 shows the variation of waste categories quantity during one week based on random truck sampling method.

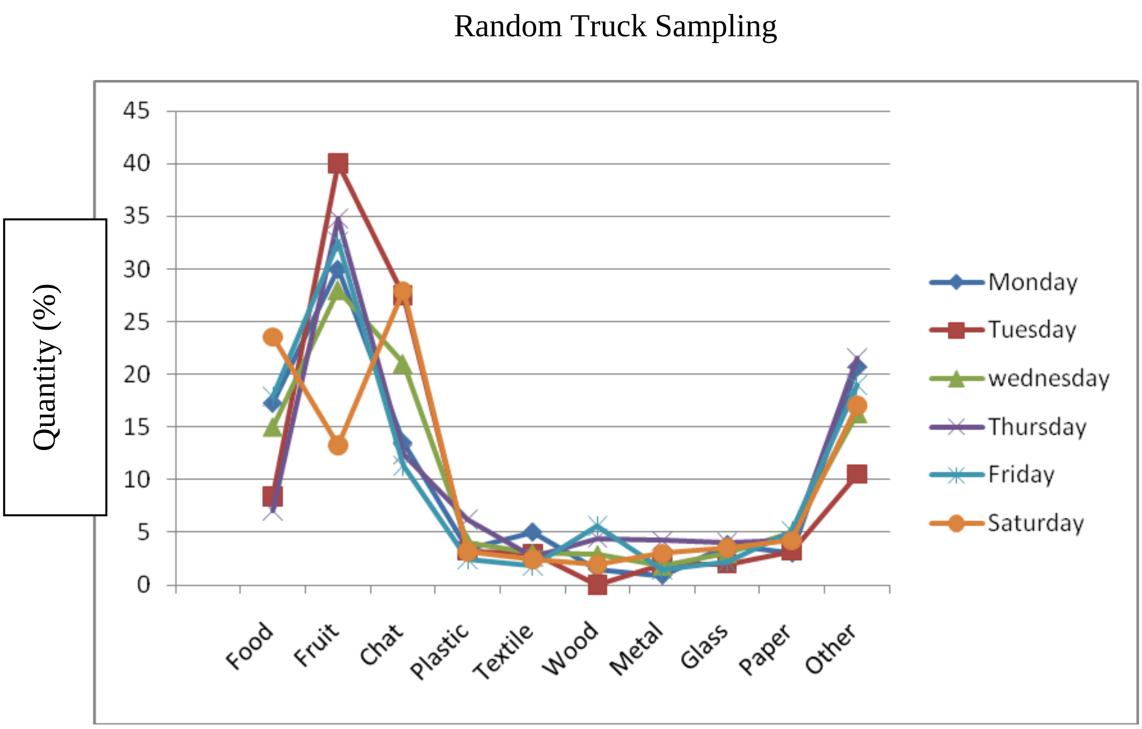


Figure 4.1 Variation of waste categories quantity during one week

Based on percentage of collected solid waste by random sampling method, it was evident that fruit waste (approximately 29.77 %) is the main constituent of the waste. As Figure 4.1 shows, the result from quantity of food waste wasn't consistent during the sampling period and fluctuated from 7.09 to 23.55 percent. Chat another important ingredient of domestic waste found in large amount, on average 18.95 % next to fruit waste. Another main component was other waste type which made about 17.5% of the total weight. According to the result from sorting process, the amount of paper, plastic, textile, wood, glass and metal waste that comes to this dumpsite wasn't much different during the sampling period, with an average from 2.22%-4.12% of total waste per week. From these waste types paper waste the highest percentage in mass, on average

4.12%. Result from Figure 4.1 indicate that fruit waste, chat, other waste type followed by food waste make up the largest fraction of domestic waste around Reppi dumpsite.

4.3 Proximate Analysis Result

Proximate analysis involves determination of moisture content, volatile matter, ash content and fixed carbon of composite sample and individual waste category. The analysis was conducted according to ASTM method. The over all proximate analysis result of composite waste samples and individual waste type for a week is presented in Table 4.4 and Table 4.5. The values in the tables are percentages based on dry (moisture-free) content.

Table 4.4 Proximate analysis of individual MSW (%)

Proximate analysis of Individual MSW	Moisture content (%)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)
Fruit waste	81	13.71	85.84	0.45
Chat waste	67	5.67	82.25	12.08
Food waste	53.86	8.54	84.07	7.39
Wood waste	11.71	4.36	87.53	8.11
Plastic waste	1.59	2.26	92.79	4.95
Paper waste	6.89	4.69	87.23	8.08
Textile waste	4.25	12.47	86.63	0.90`

Table 4.5 Proximate analysis of composite MSW (%)

Proximate analysis Composite MSW	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Moisture content	58.75	64.16	44.72	54.53	45.29	58.26
Ash content	9.85	10.53	9.04	9.65	9.65	7.93

Volatile matter	85.23	84.85	85.58	85.83	85.35	84.43
Fixed carbon	4.92	4.62	5.38	4.52	5	7.64

