ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF CHEMICAL ENGINEERING

STUDY ON MUNICIPAL SOLID WASTE MANAGEMENT OF ADDIS ABABA UNIVERSITY

A Thesis Submitted To the School of Graduate Studies of Addis Ababa University on Partial Fulfillment of the Requirement for Master of Science in Environmental Engineering

BY:
Kassahun Seyoum

ADVISORS: Ato Teshome Worku
Dr. Tassisa Kaba

July 2007

Addis Ababa University

School of Graduate Studies

Environmental Engineering Program

STUDIES ON MUNICIPAL SOLID WASTE MANAGEMENT OF ADDIS ABABA UNIVERSITY

By

KASSAHUN SEYOUM

Approved by the Examining Board:

______________________ ____________________

Chairman, Department's Graduate Committee

____________________ ____________________

Advisor

____________________ ____________________

Advisor

_________________________ ___________________

External Examiner

_________________________ ___________________

Internal Examiner

ACKNOWLEDGEMENTS

I take this opportunity to express my sincere gratitude to Dr. Tassisa Kaba and Ato Teshome Worku, Instructors, Department of Chemical Engineering, Addis Ababa University, Addis Ababa for their expert guidance, helpful criticism, valuable suggestions and encouragement at every stage during the completion of this work. It was pleasant and inspiring experience for me to work under their guidance.

Thanks to Mrs. Mengistu G/Tsadik and Yohannes Assefa, Ethiopian health & Nutrition Research Institute as well as Ato Belachew Alemu Ethiopian Geological survey, lab staffs, who sacrified their valuable time in assisting me during the analysis work.

I add a special note of admiration and gratitude to my friends, without their moral support, it would have been impossible for me to go through this piece of work.

I also thank Mrs. Anteneh and Tezera, Head of student Cafeteria in main campus and technology faculty, who provided me valuable information about the existing solid waste management system in Addis Ababa University.

At last but not least of express my deep gratitude to Addis Ababa University (A.A.U) for sponsoring me throughout my work, and for all those who stood by my side during this work.

Abstract

The activities involved with the management of solid wastes are the control of generation, storage, collection, transfer and transport, processing and disposal of the waste with best principles of environmental considerations. Physical and chemical analyses of refuse must be known to develop and design proper management of the waste.

Prior to sample collection for the analysis, preliminary site visits were made to observe the physical nature of the solid wastes in dust bins at different localities of the university, and sites were selected for sample collection.

Following stratified random sampling technique and using preliminary site investigation, a total number of 8 sites were selected to get representative sample for the study.

Physical and chemical analyses were done to determine selected parameters, which were considered relevant for selection of appropriate solid waste disposal method

The characterization of MSW from 8 sites belonging to the three categories viz. students mess; student hostels; and offices- have shown that the quantum and physical characteristics from A.A.U. campuses show trend towards developed countries and major metropolitan cities in Ethiopia, depicting a higher standard of living.

In chemical analysis a modified equation, based on percentages of compostable fractions, paper, and plastics with rags, has been suggested for estimation of energy content of the solid waste.

Based on the analysed parameters, proposal for solid waste disposal of A.A.U. has been presented.

Table of Content

Content **Page**

List of Tables

List of Figures

Abbreviations

A.A.U	Addis Ababa University
Btu	British thermal unit
C	Carbon
ChED	Chemical Engineering Department
CP	Cardboard & Paper Component
Cu.m.	Cubic Meter
e	Base of Natural Logarithms
E	Energy Content
F	Food Waste, Leaves, Grass component
H	Hydrogen
ISWM	Integrated Sustainable Waste Management
Kg	Kilograms
KJ	Kilojoules
Kms.	Kilometers
lb	Pound
m	Meter
MDE	Modified Dulong Equation
MSW	Municipal Solid Waste
NPK	Nitrogen, Phosphorus, Potassium
N	Nitrogen
O	Oxygen
P	Paper
PLR	Plastic, Leather, Rubber
S	Sulfur
SWM	Solid Waste Management
USEPA	United state Environmental protection authority
X	Percent Sampling Error
Y	Sampling Ratio

CHAPTER ONE

1.0 INTRODUCTION

1.1 General

Solid wastes, like other wastes, are a result of human activities. The type of solid waste produced depends upon various factors, such as the standard of living, occupation, habits of the contributing population which, in turn, are also affected by the climatic and dietary habits. Thus, these various factors determine the type and amount of the solid waste that will be generated in a particular case. These differences mean that waste management systems each require distinct approaches. For example, as the waste content in developing countries is highly organic and susceptible to rapid decay, the emphasis of the SWM process in these countries should be on the collection process.

