Addis Ababa Institute of Technology (AAiT)
School of Graduate Studies

Assessment of Energy recovery options and its Economic evaluation from Municipal solid wastes in Addis Ababa (Arada subcity)

A thesis submitted to the School of Graduate Studies of Addis Ababa Institute of Technology in partial fulfillment of the Degree of Masters of Science in Mechanical Engineering
(Thermal Engineering stream.)

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Oct 2011

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MSW…………….Municipal solid waste

RDF………………Refuse Derived Fuel

LHV………………Lower heating value

SWM …………….Solid waste management

Mg………………..Mega gram

WtE………………Waste-to-energy

MSE……………....Micro and small enterprises

OECD ……………Organization for Economic Co-operation and Development

EEPCo ……………Ethiopian Electric Power Corporation

Abstract

This thesis is intended to assess the energy recovery options from Municipal solid wastes that are collected from Arada Subcity. In the analysis, two particular schemes are analyzed and evaluated for their economic viability. They are Energy recovery through *incineration* and *Landfilling*. A detail analysis of each of these options is done to determine how much energy can be recovered by implementing them. Also the detail economic evaluation is conducted to decide on the more viable scheme. The analysis shows that the implementation of the Landfill gas-to-Energy scheme incurs the total estimated capital cost of around 37 million birr. The electricity generation potential of this scheme is around 23MW, which will make a financial value of around 160,000birr.While the capital cost required to implement incineration with energy recovery is estimated around 120 million birr. By implementing this option, around 2600MW of electricity can be produced, which makes a saving of 18,049,681birr, where the current electricity selling price is 0.29 birr/kWh. The analysis is done for the waste capacity of 25,000t per year.

CHAPTER 1

1. Introduction

1.1. Background

Addis Ababa is the capital city of Ethiopia and diplomatic capital for Africa .It enjoys a mid Afro-Alpine climate with an average temperature of around 21^0C .The population of the city is above 3 million, living in 10 sub-cities and 204 kebeles divided for administrative purpose. It is center for modern economic and social activities that infrastructure services are found relatively in better situation than other cities of Ethiopia. However their development is too slow to meet the demands of the increasing population due to both natural growth and rural urban migration. In particular, the complete inadequacy of the dry waste management is major environmental problem in Addis Ababa .The daily waste generation is estimated 0.252kg/capital/day. The current daily waste generation of the city is around 2,300m^3. Of municipal waste per day, 65 % (1,495m^3) is collected [10]. The remaining 35per cent of waste is disposed off through informal means, except smaller percentage going to incineration and dumped on open sites, drainage channels, rivers and valleys as well as on the streets. Various concepts have been developed over the years to provide the basis for improving the solid waste conditions in developing countries.

Economic development and prosperity are accompanied by the generation of large amount of wastes that must be re-used in some way or disposed in landfills. The generation of wastes can be reduced to some extent by improved design of products and packaging materials and by increasing intensity of service per unit mass of material used. However, even after such measures are taken, there will remain a large amount of solid wastes to be dealt with. Solid wastes can be classified in various classes. The broadest classification is in municipal (residential and commercial), industrial, construction and demolition wastes. MSWs are the most non homogeneous since they consist of the residues of nearly all materials used by humanity: Food and other organic wastes, papers, plastics, fabrics, leather, metals, glass and miscellaneous other inorganic materials. Everything wears out gradually or abruptly and then ends up either in MSW or is discarded in land or water.

In the early days, the disposal of human and other wastes did not pose any significant problems for, the population was small and the amount of land available for the accumulation of wastes was large. Now, the scenario has changed quite a lot owing to the rapid urbanization and industrialization. This has resulted in a tremendous increase in the migration of the public towards urbanized pockets. In this work, an attempt will be made to explore the potential recovery options of the energy available in Addis Ababa (Arada sub city) Municipal Solid Wastes (MSWs). The energy recovered from them can supplement the energy available for its supply to the citizens of Addis Ababa. Municipal Solid Waste (MSW) contains organic as well as inorganic matter. The latent energy present in its organic fraction can be recovered for gainful utilization through adoption of suitable Waste Processing and Treatment technologies. The recovery of energy from solid wastes also offers additional benefits as follows:

- The total quantity of waste gets reduced by significant amount 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 far-away landfill sites also gets reduced Proportionately; and
- Net reduction in environmental pollution

1.2. Thesis objectives

The general objective of this thesis is to assess the potential energy recovery options from the MSW disposed from the Arada Sub city and to analyze them from many points of views. Detailed analysis of these options and economic analysis to decide on the most viable option and finally recommending is the overall goal of this thesis work. Consequently, the concerned authorities (particularly the municipality) and thus the country will be benefited in that

- The energy recovered from them can supplement the energy available for its supply to the citizens of Addis Ababa
- Awareness will be created about the amount of energy saved from recovery option
- The amount of wastes disposed will be reduced in volume through the implementation of the best option
- Appreciates effective City energy planning programs in accordance with federal, state and regional policies and goals.
- This work empowers the effort made to minimize dependence on imported energy in favor of local self-sufficiency.

The specific objectives of this thesis are

- ✓ To reveal the existing practices of solid wastes in Addis Ababa
- ✓ To put the clear understanding about the fraction of energy that can be saved
- ✓ To analyze and compare the two energy recovery mechanisms
- ✓ To perform the economic analysis of the saved energy.

1.3. Methodology

Several techniques have been used to achieve the objectives of this thesis. The methods employed are:

1. **Literature review**: - A review of literature is conducted on the area of energy recovery from MSW in different countries' municipalities. Available books, journals, case studies, previous research works, policies & guidelines are surveyed in order to have a clear understanding of the subject matter.

2. Data collection

The necessary data for the thesis are collected from different sources. The necessary data are:

- ✓ The amount of current solid waste generation in the city per
    - Year
    - Month
    - Day
- ✓ The composition of the wastes
- ✓ How much of the wastes generated is collected(collection efficiency)and disposed
- ✓ The current energy demand of Ethiopia
    - To provide a basis for comparison with saved energy

These datas are collected by several means.

- ▪ By conducting interviews with the concerned authorities in Arada Sub city Administration
- ▪ By observation of the disposal site(Repi)

- By reviewing the works of others on the related area

3. Analysis and Evaluation

By making use of the datas collected wherever necessary, the potential energy recovery options are analyzed in detail and then evaluated for identifying the most viable alternative.

4. Conclusion and recommendation

After the detail analysis of these options, conclusion and recommendations is done.

1.4. Thesis Outline

The overall outline of this thesis is presented below. Chapter 1 discusses about the background of the study area and specifies the problem statement. In Chapter 2, the existing solid waste management practice in Addis Ababa, the challenges associated with the disposal of the wastes is studied. Chapter 3 presents the overview of Energy recovery from MSW. Chapter 4 focuses on the history and the brief description of the incineration technology. In chapter 5, the description of the landfill gas recovery along with the mathematical modeling and analysis of gas recovery potential is studied. Chapter 6 analyzes the potential of energy recovery from incineration. The two alternatives of energy recovery (Incineration and Landfill Gas Recovery) are discussed in detail in chapter 4 and 5 respectively. In chapter 7, the feasibility of the two options will be discussed and the best option will be recommended.

1.5. Boundary Setting

This thesis focuses on determining how much energy can be recovered through the adoption of the possible energy recovery techniques. The techniques particularly investigated in this work are incineration and landfill gas recovery options. Also the economic evaluation of these two alternatives is also studied.

1.6. Problem statement and research gap

In recent years,it has become necessary to effectively utilize untapped energy sources because of energy resource depletion and to protect the global environment. The world has come to realize that the energy crisis is a reality. Not only are there periodic local shortages of energy in various parts of the world, but it is now apparent that petroleum will be the world's major source of energy for only a very limited time. Most of the countries have already passed their peak for petroleum production, and demand for energy is expected to continue to rise. The energy experts have looked for single energy alternative which will solve all the world's future problems. At the present time, there is no such single alternative. It is certainly not coal nor nuclear fission, both of which involve consumption of a finite resource. In addition, coal is very unevenly distributed over the world. It has been estimated that coal would serve the world as a major source of energy for only about 450 years .Winds and tides represent insignificant sources. While oil shale, solar, geothermal, and nuclear fusion are very promising sources of energy, their commercial implementation is still in the future. The mistake that many energy experts make is to calculate how much energy or material resources can be obtained from any one particular alternative. When they find that it represents only a small portion of national needs, they lose interest. In so doing, they have missed a vital point. In order to meet the world's needs, every available energy and material source must be utilized including such minor sources as winds and tides. No possible alternative source should be overlooked since for the next few decades our total requirement must be made up from many sources. The utilization of solid waste represents just such a source of energy and resources. So, any alternative means of saving global energy should be encouraged for the well being of the nation's energy sources.

Various concepts have been developed over the years to provide the basis for improving the solid waste conditions in developing countries .This challenge in solid waste handling is not the case only for Ethiopia, but also of developing countries. Energy recovery from these solid wastes act as compromise between environmental aspect and the current energy demand. In this thesis, the energy recovery potential options from municipal solid wastes in Arada Sub city, Addis Ababa, is studied along with economic analysis. Not only analysis, recommending on the best alternative is also to be conducted.

CHAPTER 2

2. MSW Management in Addis Ababa

2.1 Existing Solid waste practices in Addis Ababa

2.1.1. Collection of waste

Waste collection service is one of the chief components of municipal solid waste management. The Municipality Spends large proportion of its budget on collection, transport, and disposal of solid waste. Solid waste collection services are divided in to two sub-systems: *primary* and *secondary* collection .Primary collection is done by **MSE**. Payment is Volume based rate (30 birr per m^3) [9] .Residents are divided in to Zones. One Zone constitutes 800-1000 residents. In each zone one **MSE** is assigned to work. The city is divided in to 549 zones each zone comprising 800-1000households.The number of enterprises organized to work on solid waste collection is 520 with a total number of 5815 operators [9]. Most residents are willing to cooperate with the government in financing SWM. Service Charges are collected with water consumption rate. Services charges are fixed according to the amount of water consumed in terms of the ability and willingness to pay. Residential houses comprise 20%while Commercial houses 42.5% of the total water consumed [9]. Collection is regular and full coverage. The municipality has placed several garbage containers.

Fig 2.1.Primary collection of MSW

Fig 2.2.Secondary collection of MSW

2.1.2 .Separation, Reuse and Recycling of Wastes

Separation of waste at home differs between well-to-do and poor households. Strict separation of household waste is practiced in poor households, since they make a varied use of their waste. 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. At household level, especially in low-income groups, waste is widely used as an economic resource. If there is the least advantage to be gained, housewives, maids or children will sort the waste and make sure that they get the benefit, whether in terms of cash , equipment, bio-fertilizer (vegetable gardens and vegetable growers), cattle feed or energy. Such practices have to be encouraged because they contribute to reducing the quantity of waste that needs to be carried to the collection containers and transported to the landfill.

Several collectors represent the second stage: Street boys, private sector enterprises, scavengers at municipal landfill, and the **korales**. Recyclable materials include: metal, wood, tyres, electricity products, old shoes and plastic. The municipality role in recycling is absent and mainly focuses on collection, storage, transportation and disposal of solid waste. Most of the collection of recyclable wastes in the city is performed by the informal sector .The Recyclable materials are used by local plastic, shoe, and metal factories

2.1.3. Transport and disposal

Municipality transports from garbage containers (Secondary collection) to the final dumping site. The highest level in the transportation system is represented by municipality. The role of private sector on transportation of solid waste is highly limited. There is currently one open dumpsite where all collected waste is disposed off. It has been established 47 years ago. The site is known as "Repi" or "Koshe" which is South West part of the city Located 13 km away from the city center. It has a surface area of 25 hectares. The present method of disposal is crude open dumping: hauling the wastes by truck, spreading and leveling by bulldozer and compacting by compactor or bulldozer.

Fig 2.3.Reppi solid waste disposal site

2.2. Challenges of Solid Waste Disposal

Waste disposal is one of the most important management activities which needs to be carefully planned. The disposal of wastes is the final task conducted by the municipality. But, there are challenges associated with the disposal. The major problems associated with the disposal site (Repi) are:

- The site is getting full
- It is surrounded by housing areas and institutions
- Nuisance and health hazard for people living nearby
- A large number of waste pickers per day work continuously and obviously living nearby the site and interfering the operation of the work for collection of salvageable materials such as wood scrap metals and discarded food.
- No daily cover with soil

- No leachate containment or treatment
- No rainwater drain-off
- No odor or vector control
- No fence
- No weigh bridge, inaccurate weighing of waste

Fig 2.4.Repi solid waste disposal site

2.3. Study Design

2.3.1. Study area

The study is conducted in Addis Ababa, which is both the political and administrative capital of Ethiopia .Particularly, the assessment is conducted over wastes collected from Arada Sub city .

It is one of the broadest sub cities of Addis Ababa. It is estimated to contain a population of 350,000.Below is the flow chart showing the organizational structure of Addis Ababa SWM

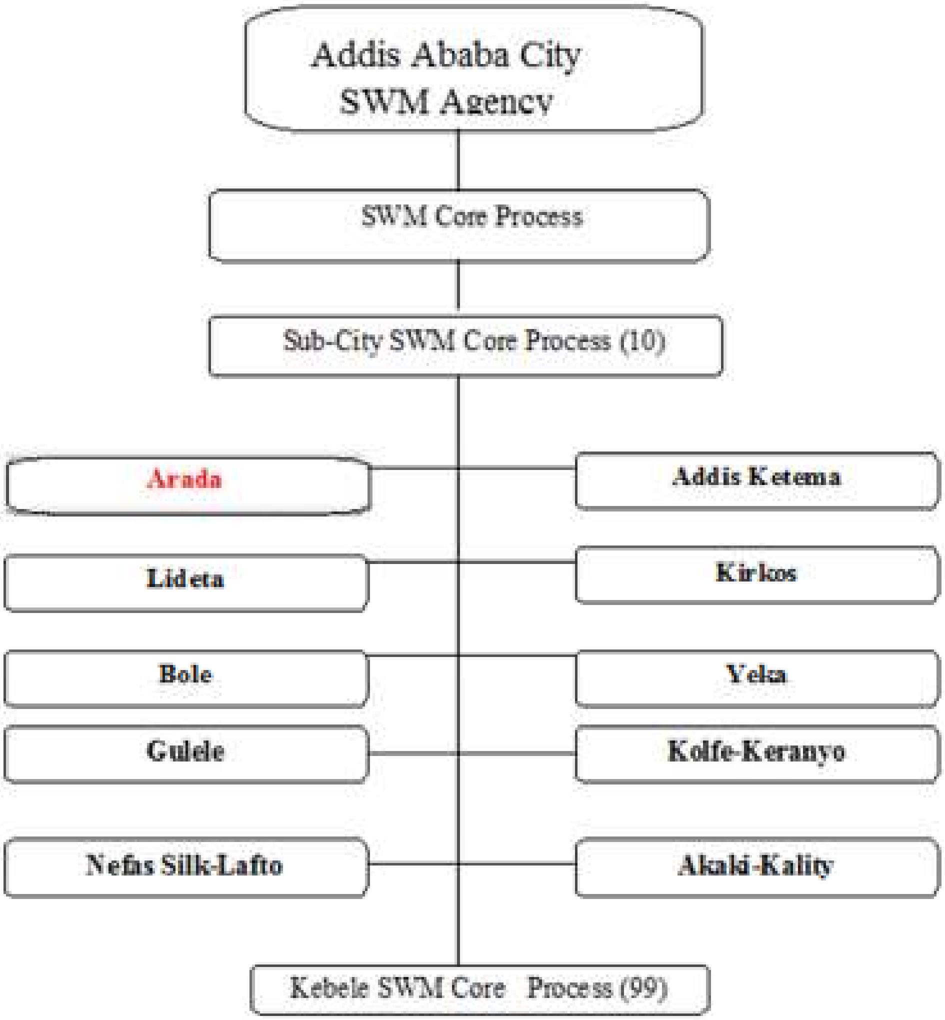


Fig 2.5.The organizational structure of Addis Ababa SWM Agency

2.4. Literature Review

Like most of the fast growing African countries, Our country's economy has been growing rapidly for the past few consecutive years. But among the key infrastructures and base for development, Energy is the main. Moreover energy is being a unit or measurement of a nation's economy as a result to continue the momentum of economic growth; we have to give attention to energy. Although Ethiopia generates almost 99% of its electricity from hydropower, around half of the country's foreign currency income is put away to import petroleum. But there are so many opportunities locally which can reduce the oil import. That is by using the available energy effectively and efficiently, searching for other resources and shifting petroleum usage by locally available fuels are among the solutions. Definitely, one of the potential solutions is the recovery of energy from solid wastes collected by the municipality

The benefits of energy recovery from municipal solid wastes (MSW) are largely unquestionable, both for the energy benefits itself and for the positive environmental implications, mainly related to the saving of primary energy derived from fossil fuel .However the waste-to-energy options can be several, leading to different strategies based on the conversion plant itself and on the possible inclusion of waste pre-treatment units.

Several studies have been published in recent years that compare different strategies of waste-to-energy (WTE) management of residual waste collected downstream of material recovery (MR). Hypotheses and conclusions of the most interesting and complete works are briefly reported.

1. **Baggio et al. (2003a, b)**-compared different strategies of MSW management: traditional combustion in a dedicated grate combustor, the Thermo select gasification process and the high temperature pyrolysis process associated with a plasma system. They concluded that from an energetic point of view, pyrolysis with a plasma system is convenient only when coupled with a combined cycle, while the use of steam cycles has more advantages when applied to traditional combustion plants. Gasification and pyrolysis technologies allow the production of a smaller volume of gas to be treated than traditional combustion. Also, emission factors from gasification are lower than those from traditional combustion, except for NOx and mercury.

2. **IEA Bioenergy and IEA CADDET (1998)-**made a comparison between advanced thermal conversion, like pyrolysis and gasification, and mass burn combustion technologies. The indications are that advanced thermal conversion technologies have similar costs, may have lower environmental emissions and there are perspectives for higher energy recovery efficiency. However, none of these aspects have yet been fully proven due to the lack of commercial full-scale plants; it may be the case that initially, whilst the technologies are being established, advanced thermal conversion plants will be more expensive than mass burn combustion plants.
3. **Klein (2002)**-compared the process of gasification developed by TPS Termiska, the process of Battelle gasification, the traditional combustion of MSW in a dedicated grate combustor and the combustion of RDF in a dedicated grate combustor. He concluded that gasification shows the best electrical conversion efficiency but has higher operating costs which outweigh the lower capital costs, thus leading to higher total costs.
4. **Murphy and Mckeogh (2004)-**analyzed the processes of traditional combustion and of Gasification from a technical, economic and environmental point of view. The results show that if there is no market for thermal energy, Gasification is more suitable than traditional combustion; in fact it produces a greater quantity of electricity and implies lower specific total costs and lower emissions of CO2 per kWh. The presence of a market for thermal energy is necessary for reducing total specific costs and CO2 emissions of traditional combustion, thus making the two strategies comparable

CHAPTER 3

3. Introduction

3.1. Overview of Energy Recovery from MSW

3.1.1. Introduction

Municipal Solid Waste contains organic as well as inorganic matter. The latent energy present in its organic fraction can be recovered for gainful utilization through adoption of suitable Waste Processing and Treatment technologies. The recovery of energy from wastes also offers several additional advantages

- The total quantity of waste gets reduced 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 far -away 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 minimize generation of waste materials and to recycle and reuse them to the extent feasible, the option of Energy Recovery from solid Wastes be also duly examined.

3.1.2. 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:

(i) **Thermo-chemical conversion**: This process entails thermal de-composition of organic matter to produce either heat energy or fuel oil or gas; and

(ii) **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.