Moisture Content Analysis

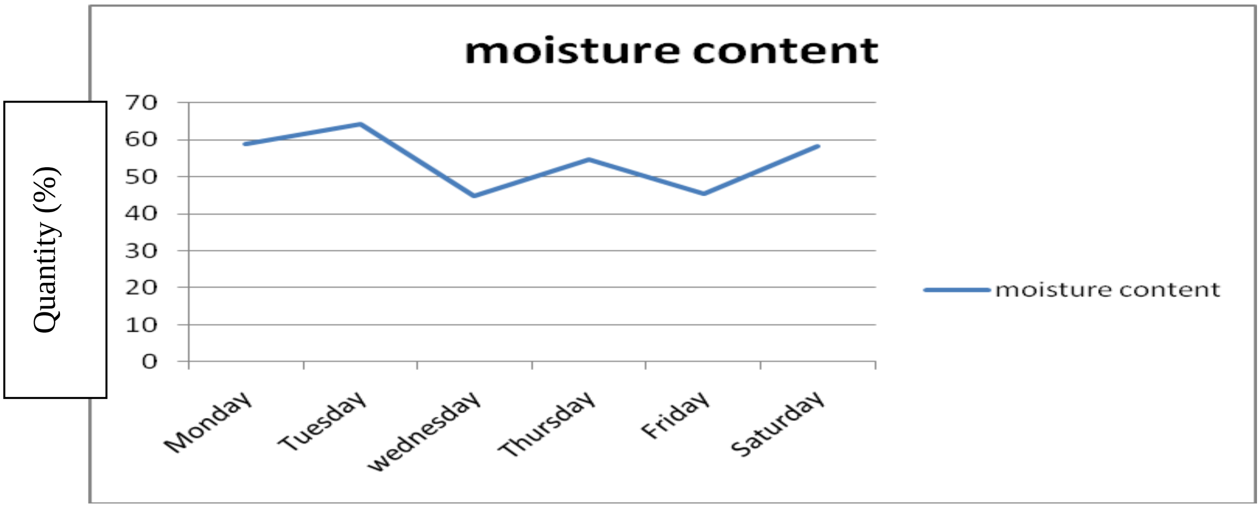


Figure 4.2 Moisture content analysis (random truck sampling)

4.3.1 Moisture content

The moisture content is a measure of the amount of water lost from materials upon drying to a constant weight. It is directly affected by physical and chemical properties of material which enable it to absorb the exiting water in the environment. Table 4.4 shows the moisture content analysis of each individual waste category in Reppi dump site. Based on laboratory analysis result, fruit waste with 81 percent, chat with 67 percent and food with 53.86 percent have the highest moisture content in this dumpsite. The moisture content of composite MSW based on the composition result of the week presented in Table 4.5. The moisture content is different in each day of the week due to the variation of the MSW composition. Average of moisture content analysis based on random truck sampling is 54.44 % where the highest percentage of the moisture content (64.16%) was on Tuesday whereas Wednesday was the lowest (44.72%) as shown in Figure 4.2. Result from moisture content analysis directly affected by the quantity of wet basis materials such as fruit waste and chat waste in waste stream. As shown in Table 4.3, higher percentage of fruit waste (40%) and chat waste (27.5%) on Tuesday compared with result on Wednesday (fruit waste 28 % and chat waste 21%) is the reason increasing the percentage of the moisture content. The Desirable range of moisture content for technical Viability of energy recovery is less than 45%. Generally from the week day only Wednesday fulfil the desirable range of moisture content for technical Viability of energy recovery by incineration which is 44.72%.when we see individual waste type moisture content wood, plastic, paper and textile waste are in the desirable range.

Wastes with different moisture contents have different drying characteristics. Those with higher moisture content require a longer drying time and much more heat energy, causing a lower temperature in the furnace; and vice versa. If the moisture content is too high, the furnace temperature will be too low for combustion, such that auxiliary fuel is needed to raise the furnace temperature and to ensure normal combustion.

4.3.2 Ash

The ash content is the remaining ash after volatile matter and fixed carbon are removed. Table 4.4 shows that the high percentage of ash content in fruit, textile and food waste with 13.71%, 12.47% and 8.54% respectively, dominating in the ash content percentage. The higher percentage of ash content was referred to quantity of fruit waste, textile and food. The percentage of these materials in collected composite sample on Tuesday was relatively higher than other days and the value is 10.53%. From the ash content value of the week day Tuesday have high percentage. Generally the ash content in the week day shows that the MSW in Reppi dumpsite small ash this indicates that it has high flue gases.

4.3.3 Volatile Matter

Organic and combustible materials such as plastic, wood and paper are the components with high percentage of volatile matter usually between 85 to 97 percent. From the waste type plastic waste have higher volatile matter with 92.79 percent. Collected samples from random truck sampling method shows the higher volume of these materials on Thursday compare to other sampling days, is the reason on increasing the volatile matter up to 85.83 percent. Volatile matter is that portion of the wastes which is converted into the gas phases during the heating process (950°C). As shown in Table 4.5, the percentage of volatile content for composite waste sample is relatively high for all day of the week. The useful range of volatile matter for technical Viability of energy recovery is greater than 40%. From the result of volatile matter in the week day all are in the desirable range. From this we can conclude that the selected municipal solid waste in Reppi dumpsite have high organic matter. So it has the capacity to generate more flue gases for heating.

4.3.4 Fixed Carbon

Fixed carbon is the carbon remaining on surface as charcoal. From comparisons of the waste type chat have high fixed carbon load. The high percentage of the fixed carbon in waste materials such as chat (12.08%) shows that this element requires a longer detention time on the surface of the furnace to achieve complete combustion compared to fruit waste, textile waste or even plastic. From the collected samples the higher percentage of chat waste on Saturday compared to other sampling days, is the reason on increasing the fixed carbon up to 7.64 percent. The desirable range of fixed carbon for technical viability of energy recovery is less than 15%. Fixed carbon result of composite and individual municipal solid waste in the week are in the given range. So the waste in the sampling day is feasible for energy recovery from municipal solid waste by incineration.