Addis Ababa University (A.A.U), being the largest university in the country, with potential of development and expansion due to its proximity to other international institutions is expected to rapidly expand. This will put further demands on the university to increase correspondingly municipal infrastructures. Among others, there is a considerable need to improve the Solid Waste Management (SWM) with effective organizational setup. There fore in order to propose an appropriate disposal method, and to give an overview of the nature of solid wastes from similar institutions, it was planned to study the characteristics of the Municipal Solid Waste (MSW) generated from different campuses of the university and the mitigation methods as the existing system is not in accordance with basic waste management principles.

Though every individual, institution or city will give different results, it is always desirable to have a general idea or a first estimate of the probable quality and quantity that may be encountered.

Generally, the greater the economic prosperity and higher percentage of population, the greater the amount of solid waste produced. Knowledge of the amount of solid waste generation is necessary to design management strategies to effectively handle those wastes.

The term municipal solid wastes (MSW) generally implies all the wastes generated in a community with the exception of industrial process wastes and agricultural solid wastes. And the sources of these wastes are mainly institutional, commercial, residential, construction and demolition, and municipal services excluding treatment works.

The composition and source of refuse must be known for local authorities to select the most economical collection technique; to design and operate an efficient central incineration plant; to plan ahead for suitable sanitary landfill sites or design a composting plant; and to forecast the cost and efficiency of operation when choosing a particular method of disposal.

Large variations in solid waste characteristics have been observed across the world. These differences are linked to differences in prosperity, climate, industrialization, community size, and consumption habits. Therefore, it is necessary to obtain information from the area concerned; global values can not be assumed.

Waste management in general and solid waste management in particular evolved from a strategy which assumes the environment to have an infinite waste assimilative capacity to that which recognizes the limits of the environment.

Environmentally sound waste management, however, requires the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals.

The integration of environmental management and monitoring plan in the overall study management exercise would enable to evaluate the proper implementation of the proposed study. This should aim at providing a quantity control, leading to a program which will be properly designed, constructed and functions efficiently and sustainably.

There has been no attempt to study the nature of the solid waste generated so that it would be necessary to work for the characteristics from the various categories in the campuses.

Accordingly, contemplations of the characteristics of solid wastes, sitting considerations, projected population growth, and socio-economic conditions were assessed to determine the most ideal system.

1.2 Problem Statement

A.A.U. being a recognized university should be aesthetically attractive, environmentally safe and could be a model in its waste management activities.

But observation reveals that wastes from dormitory and offices are disposed improperly which brought the aesthetic deterioration of the compound. Of course some of the combustible wastes from these areas like paper, woods and garden trimmings are collected and improperly burned. This can adversely affect the environment.

The major components of the waste in the university, the compostable component, which are left from scavengers, are collected in open containers, which easily create fermentation and habitat for bacterial growth. In this environment, insects, rodents and some bird species proliferate and act as passive vectors in the transmission of some infection diseases and indirect risks. The most important indirect risk is the proliferation of insects that are carriers of microorganisms and that transmit diseases to the whole population of the university. Such an activity may result in criticism from different concerned health organizations.

Hence a proper management system must devised.

1.3 Objectives of the Study

General objective

Assessment and characterization of Addis Ababa University's municipal solid waste and proposal of appropriate management systems

Specific objectives

- Investigation and identification of major solid waste sources in the university
- Assessment of the existing management and organizational structure and propose improvement measures.
- Generation of usable data and evaluation of the data to determine the waste generation rate and appropriate waste management systems.

1.4 Scope

The study includes waste sampling, characterization, laboratory analysis, and proposal of appropriate disposal methods for main campus, technology and science faculties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Knowledge about the composition of refuse is essential as it enables to decide the type of disposal methods that will have to be adopted and the desired frequency of collection.

The municipal solid wastes, excluding special and hazardous wastes, consist of organic and inorganic solid wastes from residential areas and commercial establishments. Typically the organic wastes include food waste (also known as garbage), paper, plastics, textiles, wood, yard wastes etc. The inorganic fraction includes glass, metals, and dirt.

The types of municipal wastes are generally classified as follows:

1) *Residential solid waste:* food waste, paper, plastics, textiles, leather, yard waste, glass, metals, ashes, street leaves, and consumer goods.
2) *Commercial solid waste:* paper, plastics, wood, food waste, glass, metals.
3) *Institutional solid waste:* similar to commercial solid waste.
4) *Construction and demolition solid waste:* concrete, steel, bricks, wood plastics, glass, dirt, etc...
5) *Municipal service solid waste:* special wastes, rubbish, street waste, land scape and tree trimmings, catch basins debris etc.
6) *Treatment plants solid waste:* treatment plant waste residential sludges

The largest percentage of waste delivered to municipal waste disposal facilities consists of excavated material, and building and road construction debris.