Some of the techniques of energy recovery from MSW are shown below

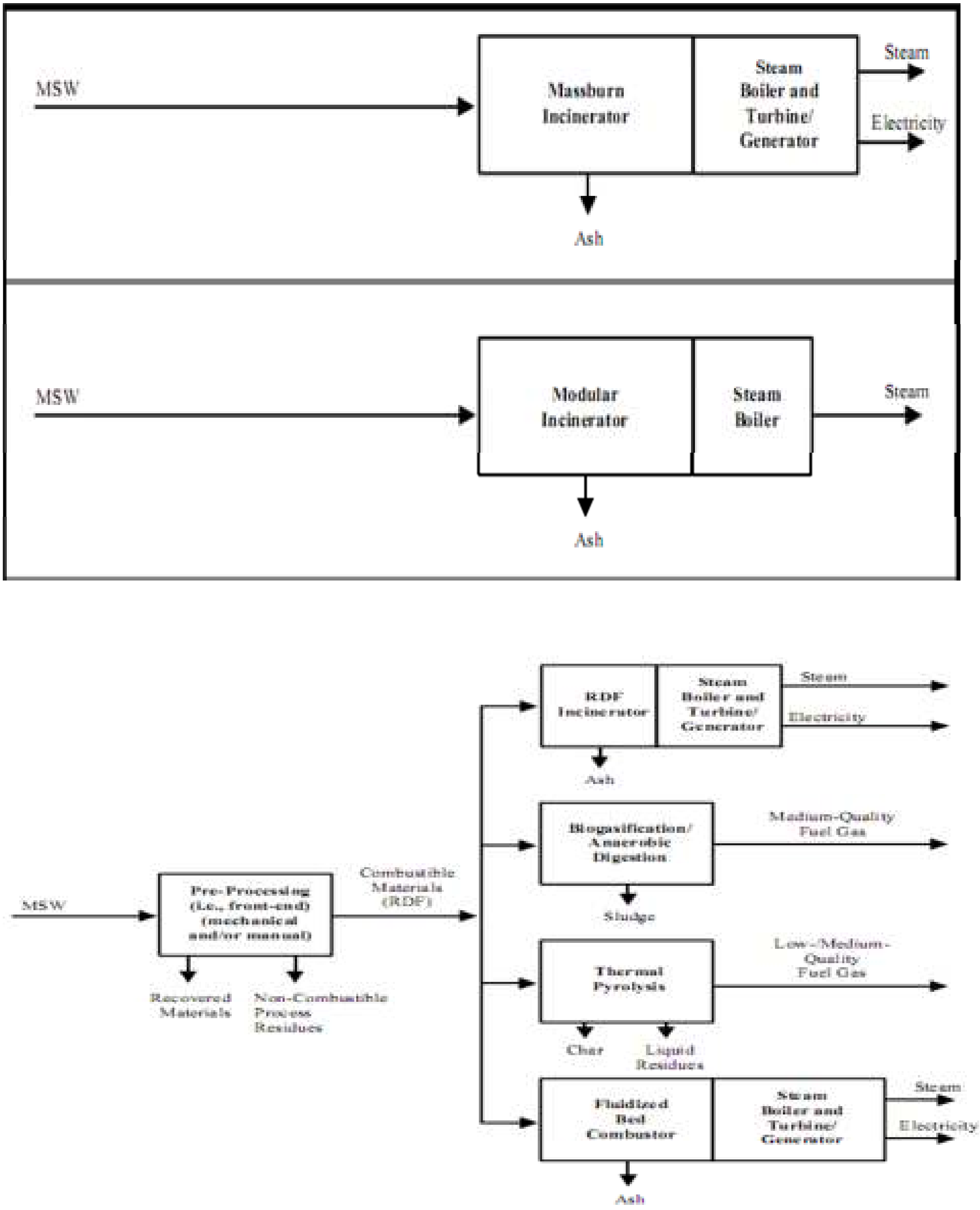


Fig3.1.Examples of methods of recovering energy from solid wastes

3.1.3. 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 important physical parameters requiring consideration include:

- ➢ size of constituents
- ➢ density
- ➢ 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.

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 include: -

- Volatile Solids
- Fixed Carbon content
- Inerts,
- Calorific Value
- C/N ratio (Carbon/Nitrogen ratio)
- Toxicity

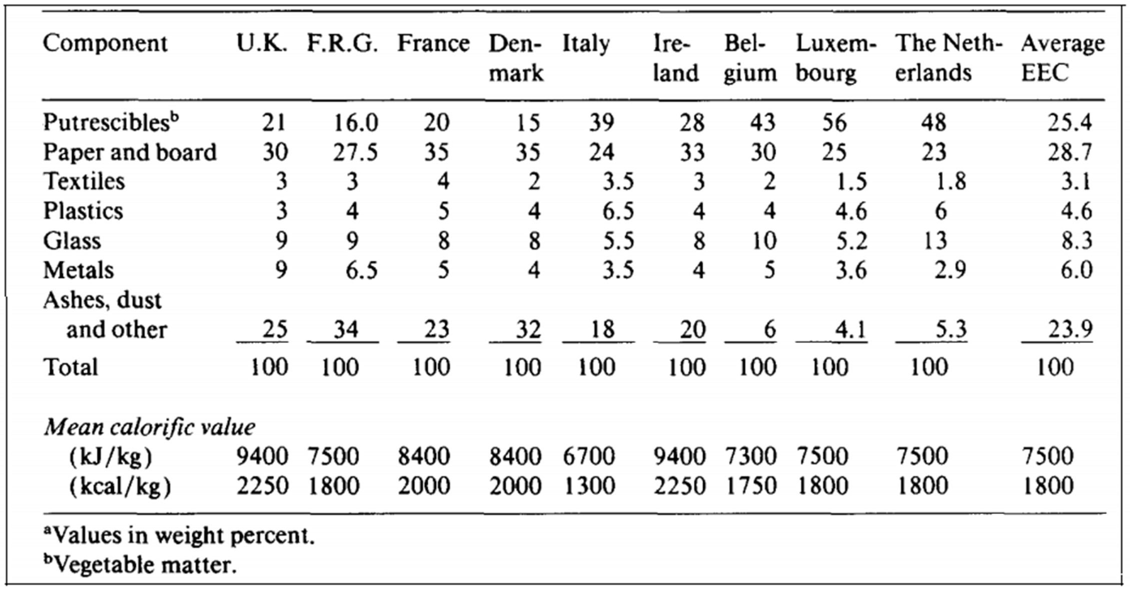
However, the components of the wastes vary increasingly with the life style and economic standards of the population. It is therefore necessary to know the exact composition of wastes under study. The basic component materials in the citywide waste stream can be classified as:

- ✓ Organic or putrescible materials
- ✓ Paper and cardboard
- ✓ Plastics and rubber
- ✓ Glass

- ✓ Metals and cans
- ✓ Textile
- ✓ Inert or residues
- ✓ Miscellaneous or other waste.

Below is the composition of solid wastes in various studies

Table 3.1.Composition of municipal waste arising in the EEC [4]

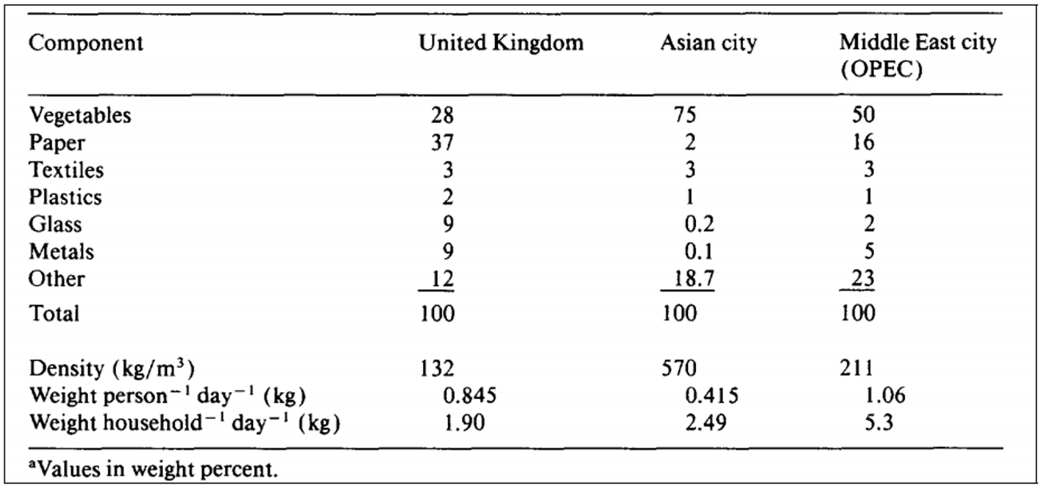


Component	U.K.	F.R.G.	France	Denmark	Italy	Ireland	Belgium	Luxembourg	The Netherlands	Average EEC
Putrescibles[b]	21	16.0	20	15	39	28	43	56	48	25.4
Paper and board	30	27.5	35	35	24	33	30	25	23	28.7
Textiles	3	3	4	2	3.5	3	2	1.5	1.8	3.1
Plastics	3	4	5	4	6.5	4	4	4.6	6	4.6
Glass	9	9	8	8	5.5	8	10	5.2	13	8.3
Metals	9	6.5	5	4	3.5	4	5	3.6	2.9	6.0
Ashes, dust and other	25	34	23	32	18	20	6	4.1	5.3	23.9
Total	100	100	100	100	100	100	100	100	100	100
Mean calorific value										
(kJ/kg)	9400	7500	8400	8400	6700	9400	7300	7500	7500	7500
(kcal/kg)	2250	1800	2000	2000	1300	2250	1750	1800	1800	1800

[a] Values in weight percent.

[b] Vegetable matter.

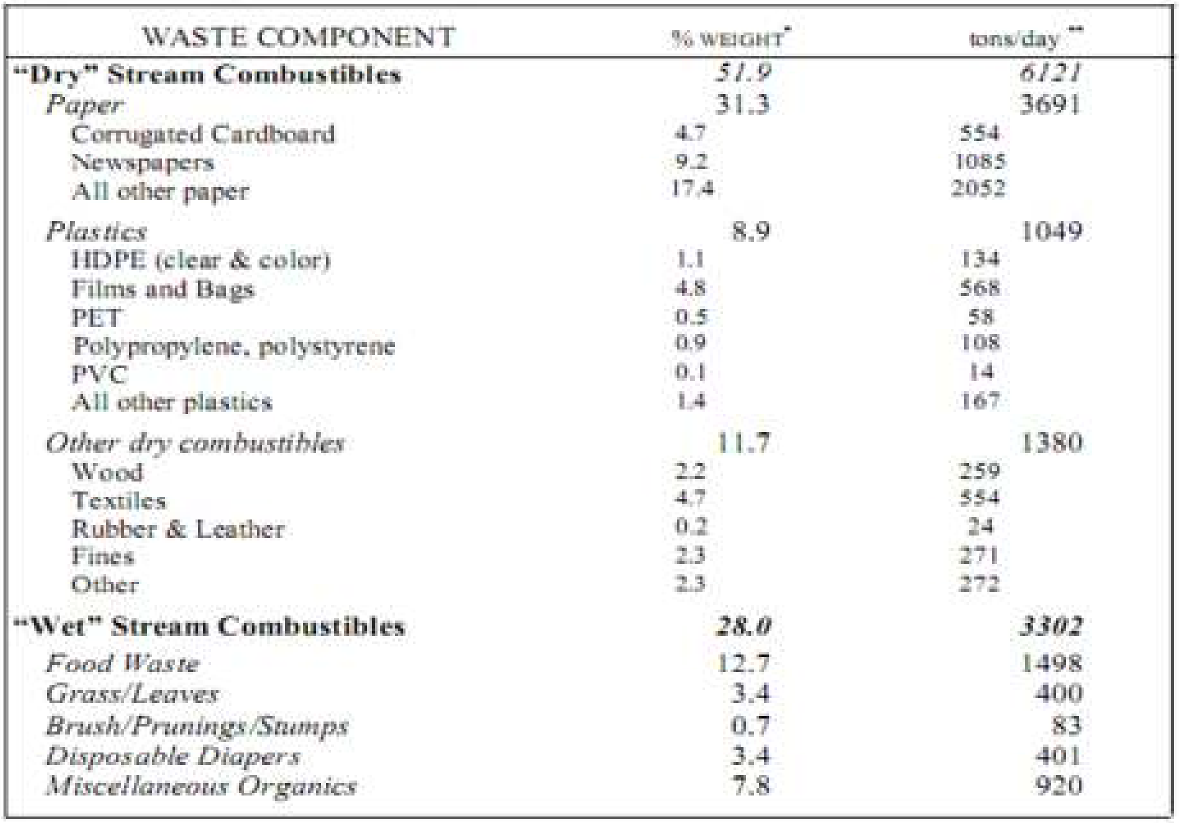
Table3.2.Some comparisons in waste characteristics [4]



Component	United Kingdom	Asian city	Middle East city (OPEC)
Vegetables	28	75	50
Paper	37	2	16
Textiles	3	3	3
Plastics	2	1	1
Glass	9	0.2	2
Metals	9	0.1	5
Other	12	18.7	23
Total	100	100	100
Density (kg/m^3)	132	570	211
Weight person^{-1} day^{-1} (kg)	0.845	0.415	1.06
Weight household^{-1} day^{-1} (kg)	1.90	2.49	5.3

[a] Values in weight percent.

Table 3.3.Composition of New York City MSW [7]



WASTE COMPONENT	% WEIGHT*	tons/day**
"Dry" Stream Combustibles	*51.9*	*6121*
Paper	31.3	3691
Corrugated Cardboard	4.7	554
Newspapers	9.2	1085
All other paper	17.4	2052
Plastics	8.9	1049
HDPE (clear & color)	1.1	134
Films and Bags	4.8	568
PET	0.5	58
Polypropylene, polystyrene	0.9	108
PVC	0.1	14
All other plastics	1.4	167
Other dry combustibles	11.7	1380
Wood	2.2	259
Textiles	4.7	554
Rubber & Leather	0.2	24
Fines	2.3	271
Other	2.3	272
"Wet" Stream Combustibles	***28.0***	***3302***
Food Waste	12.7	1498
Grass/Leaves	3.4	400
Brush/Prunings/Stumps	0.7	83
Disposable Diapers	3.4	401
Miscellaneous Organics	7.8	920

The desirable range of important waste parameters for technical viability of energy recovery through different treatment routes is given in the following Table

Waste Treatment Method	**Basic principle**	**Important Waste Parameters**	**Desirable Range**
Thermo-chemical conversion ➢ Incineration ➢ Pyrolysis ➢ Gasification	Decomposition of organic matter by action of heat.	Moisture content	< 45 %
		Organic/ Volatile matter	> 40 %
		Fixed Carbon	< 15 %
		Total Inerts	< 35 %
		Calorific Value(Net Calorific Value)	>1200k-cal/kg
Bio-chemical	Decomposition of organic matter by	Moisture content	>50 %
		Organic/Volatile matter	> 40 %

Conversion - Anaerobic Digestion/ Bio-methanation	Microbial action.	C/N ratio	25-30

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

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.

3.1.4. Assessment of Energy Recovery Potential

A detailed 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. In order to evaluate the feasibility of energy recovery from MSWs, it is of great importance to determine the energy content or calorific value (CV) of the solid waste, which is defined as the number of heat units evolved when unit mass of material is completely burned and is measured in joules per gram (J/g) or British thermal units per pound (Btu/lb).

The energy content of any material, such as solid waste, is a function of many parameters, namely, physical composition of the waste, moisture content and ash content. There are several experimental and empirical approaches available for determining the CV of materials such as MSW. Calorimetric measurement is the common method for determining the energy content of MSW [2]. One method of determining the CV of a given material is by means of an open calorimeter in which pressure is maintained at 1atmosphere.

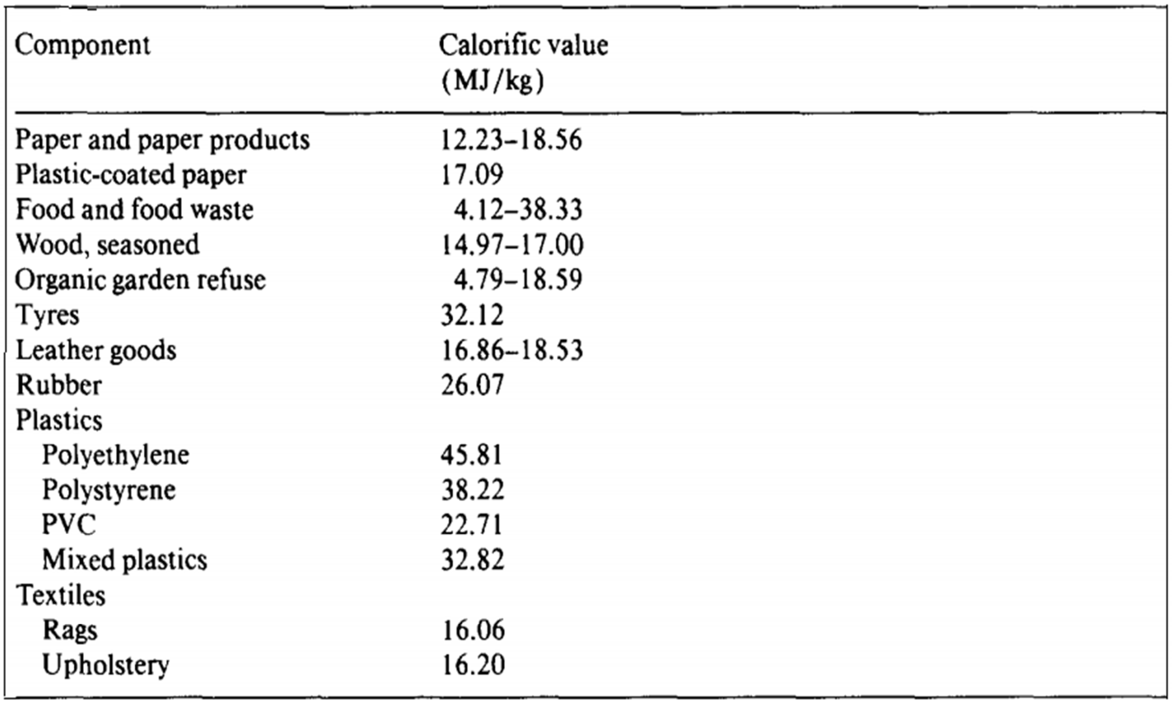
Under constant pressure conditions, the heat released is equal to the enthalpy change for the reaction. Another type of calorimeter is the bomb calorimeter in which combustion is conducted under conditions of constant volume.

Regarding the empirical approaches, there are three types of models that are used to predict CV values based on the following analyses [3]:

1. Physical composition
2. Ultimate analysis
3. Proximate analysis

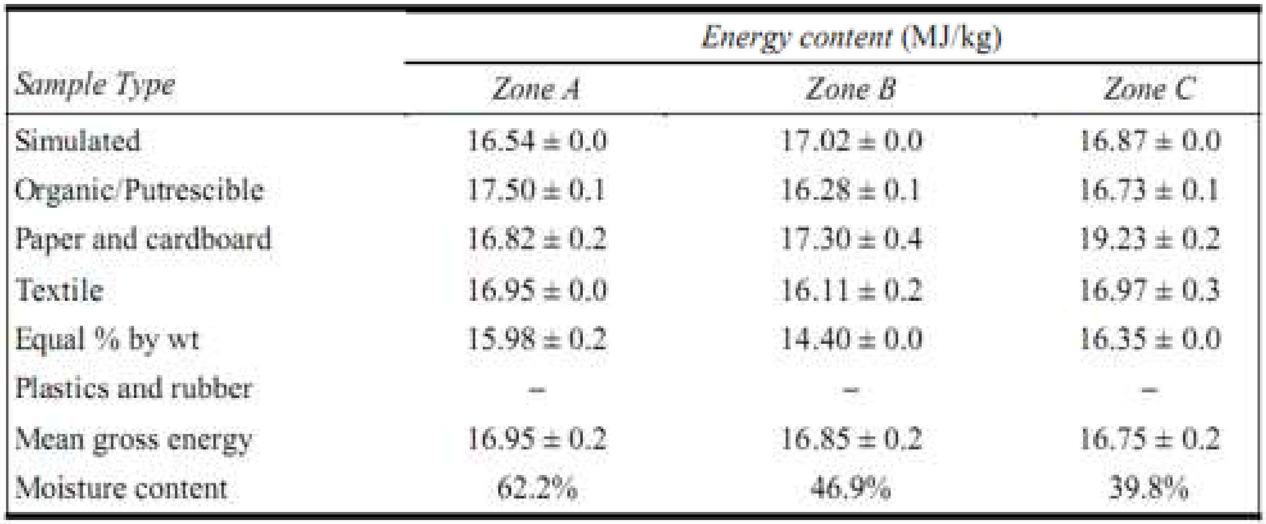
Determination of the energy content of the MSW is not an easy task. This is because of the equipment limitation and the complex nature of the wastes. Also, MSW composition varies amongst communities and even within one community from year to year, but the differences is not substantial. Below is the energy content of various types of waste components.