4.4 Elemental (Ultimate) analysis result

The ultimate analysis indicates the various elemental chemical constituents such as carbon, hydrogen, oxygen, sulphur, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design etc. Ultimate analysis result of composite waste samples for the selected two days of a week are presented in Table 4.6.

Table 4.6 Elemental analysis of composite MSW

Sample	%C	%H	%O	%N	%S	%Ash
Wednesday	43.57	5.92	41.28	1.23	0.3	7.5
Friday	43.91	7.09	39.31	1.29	0.4	8.1

4.5 Heating value result

As a mixture of various kinds of waste, MSW has very complex ingredients. Heating value of MSW, as an indicator of combustible contents in MSW, plays a key role in determining the measure of MSW handling. If MSW can be handled with incineration and pyrolysis, heating value serves as an important parameter in deciding for incineration plan (Zhang, 1997).

Removing particular materials from MSW prior to incineration (e.g., through source separation) can affect combustibility. For example, removing other wastes and inorganic recyclable such as glass and metals can reduce moisture and increase average HHV. In contrast, removing paper and plastics lowers HHV and increases moisture content. The net effect will depend on exactly what is removed.

Table 4.7 shows individual high heating value of MSW based on the weekly sampling determination. From the MSW disposed in the dumpsite plastic waste presents the highest HHV among all tested wastes, with an average of 22014.28KJ/Kg and the highest of 31368.88KJ/Kg. Fruit waste has high moisture, but due to high combustible content, it demonstrates large HHV next to plastic waste with 18761.07KJ/Kg.

The high heating value of composite waste fraction from Monday to Saturday showed in Table 4.8. From the sampling day Friday has the highest high heating value, due to the highest composition of high calorific value waste fraction. Saturday has the lowest high heating value in case of low waste composition of high calorific value waste fraction, for example fruit waste. The high calorific values of various waste fractions are presented in Table 4.8

Table 4.7 Heating value of individual waste component

Individual waste	Fruit	Food	Plastic	Paper	Textile	Wood	Chat
Calorie/gram	4465.14	4153.12	7465.795	3101.885	4172.065	3922.935	4155.47
Joule/gram or KJ/Kg	18761.07	17450.07	31368.88	13033.13	17529.68	16482.92	17459.95

The high calorific values of composite waste fractions are presented in Table 4.9

Table 4.8 Heating value result (composite sample)

Composite samples of MSW	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Calorie/gram	4480.21	4548.2475	4454.03	4599.09	5958.97	4212.36
Joule/gram or KJ/Kg	18824.40	19110.28	18714.40	19323.9	25037.73	17699

The lower calorific value (net calorific value) result of the individual and composite municipal solid waste samples determined based on the high heating value. One of the criteria for incineration plan is based on lower heating value result. The lower heating value of individual and composite municipal solid waste showed in Table 4.9 and Table 4.10 respectively.

Table 4.9 Lower calorific values of individual waste fractions

Individual waste	Fruit	Food	Plastic	Paper	Textile	Wood	Chat
Calorie/gram	3318.44	3004.88	6334.66	1948.12	3023.85	3012.66	3007.17
Joule/gram or KJ/Kg	13871.07	12560.07	26478.88	8143.13	12639.68	12592.92	12569.95

Table 4.10 lower calorific values of composite waste fractions

Composite samples of MSW	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Calorie/gram	3333.58	3401.98	3307.27	3453.08	4820.03	3064.35
Joule/gram or KJ/Kg	13934.40	14220.28	13824.40	14433.9	20147.73	12809

World Bank guide on incineration of municipal solid waste recommends that a lower heat value (LCV) of 6000 KJ/Kg (1435 Kcal/Kg) during all the seasons is required for sustained combustion for adopting the thermal treatment process (the World Bank, 1999).

The desirable range of heating value (Net calorific value)) for technical Viability of energy recovery is greater than 1200k-cal/kg. The result of net calorific value shows that in all day of the week fulfil the desirable range. From this we can conclude the calorific value of the composite sample of the waste in the week is feasible for incineration.

4.6 Energy potential from municipal solid wastes

The net energy and recovery potential of MSW estimated by correlating the result of high heating value, moisture content and 1 Kg MSW sample. When waste is combusted, energy is given out as heat. Some of the energy is consumed in drying of the waste (to evaporate the water in the waste) and the rest (net) is available for conversion into useful work or power generation. The water in the waste is represented by the moisture content. Hence,

Net energy (N_e) = gross total annual energy (G_{te}) – energy required in drying the waste (E_d).

Ne = Gte – Ed--- (1)

But the energy required for drying MSW to a constant weight (E_d) is given by the sum of the energy required to raise the temperature of the water in waste from its initial temperature to a vaporisation temperature of 100°C (H_I) and the energy required to completely vaporise the water in the waste at 100^0C or heat of vaporisation (iV).

This means that $E_d = H_I + H_V$

Therefore, equation (1) becomes,

$N_e = G_{te} – (H_I + H_V)$ -- (2)

Let m = mass of a sample of MSW. The mass of dry MSW = m – m_w.