The materials that comprise construction and demolition wastes are divided in to separate waste groups as: excavated material, road construction debris, construction debris and construction site debris. The characteristics analysis of these waste have also been incorporated for the selected sampling sites of the university.

There are considerable problems involved in obtaining a representative sample of MSW because of the heterogeneous and constantly variable nature of the material.

To produce a representative sample to the fine size required for laboratory analysis, it is necessary to separate physically the material in to individual components, and those materials to be crushed are mixed and analyzed in order to obtain the analysis of the overall sample.

2.2 Sampling

To obtain a good representative sample of a material of uniform composition is quite simple. However, Municipal refuse is of such variable, non-uniform and inconsistent nature that the method by which the sample is obtained is critical if the results are to be reliable.

There are no generally accepted or standardized methods for the sampling and analysis of municipal refuse. Previous workers in this field have used varying sampling techniques depending upon local conditions and type data required.

As far as can be ascertained, the first detailed refuse sampling accuracy, was initiated by Bell and Etzel in 1957 at Purdue University [5]. In the early states of this work, truckloads of refuse were sampled, and in addition refuse from individual households was examined to determine the number of households that will be required to provide a representative sample from a particular area. As a result of this study, a sampling technique based on stratified random sampling was developed.

Whenever a population is divided in to groups such that the elements within each group are more alike than are the elements in the population as a whole, and same kind of sample is taken in each group, the sample is called a stratified sample; the groups from which the sample is drawn are called strata. If a simple random sample is taken in each stratum, the whole procedure is described as stratified random sampling.

In this study by Bell in the U.S.A., the total quantity of refuse generated by the population of the sampling areas (usually several blocks selected at random, each consisting of about twenty-five households) was collected by a special crew either on a routine basis or throughout the year. The samples were manually sorted into three major components:

a) Paper, wood, leaves, etc;
b) Garbage;
c) Non-combustibles.

The first two components were analysed for moisture content, ash residues, etc.
Using this technique, Bell conducted surveys in four major U.S. cities of different size. In evaluating the results from these surveys, two sampling parameters were defined:

1) Sampling ratio, the population of all sampling areas divided by the total city population, and

2) Percent sampling error, which represents the discrepancy between the total weight of refuse generated by the city as extrapolated from the sample data compared with actual periodic weighing. Thus:

$$Sampling\ ratio = \frac{Population\ of\ all\ Sample\ areas}{Total\ City\ Population}$$

$$Percent\ Sampling\ Error = \frac{Total\ City\ refuse\ as\ weighted - Extrapolated\ Weight}{Total\ City\ refuse\ as\ weighted}$$

The results form a logarithmic relationship between the sampling ratio and average percent sampling error and the following linear regression equation was derived:

$$Y = 0.122e^{-0.781X}$$

Where Y = Sampling ratio, expressed as decimal

X = Percent sampling error

e = base of natural logarithms

This equation may be used to calculate a suitable sampling ratio for a city of known population if a given sampling error is not to be exceeded, or vice versa.

It must be emphasized that experience and trends in one country can be quite different from those of another. Failure to recognize this fact in further planning and design of efficient and economic disposal plants may have disastrous consequences.

In Ethiopia it is observed that the salvage of items like paper and glass commonly occurs at the collection point. Hence, it was felt necessary to collect samples both at the source and at the disposal site [5], [18].

2.3 Characteristics of MSW

While the problem of collection and disposal of refuse was for many years left to the ever changing whims of the individual, public recognition of the implications for health, together with a general desire for more sanitary surroundings, is forcing municipal authorities to accept responsibility for this vital phase of the community environmental sanitation program. Modern conceptions of municipal refuse sanitation have justly elevated the refuse removal and disposal service to a position similar to that accorded to other public utilities. A sound basis for this new respect for refuse sanitation is seen in the fact that the service in larger cities necessitates expenditure of about 5 per cent of the total city budget and approximately 25 percent of that portion of the entire budget which is allotted to all public works.

The primary consideration of the problem is sanitation, which must be adequate if the over all environmental sanitation program is to be efficient in the protection of public health. The secondary consideration is the procurement of satisfactory results with a minimum expenditure of funds. The attainment of both these objectives will require close study of local conditions, technical assistance with regard to the initiation and operation of the program, and the close cooperation of health authorities in the regulation of the program in its three phases: Storage, collection and disposal.