Table3.4. Typical heating values of principal constituents of municipal wastes[4]



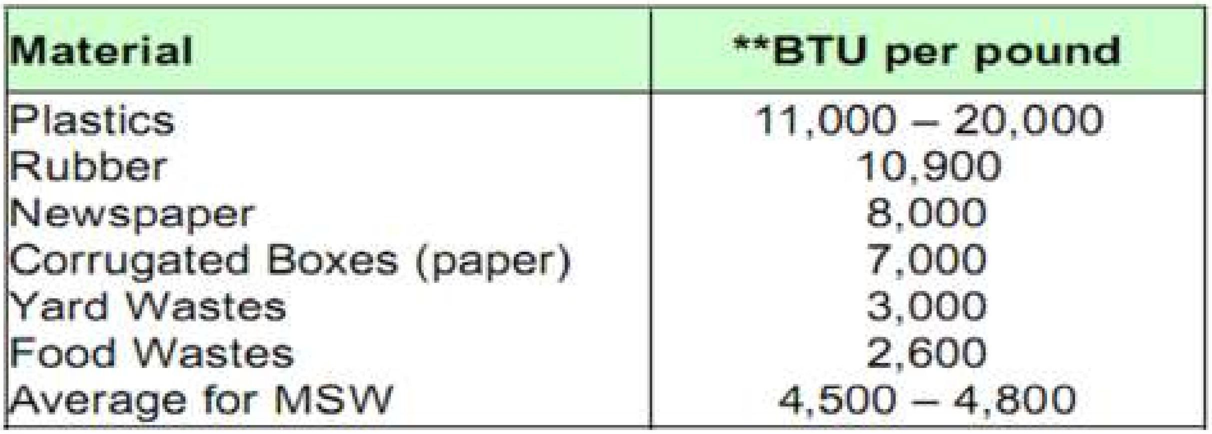
Component	Calorific value (MJ/kg)
Paper and paper products	12.23–18.56
Plastic-coated paper	17.09
Food and food waste	4.12–38.33
Wood, seasoned	14.97–17.00
Organic garden refuse	4.79–18.59
Tyres	32.12
Leather goods	16.86–18.53
Rubber	26.07
Plastics	
Polyethylene	45.81
Polystyrene	38.22
PVC	22.71
Mixed plastics	32.82
Textiles	
Rags	16.06
Upholstery	16.20

Table 3.5. Calorific content of MSW from urban wastes [5]



	Energy content (MJ/kg)		
Sample Type	*Zone A*	*Zone B*	*Zone C*
Simulated	16.54 ± 0.0	17.02 ± 0.0	16.87 ± 0.0
Organic/Putrescible	17.50 ± 0.1	16.28 ± 0.1	16.73 ± 0.1
Paper and cardboard	16.82 ± 0.2	17.30 ± 0.4	19.23 ± 0.2
Textile	16.95 ± 0.0	16.11 ± 0.2	16.97 ± 0.3
Equal % by wt	15.98 ± 0.2	14.40 ± 0.0	16.35 ± 0.0
Plastics and rubber	–	–	–
Mean gross energy	16.95 ± 0.2	16.85 ± 0.2	16.75 ± 0.2
Moisture content	62.2%	46.9%	39.8%

Table 3.6.The energy values of different materials[6]



Material	**BTU per pound
Plastics	11,000 – 20,000
Rubber	10,900
Newspaper	8,000
Corrugated Boxes (paper)	7,000
Yard Wastes	3,000
Food Wastes	2,600
Average for MSW	4,500 – 4,800

In this thesis, two energy recovery mechanisms are studied. These are Incineration and Landfill Gas Recovery. On the following two chapters, these alternatives are discussed in detail.

CHAPTER 4

4. Incineration overview

4.1. Introduction

Incineration is defined as “reducing the volume of solid wastes by use of an enclosed device, using controlled-flame combustion”. It is a thermal waste treatment process where raw or unprocessed waste can be used as feedstock. The incineration process takes place in the presence of sufficient quantity of air to oxidize the feedstock (fuel).Waste is combusted at high temperature and in this stage waste converted to carbon dioxide, water and non-combustible materials with solid residue state called incinerator bottom ash (IBA) that always contains a small amount of residual carbon. It is the process of direct burning of wastes in the presence of excess air (oxygen) at temperatures of about 800^0C and above, liberating heat energy, inert gases and ash. Net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system (fixed bed/ fluidized bed), etc. In practice, about 65 to 80 % of the energy content of the organic matter can be recovered as heat energy, which can be utilized either for direct thermal applications, or for producing power via steam turbine.

The combustion temperatures of conventional incinerators fuelled only by wastes are about 760^o C in the furnace, and in excess of about 870^oC in the secondary Combustion chamber. These temperatures are needed to avoid odor from incomplete combustion but are insufficient to burn or even melt glass. To avoid the deficiencies of conventional incinerators, some modern incinerators utilize higher temperatures of up to 1650^oC using supplementary fuel. These reduce waste volume by 97% and convert metal and glass to ash. Wastes burned solely for volume reduction may not need any auxiliary fuel except for start-up. When the objective is steam production, supplementary fuel may have to be used with the pulverized refuse, because of the variable energy content of the waste or in the event that the quantity of waste available is insufficient.

Incineration may also be implemented without energy and materials recovery. In some countries, incinerators built just a few decades ago often did not include a materials separation to remove hazardous, bulky or recyclable materials before combustion. These facilities tended to risk the health of the plant workers and the local environment due to inadequate levels of gas cleaning and combustion process control. Most of these facilities did not generate electricity.

4.2. History

The first attempts to dispose of urban refuse through combustion in a furnace are reported to have taken place in the north of England in the 1870s [1]. By the turn of the century, emphasis was placed on the development of furnaces capable of burning solid wastes. During this time, a number of communities found incineration to be a satisfactory and sanitary method of waste disposal. The reason for the satisfaction lay in the fact that the main objective was to achieve maximum volume or weight reduction. Little or no concern was given for energy recovery or for control of air pollution from incinerators. The situation changed completely in the 1960s in that the majority of incinerators in the United States were closed down, primarily because of excessive particulate emissions. However, the popularity of incineration continued undiminished.

4.3. Principles of Incineration

Incineration facilities may use either mass burning systems or prepared fuel systems.

- Mass burning systems- involve feeding mixed municipal solid waste into a furnace or boiler without mechanically separating or preparing the waste in any way. These facilities can be either large field-erected furnace-boiler systems or smaller modular furnace-boiler systems.
- In prepared fuel systems, mixed municipal solid waste is mechanically separated and processed to make RDF, either as a supplemental fuel for an existing furnace-boiler or to be used alone in a dedicated furnace-boiler.

From the experiences of some Developed countries, Energy recovery is rarely associated with small incinerators; incinerators burning less than 250 tons per day do not produce cost effective steam.

Medium and large MSW incinerators, however, can install larger boilers, which will generate cost-effective steam. This steam can then be used to generate electricity, power industrial processes, or provide heat.

Incinerators may be classified in a variety of fashions. This classification can have one of the following forms.

- ✓ By type and form of the waste input;
- ✓ By the throughput capacity (with or without heat recovery);
- ✓ By the rate of heat production (for systems with energy recovery);
- ✓ By the state in which the residue emerges from the combustion chamber (e.g., slagging); and
- ✓ By the shape and number of furnaces (e.g., rectangular, multiple).

The key system elements involved in the incineration of urban solid wastes are:
1) Tipping area,
2) Storage pit,
3) Equipment for charging the incinerator,
4) Combustion chamber,
5) Bottom ash removal system, and
6) Gas cleaning equipment (i.e., air pollution control system). If energy is to be recovered, a boiler is included.

4.4. Combustion Air

Combustion air may be classified either as “under-fire” or as “over-fire” air. Under-fire air is that which is forced into the furnace through and around the grates. Over-fire air is forced into the furnace through the sides or the ceiling. Over-fire air typically is introduced through jets located at specific points in the furnace. It is used to regulate and complete the combustion of combustible gases evolved by the thermal reactions that are occurring in the lower part of the furnace. The flow of air and combustion gases through the furnace can be controlled by means of forced draft and induced draft fans. The forced draft fan, as its name implies, forces air into the furnace, while the induced draft fan draws the air. Both types are used in modern combustion units. Forced draft fans provide for the central over-fire and under-fire air, and induced draft fans for the exhausting of the flue gases.

4.5. Incineration Technologies

Various types of incineration technologies can be employed to burn MSW or RDF. These technologies will satisfy the majority of applications of incineration (with or without heat recovery) that will exist in many of the developing nations for the next several years. A brief overview of the main incineration technologies is given below.

- Modular (small capacity) technology
- Large-capacity stoker technology, and
- Fluidized bed technology

4.5.1. Modular (small capacity) technology

Modular combustion systems are so named because each combustion unit is of relatively low throughput capacity in comparison to the typical capacity of a mass burn or RDF incinerator. As used here, a unit, or module, consists of one primary combustion chamber (i.e., a chamber in which the solid waste is converted to gaseous compounds). To achieve an equivalent processing capacity of a typical large-capacity, stoker-type mass burn or RDF incinerator, multiple modules would be required; thus, the derivation of the term “modular” for this type and capacity of combustion technology.

Working Principle

The charging chamber of a modular incinerator is typically loaded by a front-end loader. Wastes are fed into the primary combustion chamber by a hydraulic ram. Wastes are moved through the primary combustion chamber of large-capacity modular incinerators by moving grates, usually reciprocating grates. A modular incinerator (with or without an energy recovery system) also has a separate, secondary combustion chamber dedicated to completing the combustion of the partially oxidized gases produced in the primary combustion chamber.

Modular units typically are designed to process up to about 300 Mg of waste per day. As mentioned earlier, the design of most modular incinerators includes a primary and a secondary combustion chamber and provides for the introduction of the air needed to attain complete combustion. Thus, sometimes they are termed “controlled air modular incinerators”.

Some designs also incorporate energy recovery equipment. The majority of modular incinerators usually can function quite well when burning commercial and industrial wastes. However, some designs and facilities have encountered an assortment of difficulties in processing unsorted MSWs. The difficulties usually presented themselves in the form of unreliable operation of the **ash handling system** and of unacceptably high **wear-and-tear** on the equipment. Small-capacity modular incinerators are commonly used to combust solid wastes from a single generator, e.g., a hospital (medical wastes) or manufacturing facility. Small modular incinerators that process a few Mg per day commonly are supplied as batch systems without provisions for automatic feeding of wastes or for ash removal.

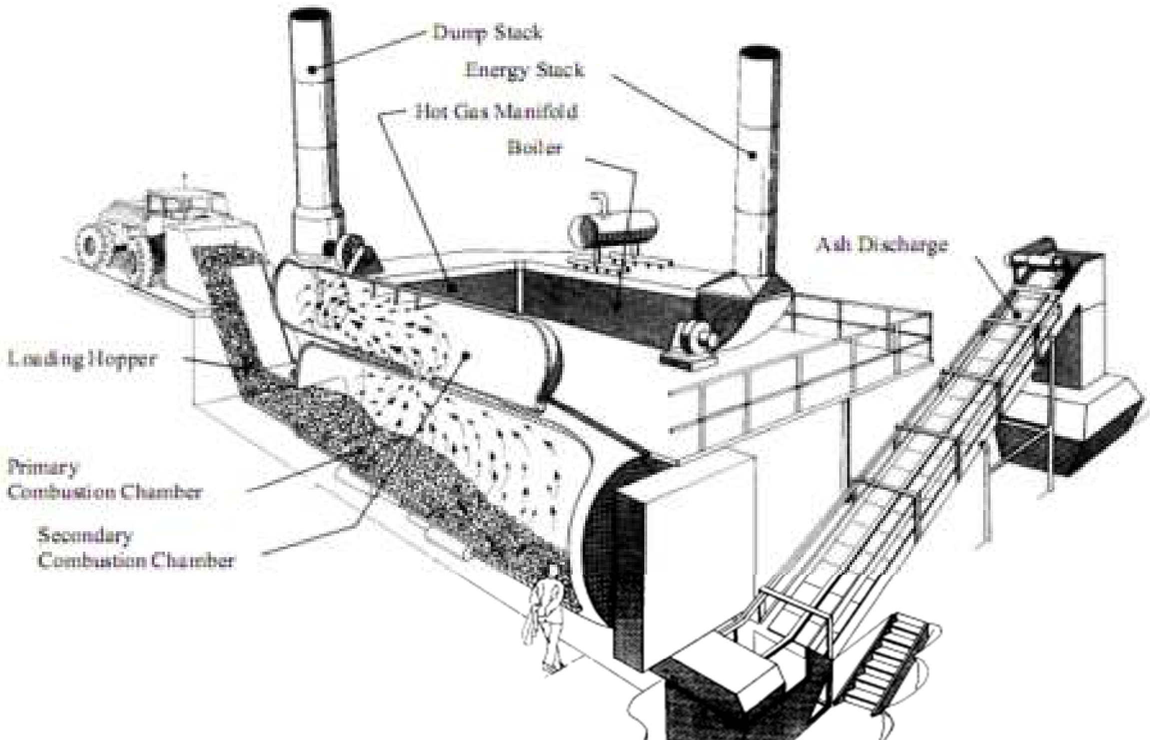


Figure4.1. Modular combustion unit used for residential and commercial MSW

4.5.2. Large-capacity stoker technology

A stoker is a system of grates that moves the solid fuel through the combustion chamber. A variety of types of stokers are available. Typically, the grates in large-capacity mass burn incinerators are movable (vibrating, rocking, reciprocating, or rotating) to provide agitation to the wastes, thereby promoting combustion. The movement also serves to remove the residue from the furnace. The stoker commonly employed in large incinerators designed to combust RDF is a “travelling” grate. A travelling grate consists of a set of hinged grate sections that are configured as a conveyor belt. In the case of mass burn systems, the primary combustion of the waste occurs on the grate.

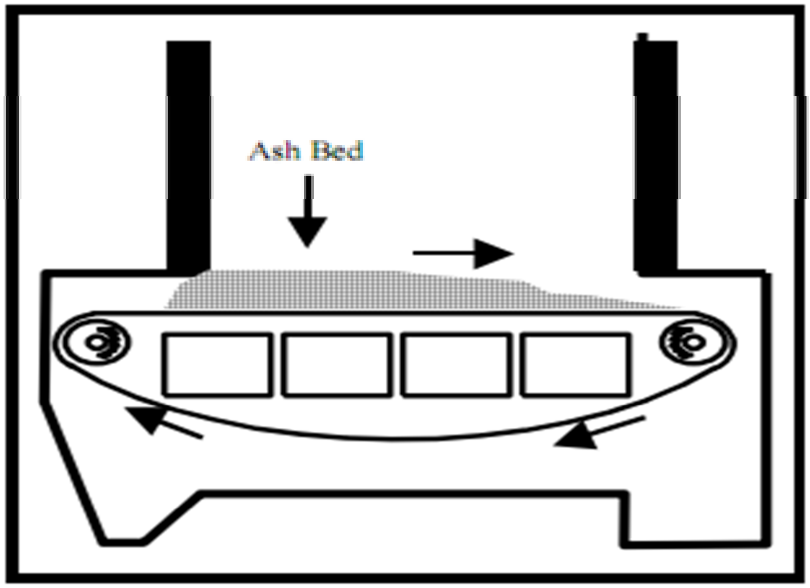


Figure 4.2. Travelling grate system used in RDF-fired incinerators

In the case of an RDF incinerator, a substantial portion of the combustion of the RDF occurs while the fuel is in suspension or falling toward the grate. Thus, only a portion of the combustion of the fuel occurs on the grate itself. In the case of all grate systems, air is introduced below the grate in order to: 1) cool the grate and, therefore, maintain the temperature of the grate below its maximum design temperature; and 2) provide a supply of combustion air to the waste burning on the grate (i.e.underfire air).

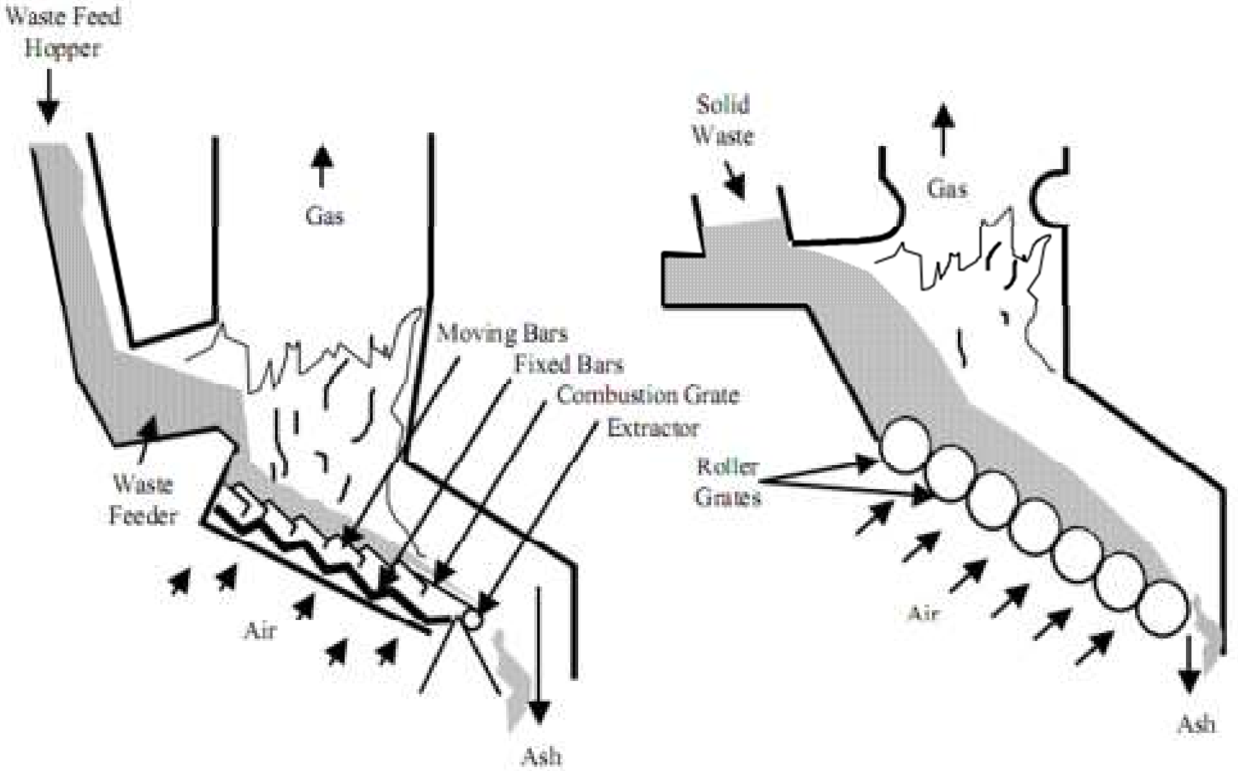


Figure 4.3. Grate systems used in mass burn MSW combustors

Large-capacity stoker systems that combust raw MSW are commonly referred to as "mass burn" incinerators. On the other hand, as the name implies, RDF combustion systems are designed to burn a combustible mixture of materials that is recovered from MSW. Another name commonly used to describe RDF is "prepared fuel". The definition of two subtypes in the case of large-capacity stoker combustors is appropriate due to some important differences between the two types of feed stocks (i.e., raw MSW and RDF) with respect to combustion system design. Among the more important distinctions, MSW has a lower heating value and higher ash content than would be exhibited by an RDF recovered from the same MSW.