G_{te}= (m-m_w) x c_v

Cv = Calorific value of dry MSW.

But, H_I = mass (m_w) of moisture in MSW × heat capacity (c) of water in MSW × change in temperature (o).

This implies that $H_I = m_w \bullet c \bullet o$

But, o = final temperature T_s (100°C) – initial temperature(T_i) of water in MSW assumed to be the average annual temperature in Addis Ababa city (16.9°C).

Also, o = (100 + 273) – (16.9+ 273) = 83.1K.

And H_V = mass (m_w) of moisture in MSW × latent heat of vaporisation (h_{fg}).

This also implies that $H_V = m_w \bullet h_{fg}$.

Therefore, equation (2) becomes $N_e = G_{te} – (m_w \bullet c \bullet o + m_w \bullet h_{fg})$ = (m-m_w) x c_v-($m_w \bullet c \bullet o + m_w \bullet h_{fg}$)

Substituting the values into equation (2):

For Addis Ababa, the annual average temperature is typically 16.9° C.

Hence, the following values may be used to estimate Net energy available.

Ti = 16.9°C, Ts = 100°C, C = 4.2 kJ/kg-K, hfg = 2260 kJ/kg, Moisture content=54.44%

For 1 kg of MSW, m = 1 kg, m_w = 0.54 kg and the determined average calorific value, C_v = 19.78 MJ/kg.

G_{te}= (m-m_w) x c_v= (1Kg-0.54Kg) x 19.78 MJ/kg =9.09 MJ

E_d= (m_w • c • o + m_w • h_{fg}) = (0.54Kg x 4.2 kJ/kg-K x 83.1+0.54Kgx2260KJ/Kg)=1408.87 KJ=1.408MJ

N_e= G_{te}- E_d=9.09MJ -1.408MJ=7.682MJ

The potential energy efficiency may be obtained as;

Energy efficiency = (Net energy / Gross total annual energy) x 100

= (7.682/9.09) x 100=84.5%, that is, 84.5% of the energy in the MSW is potentially recoverable as heat.

The calculated net energy values in the sampling days of the week for 1Kg waste sample are presented in Table 4.11.

Table 4.11 Net energy potential of MSW in the sampling week

Parameter	Mon day	Tues Day	Wednes day	Thurs day	Fri day	Satur day	Average
Moisture content(MC) in %	58.75	64.16	44.72	54.53	45.29	58.26	54.44
Calorific value MJ/Kg	18.82	19.11	18.71	19.32	25.03	17.69	19.78
Energy required to dry MSW in MJ	1.53	1.66	1.16	1.42	1.17	1.51	1.408
Net energy(N_e) in MJ	6.24	5.20	9.18	7.37	12.52	5.87	7.68
Energy efficiency (%)	80.29	75.70	88.78	83.83	91.38	79.43	84.5

In the Table 4.11, Wastes with different moisture contents have different drying characteristics and net energy potential. Those with higher moisture content require more heat energy and causing lower energy efficiency. The energy efficiency of MSW in Addis Ababa city in the sampling date indicates that it is feasible for incineration programme.

4.7 Environmental Aspect of Reppi Municipal Solid Waste

Environmental issues thorough observation of the study area showed that the disposal of waste in open spaces, in household area, as well as near to the main road places and river banks decreased the aesthetic value of those areas .The decomposition of waste into constituent chemicals is also a common source of local environmental pollution.

Figure 4.3 Disposal of solid waste in Reppi dumpsite

Since the collected waste are disposed in the only open disposal site 'Reppi' it is wise to see the environmental issues concerned with this open disposal site. The major environmental concern is gas released by decomposing garbage. Methane is a by product of anaerobic respiration of bacteria, and these bacteria grow on landfills with high amount of moisture. Methane concentration can reach up to 50 % of the composition of landfill gas at maximum anaerobic decomposition (Cointreau-Levine, 1996). In well-designed and well-sited landfills there is a potential for methane recovery; few landfills in the developing world are designed to capture and make use of methane (UNEP, 1996). Such is the case with the Addis Ababa city solid waste disposal site. Generally, the required capital for methane recovery installation is lacking, and the low price of commercially produced gas does not make methane recovery an economically viable enterprise. Carbon dioxide is a second predominant gas emitted by landfills. Although less reactive, carbon dioxide build up in neighbourhoods could be a cause of asphyxiation (Olar Zerbock, 2003). The second problem with these gases is their contribution to the so-called green house gases (GHGs), which are blamed for global warming. Both gases are major constituents of the world's problem of GHGs; however while CO_2 is readily absorbed for use in photosynthesis; methane is less easily broken down, and is considered 20 times more potent as GHG (Johannessen, 1999). Hoornweg, et al (1999) states that for every metric ton of unsorted municipal solid waste, 0.2 Mt are converted to land fill gases. Of these gases, CO_2 and CH_4 each comprise 0.09 Mt, since it is believed that landfill gases supply 50% of human- caused methane emission and 2.4 % of all world wide greenhouse gases (Johannessen, 1999), this is clearly an area of concern in global environmental issues.

4.7.1 Combustion Analysis of Municipal Solid Waste

The main environmental issue is air pollution when the municipal solid waste incinerated. The different types of pollutants due to combustion of municipal solid waste are as follows Particulate matter, oxides of sulphur, oxides of nitrogen, carbon monoxide, carbon dioxide, methane and other related impact.

The chemical reaction in combustion is occurring according to (Eq. 1) (Vallero, 2008).