2.3.1 Waste Generation Rate

Estimating the quantity of waste and characterization of composition of waste generated is vital for the design of effective and sustainable waste management system. Solid waste generation rate vary greatly from country to country, city to city, and it largely depends on the socio-economic factors, and the level of development of the society. In general solid waste generation in low income countries are low compared with the rates in more prosperous country. However, the absence of the technology for recycling of some of the waste generated, minimization of waste, less public awareness and absence or less reinforcement of environmental policies /laws have resulted in poor solid waste management in most of the developing world.

According to the available study made in Addis Ababa, based on the income level, the unit of domestic waste generation per capital per day as well as density is as follows.

Table 2.1: Waste generation rate and Density according to income level in Addis Ababa [2, 3]

Income level	Generation rate (Kg/cap/day)	Density Kg/m^3
High income level	0.35	271
Medium income level	0.28	296
Low income level	0.17	258

The percentage composition for organic component of solid waste of A.A. city is about 64% by weight. The breakdown by weight shows:

- The combustible materials 21%
- Non-combustible materials.......................3%
- Organic fines...34%
- Fines less than 10mm size 29%
- Recyclable materials..................................13%

2.3.2 Physical Characteristics

The important properties of MSW include density, moisture content, particle size sand distribution, field capacity, and porosity.

Density

This is the weight per unit volume and is expressed as kg/m^3. Density varies because of the large variety of waste constituents, the degree of compaction, the state of decomposition, and in land fills because of the amount of daily cover and the total depth of waste. Inert wastes such as construction and demolition materials may have higher densities, and density can change as in land fills where the formation of land fill gas and decomposition may bring about significant mass loss. Density is important because it is needed to assess the total mass and volume of waste which must be managed.

The density of MSW is often referred to as loose, as found in containers, uncompacted, compacted etc. so it is important to specify what sort of waste is being referred to.
Density varies not only because of the type of treatment t gets (collection vs compaction etc) but also because of geographic location, season, and length of time in storage.

Moisture content

The most commonly used method of expressing moisture content is as a percentage of the wet weight of material. Moisture content is important in regards to density, compaction, the role moisture plays in decomposition processes, the flushing of inorganic components, and the use of MSW incinerators. Pre-treatment of waste to ensure uniform moisture content can be carried out prior to landfill disposal. The wet weight moisture content can be determined using the following equation:

$$M = \left(\frac{w-d}{w}\right)100$$

Where M = moisture content (%)

W= initial weight of sample (kg)

d= weight of sample after drying at 100- 105^{o}C (kg)

Particle Size and Distribution

The size and distribution of the components of waste are important for the recovery of materials, especially when mechanical means are used, such as trammel screens and magnetic separators. For example, ferrous items which are of a large size may be to heavy to be separated by a magnetic belt or drum system. The size of the waste component can be computed using length, height or width.

Field Capacity

The field capacity of MSW is the total amount of moisture which can be retained in a waste sample subject to gravitational pull. It is a critical measure because water in excess of field capacity will form leachate, and leachate can be a major problem in landfills.

Field capacity varies with the degree of applied pressure and the state of decomposition of the waste.

Permeability of compacted wastes

The hydraulic conductivity of compacted wastes is an important physical property because it governs the movement of liquids and gases in a landfill. Permeability depends on the other properties of the solid material include pore size distribution, surface area and porosity.

2.3.3 Chemical Characteristics

Information on the chemical composition of the components that constitute MSW is important in evaluating alternative processing and recovery options.

In the cities studied, in a large majority of the samples collected, the organic content was found to be between 10 and 30 percent. No specific trend could be observed in organic content values when grouped according to the population range.

If solid wastes are to be used as fuel, the four most important properties to be known are [10]:

1. Proximate analysis
2. Fusing point of ash
3. Ultimate analysis (major elements)
4. Energy content

Where the organic fraction of MSW is to be composted or is to be used as feedstock for the production of other biological conversion products, not only will information on the major elements (ultimate analysis) that compose the waste be important, but also information will be required on the trace elements in the waste materials.