4.5.2.1. Massburn incinerators

In a typical mass burn incinerator operation, the MSW to be burned is unloaded from the collection vehicles onto the tipping floor or directly into a storage pit. A pit is included so that sufficient solid waste can be stored to permit a continuous operation of the incinerator (i.e., 24 hr/day, 7 day/wk).

The pit also serves as an area in which large non-combustible materials can be removed, and the wastes can be blended to achieve a fairly uniform and constant charge. From the pit, the waste is transported to a charging hopper.

Charging hoppers are used for maintaining a continuous feeding of waste into the furnace. Mass burn incinerators do not use pneumatic or mechanical systems for injecting or charging the waste into the combustion chamber. (Mechanical and pneumatic injection systems are typically used when RDF is the feedstock.) Wastes fall from the hopper onto the stoker (i.e., grate system) where the combustion takes place

An illustration of a large-capacity mass burn incinerator and its key components is shown in the figure below.

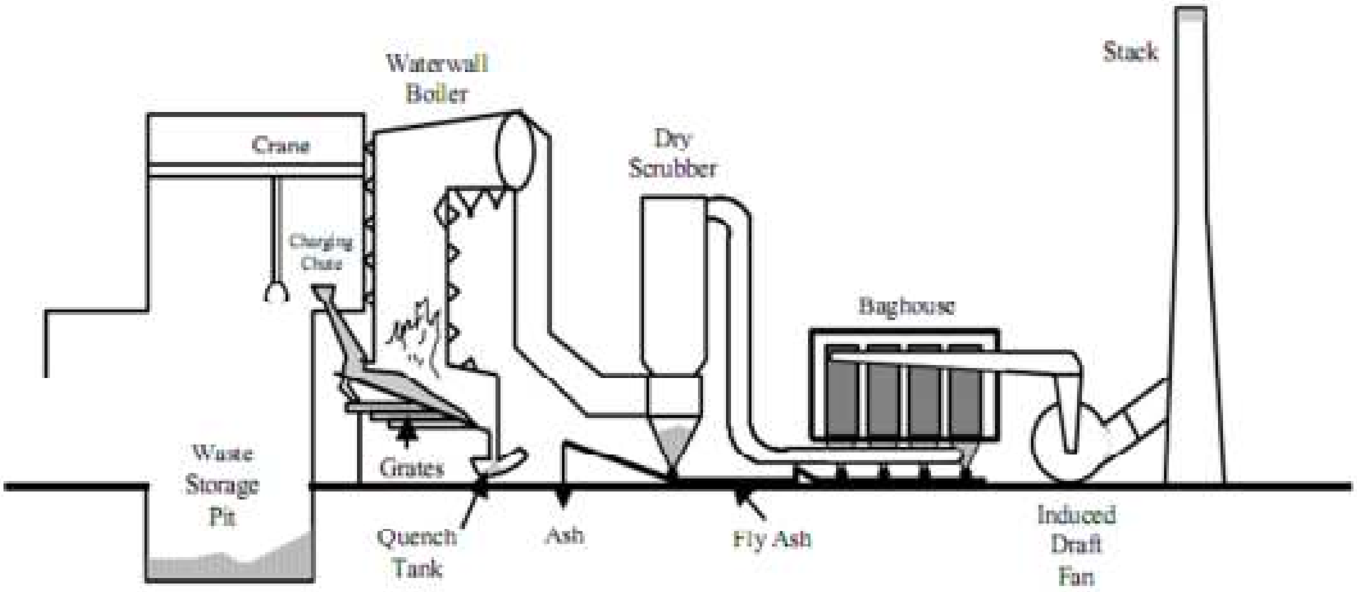


Figure 4.4. Key Components of a mass burn incinerator system with energy recovery

4.5.2.2. RDF-fired incinerators

Large RDF-fired incinerators are similar in overall design to mass burn units. However, key distinctions exist between the designs. As mentioned previously, RDF incinerators usually have a travelling grate at the bottom of the furnace, as opposed to the agitating form of grates used in most mass burn incinerators. Secondly, since RDF has a finer size distribution than raw MSW, the charging system is different. RDF combustion systems commonly employ a ballistic type of feeding system, i.e., the fuel is injected into the combustion chamber above the grate at a relatively high velocity using mechanical or pneumatic injection, or a combination of the two injection methods. On the other hand, as noted above, mass burn incinerators are fed by gravity through a charging chute.

An illustration of an RDF incinerator and its key equipment is presented in the figure below.

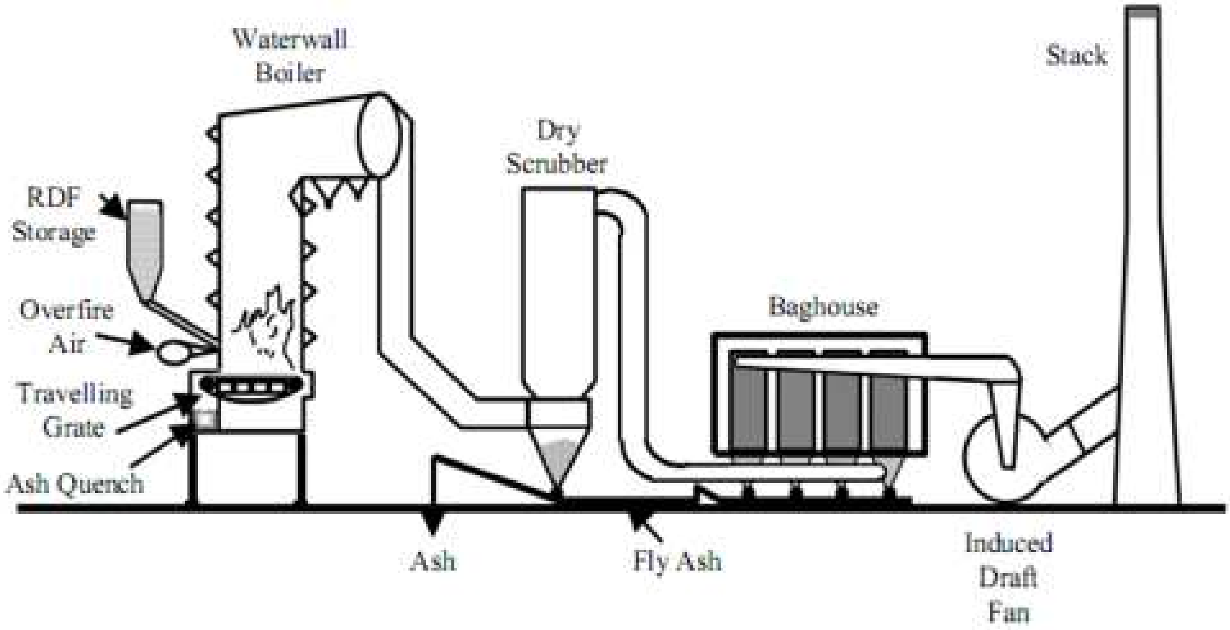


Figure 4.5. Key features of a dedicated RDF incineration system with energy recovery

4.6. Incineration Process

Incineration of municipal solid waste with energy recovery is a process that involves several stages.

a) Waste delivery, bunker and feeding system

The fuel properties of MSW will depend on several factors, including the composition and moisture content. Wetter waste with a higher organic content requires greater energy input to reach the correct combustion temperatures.

Waste with a high metal content will also be less combustible. Pre-sorting and mixing of waste to increase its homogeneity and to remove any recyclable portion can influence combustibility.

b) Furnace

The most common form of incineration of MSW is mass burn. This involves a series of furnaces into which the waste is fed and where temperatures are in the region of 850^{o}C to1200^{o}C, the optimum temperature being 1100^{o}C. The waste remains in the furnace for 45to 70 minutes to ensure complete combustion. There may be auxiliary burners as part of the furnace to ensure that temperatures are maintained. The solid fraction of the combusted waste, the bottom ash, is removed via conveyor belt and collected for disposal or further use.

c) Heat and Energy Recovery

The temperature of gases leaving the furnace is in the range of 800-1100^{o}C. Gas temperatures must be no higher than 250-300^{o}C to ensure pollution removing measures are carried out efficiently, therefore gases have to be cooled. This is done by using them to heat water which can then be used within the incinerator, or externally in community heating systems. The resulting steam can also be used to drive turbines and generate electricity.

d) Pollution Control

Cooled gases and the airborne fraction of the ash (fly ash) are passed through several filters and precipitators designed to remove a large proportion of particulate and gaseous pollutants, before being released into the atmosphere. A complete description of the incineration process with electricity generation is given below.

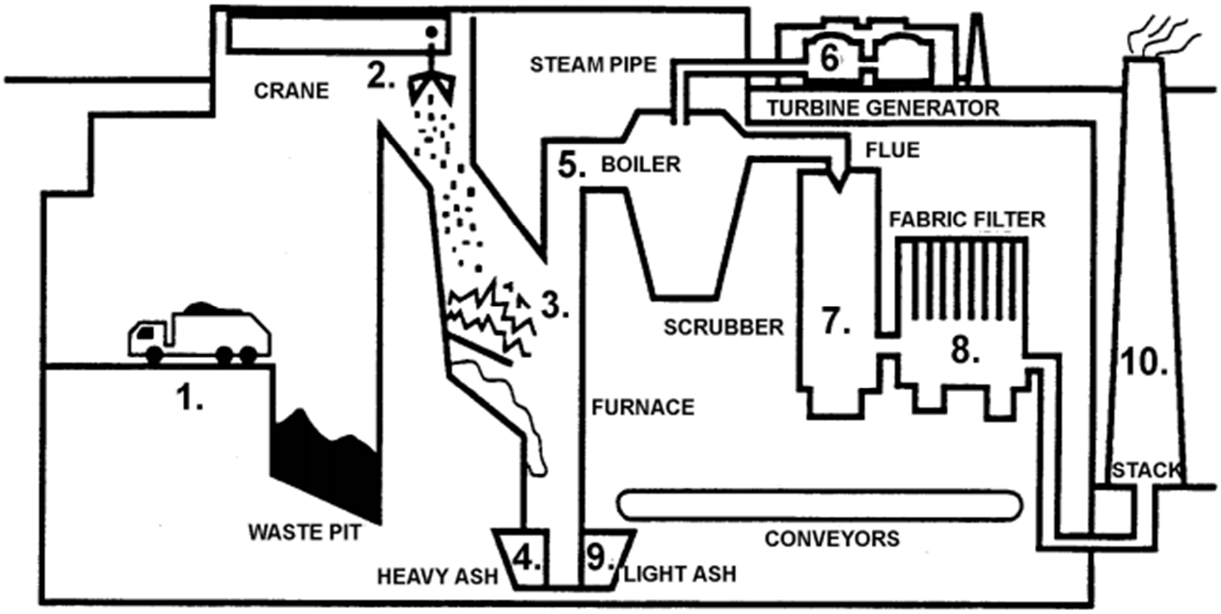


Fig 4.6.Incineration process with electricity generation

Description of the figure

1. Trucks dump trash ready for burning.
2. Crane lifts waste from pit up into furnace.
3. Trash is burned at high temperatures
4. Heavy ash is collected and removed for disposal.
5. Heat from furnace makes steam in boiler.
6. Steam drives turbines and makes electricity.
7. Smokes and gases pass through scrubber to remove dangerous chemicals.
8. Fabric filter removes any leftover tiny ash particles.
9. Light ash is collected after scrubbing and filtering.
10. Remaining gases escape up smoke stack

CHAPTER 5

5. Landfill Gas Recovery and Analysis of Energy Potential

5.1. Landfill

A landfill is a facility in which solid wastes are disposed in a manner which limits their impact on the environment. Landfills consist of a complex system of interrelated components and sub-systems that act together to break down and stabilize disposed wastes over time. Landfill is very old but still one of the extensively used technologies for MSW management. Most of the landfill does not have the energy production facilities. In this study, a sanitary landfill with energy recovery system has been studied. Landfill gas are generated from the landfill site in different gas generation phases. Generally, five different phases like initial adjustment, transition phase, acid phase, methane fermentation and maturation phases are observed in waste landfill. Below is the typical WtE generation by landfill process shown.

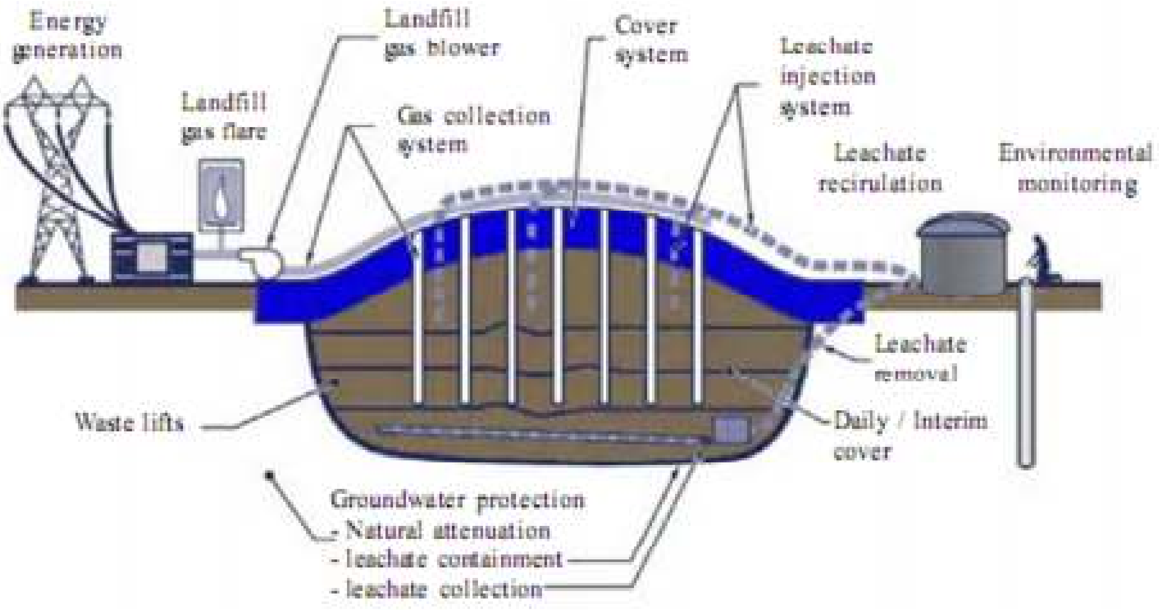


Fig5.1: Principal technical elements of a landfill

Most of the disposal systems that are often used by developing countries cities fall into one of the following categories.

Open Landfill: An open landfill is a poorly sited disposal and devoid of infrastructures. This kind of site is often without prior studies of capacity, leachate management, gas management, and fence and cell planning to estimate its lifespan. Such sites have considerable impact on humans and the environment due to high levels of environmental contamination, human health risks, ground and surface water contamination, and the overuse of the site due to its unknown capacity. Given these drawbacks, open landfills are easy to access and need minimum capital and operational costs. In many respects, the Repi landfill site is a good example of open landfill.

Sanitary Landfill: A sanitary landfill is sited on the basis of environmental risk assessment. It has full leachate and gas control management, with planned capacity and cell development. A sanitary landfill requires extensive site preparation, and covering materials on daily basis as well as fencing with gates for accurate recording and control of illegal access. Thus, sanitary landfills have the minimum social and environmental risks. The preparation of such sites demands a considerable amount of money, and hence may not be affordable for the developing countries.

5.2. Landfill Gas Recovery

Landfill gas (LFG) is the natural by-product of the decomposition of solid waste in landfills and is composed primarily of carbon dioxide and methane. Instead of allowing LFG to escape into the air, it can be captured, converted, and used as an energy source. Using LFG helps to reduce odors and other hazards associated with LFG emissions, and it helps businesses, states, energy providers, and communities protect the environment and build a sustainable future.

5.2.1. Process description

The waste deposited in a landfill gets subjected, over a period of time, to anaerobic conditions and its organic fraction gets slowly volatilized and decomposed. This leads to production of landfill gas containing methane, which can be recovered through a network of gas collection pipes and utilized as a source of energy. Typically, production of landfill gas starts within a few months after disposal of the wastes and generally lasts for about ten years or even more depending upon mainly the composition of wastes and availability / distribution of moisture. This gas can be recovered through an active system of vertical or horizontal wells, which are drilled into the waste where methane is being produced. Vertical wells are the most common type used and are located at the rate of about two wells per acre (1 acre=4046.86m^2). The wells normally consist of perforated High Density Poly Ethylene or Poly Vinyl Chloride pipes of 50 to 300mm diameter surrounded by 300mm thickness of 25-35 mm size gravel. The gas wells are provided at the time of filling of the landfill. Generally depth of the gas well is 80% of the height of landfill. The wells are connected by a main collection Header and the gas is pumped out under negative pressure by a blower. The gas is passed through a moisture trap, gas cleaning unit, (containing activated alumina, silica gel or molecular sieves) a flame arrester, a non-return valve and gate value before its connection to the compressor.

Not all landfill gas generated in the landfill can be collected; some of it will escape through the cover of even the most tightly constructed and collection system. Newer systems may be more efficient than the average system in operation today. A reasonable assumption for the gas collection efficiency for a properly planned gas collection system is 70 - 85%.

5.2.2. How is the gas utilized?

Landfill gas can be used as a good source of energy, either for direct thermal applications or for power generation. There are three primary approaches to using the landfill gas:

(a) Direct use of the gas locally (either on-site or nearby):

(b) Generation of electricity and distribution through the power grid; and

(c) Injection into a gas distribution grid.

Direct use of the gas locally is often the simplest and most cost-effective approach. The medium quality gas can be used in a wide variety of ways, including; residential use (cooking, hot water heating, space heating); boiler fuel for district heating; and various industrial uses requiring process heat or steam (such as in cement manufacture, glass manufacture, and stone drying).

5.2.3. Assessment of Waste Characteristics:

Waste characteristics influence both the amount and the extent of gas production within landfills. Different countries and regions have MSW with widely differing compositions. Wastes from developing countries, are generally high in food and yard wastes, whereas developed countries, have a very high paper and cardboard content in their MSW. Landfills in developing countries will tend to produce gas quickly (completing methane production within 10-15 years) because putrescible material decomposes rapidly. Landfills with high paper and cardboard content will tend to produce methane for 20 years or more, at a lower rate. If hazardous materials are mixed with the MSW, the recovered gas may contain trace quantities of hazardous chemicals, which would need to be removed from the gas prior to utilization. Higher gas purification requirements translate to higher costs.

An accurate estimate of waste composition is required to accurately predict the LFG generation potential of a site. The total amount of LFG that can be generated from a unit mass of waste is dependent on the fraction and type of organic content of the waste, because the decomposing organic wastes are the source for all LFG produced. For the purposes of this study, waste is characterized into three categories: slowly decomposable, moderately decomposable, and rapidly decomposable.

5.2.4. The Existing Landfill Site: Repi

Currently, wastes collected from every corner of Addis Ababa are disposed off in one open dumpsite. It has been established 47 years ago. The site is known as "Repi" or "Koshe" which is South West part of the city Located 13 km away from the city center. It has a surface area of 25 hectares. The present method of disposal is crude open dumping: hauling the wastes by truck, spreading and leveling by bulldozer and compacting by compactor or bulldozer.

The design of this site is solely for the purpose of disposal only. If this landfill site is intended for the purpose of extracting landfill gas as a means of energy recovery, it should fulfill the minimum requirements of a good landfill design.