$(CH)x + O_2 \rightarrow CO_2 + H_2O$-------------------------- (1)

Excess oxygen ensures that oxidative processes can occur. If the oxygen concentration is less than 6% (by volume) in the combustion chamber, CO emissions will be high (D. Schneider). On the other hand, oxygen concentrations higher than 9% (by volume) will promote the creation of NO_x, dioxins and furans. For these reasons, CO and oxygen monitoring is very important (D. Schneider).

The incineration of municipal waste involves the generation of climate-relevant emissions. These are mainly emissions of CO_2 (carbon dioxide) as well as N_2O (nitrous oxide), NO_x (oxides of nitrogen) NH_3 (ammonia) and organic C, measured as total carbon. CH_4 (methane) is not generated in waste incineration during normal operation. It only arises in particular, exceptional, cases and to a small extent (from waste remaining in the waste bunker), so that in quantitative terms CH_4 is not to be regarded as climate-relevant. CO_2 constitutes the chief climate-relevant emission of waste incineration and is considerably higher, by not less than 10^2, than the other emissions.

It is known that nitrogen react with oxygen over about 1200^{o}C to form NO_x. So, nitrogen is not considered to react with oxygen during combustion reaction.(Coskun et al., 2009)

Calculation of Combustion Air Supply

The mass balance equation can be expressed as showed in Figure 4.4 in the form as, $m_{in} = m_{out}$

i.e. The mass of reactants is equal to the mass of products

$$m_{fuel} + m_{air} = m_{flue\ gas} + m_{ash} + m_{mst}$$

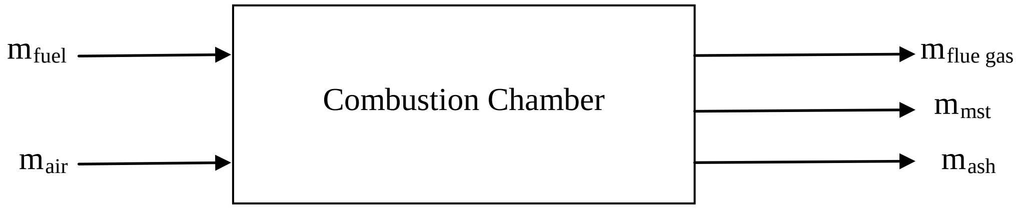


Figure 4.4 Mass balances in the Furnace

Using the elemental composition of municipal solid waste as shown in Figure 4.4, the calculation of amount of air required and the flue gas produced can be done considering the above equations.

Considering theoretical combustion reaction for the elemental analysis of MSW shown in Table 4.6, based on Friday result.

Carbon (C):

$C+O_2 \rightarrow CO_2$

$12KgC+32KgO_2 \rightarrow 44KgCO_2$

Oxygen required = 0.439 * (32/12) = 1.171/Kg MSW

Carbon dioxide produced = 0.439 * (44/12) = 1.609/Kg MSW

Hydrogen (H):

$H_2 + O_2 \rightarrow H_2O$

$2Kg\ H_2 + 16Kg\ O_2 \rightarrow 18Kg\ H_2O$

$1Kg\ H_2 + 8Kg\ O_2 \rightarrow 9Kg\ H_2O$

Oxygen required = 0.0709* 8 = 0.567 Kg/Kg MSW

Steam produced = 0.0709* 9 = 0.638 Kg/Kg MSW

Sulphur (S):

$S + O_2 \rightarrow SO_2$

$32Kg\ S + 32KgO_2 \rightarrow 64KgSO_2$

$1KgS + 1KgO_2 \rightarrow 2KgSO_2$

Oxygen required = 0.004 Kg/Kg MSW

Sulphur dioxide produced = 2 *0.004 = 0.008 Kg/Kg MSW

Table 4.12 Oxygen Required per Kilogram of MSW

Constituent	Mass fraction	Oxygen required (Kg/Kg MSW)	Gases produced	
			Gases	Kg of gases produced /Kg of MSW
Carbon (C)	0.439	1.171	CO_2	1.609
Hydrogen (H)	0.709	0.567	H_2O(steam)	0.638
Sulphur (S)	0.004	0.004	SO_2	0.008
Oxygen (O)	0.393	-0.393		
Nitrogen (N)	0.0129			
Ash	0.081			
Total		1.349		

O_2 required per Kilogram of MSW = 1.349 Kg

Air required per Kilogram of MSW = 1.349/0.233=5.789 Kg. Where air is assumed to contain 23.3% O_2 by mass.

Carbon, hydrogen and sulphur in the fuel combine with oxygen in the air to form carbon dioxide, water vapour and sulphur dioxide, under certain conditions, carbon may also combine with oxygen to form carbon monoxide.

$C + O_2 \longrightarrow CO_2$

$2C + O_2 \longrightarrow 2CO$

$2H_2 + O_2 \longrightarrow 2H_2O$

$S + O_2 \longrightarrow SO_2$

4.8 Collection and transportation cost of Addis Ababa city solid waste

One of the important factors which need to be considered and taken into account while planning any Waste to Energy facility and for selecting most appropriate, techno-economically viable technology is cost of collection and transportation of wastes. The logistics of waste collection/ segregation and its transport to plant site are of fundamental importance. Sufficient consideration should be given to the costs involved in the same. In the specific case of MSW, collection and transportation costs often account for the largest proportion of MSW treatment costs, which may be as high as 70% and may preclude consideration of certain technologies e.g. Sanitary Land filling at faraway sites.

The budget given for the cleansing management agency of Addis Ababa city originate from Finance and Economy development Bureau and city government of Addis Ababa. Finance and Economy development Bureau which is served for Running Conducting capita Projects /Vehicles and Machineries being used for solid waste Transportation, Dustbins, and Silos…/, conducting studies and researches, doing awareness creation activities. From City government of Addis Ababa the budget found from here is obtained from the society which is collected as a waste treatment / sanitary fee. As the agreement is done with the water and sewerage ministry, the money is gathered through water fee. That is, from each house hold, 20%; from industries and organizations, 42.5 %, from public water service 5% sanitary fee is expected to be paid with water fee. The income generated in this way is going to be used for Pre – Collectors and street weepers' salary, Private institute / organizations in service payment which are worked is collecting and transporting solid waste, making the agency well equipped in materials needed for solid waste collection, transportation and management.

Budget usage follows the rules and regulations of Addis Ababa City government Finance and Economy Development for Pre- Collectors the amount of money paid for them depends upon the amount of waste they collect from householders. As they bring receipt showing the waste amount bring receipt showing the waste amount collected in a month, paying the required paying will be undergoing. Private sanitary companies are organized to collect solid wastes from governmental and non government, organizations, embassies and industries. The payment will be held as they bring receipt showing the amount of waste collected in m^3 and checked or confirmed by solid waste re- cycling and disposal project office. The Appraisal Payment system of solid waste collector in Addis Ababa city is presented in Table 4.13. Collection and transportation cost of Addis Ababa city solid waste from Water fee based sanitary fee and finance and economy development bureau are presented in Table 4.14.

Table 4.13 Appraisal Payment system

Time – From	Cost given to 1 m^3 waste
February 2002 E.C up to	30 birr
December 2003 E.C	40 birr
March 2005 -	50 birr

Table 4.14 Collection and transportation cost of Addis Ababa city solid waste from Water fee based Sanitary fee and finance and economy development bureau

Sub city	Total waste removed in m^3	Expenditure			Revenue (budget)	
		Amount paid for Collection in birr		Transportation cost (Fuel and lubricant used)	Water fee based sanitary fee	Finance and Economy development Bureau for fuel and lubricant
		private sanitary company	Pre collector			
Arada	82853.67		3,314,146.76	1,678,468.26		1,678,469.00
Addis ketema	123968.18		4,958,727.27	2,804,900.00		2,804,900.00
Lideta	85916.04		3,436,641.53	1,642,367.00		1,642,367.00
Kirkose	91421.38		3,656,855.00	1,925,116.28		2,469,597.00
Yeka	88263.13		3,530,525.00	2,997,190.94		2,997,190.94
Bole	146065.48		5,842,619.00	3,731,336.14		3,731,341.14
Akaki kality	79226.86		3,169,074.55	1,858,610.70		1,927,009.00
Nifas silk	140230.4		5,609,216.00	1,997,151.00		1,997,162.00

Kolfe	109682.85		4,387,314.00	1,939,500.00		1,939,800.00
Gullele	77239.63		3,089,585.00	2,022,038.42		2,022,039.00
Total	1,024,867.62	11,915,388.00	40,994,704.11	22596678.74	71,900,770.00	23,209,875.08
Total		75,506,770.84				

The cost of collection and transportation result of Addis Ababa city solid waste shows that the amount of waste removed, payment for collector and transportation cost (Fuel and lubricant used) in each sub city are different. From the total expenditure cost of each sub city for transportation is different due to the distance from the waste source to disposal site. When we compare the sub city fuel and lubricant used yeka and gullele are the highest next to bole due to their long kilometre to the dumpsite. On the hand the sub city near to the dumpsite, for example nifas silk and kolfe dispose much meter cube waste by small fuel and lubricant used. Due to people living standard and number of population living in the sub city the waste removed are different. From the total expenditure and revenue cost for collection and transportation of waste in Addis Ababa sub cities are different due to the disposal site placement.

5. Conclusions and Recommendation

5.1 Conclusion

Based on the agency report and from composition determination in weekly analysis of MSW, the dumpsite contains sufficient quantity of municipal solid waste (about 3800 meter cube per day). However no attempt was made so far towards evaluating and energy recovery to tackle problems associated to municipal solid waste management.

In this work, based on the experimental analysis of the Reppi MSW, it has been observed that food, fruit and chat wastes constitutes about 55% of the dumped waste. The compositional analysis result showed that the composition and waste type of the composite municipal solid waste disposed at Reppi dumpsite were different in each day of the week. The result of proximate analysis showed except one day of a week the moisture content are above 45% and this directly related to the trend of high consumption of fresh fruit and vegetables. This affects net energy potential. For example on Friday the net energy is 12.52MJ/Kg which is higher than other sampling days, due to smaller ratio of high moisture content wastes and presence of high calorific value waste.

Municipal solid waste (MSW) is a domestic energy resource with the potential to provide a significant amount of energy. The amount of this energy identified as an important issues affecting the suitability of design the waste to energy plan. The higher average heating value (about 25037.73kJ/kg) of collected MSW on Friday showed the potential for incineration and energy recovery.

MSW in Addis Ababa shows high temporal and special fluctuation in terms of heating value and physical ingredients; very high moisture, some of which reaches 80%, disadvantageous for incineration; high heating value in the dry basis, generally able to be handled by incineration.