5.2.5. General requirements of landfill

Proper design is vital to the successful operation of a landfill disposal facility in even the most suitable location. All technological alternatives which meet requirements of the proposed landfill should be reviewed prior to incorporation into the design. The design should produce a landfill capable of accepting given solid waste materials for disposal.

All landfills should be designed to incorporate the following components:

- Landfill liner system
- Landfill final cover system
- Leachate management system
- Landfill gas management system
- Surface water management system
- Groundwater management system
- Disposal material monitoring
- Separation distances
- Quality control/assurance

5.2.6. Stages of conversion

To obtain electricity as a final energy, the primary task is extracting landfill gas from the site. The extracted landfill gas can then be used as a fuel to generate electricity. The electricity generation can be done with the introduction of appropriate engine based on the volume flow rate of the landfill gas.

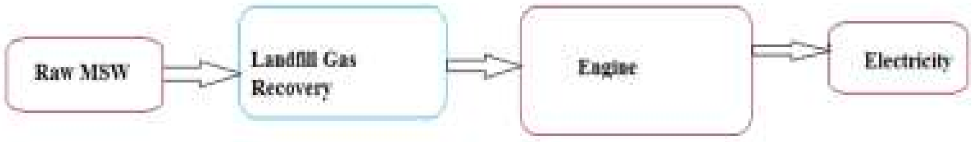


Fig 5.2.Electricity Generation by Landfilling MSW

5.2.7. Electricity Generation

Electricity can be generated for on-site or for distribution through the local electric power grid. Internal combustion engines (ICs) and Gas turbines are the most commonly used for landfill gas-to-power generation projects.

- **Internal Combustion Engines**. Internal combustion engines are the most commonly used conversion technology in landfill gas applications. They are stationary engines, similar to conventional automobile engines, which can use medium quality gas to generate electricity. While they can range from 30 to 2000 kilowatts (kW), IC engines associated with landfills typically have capacities of several hundred kW.

IC engines are a proven and cost-effective technology. Their flexibility, especially for small generating capacities, makes them the only electricity generating option for smaller landfills. In this work, too, IC engine will be employed to make economic viability.

- **Gas Turbines**. Gas turbines can use medium quality gas to generate power of sale to nearby users or electricity supply companies. Gas turbines typically require higher gas flows than IC engines in order to be economically attractive, and have therefore been used at larger landfills; they are available in sizes from 500 kW to 10 MW, but are most useful for landfills when they are 2 to 4 MW (USEPA, 1993c).
- **Steam turbines**: In cases where extremely large gas flows are available, steam turbines can be used for power generation.

5.3. Factors to be considered for Landfill Design

a) Volume Minimization

Reducing the need for a landfill should be a priority for all installations. The type and extent of compaction should be considered in design to reduce landfill volume.

b) Site Layout

The configuration of the landfill, supporting buildings, and access roads should be to facilitate effective storm water drainage, erosion control, leachate collection, and operation at a minimum cost. The layout should make optimum use of the existing terrain to minimize excavation and construction costs. Supporting buildings should be near the landfill. If the waste is to be weighed, a truck scale should be adjacent to the access road and situated where all vehicles entering and exiting the landfill must pass directly in front of the scale

c) Leachate Control

Leachate is a liquid generated as a result of percolation of water or other liquid through land filled waste, and compression of the waste as the weight of overlying materials increases. Leachate is considered to be a contaminated liquid, since it contains many dissolved and suspended materials. Good management techniques that can limit adverse impact of leachate on ground and surface waters include control of leachate production and discharge from a landfill, and collection of the leachate with final treatment and/or disposal. The minimization and containment of leachate within a landfill ultimately depends on the design of the landfill. Providing an impervious cover, minimizing the working face of the landfill, and limiting liquids to household containers and normal moisture found in refuse, are all methods that will minimize leachate production. Studies show that recycling leachate through the landfill can speed up stabilization. The following table lists some of the characteristics and common constituents of leachate for municipal landfills [11].

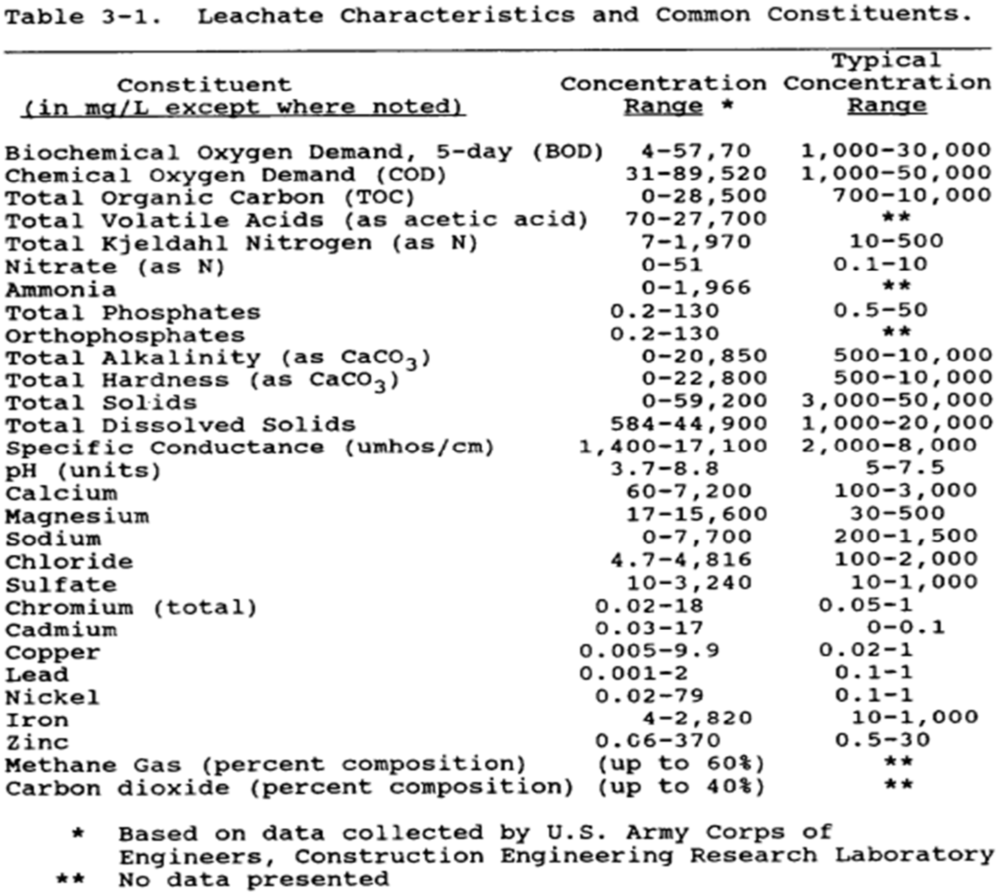


Table 3-1. Leachate Characteristics and Common Constituents.

Constituent (in mg/L except where noted)	Concentration Range *	Typical Concentration Range
Biochemical Oxygen Demand, 5-day (BOD)	4-57,70	1,000-30,000
Chemical Oxygen Demand (COD)	31-89,520	1,000-50,000
Total Organic Carbon (TOC)	0-28,500	700-10,000
Total Volatile Acids (as acetic acid)	70-27,700	**
Total Kjeldahl Nitrogen (as N)	7-1,970	10-500
Nitrate (as N)	0-51	0.1-10
Ammonia	0-1,966	**
Total Phosphates	0.2-130	0.5-50
Orthophosphates	0.2-130	**
Total Alkalinity (as $CaCO_3$)	0-20,850	500-10,000
Total Hardness (as $CaCO_3$)	0-22,800	500-10,000
Total Solids	0-59,200	3,000-50,000
Total Dissolved Solids	584-44,900	1,000-20,000
Specific Conductance (umhos/cm)	1,400-17,100	2,000-8,000
pH (units)	3.7-8.8	5-7.5
Calcium	60-7,200	100-3,000
Magnesium	17-15,600	30-500
Sodium	0-7,700	200-1,500
Chloride	4.7-4,816	100-2,000
Sulfate	10-3,240	10-1,000
Chromium (total)	0.02-18	0.05-1
Cadmium	0.03-17	0-0.1
Copper	0.005-9.9	0.02-1
Lead	0.001-2	0.1-1
Nickel	0.02-79	0.1-1
Iron	4-2,820	10-1,000
Zinc	0.06-370	0.5-30
Methane Gas (percent composition)	(up to 60%)	**
Carbon dioxide (percent composition)	(up to 40%)	**

* Based on data collected by U.S. Army Corps of Engineers, Construction Engineering Research Laboratory

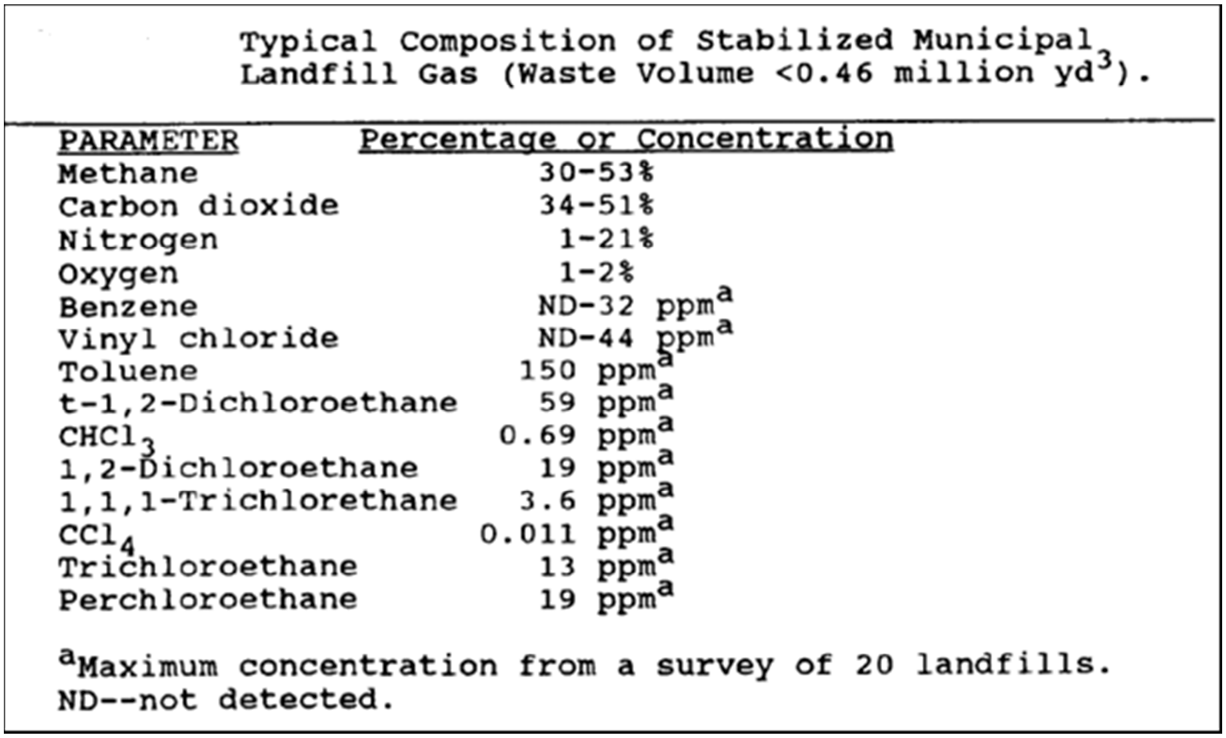
** No data presented

d) Gas Control.

Although gas generated within some types of landfills may be negligible, most landfills are expected to generate a significant quantity of gas. The quality of gas depends mainly on the type of solid waste. As with leachate, the quality and quantity of landfill gas both vary with time. The following discussion on gas quality and quantity pertains mainly to landfills with municipal type wastes, which would be expected at most installations.

Quality: Landfill gases, specifically methane gas, are natural by-products of anaerobic microbial activity in the landfill. The anaerobic process requires water and the proper mix of nutrients to maintain optimal conditions. The quality of gas varies with time, and may be characterized by four distinct phases. In the first phase, which may last several weeks under optimum conditions, aerobic decomposition takes place depleting the oxygen present and producing carbon dioxide. In the second phase, the percentages of both nitrogen and oxygen are reduced very rapidly, and anaerobic conditions lead to the production of hydrogen and carbon dioxide, the latter reaching its peak during this phase. Some experts consider the second phase to have started when the free oxygen is depleted.

In the third phase, the percentages of carbon dioxide and nitrogen are reduced significantly, hydrogen and oxygen concentrations are reduced to zero, and the percentage of methane increases rapidly to reach a relatively constant level. The fourth phase, which occurs after the landfill has become more stable, may be termed pseudo steady-state because the percentages of methane, carbon dioxide, and nitrogen all reach stable values. The time dependency of methane production is critical for landfill gas recovery and reuse projects. In most cases, over 90 percent of the gas volume produced from the decomposition of solid wastes consists of methane and carbon dioxide. A typical analysis of landfill gas is shown in the following table



Typical Composition of Stabilized Municipal Landfill Gas (Waste Volume <0.46 million yd^3).

PARAMETER	Percentage or Concentration
Methane	30-53%
Carbon dioxide	34-51%
Nitrogen	1-21%
Oxygen	1-2%
Benzene	ND-32 ppm[a]
Vinyl chloride	ND-44 ppm[a]
Toluene	150 ppm[a]
t-1,2-Dichloroethane	59 ppm[a]
$CHCl_3$	0.69 ppm[a]
1,2-Dichloroethane	19 ppm[a]
1,1,1-Trichlorethane	3.6 ppm[a]
CCl_4	0.011 ppm[a]
Trichloroethane	13 ppm[a]
Perchloroethane	19 ppm[a]

[a] Maximum concentration from a survey of 20 landfills.
ND--not detected.

Quantity: The quantity of gas generated depends on waste volume, waste composition, and time since deposition of waste in the landfill. Methane production ranges from 0.04-0.24 cubic feet per pound of waste per year [11]. Gas production may be increased by adding nutrients, such as sewage sludge or agricultural waste, the removal of bulky metallic goods, and the use of less daily and intermediate cover soil.

e) Runoff Control

Control of storm water runoff at a landfill disposal facility is necessary to minimize the potential of environmental damage to ground and surface waters. Direct surface water contamination can result when solid waste and other dissolved or suspended contaminants are picked up and carried by storm water runoff that comes into contact with the working face of the landfill. Uncontrolled surface water runoff can also increase leachate production, thereby increasing the potential foreground-water contamination. The resulting unwanted gas generation may also increase the potential for explosions.

5.4. Analysis of the LFG Potential

5.4.1. LFG Mathematical Modeling

Energy recovery from landfill gas is strongly recommended by most of the countries states' regulation as a means to reduce the environmental impact, in terms of Greenhouse Effect, arising from landfills containing biodegradable wastes. As a matter of fact, biodegradable organic matter contained in municipal solid wastes is degraded by anaerobic biological processes in landfills giving place to a LFG, which is largely composed of methane and carbon dioxide [Table above]. Hence the LFG has two main features: it is composed by two of the main Greenhouse gases and it has a significant heating value.

5.4.1.1 .The model

The applied model is based on the Scholl Canyon Equation [13] which assumes that LFG generation is a function of first-order kinetics. The LFG production rate is assumed to be at its peak upon initial placement after a negligible lag time in the original version, during which anaerobic conditions are established and decreases exponentially (first-order decay) as the organic content of the waste is consumed .In the model, average annual placement rates are used, and the time measurements are in years. The model equation takes the form:

$Q_{LFG}=R_{avg}*L_0*(e^{-kc}- e^{-kT})$.. [1]

Where:

Q_{LFG}= LFG generation rate at time T [$m^3/year$]

L_0= waste potential LFG generation capacity [m^3/t]

R_{avg} = average annual acceptance rate of waste [$t/year$]

k = LFG generation rate constant [$1/year$]

c = time since landfill closure [$year$] (c = 0 for active landfills)

T = time since initial waste placement [$year$]

But in the above equation, the average annual acceptance rate of waste is considered. This may not represent the actual case because the acceptance rate of wastes varies from year to year. To allow for variances in annual acceptance rates, the derivative of Equation 1 with respect to the time can be used to estimate LFG generation from waste land filled in a single year (R_i). In this equation, the variable T is replaced with $t-i$, which represents the number of years the waste has been in the landfill. The resulting equation thus becomes:

$$Q_{LFG,\,t,\,i} = R_i * L_0 * k * e^{-k\,(t-i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[2]$$

Where

$Q_{LFG,\,t,\,i}$ = the amount of LFG generated in the current year (t) by the waste R_i [$m^3/year$]

R_i = amount of waste disposed in year i [$t/year$]

i = the year of waste placement [$year$]

t = current year [$year$]

Lag time due to the establishment of anaerobic conditions could also be incorporated into the model by replacing "t" by "t + $lag\ time$". Literatures reveal that the lag time before which anaerobic conditions are established may range from two-hundred days to several years [13]:

$$Q_{LFG,\,t,\,i} = R_i * L_0 * k * e^{-k\,(t-i-lag)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[3]$$

lag = time to reach anaerobic conditions [year]

The total generation of LFG from waste placed in all years can be obtained by summing up the amount generated in each year.

$$Q_{LFG,t} = \sum_{i=initial\ year}^{t} QLFG, t, i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[4]$$

5.4.1.2. Application of the model to the study case (Arada Sub city)

Nothing has been done before regarding the Landfill gas recovery in Addis Ababa. This is due to the huge investment required and the technological background of the country.

Therefore, it is necessary to take reasonable assumptions as the target of this thesis is to determine how much energy can be recovered.

The tricky parameters in the above first order model are:

- ✓ *The gas generation rate constant (**k**)* - It is a function of MSW moisture content, nutrient availability, pH, and temperature.
- ✓ *The waste potential LFG generation capacity (L_0)* - is the total amount of LFG that a unit mass of MSW will produce given enough time. L_0 is a function of the organic content of the waste. It is theoretically independent of moisture. It can be estimated based on theoretical prediction, laboratory experiments or actual gas production data.