From the observation of Reppi dumpsite we can conclude that it affects the health of people living near to the site and also pose considerable negative effect on the environment. Based on the elemental analysis result when the city MSW is combusted they have the possibility to release high amount of carbon dioxide and steam (H_2O) and needs excess oxygen. The cost of solid waste collection and transportation in the city shows economic loss due to long haulage distances, absence of transfer station and the disposal site is not centre for all sub cities.

This study provides an overall picture and impacts, and hence, can support a decision-making process for implementation of MSW incineration. The results obtained in this study could provide valuable information to implement incineration. But it should be noted that the results show the characteristics only from some viewpoints.

5.2 Recommendations

1. The existing Addis Ababa city municipal solid waste which is disposed at Reppi dumpsite is the potential for energy recovery by combustion. From the result high moisture content and other waste type (inert and inorganic) are present, these affects net energy; therefore strongly recommend that there is a need for sorting out inorganic waste type and decrease the ratio of moist waste fraction to improve net energy potential.

2. Mixing different types of wastes may therefore make incineration possible. However, the collection system must be managed well to maintain segregated collection under these circumstances.

3. Government and different stakeholder as well as private organizations should invest on utilization of Reppi municipal solid waste for energy use by incineration and can improve the people attention for solid waste. For example, implement small scale incineration plant for heating and electricity (For industries and condominium) or small scale incineration that only use as heating purpose. It is the least expensive plant equipped with hot water boiler only.

4. The transportation cost and haulage time to dispose the city solid waste are high, so to reduce the cost and to save time establish transfer station in each sub city and build additional disposal site.

5. Suggestions for Further Research

- Design of a simple solid waste incinerator
- Utilization of a small-scale municipal solid waste for power generation
- Studies related to design and implementation of incineration plant
- Studies on efficient management of incineration gases
- Cost analysis of the solid waste management of Addis Ababa City

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Appendices

Appendices 1: Composition determination

Date: May 2005

Weather condition: No rain

Waste mass in kg																	
Monday			Tuesday			Wednesday			Thursday			Friday			Saturday		
SC	W	Mass	SC	W	Mass	SC	W	Mass	SC	W	Mass	SC	W	Mass	SC	W	Mass
NS	4	10	AR	5	10	Yk	3	10	KO	5	10	LD		10	KQ	7	10
AQ	6	10	AK	9	10	GU	8	10	LD	3	10	AR	9	10	BO	5	10
AR	3	10	KQ	7	10	KO	5	10	Yk	6	10	Yk	10	10	AR	9	10
AK	1	10	BO	3	10	LD	9	10	GU	7	10	GU	3	10	AK	2	10
KQ	8	10	NS	6	10	AR	1	10	NS	8	10	KO	4	10	GU	5	10
BO	3	10	AQ	5	10	AK	6	10	AQ	9	10	NS	8	10	NS	7	10
Yk	4	10	Yk	10	10	KQ	3	10	KQ	2	10	AQ	6	10	AQ	2	10
GU	7	10	GU	6	10	BO	8	10	BO	4	10	AK	8	10	KO	4	10

KO	1	10	KO	2	10	NS	6	10	AR	5	10	KQ	7	10	LD	6	10
LD	5	10	LD	1	10	AQ	2	10	AK	7	10	BO	6	10	Yk	7	10
100 kg composite sample																	

SC=Sub City W=Woreda

Picture of waste drop, quartering, weight measurement and sorting

Preparation for sorting

Weight determination of the different waste components

The crews participated in waste composition determination

Laboratory analysis

Appendices 2: composite and individual municipal solid waste sample for moisture content determination based on composition result

Composite MSW samples taken in gram

Waste type	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
food	72.55	33	63	32	74	72.49
Fruit	125	156	118	157	135	40.75
Chat	56	106	88	56	47	86
Plastic	13	13	16	28	9.93	9.65
Textile	21	12	13	21	7.7	7.57
Wood	6	0	12	20	23.3	6
Paper	12	13	21	19	21	13

Individual waste fraction samples taken in gram

Waste type	Sample in gram
food	500
Fruit	500
Chat	100
Plastic	20
Textile	20
Wood	20
Paper	20

Appendices 3: proximate analysis determination

1. Moisture content

First analyzing date: May 5-10, 2013

Place: Amest kilo laboratory

Residual moisture after dry at 105°C for 1 hour

	Container Weight (g)	Before 105 °C (g)	After 105 °C (g)
Monday	480.62	786.17	606.63
Tuesday	295.4	628.4	414.74
Wednesday	267.57	598.57	450.53
Thursday	295.38	619.32	442.69
Friday	300.83	618.76	474.77
Saturday	267.6	503.06	365.89

Moisture content determination for sample day (Monday)

MC=W-D/W*100 MC=moisture content, W=wet mass, D=dry mass

MC= (786.17-606.63)/ (786.17-480.62) X100

= 58.75%

2. Ash content

First analyzing date: May 5-10, 2013

Place: Amest kilo laboratory

Put in the furnace at 750°C for 1hour

	label	Crucible weight(gram)	Crucible weight + sample waste weight	
			initial	final
Monday	A	38.46	50.08	39.60
Tuesday	A	52.18	66.98	53.74
Wednesday	C	36.30	41.11	36.74
Thursday	A	33.55	43.48	34.51