Determination of L_0 and k

With reference to the unit mass of waste, given the generic formula $\mathbf{C_aH_bO_cN_dS_e}$, The biodegradation process of the organic biodegradable fraction to form the LFG can be described by the global stoichiometric reaction (Tchobanoglous, 1993):

$C_aH_bO_cN_dS_e + w.H_2O \longrightarrow x.CH_4 + y.CO_2 + z.NH_3 + k.H_2S$ ……………………… [5]

Applying the stoichiometric balance to the reaction above it is possible to obtain the stoichiometric coefficients *w, x, y, z* and *k* as a function of *a, b, c, d*, and *e*:

$C_aH_bO_cN_dS_e + ((4a-b-2c+3d+2e)/4).H_2O \longrightarrow ((4a+b-2c-3d-2e)/8).CH_4 +$

$((4a-b+2c+3d+2e)/8).CO_2 + d.NH_3 + e.H_2S$ ……………………………………..[6]

Hence, total number of dry kilo moles of LFG will be:

$LFG_{kmol,\ dry} = x+y+z+k = \{((4a+b-2c-3d-2e)/8) + ((4a-b+2c+3d+2e)/8) + d+e\}$

$= a+d+e\ [kmol/t]$ ………………………………………………………… [7]

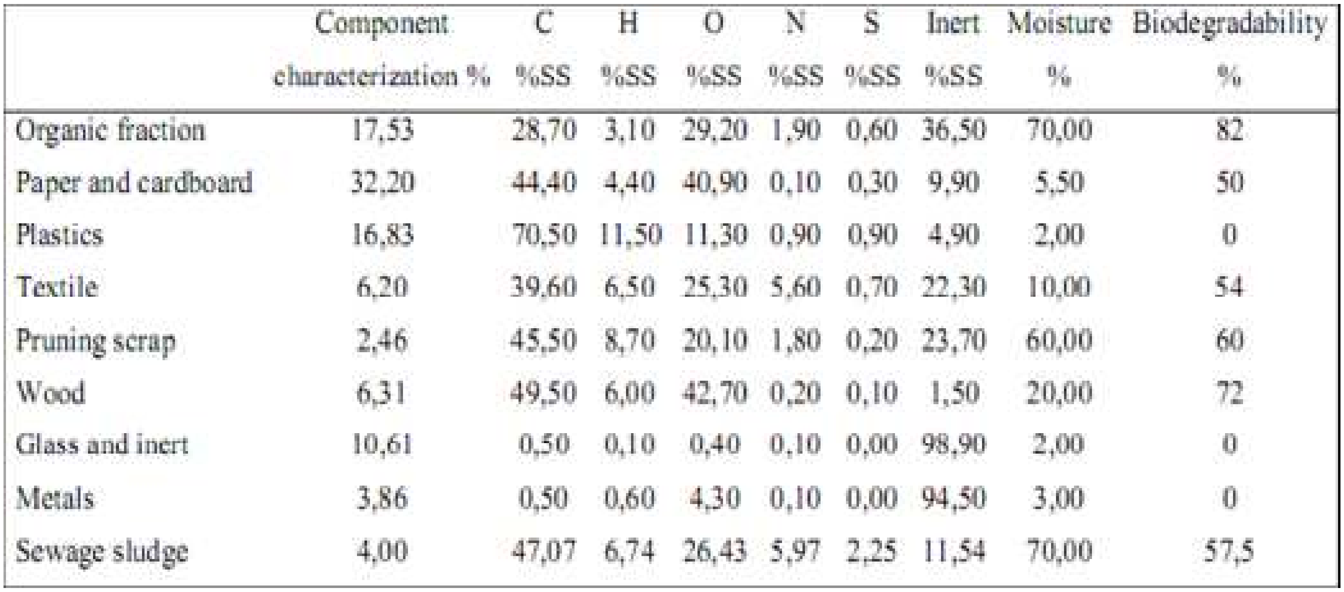
From the total number of kilomoles it is then possible to calculate the potential gas generation capacity (L_0) [13].

$L_0[m^3/t] = LFG_{kmol}[kmol/t] * 22414.[m^3/kmol]$ ……………………………[8]

5.4.1.3. Limitation to the application

To determine the potential gas generation capacity (L_0) using the above approach, the exact analysis of component characterization, the chemical composition and biodegradability of each component is necessary.

Table5.1 .Waste component characterization for some study case site and assumed values for chemical composition, moisture and biodegradability [13].



	Component characterization %	C %SS	H %SS	O %SS	N %SS	S %SS	Inert %SS	Moisture %	Biodegradability %
Organic fraction	17,53	28,70	3,10	29,20	1,90	0,60	36,50	70,00	82
Paper and cardboard	32,20	44,40	4,40	40,90	0,10	0,30	9,90	5,50	50
Plastics	16,83	70,50	11,50	11,30	0,90	0,90	4,90	2,00	0
Textile	6,20	39,60	6,50	25,30	5,60	0,70	22,30	10,00	54
Pruning scrap	2,46	45,50	8,70	20,10	1,80	0,20	23,70	60,00	60
Wood	6,31	49,50	6,00	42,70	0,20	0,10	1,50	20,00	72
Glass and inert	10,61	0,50	0,10	0,40	0,10	0,00	98,90	2,00	0
Metals	3,86	0,50	0,60	4,30	0,10	0,00	94,50	3,00	0
Sewage sludge	4,00	47,07	6,74	26,43	5,97	2,25	11,54	70,00	57,5

Finally, the contributions of the each component LFG generation capacity will be added up to yield the total value. But, as said before, the chemical composition of the wastes from Arada subcity is not known yet. Therefore, alternative approach should be used.

Actually, the different components of waste undergo biodegradation according to different degradation rates. The different behaviors have been considered distinguishing the materials in rapidly, moderately and slowly biodegradable, according to [22]. At present, there is no method for determining gas potential that is without fault. In the literatures of various studies, different values for LFG generation rate constant have been assumed for each class of materials with different biodegradation velocity. The LFG generation constant values for different class of wastes is given in the literature [22].The average values of each category is given in the following table.

So, these values will be applied in this work. The values of gas generation capacity (L_0), the gas generation rate constant (k) and the lag time will be applied as it is with minor loss of generality.

Table5.2. Values for Landfill Gas Generation Rate k, LFG Generation potential L_0 and lag time of materials with different biodegradation velocity

Waste characterization	**Components**	**LFG Generation potential L_0[m^3/ton]** *	**Landfill Gas Generation Rate, K[1/year]** **	**Lag time[year]** ***
Slowly biodegradable fractions	➢ Textiles ➢ Wood	20	0.02	5
Moderately biodegradable fractions	➢ Paper ➢ Cardboard ➢ Fines	120	0.046	2
Rapidly biodegradable fractions	➢ Vegetable[food waste] ➢ Combustible leaves and grass	160	0.088	0.3

*……….values taken from [22]

**……….values taken from [22]

***………values taken from [13]

Based on the above assumption, the estimated values of the parameters for the ***organic portion*** of Arada subcity wastes are categorized as follows.

Table5.3.The estimated values of the parameters for the organic portion of Arada subcity wastes

Biodegradability	***Components***	***k[1/year]***	***L_0[m^3/t]***	***Lag time[year]***
Rapidly biodegradable fractions	➢ Vegetable[food waste] ➢ Combustible leaves and grass	0.088	160	0.3
Moderately biodegradable fractions	➢ Paper ➢ Cardboard ➢ Fines	0.046	120	2
Slowly biodegradable fractions	➢ Textiles ➢ Wood	0.02	20	5

Assumptions

1. The year at which the LFG gas recovery analyzed is assumed to be 2018(assuming that anaerobic conditions are achieved after 7 years of initial waste placement).
2. The year of initial waste placement is assumed to be the current year(2011)
3. All the wastes disposed are not collected in practice. But for the analysis, wastes collected each year are assumed to be completely land filled.
4. The heating value of the LFG used in the analysis is that of the raw(unprocessed LFG)

Thus, the LFG generation rate of each component is calculated separately and summed up to give the overall LFG generation rate.

Rapidly biodegradable fractions

The components under this category are

- Vegetable[food waste]
- Combustible leaves and grass

$Q_{LFG} = Q_{LFG,\,t,\,i} = R_i * L_0 * k * e^{-k\,(t-i-lag)}$

Where R_i=the sum of amount of food waste and combustible leaves (grass)

=2148734.73kg/year+3125344.65Kg/year

=5274.08t/year

L_0=160m^3/year [from the above table]

k=0.088 [from the above table]

t= the current year at which the LFG is collected

t=2018

i=the year of waste placement=2011

Lag time=0.3year

Substituting all values, we obtain

$\boldsymbol{Q_{LFG,\,t,\,2011}}$**=49107.044m^3/year**

Following the same trend, the LFG generation capacity for each class of waste components in each year can be calculated. The results of this analysis are summarized in the following table.

Table5.4.The LFG generation capacity for each class of waste components

Biodegradability	***Components***	***Year of waste***	***Year of LFG collection***	***Amount land filled,***	***Q_{LFG}[m^3/year]***

		placement		***R_i[ton]***	
Rapidly biodegradable fraction	✓ Vegetable [Food waste] ✓ Combustible leaves	2011	2018	5274.08	49107.044
Moderately biodegradable fraction	✓ Paper ✓ Cardboard ✓ Fines	2011	2018	16175.63	70945.2
Slowly biodegradable fractions	✓ Textiles ✓ Wood	2011	2018	566.73	217.804
					Total =120270.05

In general, if all the wastes collected from the subcity are landfilled for gas recovery, the indicated amount of the landfill gas can be obtained given that all the necessary conditions are fulfilled. But in the actual case, all the disposed wastes are not collected. If the collection efficiency of the waste management system is improved such that more wastes are collected, there would be an increase in gas recovery potential.

Analysis of energy recovery potential

The amount of potential electric energy has been calculated according to [13]:

$EE=\eta_{el}*LHV_{LFG}*V_{LFG}$…………………………………… [9]

Where

EE=electric energy [kW]

η_{el}=*Engine electric energy conversion efficiency.*

V_{LFG}=*LFG flow rate* $[m^3/h]$

LHV_{LFG}=*LFG heating value* $[kWh/m^3]$

The values of engine maximum LFG flow rate and energy conversion efficiency are usually retrieved from engine technical forms. Energy conversion efficiency was considered dependant on the engine load (i.e. decreasing when load decreases) according to the indications on engine technical forms. Despite the specific type of engine with full technical data is selected, the primary purpose is to reveal the potential energy generation from the collected LFG.The LFG flow rate obtained from the analysis is on annual basis. Therefore, this gross value is used for calculation.

LFG heating value

The heating value of the raw landfill gas varies from region to region based on various factors such as the waste characterization, moisture content, temperature etc. It is usual to take the average value that applies over the wider range. In this work too, various literatures are reviewed and the average value is applied. The heating values of various fuels are cited in the reference [15], [16] & [17].In all of them, the variation in heating values is minimal. For this purpose, the most representative value is taken from [16] where the heating value is reported as $38.6MJ/m^3$.

Efficiency of the engine

The electrical energy conversion efficiencies of IC engines with the given specification are given in the reference [18].

Technology =IC engine

Preferred Plant size=0.5-12MW

Fuel grade=low-medium

Gross efficiency=35-50%

For this purpose, the average value of the efficiency is taken for analysis. Thus, the available energy in the landfill gas can be calculated as:

$$EE=\eta_{el}*LHV_{LFG}*V_{LFG}$$

$$=0.425*38.6MJ/m^3*120270.05m^3/year$$

$$=1,973,030.17MJ/year$$

Conversion to standard basis

This value of the available energy is converted to the standard basis (KWh) according to:

1KWh=3.6MJ

⟹EE=548,063.94KWh

If this electrical energy is converted to money according to the current electricity selling price in Ethiopia (0.29birr/KWh), the revenue will be:

Revenue=EE from LFG*sale/KWh

=548,063.94KWh*0.29birr/KWh

=158938.54birr

If the electricity generation project from LFG is implemented in small scale in Arada subcity, the produced electricity can yield the indicated amount of money. However, In order to make sound technology decisions, there must be information on the basis of the full range of advantages and disadvantages of a particular policy. Thus, economic evaluation will be conducted in the next chapter.

CHAPTER 6

6. Incineration analysis

6.1. Introduction

6.1.1. Determination of energy content of MSW

In order to evaluate the feasibility of energy recovery as an integral part of a solid waste management system, it is of great importance to determine the energy content or calorific value of the solid waste, which is defined as the number of heat units evolved when unit mass of material is completely burned and is measured in joules per gram (J/g) or British thermal units per pound (Btu/lb). The energy content of any material, such as solid waste, is a function of many parameters, namely,

- ✓ Physical composition of the waste
- ✓ Moisture content and
- ✓ Ash content.

However, the exact determination of the energy available in the municipal solid wastes is very difficult. This is because the composition of the wastes varies amongst communities and even within one community from year to year, but the difference may not be substantial in most cases. Therefore, it is expected that there may exist a little inaccuracy in the determination of energy content and it is tolerated due to the complex nature of the wastes.

Procedure

There are two possible approaches available for determining the calorific value of materials such as MSW. They can be

- ✓ Experimental approach
- ✓ Empirical approach

6.1.1.1. Experimental Approach

Of the experimental approaches, Calorimetric measurement is the common method for determining the energy content of MSW.

One method of determining the CV of a given material is by means of an ***open calorimeter*** in which pressure is maintained at 1atmosphere. Under constant pressure conditions, the heat released is equal to the enthalpy change for the reaction. Another type of calorimeter is the ***bomb calorimeter*** in which combustion is conducted under conditions of constant volume. In order to determine the CV of MSW, samples of MSW are selected randomly from solid waste generation sites and subjected to separation of the organic components (food, paper, plastic). The CV can be measured for each of the components individually by burning a weighed sample in an oxygen bomb calorimeter. To get an overall energy content of MSW, the measured values of CV can then be summed based on the percentage by weight of each component in the MSW stream.

6.1.1.2. Empirical Approach

Empirical approach is alternative way of determining energy content of solid wastes. This approach is preferable when there is a limitation in the equipment to conduct experiment. Regarding the empirical approaches, there are three types of models that are used to predict CV values based on the following analyses [8]:

1. Physical composition analysis

2. Ultimate analysis

3. Proximate analysis

Various models of empirical approach for determining the energy content of the solid wastes are presented below. These models are used based on the data available regarding the composition of wastes.

Physical Composition analysis

The physical composition analysis is based on the levels of different components of the solid waste matrix, such as plastics, paper etc. The following model applies to estimate the energy content of MSW on the physical composition basis [8].

Conventional Model:

1. $LHV=88.2R+40.5\ (G+P)-6W$……………………………………Eq.1

Where

LHV=Net calorific value (kcal/kg)

P= paper and cardboard (wt %)

R=plastic (wt %)

W=moisture content (wt %)

G=garbage (wt%: textiles, wood, food waste, miscellaneous also included)

2. LHV=2229.91+7.90P+28.16R+4.87G-37.28W…………………………Eq.2

Where

LHV=Net Calorific value (kcal/kg)

P= paper and cardboard (wt %)

R=plastic (wt %)

W=moisture content (wt %)

G=garbage (wt%: textiles, wood, food waste, miscellaneous also included)

Ultimate analysis

The ultimate analysis of waste typically involves determination of the carbon, oxygen, nitrogen and sulfur contents. The following model is applicable on ultimate analysis basis [8].

- ✓ ***Dulong's Model***:

LHV=81C+342.5 (H-O/8) +22.5 S-6(9H+W)

Where

LHV=net calorific value (kcal/kg)

C=carbon (wt %)

H=hydrogen (wt %)

O=oxygen (wt %)

S=sulfur (wt %)

- ✓ ***Steuer's Model***:

$$LHV=81(C-30/8)+57(3O/8)+345(H-O/16)+25\,S-6(9H+W)$$

Where

LHV=net calorific value (kcal/kg

C=carbon (wt %)

H=hydrogen (wt %)

O=oxygen (wt %)

S=sulfur (wt %)

- ✓ ***Scheurer–Kestner's Model:***

$$LHV=81(C-3O/4)+342.5H+22.5\,S+57(3O/4)-6(9H+W)$$

Where

LHV=net calorific value (kcal/kg

C=carbon (wt %)

H=hydrogen (wt %)

O=oxygen (wt %)

S=sulfur (wt %)

<u>Proximate Analysis</u>

The proximate analysis includes an assessment of the levels of moisture, volatile combustible matter, fixed carbon and ash. The following model is pertinent for proximate analysis [8].

- ✓ ***Traditional Model***:

LHV=45B - 6W

Where

B=combustible volatile matter

W=water (% dry basis)

- ✓ ***Bento's Model***:

LHV=44.75B -5.85W+21.2

But, when using proximate analysis, it is necessary to determine the moisture content and volatile matter content. This needs conducting experiment.

Moisture content determination

The percent moisture of the MSW samples can be determined by weighing fixed mass(say 100g) of sample into a preweighed dish and drying the samples in an oven at fixed temperature(say 105^0C) to a constant weight. The percent moisture content can be calculated as a percentage loss in weight before and after drying as follows:

% Moisture content = [(Wet Weight - Dry Weight)]/Wet weight]* 100%:

Volatile matter content determination

The volatile matter content can be determined by the method of ignition of the sample at fixed higher temperature (say550^0C).The similar sample of MSW is weighed and placed in a furnace for some time at fixed temperature. After combustion, the samples are then weighed to determine the ash dry weight, with volatile solids being the difference between the dried solids and the ash as follows:

% VS = [(Dry sample weight - Ash weight)/Dry sample weight]*100%:

Limitation in Applicability of the empirical approaches

As said above, to determine the energy content of the wastes, it is necessary to have the composition of the wastes in accordance with the above three basis. But, there have not been any data about the wastes from Arada Sub city as told from Arada Sub city cleansing Management office. Instead the available information is for the *total* basis.

6.1.1.3. Data collected

In the following table, the waste collected from Arada Sub city for three years is presented. This data is obtained from Arada Sub city cleansing Management office [9].

Table6.1. Collected MSW data from Arada Sub city for three years

Month	Waste collected in Year[m^3]		
	2000	**2001**	**2002**
July	5192	7159	5638
August	6547	6983	5626
September	8860	7960	7181
October	6651	7480	7450
November	6672	8012	6182
December	6322	7124	6349
January	6171	7996	7129
February	6362	7621	7419

March	4496	7683	7538
April	5780	8123	6048
May	6682	7025	7880
June	6423	7618	6835
Total	68614	91920	81380

As we see from the table, the generation of wastes within the region doesn't follow the smooth pattern. This is one of the complex natures of the municipal wastes. They vary from season to season even within the same community.

6.1.1.4. Physical and Chemical Characteristics of Solid Waste

In most cases, municipal solid wastes can have organic substances such as nitrogen, carbon, and hydrogen, and inorganic substances such as potassium, and phosphorous. The chemical composition of solid waste in Addis Ababa is not well known yet. In the following table, Percent composition of waste by weight in A.A is given [12].

Table 6.2.Percent composition of MSW by weight in A.A

Constituents	**% Composition by weight**
Vegetable	4.2
Paper	2.5
Plastics	2.9

Wood	2.3
Bones	1.1
Textiles	2.4
Metals	0.9
Glass	0.5
Combustible leaves, grass	15.1
Non combustible stones	2.5
Fines	65

6.1.2. How much energy can be recovered?

To calculate the heating value of the wastes, the empirical formulas are used. The data obtained from the Arada Sub city cleansing Management office is given in volume basis. Since the weight approach is better to determine the heating value, it is necessary to convert the *volume analysis* to *weight basis*. The following relation is applied.

$$\rho=m/v$$

Where ρ=density of the waste component

m=the weight of the waste component

v=volume of the waste component

The density of various waste components are given below

Waste Material	Density - kilograms per cubic metre		
	Low	Medium	Compacted
Paper	76	152	228
Cardboard – Compacted Dry	130	130	130
Cardboard - Compacted Wet	260	260	260
Cardboard - Loose Dry	55	55	55
Cardboard - Loose Wet	190	190	190
Cardboard - Waxed	55	92	130
Food - Kitchen	343	514	1029
Food - Dense	514	1029	1029
Vegetation - Garden	91	227	445
Garden - Grass	91	227	445
Garden - Trees	150	450	900
Wood - Timber	156	156	156
Wood - Pallets	156	156	156
Wood - Furniture	160	170	400
Wood - Fencing	170	170	170
Wood - MDF	156	156	156
Wood - Posts	900	1000	1100
Leather - Textiles Furniture	90	100	450
Leather - Textiles	91	91	240
Leather - Textiles Car	100	150	350
Mattress	50	50	50
Foam	30	30	90
Tyres - Rubber	200	200	400
Other - Rubber	200	200	400
Glass	411	411	411
Glass Jars	250	250	411
Plasticbags	39	78	156
Plastic - Hard	72	72	72
Polystyrene	14	21	28
Garbage Bags	87	170	348
Metal - Ferrous	120	120	120
Metal - NonFerrous	139	139	139
Low Level Contaminated Soil	922	922	922
Cleanfill / Soil	950	950	950
Rubble	1048	1048	1048
Clay	1150	1150	1150
Concrete	830	830	830
Tiles	900	1500	2000
Bricks	828	828	828
Sand	1000	1000	1000
Asphalt	680	680	680
Plasterboard	227	227	227
Linoleum	100	150	350
Insulation	60	100	350
Clinical Waste	227	227	227
Electronics	105	113	120
Whitegoods	105	113	120
Batteries	900	1000	1500
Fluorescent Tubes	285	285	285
Sawdust	250	300	350
Cement Sheets	830	830	830
Hospital General Waste Garbage Bags	87	170	348

6.1.2.1. Determination of total mass of wastes

First, the total mass of wastes collected is calculated from the above formula. The analysis is done for 2002 since it represents the recent data on wastes.

General assumptions

- ✓ The necessary datas like density, heating values in particular for Arada subcity wastes are not available. Therefore, values most widely applied in various researches are accepted with minor loss of generality.
- ✓ The yearly variation of the wastes is assumed to be uniform.
- ✓ The moisture content of the wastes is assumed to be uniform even if this may not be the actual case.

A total of **81380m³** of waste is collected in 2002. Also from the table, the average of density values of the components is accepted.

Combustible Components

Mass of paper

ρ=150.66 kg/m^3 (average value)

Mass of paper=%paper*density*total volume

=0.025*150.66kg/m^3*81380 m^3/year

=306531.33Kg/year

Mass of plastics

ρ=72kg/m^3 (average value)

Mass of plastics=%plastics*density *total volume

=0.029*72*81380

=169921.24kg/year

Mass of Food waste

ρ=628.66 kg/m^3 (average value)

Mass of food waste=%food waste*density *total volume

=0.42*628.66*81380

=2148734.73kg/year

Mass of wood waste

ρ=156 kg/m^3 (average value)

Mass of wood waste=%wood waste *density*total volume

= 0.023*156*81380

=291991.44kg/year

Mass of Textiles

ρ=140.66 kg/m^3 (average value)

Mass of textiles=%textiles*density total volume

=0.024*140.66*81380

=2747381.88kg/year

Mass of combustible leaves, Grass

ρ=254.33 kg/m^3 (average value)

Mass of combustible leaves, Grass=%leaves*density*total volume

=0.151*254.33*81380

=3125344.65Kg/year

Mass of Fines

Mass of fines =%fines *density*total volume

But, the density of Fines is not easily available since it consists of very small amounts of various components. In various works, the density of fines ranges from 200-400Kg/m^3. To be more safe, the average value is taken for the analysis. So the value of 300Kg/m^3 is accepted.

Mass of fines=0.65*300Kg/m^3*81380m^3/year

=15,869,100Kg/year

Total mass of combustibles=21894370.83Kg/year

The *combustible components* generated annually are summed up to give **21894.37tons**

Incombustible Components

Mass of Glass

Mass of Glass=%glass*density*total volume

=0.005*411*81380

=167235.9kg/year

Mass of Metals

Mass of Metals=%metals*density*total volume

=0.009*120*81380

=87890.4kg/year

Subtotal: 255126.3Kg/year

The incombustible components are summed up to give around 255.2 tons per annum

Sum =255126.3+21894370.83

=22149497.13Kg/year

The total mass of combustible and incombustible components generated annually is around **22150tons**

6.1.2.2. Analysis of heating value

The annual generation rate and the corresponding heating values of each component of MSW are taken in to account to compute the available energy.

A more general and widely applicable formula to calculate the heating value of MSW is given as follows [7].

Heating value of mixed MSW = (Heating value of Combustibles)*X_{comb}

- (Heat loss due to Water in feed)*X_{H2O}

- (Heat loss due to Glass in feed)* X_{glass}

- (Heat loss due to Metal in feed)*X_{metal}

Where $\mathbf{X_{comb}}$, $\mathbf{X_{H2O}}$, etc. are the fractions of combustible matter, water, etc. in the MSW.

But the heating value of each of the combustibles should be calculated in detail. The combustibles available in the waste stream of Arada Sub city are.

- ✓ Paper
- ✓ Plastics
- ✓ Food waste /vegetables
- ✓ Wood waste
- ✓ Textiles
- ✓ Combustible leaves
- ✓ Fines

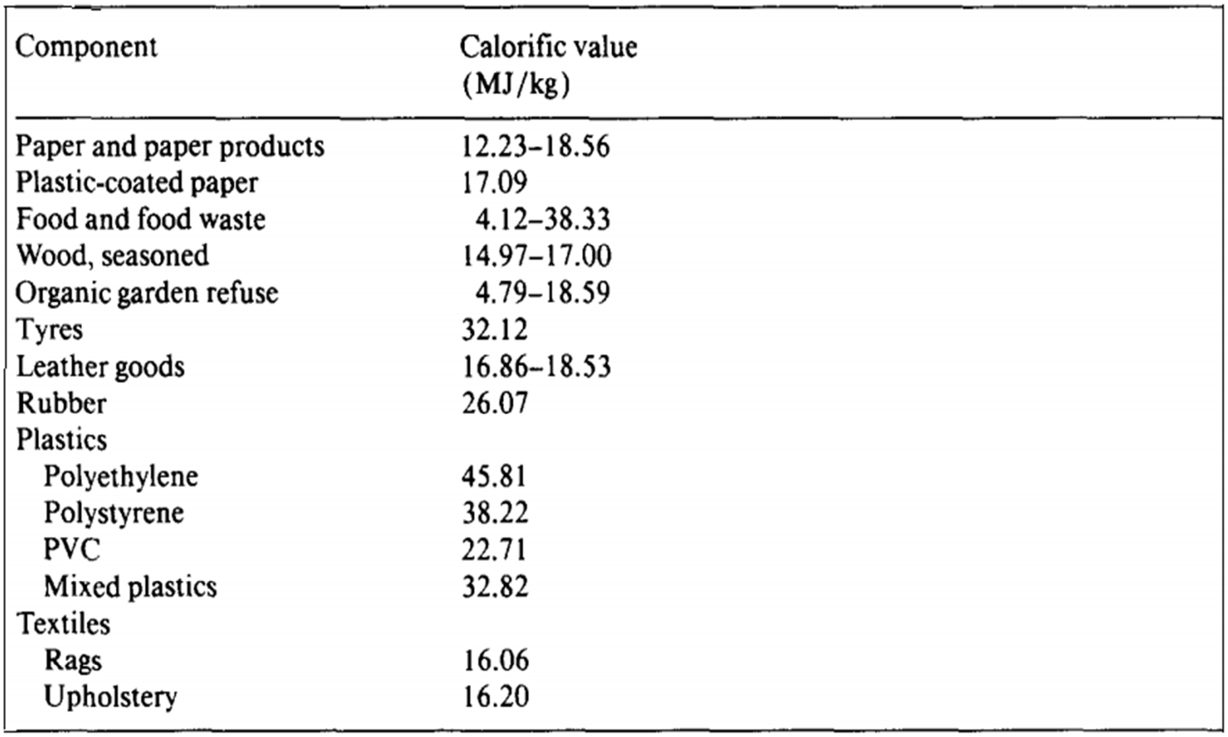
The heating value of each component is calculated from the basic thermodynamic equation

$Q=m*q$

Where Q =the available heat in the component stream

m=the mass of the component (annually generated) q=the specific heat of the component

The Typical heating values of principal constituents of municipal wastes is given below.The source of this data is [4].



Component	Calorific value (MJ/kg)
Paper and paper products	12.23–18.56
Plastic-coated paper	17.09
Food and food waste	4.12–38.33
Wood, seasoned	14.97–17.00
Organic garden refuse	4.79–18.59
Tyres	32.12
Leather goods	16.86–18.53
Rubber	26.07
Plastics	
Polyethylene	45.81
Polystyrene	38.22
PVC	22.71
Mixed plastics	32.82
Textiles	
Rags	16.06
Upholstery	16.20

Heating value of combustibles

Note: In incineration of wastes, all of the organic matter, biodegradable as well as non-biodegradable, contributes to the energy output.

For Paper

For better computation, the ***average*** calorific values are taken

Q=m*q

m=the annual generation of paper=3065311.33kg/year

q=15.395MJ/kg

Q=3065311.33kg/year*15.395MJ/kg

Q=47,190,467.93MJ/year

For plastics (mixed)

Q=m*q

=1699211.24*32.83

=55,785,105.01MJ/year

For Food waste

Q=m*q

=2148734.73*21.225

=45, 606,894.64MJ/year

For Wood waste

Q=m*q

=291991.44*15.985

=46,674,831.17MJ/year

For Textiles (rags)

Q=m*q

=2747381.88kg/year*16.06MJ/kg

=44,122,952.99MJ/year

For combustible leaves(grass)

The specific heat of combustible leaves is taken to be that of the organic garden refuse

Q=m*q

=3125344.65Kg/year*11.69MJ/kg

=36,535,278.96MJ/year

For Fines

Q=m*q

Once again, the heating value of the fines is not easily available. A research, particular to the wastes from Newyork city [7], uses the heating value of fines as 8534MJ/ton. With minor loss of generality, we again take this value even if the characteristics of both waste types are significantly different.

Q=15869100Kg/year*8.534MJ/kg

Q=135,426,899.4MJ/year

Total available energy

The available heat in the combustible components of MSW is summed up to give

$Q_{combustibles}$=411,342,430.1MJ/year

=411,342.43GJ/year

Effect of moisture and incombustible materials on available heating value

Let us now examine how the inclusion of moisture and non-combustible materials in the MSW affects the available heat in WTE plants that produce electricity and steam.

Heat loss due to moisture

The presence of moisture affects the available heating value. Therefore, it is necessary to account for this effect. Based on the literatures and experiences from concerned authorities, wastes from Addis Ababa contain around 15%.So,this value is taken for the analysis[12].

The heat required to completely vaporize the moisture in the waste stream at 100^0C is calculated as

Q_{H2O}= mass of moisture in MSW × heat capacity of water in MSW × change in temperature

$Q_{H2O} = m*c*\Delta T$

But, ΔT = final temperature (100°C) – initial temperature of water in MSW assumed to be the average annual temperature in Addis Ababa (21°C).

$\Delta T = (100 + 273) - (21 + 273) = 75K.$

The mass of moisture is given as

$m=\%moisture*density*total\ volume$

$\rho=965Kg/m^3$[density of impure water]

$m = 0.15*965Kg/m^3*81380\ m^3$

$\mathbf{m = 11779755Kg/year}$

Thus, the heat loss due to the moisture in the feed is

$Q_{H2O} = 11779755Kg/year*0.0042MJ/KgK*75K$

$\mathbf{Q_{H2O} = 3,809,572.767MJ/year}$

Heat loss due to Incombustibles (Inerts)

The non-combustible materials in the feed, mainly glass and metals, will end up mostly in the bottom ash. If it is assumed that the ash leaves the grate at about 700^oC and a reasonable value for the specific heat of ash, the corresponding heat loss to inorganic materials fed with the combustibles is estimated to be as follows[7]:

- Glass and other siliceous materials: 628 KJ/kg
- Iron: 420 KJ/kg

The heat loss due to **glass** in the feed is calculated as

$Q_{glass}=m*q_{\ loss}$

=167235.9kg/year*628 kJ/kg

=105,024.1452MJ/year

The heat loss due to **metal (iron)** in the feed is calculated as

$Q_{iron}=m*q_{loss}$

=87890.4kg/year*420 kJ/kg

=36,913.97MJ/year

At this point, it is possible to calculate the total available heat in the MSW from Arada Sub city.

$$Q_{MSW}= Q_{combustibles}-(Q_{H2O}+ Q_{glass}+ Q_{iron})$$

$$Q_{MSW} =411,342,430.1-(3,809,572.767+105,024.1452+36,913.97)$$

$$=407390919.2MJ/year$$

$$\underline{Q_{MSW} =407,390.92GJ/year}$$

This is the total amount of potentially available chemical energy in the wastes per year. But, the actual value that can be obtained is reasonably less than this .This is due to the combustion efficiency of the incinerator used.

6.1.2.3. Analysis of Potential Energy Generation

In order to proceed with the next step of converting energy, there is formula that must be used to calculate the potential energy generation. That formula is given below [14]:

Energy, P:

$$= \frac{\text{Total of average solid waste generation/hour * heat value * efficiency}}{\text{3412 Btu/ hour}}$$

= kWh

***The value of 3412 Btu/hour is being used because to obtain value in electrical energy produced that is kWh. 1 kWh equal to 3412 Btu/hour or 1.341 hp*

But the product of the first two (including the term 3412Btu/hr) terms is already determined above on the SI unit basis. Here, what we have to include is the combustion efficiency.

Efficiency

Various types of incinerators are currently manufactured. Efficiency of waste combustion depends on the incineration technologies, the wastes' combustibility characteristics, such as ignition temperature, flash point, and flammability limits.

Efficiency of waste combustion commonly can reach at range 50% to 85%. And there can reach 70% complete combustion of waste for incinerator which converts heat to electricity [14]. But this value mostly applies to technology where advanced pretreatment is implemented. In this work, the smaller value of the efficiency is accepted since the study is made for raw MSW.

Considering the combustion efficiency of 55 %($\eta=0.55$), the amount of electrical energy that can be generated is calculated as

$$\textit{Energy}, P = Q_{MSW} * \textit{efficiency}$$

$$= 407{,}390.92\,\mathrm{GJ} * 0.55$$

$$= 224{,}065.0056\,\mathrm{GJ}$$

Conversion to standard basis

The obtained value of the energy is converted to the standard basis (KWh) in order to make it better for comparison.

1KWh=3.6MJ

$$\Longrightarrow \textit{Energy}, P = 62{,}240{,}279.33\,\mathrm{KWh}$$

$$= 2593344.972\,\mathrm{KW}$$

This is an implication that, if proper technology of energy recovery is implemented, significant contribution to the country's electricity generation capacity can be made.

Current electricity price

The current selling price of electricity to the end users is as follows.

Electricity: 0.29 birr per kWh Ethiopian electricity selling price

If this electrical energy is converted to money according the current electricity selling price in Ethiopia (0.29birr/KWh), the revenue will be:

Revenue=EE from incineration*sales price/KWh

=62,240,279.33KWh*0.29Birr/KWh

=18,049,681birr

Generally, if the concerned Authority implements the small scale incineration for electricity generation, the profit of around 18 million birr can be made. But, this doesn’t mean that the project is viable. To decide on the most viable project, the economic evaluation is to be conducted in the next chapter

CHAPTER 7

7. Comparison of the Alternatives

It is amply clear that waste-to-energy technology, like any other energy source, has its *merits* and *demerits*, but the decision to select a given energy source for development would depend on a number of factors such as economic, social and environmental benefits that would be achieved in the implementation of such a scheme. This will also include the evaluation of alternative energy sources and social as well as political acceptability of such a scheme in the region. There are a lot of public and environmental health concerns with respect to the quality of emission from incineration and landfill gas recovery. Therefore, a final decision to adopt waste-to-energy source for a given region rests firmly upon a careful consideration of all technical and non-technical issues prevailing in its implementation. In this work, the comparative analysis is done based on these key factors.

7.1. Economic evaluation

The viability of the particular waste to energy process depends on the economic rent obtainable after weighing the sum of capital and operational costs against the value of the net annual energy obtainable from MSW.A comparison of the costs and benefits of an alternative is often required to judge the absolute or relative profitability of the investment made towards the better alternatives. This chapter presents the economic and financial feasibility for the alternative energy recovery option.

7.1.1. Economic evaluation methodology

The most widely and commonly used appraisal criterias for the feasibility of the particular project are:

1. Payback period
2. Net present value
3. Benefit cost ratio
4. Internal rate of return

1. The payback period

The payback period essentially measures the time elapsed between the point of initial investment and the point at which accumulated saving, net of other accumulated costs, are sufficient to offset the initial investment outlay. In the case of simple payback period the interest rate is assumed to be equal to zero and the payback period is computed as the smallest value of n that satisfies the equation

$$\sum_{n=0}^{nsp} (\mathrm{Bn} - \mathrm{Cn}) \geq 0$$

Where

B_n = the cash receipts (benefits) and

C_n=the cash expenses (costs) associated with the investment at the

end of each period n.

2. Net present value

The difference between the present value of the benefit and the cost resulting from an investment is the net present value (NPV) of the investment. In mathematical terms:

$$NPV = \sum_{j=0}^{n} \frac{Bj - Cj}{(1 + i)^j}$$

Where

B_j = benefit at the end of period j

C_j= cost at the end of period j

n =the useful life of the project and

i =is interest rate.

3. Benefit cost ratio method

The benefit cost (B-C) ratio method of analysis is based on the ratio of the benefit to cost associated with a particular project.

The first step in B-C ratio analysis is to identify the costs and benefits separately. The costs are the anticipated expenditures for construction, installation, operation, maintenance etc.

Let B and C be the present values of the cash inflow (benefits) and outflows (costs) defined by:

$$B = \sum_{j=0}^{n} \frac{B_j}{(1+i)^j}$$

$$C = \sum_{j=0}^{n} \frac{C_j}{(1+i)^j}$$

Where

B_j = the benefit at the end of j^{th} period.

C_j= the cost at the end of j^{th} period and

n=the useful life of the project.

4. Internal rate of return

The internal rate of return IRR is widely accepted discounted measure of investment worth and is used as an index of profitability for the appraisal of projects. The IRR is defined as the rate of interest that equates the present value of a series of cash flows to zero. In other words it is the interest rate at which the NPV of an investment is zero. Mathematically, the internal rate of return is the interest rate i that satisfies the equation:

$$NPV(i) = \sum_{j=0}^{n} \frac{B_n - C_n}{(1+i)^j} = 0$$

Based on the above criterias of feasibility, the two alternative energy recovery options will be analyzed and compared in the following section.

7.2. Evaluation of incineration

Aim: To decide whether implementing incineration for electricity generation in small scale is viable or not.

To evaluate the economic feasibility of incineration, the following conditions are assumed.

- ✓ The capacity of the plant is assumed to be **25000tpa**.The actual mass of wastes collected is around **22150tons**.This assumption accounts for uncollected wastes.
- ✓ The waste feed is assumed to be uniform to ensure continuous electricity generation.
- ✓ There is no feedstock preparation (since it incurs extra cost) where raw MSW is fed.
- ✓ No purchase of the land since the project is assumed to be implemented by the city administration.
- ✓ The profitability of the project is analyzed for the project life of 15 years. The payback period is calculated within this range.

7.2.1. Capital cost of incineration plant

7.2.1.1. Introduction

But, accurate data for the capital and operating costs of WtE plants are difficult to obtain. Detailed and accurate costs can only be determined once the plant is built and fully operational. In addition to the difficulties of obtaining reliable data, publicly available data often does not describe fully the technical details or the components included in the costs, or provide a cost-breakdown, leading to the possible misinterpretation of the cost information. Typical examples include: what is the assumed CV of the waste; does the capital cost include the purchase of the land, or was it provided as free-issue by the client; are the costs of the civil ground investigations, planning and consultants fees included; do the operating costs include/exclude feedstock preparation costs etc. In light of these difficulties, the comparison of cost data is problematic, in that it may not be comparing costs for the same configuration.

7.2.1.2. Plant Components and Cost Breakdown

The main technical and therefore the cost components of the *incineration* facility are typically:

- Waste reception
- Incinerator, boiler and auxiliaries
- Bottom ash system
- Utilities
- Instrumentation
- Power generating equipment and auxiliaries
- Miscellaneous equipment.
- Mechanical installation
- Electrical & instrumentation installation
- Chimney
- Flue gas cleaning

7.2.1.3. Incineration Capital Costs

The total capital investment for this particular alternative is the sum of the direct cost (which is the purchased equipment costs and direct installation costs), indirect installation costs, contingency costs, sales taxes and freight. The purchased equipment costs (PECs) used in this work is based on cost information found from professional works and journals in the respective area of study. However, the detail purchase cost for each of the above components of incineration facility is difficult to find. Instead, the capital cost value for the purchase of the whole plant (PEC) is taken for analysis. Where installation costs are not available, direct and indirect installation costs are developed using the factors 10 and 5 percent, respectively, of PEC.

A contingency factor of 5 percent was assumed to the total costs in all cases to cover contingencies as listed below. The Capital Investment Cost elements are

Direct costs (DC)

Purchased equipment costs (PEC):

Direct installation costs (DIC) - 10 % of PEC:

- Foundations and supports
- Handling and erection
- Mechanical installation
- Electrical & instrumentation installation, etc

Indirect installation costs (IIC) - 5 % of PEC:

- Engineering
- Contractor fees
- Startup
- Performance test, etc.