Friday	B	32.65	41.68	33.53
Saturday	C	38	46.16	38.65

Ash content for sample day (Monday)

Ash content= [(39.6-38.46)/ (50.08-38.46)] X100

=9.85%

3. Volatile Matter

First analyzing date: May, 2013

Place: Amest Kilo laboratory

Put in the furnace at 925°C for 7 minutes

	label	Crucible weight(gram)	Crucible weight + sample waste weight	
			initial	final
Monday	C	38.44	52.10	40.45
Tuesday	C	39.19	53.61	41.38
Wednesday	C	34.93	41.47	35.88
Thursday	A	43.80	50.69	44.78
Friday	B	33.81	39.66	34.67
Saturday	C	36.28	45.74	37.76

Volatile matter for sample day (Monday)

Volatile matter= [(40.45-38.44)/ (52.1-38.44)] x100

=14.71% this is the remaining in the crucible so the volatile matter is 100 minus ash content

VM=100-14.71=85.23%

Appendices 4: Heating value determination of individual and composite municipal solid waste sample

Composite MSW samples taken for each day (1 gram)

Categories of municipal solid waste	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Food waste	0.2374	0.091	0.1903	0.0988	0.2328	0.3079
Fruit	0.409	0.4685	0.3565	0.4847	0.4246	0.1731
Chat	0.1833	0.3183	0.2659	0.1729	0.1478	0.3652
Plastic	0.0425	0.0390	0.0483	0.0864	0.0312	0.0410
Textile	0.0687	0.0360	0.0393	0.0369	0.0242	0.0321
Wood	0.0196	-	0.0363	0.0617	0.0733	0.0255
Paper	0.0393	0.0390	0.0634	0.0587	0.0661	0.0552

Individual municipal solid waste sample for heating value determination

Waste type	Food waste	Fruit waste	Chat waste	Plastic waste	Textile waste	Wood waste	Paper waste
Sample in gram	0.75	0.75	0.75	0.5	0.5	0.75	0.5

From bomb calorimeter determination

$$HHV = \frac{\left(m_w * c_w + (m_c)app\right)(t_m + c - t_o) - \sum b}{M}$$

Where:

(m_c)app=heat capacity of the calorimeter=333 cal/^{o}c

M=mass of sample waste=1 gram

C_w=1 cal/g ^{o}c

m_w=mass of water that is 2 litter water =2000 gram by the relation 1L=1kg

t_o=first temperature reading of the main test[^{o}c]

t_m=last temperature reading of the main test[^{o}c]

∑b=correction for observed heat b heat value added by glowing of the ignition wire 1cm=1.5 cal

C=correction for heat exchange between calorimeter and the surrounding

$C=m'\Delta n-(\Delta n+\Delta v)\ F$ in which

m' duration of the main test[min]

Δn-average temperature fall for every minute of the after test

Δv- average temperature rise for every minute of the pre test

F=1.5, if temperature rise in the first minute of the main test less than in the second minute

Appendices 5: Net energy potential and lower heating value determination calculation

- Net Energy calculation

The calculation was based on 760 ton/d of disposed MSW with the following formula; The economic and social trade-offs, of waste-to-energy conversion are presented. This equation was adapted from Fobil et al. (2002):

Net energy (Ne) = gross total annual energy (G_{te}) – energy required in drying the waste (E_d).

$N\text{e} = G_{te} – E\text{d}= G_{te}- H_I + H_V= G_{te} – (m \bullet c \bullet \text{o} + m \bullet \text{cv})$.

HI= energy required to raise the temperature of the water in waste from its initial temperature to a vaporisation temperature of 100°C.

H_V= energy required to completely vaporise the water in the waste at 100□C or heat of vaporisation

C= heat capacity(c) of water in MSW=4.2 KJ/kg/K

O= change in temperature=final temperature (100^0c) - initial temperature of water in MSW assumed to be the average annual temperature in Addis Ababa city (16.9).

Also, o = (100 + 273) – (16.9 + 273) = 83.1K.

m = mass (m) of moisture in MSW

c_v= latent heat of vaporisation=2.26×10^3 KJ/Kg

Monday sample

-Moisture Content=58.75%

-Calorific Value=18.82MJ/Kg

-Mass of Moisture=760,000Kg x (58.75/100) =446,500 Kg

-c=4.2 KJ/kg/K

-o=83.1

- $c_{v=}2.26 \times 10^3$ KJ/Kg

G_{te}=total MSW per day x calorific value

G_{te}=760000 x 18.82 MJ/Kg

=14303200 MJ

$E_d=H_I+H_V$=m.c.o+m.c_v=446500Kg x 4.2 kJ/Kg/K x 83.1+446500Kgx2.26x103KJ/Kg

E_d= 1,164,927.43MJ

N_e= G_{te}- E_d= 14,303,200MJ-1,164,927.43MJ

N_e=13,138,272.57 MJ

- Lower Heating Value determination

Based on the relation HHV = LHV + nHv (H_2O, 25°C)

The heat of vaporization of water at 25 ^{0}C is; H_v (H_2O, 25 ^{0}C) = 44.013 kJ/mol or 2.445MJ/kg

n=moles of water produced when a mole of fuel burned

$CH_4+2O_2 = 2H_2O+CO_2$

For Monday sample HHV=18.82 MJ/Kg, n=2

LHV=HHV-nH_v=18.82 MJ/Kg-2x2.445 MJ/Kg=13.93MJ/Kg