Contingencies (C) - 3 % of PEC:

- Cost escalations
- Delays in startup

Freight (2 % of PEC)-due to the transportation of the materials

But the PEC for the plant that can handle 25000tpa is required first. Different vendors have different methodologies for the preparation of cost estimates, which can make direct comparison difficult.

In the case of most WtE technologies, the capital and operating costs should be seen as estimates, as plants based on these technologies have not yet been built and operated in Ethiopia. The capital cost datas for WtE plants with various waste handling capacities is given below [19].

Table 7.1.The capital cost data for WtE plants with various waste handling capacities

Handling Capacity [tons/year]	Capital Cost in $million
25000	6
40000	12
80000	19

The Breakdown of estimated investment cost for MSW incineration plant with the waste handling capacity of 405,000tpa is given the reference [20].For this plant, the total project cost is cited as US$54.28million.This is an implication that the capital cost increases sharply with the waste handling capacity of the plant. Therefore, with the difficulties of cost estimation in mind, the initial capital cost for small scale plant that can handle 25000 tons/year is taken for study. Note that this value is used only as the purchase of the equipments. The following table shows the cost components with their respective cost estimates. In the analysis, the dollar is converted to Ethiopian birr using the current exchange rate.

1US$=16.63(at the time of analysis).Thus, the capital cost value given as 6$million=99.78million Birr.

Table 7.2.breakdown of estimated capital cost for small scale incineration plant

No	Cost components	Cost Item	Cost in million birr	Plant layout
1	➢ Steam cycle, turbine and others ➢ Controls and balance of power system ➢ MSW combustor /incinerator ➢ MSW boiler ➢ MSW flue gas treatment facility	**Direct costs**		Basic MSW fired
		1.1. purchase equipment cost(PEC)	99.78	
		1.2.direct installation cost(10%PEC)	9.978	
2	➢ Engineering ➢ Contractor fees ➢ Startup ➢ Performance test, etc.	Indirect installation costs(5%PEC)	4.98	
3	➢ Cost escalations ➢ Delays in startup	Contingencies(3%PEC)	2.99	

4	➢ Transportation of materials	Freight (2%PEC)	1.99	
5	-	**Total**	119.72	

7.2.1.4. Incineration Operating Costs

The operating costs of an incineration plant producing electricity are basically composed of the following components.

Direct annual costs

- Operating and maintenance
- MSW, ash, material hauling and others

Indirect annual costs

- Overhead cost
- Administrative Expenses
- Assurance/insurance

No universal approach exists for the estimation of these costs. They vary depending on many factors such as the capacity of the plant, the selected combustion technology, etc.The cost estimates which apply most for small scale plants in various studies is applied in this work too. A brief description is provided below for each component of the annual operating costs used in the cost evaluation.

1. **Operating and maintenance**

Operating cost

30 operators per 8- hour shifts were assumed for the operation of the plant. Operator wage rates are estimated to be 5 birr/hr. The plant is assumed to operate 24 hours per day and 300 days a year. This gives the total operating cost3*10operators*8hr/day*5birr/hr* 300days/yr=360,000birr/year.

Maintenance cost

Including the maintenance materials cost, the maintenance cost is assumed to be equal to operating cost which is 360,000birr/year.

2. Overhead: An annual overhead charge of 60% of the total operating & maintenance cost is used. This gives 0.6*720000=432000birr/year.

3. **Administrative Expenses**: The administrative charges were assumed as 1 percent of the total capital cost of the system.

4. Assurance/insurance: The cost of insurance was assumed as 0.5 percent of the total capital cost of the system.

5. MSW, ash, material hauling and others: 15% of the total operating and maintenance costs are assumed for this category, which gives 0.15*720000=108,000birr/year. The summary of all these cost items is given below.

Table 7.3.breakdown of estimated total operating cost for small scale incineration plant

No	Cost component	Unit of measure	Quantity	Cost in Birr
1	Operating cost	Person	30	360000
	Maintenance cost	Person		360000
2	Overhead cost	Birr	-	432000
3	Administrative Expenses	Birr	-	1,011,000
4	Assurance/insurance	Birr	-	505000
5	MSW, ash, material hauling and others	Birr	-	108,000
6	**Total**	Birr	-	**2,776,500**

7.2.1.5. Feasibility Analysis of incineration

The economic feasibility of this project is evaluated by the above appraisal criterias. This study evaluates the project by using the pay-back period and Net Present Value (NPV) as it is most popular and commonly accepted. Note the following points

- In the analysis, the amount of cost and revenue values used for the successive years will be the same. This is because the trend of the variation cannot be known in the coming years. It would be better if the yearly variation is known and a little risk is taken here.
- The only revenue employed in the analysis is the profit gained from the sale of the electricity, which is calculated as 18,049,681birr/year.
- The electricity generation is expected to be a year after the installation of the plant.
- The capital cost is used only for the first year of equipment purchase and installation while the operating cost is for each year plant operation.
- The plant life span used in this analysis is 15 years of operation.

Note: the project life span is assumed to be 15 years for both alternatives to put them to the same basis of comparison

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	**Total**
I. Cash inflow		**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	**18.05**	
➢ Revenue(sales from electricity)		18.05	18.05	18.05	18.05	18.05	18.05	18.05	18.05	18.05	18.05	18.05	18.05	18.05	18.05	
➢ Salvage value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
II.Cash outflow	**119.72**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	**2.77**	
Capital cost																
➢ Equipment purchase	99.78															
➢ Direct installation cost(10%PEC)	9.978															
➢ Indirect installation costs(5%PEC)	4.98															
➢ Contingencies(3%PEC)	2.99															
➢ Freight (2%PEC)	2.99															
Operating cost(total)																
➢ Operating (labor)cost		0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	
➢ Maintenance cost		0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	
➢ Overhead cost		0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	
➢ Administrative Expenses		1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	1.011	
➢ Assurance/insurance		0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	0.505	
Gross profit(I-II)-net cash flow	**-119.72**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**15.28**	**94.2**
Discount factor(at 6% interest)	1	0.944	0.89	0.84	0.792	0.747	0.705	0.665	0.63	0.592	0.56	0.53	0.497	0.47	0.442	
Discounted cash flow (NPV)	**-119.72**	**14.42**	**13.6**	**12.83**	**12.1**	**11.41**	**10.77**	**10.16**	**9.62**	**9.04**	**8.55**	**8.1**	**7.6**	**7.2**	**6.75**	**22.43**

P.W. Gross cost	**119.72**	**2.61**	**2.46**	**2.32**	**2.2**	**2.07**	**1.95**	**1.84**	**1.745**	**1.64**	**1.55**	**1.46**	**1.37**	**1..3**	**1.22**	**145.455**
P.W. Gross profit	**0**	**17.04**	**16.06**	**15.26**	**14.3**	**13.48**	**12.72**	**12**	**11.37**	**10.68**	**10.10**	**9.56**	**8.97**	**8.48**	**7.97**	**167.99**

Table 7.4.Profitability analysis values for 15 years of period of Incineration (values are expressed in 10^6)

Discount factor=1/ $(1+i)^t$, Where t=year of discount, i=interest rate

From the above table:

- The net present value is 22.43 million birr
- The Benefit-cost ratio $= \frac{\sum \text{P.W of gross profit}}{\sum \text{P.W of gross cost}}$

$= 167.99/145.455 = 1.15$

Since the NPV is positive, the project is acceptable and

The ratio of benefit to cost is > 1 the project is profitable.

Payback period calculation

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cumulative Cash flow	-119.72	-105.3	-91.7	-78.87	-66.77	-55.36	-44.59	-34.43	-24.81	-15.77	-7.22	0.88			
Yearly Cash flow	-119.72	14.42	13.6	12.83	12.1	11.41	10.77	10.16	9.62	9.04	8.55	8.1	7.6	7.2	6.75

Payback period =11years +7.22/8.1=**11.89**years or **11** years and **10** months

7.3. Evaluation of LFG to Energy alternative

Aim: To decide whether implementing LFG to energy project for electricity generation in small scale is viable or not.

The following assumptions are made to clearly define the scope of the LFG to Energy project.

- ✓ The LFG generation is assumed to start after 7 years of the initial waste placement, as used in the analysis.
- ✓ The gas to be used is unprocessed (raw) as obtained from the landfill.
- ✓ The economic lifetime of a landfill gas energy recovery plant is assumed to be 15 years; limited by the operating life of IC engine-generator and the productive life of a landfill.
- ✓ The scope of the plant under study includes *gas collection system, engine-generator sets, powerhouse, power generation site infrastructure, connection to the grid.*

7.3.1. LFG to Energy capital costs

Once again, there are difficulties in estimating the capital cost of the LFG to energy, as said before. In this thesis, the cost estimation is based on the evaluation datas performed in various studies since the project in not implemented in our country.

The capital cost estimation of the LFG to Energy project is basically of two broad categories.

- ➢ The LFG collection facility and
- ➢ The power/electricity generation unit.

The cost components for the LFG collection facility are briefly listed below.

- Gas extraction wells
- Header and lateral Piping
- Condensate management
- Blower and flaring equipment

Likewise, the cost components of the power /electricity generation facility are

- The IC engine-generator set
- Power generation site infrastructure.

The capital costs of the LFG to energy projects have been reported in various works. The total capital cost for the project which can produce 1.6MW with the project life span of 20 years was reported as $2.8million[25].A research done on LFG to energy project for a *Standard Reciprocating Engine-Generator Set power plant* in china reported that the total capital cost and the operating and maintenance cost (for the first year of operation) to be $3,070,938 and $347,056 respectively[23].The same research reported that the *total capital cost* and the *operating and maintenance cost* (for the first year of operation) for a *Small Engine-Generator Set* to be $2,596,795 and $292,544 respectively[23]. The Pre-Feasibility Study for Landfill Gas Recovery and Utilization at Santa Tecla Landfill in Brazil reported that the capital cost for *LFG Collection System* and *Electricity Generation Unit* to be $923,600 and $1,234,000 respectively, yielding the total plant capital cost of LFG-to-energy to be $2,157,000[24].The operating and maintenance costs have also been reported as $92,000 and $140,000 respectively [24].The waste capacity of this landfill has been reported as 108,777 tons/year. The total plant cost increases with the waste handling capacity of the facility. Note that how big is the difference between the amount of wastes collected from Arada subcity and those landfills described above.

The costs and sizes of the equipments vary for different manufacturers. However, we cannot precisely describe the complete component equipments as well as their costs for LFG to energy plant in particular to Arada subcity. The costs break down and the component equipments for this study are briefly given below. The same approach used for incineration is applied here.

Direct costs (DC)

Purchased equipment costs (PEC):

Direct installation costs (DIC) - 10 % of PEC:

- Foundations and supports
- Handling and erection
- Mechanical installation
- Electrical & instrumentation installation, etc

Indirect installation costs (IIC) - 5 % of PEC:

- Engineering
- Contractor fees
- Startup

Contingencies (C) - 3 % of PEC:

- Cost escalations
- Delays in startup

Freight (2 % of PEC)-due to the transportation of the materials

Table 7.5.breakdown of estimated total capital cost for small scale LFG to energy plant

No	Cost component	Cost type	Estimated Cost in US $ ****	Plant layout
1	**1.LFG collection facility**	**Direct cost** ➢ Equipment purchase cost(PEC)		LFG fired
	1.1.Main gas header collection piping		$117,600	
	1.2. Lateral piping		$20,800	
	1.3.Condensate management		$35,500	
	1.4. Vertical extraction wells		$385,700	
	1.5. Road Crossings		$33,000	
	1.6.Blower and flaring equipment		$209,000	
2	**2. Power/electricity generation unit.**	**Direct cost** ➢ Equipment purchase cost(PEC)		
	2.1.LFG fueled engine-generator set		$848,000	
	2.2.connection to the grid		$150,000	
	2.3. LFG measuring and recording equipment		$20,000	
		Total	**$1,818300**	
3	**Direct installation costs**	Direct installation costs	$181,830	

	➢ Foundations and supports ➢ Handling and erection ➢ Mechanical installation ➢ Electrical & instrumentation installation	(DIC) - 10 % of PEC		LFG fired
4	**4. Indirect installation costs** ➢ Engineering ➢ Contractor fees ➢ Startup	Indirect installation costs(5%PEC)	$90915	
5	➢ Cost escalations ➢ Delays in startup	Contingencies(3%PEC)	$54549	
6	**Transportation of materials**	Freight (2%PEC)	$36366	
7	**Total project cost**		**$2,181,960**	

****……………..values taken from [24]

7.3.2. LFG to Energy Operating costs

Most of the literatures report that the annual estimate for operating and maintenance cost of the waste to energy plants is around 10 percent of the initial capital cost [24]. These costs include those associated with operation and maintenance of the existing collection system such as labor, testing, routine maintenance and repairs, as well as those associated with regular expansions of the collection system. This assumption is validated in many researches and used in this study too. This value of the operating costs and the total cash flow of the project are given below.

7.3.3. Feasibility analysis of LFG to Energy project

The economic feasibility of this project is evaluated by the above appraisal criterias, as used for incineration. This study evaluates the project by using the pay-back period and Net Present Value (NPV) as it is most popular and commonly accepted. Note the following points

- In the analysis, the amount of cost and revenue values used for the successive years will be the same. This is because the trend of the variation cannot be known in the coming years. It would be better if the yearly variation is known and a little risk is taken here.
- The only revenue employed in the analysis is the profit gained from the sale of the electricity, which is calculated as 158938.54birr /year.
- The electricity generation is expected to start at the same year of LFG generation. But the LFG generation is assumed to start after 7 years of initial waste placement, as used in the analysis.
- The capital cost is used only for the first year of equipment purchase and installation while the operating cost is for each year plant operation.
- The plant life span used in this analysis is 15 years of operation

In the cash flow analysis, the money value in dollar will be converted to the birr using the current exchange rate:

1US$=16.85(at the time of analysis).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	**Total**
I. Cash inflow	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	**158.94**	
➢ Revenue(sales from electricity)	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	158.94	
➢ Salvage value	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
II.Cash outflow	**36766**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	**3676.6**	
Capital cost																
➢ Equipment purchase	**30638.35**															
➢ Direct installation cost(10%PEC)	3063.83															
➢ Indirect installation costs(5%PEC)	1531.91															
➢ Contingencies(3 %PEC)	919.15															
➢ Freight (2%PEC)	612.76															
Operating cost(total) 10% capital cost		3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	3676.6	
Gross profit(I-II)-net cash flow	**-36607**	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	-3517.6	
Discount factor(at 6% interest)	1	0.944	0.89	0.84	0.792	0.747	0.705	0.665	0.63	0.592	0.56	0.53	0.497	0.47	0.442	
Discounted cash flow(NPV)	**-36607**	-3320.6	-3130.6	-2954.8	-2785.9	-2627.6	-2479.9	-2339.2	-2216	-2082.4	-1969.8	-1864.3	-1748.2	-1653.2	-1554.8	-69334.3
P.W. Gross cost	**36607**	3470.7	3272.1	3088.3	2911.9	2746.4	2592	2444.9	2316.2	2176.5	2058.9	1948.6	1827.3	1728	1625	70813.8
P.W. Gross profit	**0**	150.04	141.45	133.5	125.88	118.72	112.05	105.7	100.13	94.1	89	84.23	79	74.7	70.25	1478.75

Table 7.6.Profitability analysis values for 15 years of period of LFG to Energy (values are expressed in 10^3birr)

From the above table:

- The net present value is $-69334.3*10^3$ birr =-69.33millionbirr
- The Benefit-cost ratio $= \dfrac{\sum \text{P.W of gross profit}}{\sum \text{P.W of gross cost}}$

$= 1478.75/70813.8 = 0.02$

Since the **NPV** is **negative**, the project is **not acceptable** and

The ratio of benefit to cost is < 1 the project is **not profitable**.

CHAPTER 8

8. Conclusion and Recommendations

So far, the assessment of energy recovery options and their economic evaluations have been studied in brief. The two options under study were incineration with energy recovery and Landfill gas to Energy mechanisms. They are separately analyzed for potential energy generation capacity and the economic evaluation is performed in the chapter 7. The contribution of this thesis can be summarized as follows:

8.1. Conclusion

- ✓ The detail analysis of the two energy recovery alternatives was conducted starting at chapter 5 to the end. In chapter5, the energy recovery from MSW was conducted to determine the potential amount of the landfill gas which is fed to the engine to produce electricity. LFG generation was determined as a function of first-order kinetics .The study indicates that if the MSWs collected from Arada Subcity are landfilled, given that the assumptions made are valid, the potential LFG that can be obtained is calculated as 120270.05 $m^3/year$. Taking this value as the annual potential LFG generation, the electricity production potential is calculated in the analysis. The study indicated that around 548,063.94KWh (0.15MW) electricity can be generated by exploitation of LFG gas described above.
- ✓ Interms of the financial value, this amount of electricity can save around **158938.54birr,** considering that the current electricity selling price in Addis Ababa is 0.29birr/KWh.The detail feasibility analysis showed that the estimated capital cost of around 37 million birr(36,766,000 birr as calculated in the analysis) is required to completely implement the LFG-to-Energy project in Arada subcity. It is also shown that, even after this huge initial capital cost, the analysis showed that the revenue obtained from selling electricity annually cannot cover the annual operating and maintenance costs. This implies that it takes several years to payback the initial capital outlay of the project. The project also includes additional years it takes for LFG gas to generate (7 years in this case).All this information shall be provided for the decision making team in order to give a basis for making decision.

- ✓ In chapter 6, the potential electricity that can be generated by incineration of the wastes is done. The respective masses of each category of wastes are calculated and the total available amount for incineration is calculated as 22149497.13Kg/year. According to the analysis, if this amount of waste is incinerated for power generation, it is indicated that around 2.6MW of electricity (2.59MW as calculated) can be generated. This is equivalent to annual saving of 18,049,681birr where the current electricity selling price is 0.29 birr/KWh.
- ✓ The brief financial analysis is done on chapter7.It is estimated that around 120 million birr(119.72 million birr as calculated) is required to completely set up a small scale incineration plant .The yearly operating and maintenance costs are also estimated as 2.77 Million birr. However, the revenue obtained from the sale of electricity is calculated as 15.28 million birr. In the analysis, this monetary value is expected to be saved each year until the useful life of the project (15 years as assumed in the analysis). It is shown that if annual saving of 15.28 million birr is made each year, it takes around 12 years (11.89 years or 11 years and 10 months as calculated) to completely payback the initial capital outlay.

8.2. Recommendations

- ➢ The boundary of this thesis was limited to the MSWs collected from Arada subcity only. As indicated in the analysis, even though Energy recovery mechanism through the adoption of incineration appears to take shorter time to payback the initial capital investment, it is still significantly long time. This is because the energy generated, which directly depends on the amount of waste available, is relatively small. Therefore, the implementation of these schemes should be planned on a *City* basis rather than *Subcity* basis. By doing this, the energy generation will greatly be improved to yield the shorter payback period.
- ➢ Studies show that more than 200,000t of MSWs are collected and disposed in Addis Ababa [10]. But this study was conducted for waste capacity of 25000t per year. Various studies have shown that for plants with smaller waste handling capacities, the operating costs are higher than that of the larger plants because the revenue obtained from the electricity generation cannot offset the various costs of the plant.

- So, to payback the initial investment of the plant in a short period of time, the Waste-to-Energy scheme should be implemented in a larger scale .This is because the revenue from the electricity sales will be able to offset the operating costs in a shorter time span.
- According to the results of this study, from economic point of view, Energy recovery from incineration yielded the shorter payback period than that of the Landfill gas to energy scheme. But most researches showed that incineration is less environmentally friendly than Landfill gas to energy scheme. But, the primary target of this thesis focuses on economic aspect. Therefore, Addis Ababa city administration should implement incineration with energy recovery for better production of electricity.
- As a general recommendation, the implementation of waste to energy schemes should not be done in haste, but should first proceed cautiously in pilot schemes, which may then transform into large-scale schemes.

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