2.3.3.1 Proximate Analysis

Proximate analysis for the combustible components of MSW includes the following tests [10]:

a) Moisture (loss of moisture when heated to $105^{o}C$ for 1 h)
b) Volatile combustible matter (additional loss of weight on ignition at $950^{o}C$ in a covered crucible)
c) Fixed carbon (combustible residue left after volatile matter is removed)
d) Ash (weight of residue after combustion in an open crucible)

2.3.3.2 Fusing Point of Ash

Ash is the weight of residue after combustion in an open crucible. By resource recovery facilities, several solid residuals are produced including bottom ash and fly ash. Bottom ash is the unburned and non burnable portion of MSW. In a mass-fired facility, bottom ash can contain considerable amounts of metals and glass as well as unburned organics. Fly ash is composed of the micron and submicron particulates that have been collected by the air pollution control system, it must be handled very carefully to avoid fugitive dust emissions, which may be harmful to workers and the surrounding environment.

The fusing point of ash is the temperature at which the ash resulting from the burning of waste will form a solid (clinker) by fusion and agglomeration.

Typical fusing temperatures for the formation of clinker from solid waste range from 1100 to 1200^{o}C [21].

2.3.3.3 Ultimate Analysis of Solid Waste Components

The ultimate analysis of waste component typically involves the determination of the percent C (carbon), H (hydrogen), O (oxygen), S (sulfur), and ash.

The results of the ultimate analysis are used to characterize the chemical composition of the organic matter in MSW. They are also used to define the proper mix of waste materials to achieve suitable C/N ratios for biological conversion processes.

2.3.3.4 Energy Content

Energy recovery from MSW is on the upswing, with a growing market share for the mass burning of fossil fuels [1]. To evaluate the resource-recovery and energy generating alternatives, the MSW energy content, if known, would be very helpful. The energy content of MSW can be, at present, calculated by using the Modified Dulong Equation (MDE). To use this equation, the percentage of waste components such as food and paper must be converted in to percentages of carbon(C), hydrogen (H), oxygen(O), sulfur (S), and nitrogen (N). The Modified Dulong Equation to approximate Btu values for the individual waste materials is expressed as [22]:

$$KJ/Kg = 337C + 1419(H_2 - 1/8O_2) + 93S + 23.3N \qquad (2.1)$$

Where

- C = Carbon, percent by weight
- H_2 = Hydrogen, percent by weight
- O_2 = Oxygen, percent by weight
- S = Sulfur, percent by weight
- N = Nitrogen, percent by weight

In the expression above, the oxygen content is divided by eight and subtracted from the hydrogen to account for the amount of hydrogen that reacts with the oxygen that is present and, thus, doesn't contribute to the energy content of the waste. Often the energy content of solid wastes is based on an analysis of the heating value of individual waste components. And from the coefficients in the equation it is seen that most of the energy source is obtained from the carbon content of the waste than its nitrogen and sulfur content.

To use the above equation, the conversion of the percentage of waste components into percentages of the required elements is a time consuming process. Another option is to determine the energy content of MSW by carrying out experimental work through the use of calorimeter, which is also quite time consuming.

In 1991 Ali Khan and Abu-Ghararah [1] presented an easier and simpler equation than the MDE for use in estimating the energy content of MSW, using the MSW components for 35 countries and 86 international cities.

The new equation was developed using the energy content (Btu/lb) and percentage by weight of each individual MSW component and then combining them in the form of a single equation. The new proposed equation, which uses the percentages by weight of MSW components directly in it, is as follows:

$$E = 53.5[F + 3.6(CP)] + 372(PLR) \qquad (2.2)$$

Where E = energy content of MSW in KJ/Kg; PLR = percentage of plastic and rubber by weight; F = percentage of food by weight; and CP = percentage of cardboard and paper by weight.

Equation (2.2) doesn't include any provision for garden trimmings (yard waste), a MSW component, which is predominantly present in the MSW generated in a majority of U.S. cities. Therefore, checking the validity of equation (2.2) including the yard waste factor for global application would not be possible.

Review of Table 2.2 indicates that the new equation values are about 1-10% higher than the MDE values. About 50-70%of the total energy of MSW is contributed by the paper and plastic. The MSW from the under developed and developing countries viz. Sudan, Taiwan, India, Pakistan and Bangladesh have the lowest energy content (2790-3720KJ/Kg), while the developed and highly industrial countries such as the United States, Finland, Denmark, Norway, Belgium, Austria, and Sweden have much higher energy content (6980-11630KJ/Kg) in their municipal solid wastes.

Table 2.2: Municipal Solid Waste Components and Computed Energy Content [1]

S. No.	Country	Municipal Solid Waste Components					Computed Energy Content	
		Paper	Metal	Glass	Food	Plastic	MDE (KJ/KG)	New equation (KJ/KG)
1	Australia	38	11	18	13	0.1	7583	8050
2	Austria	35	10	9	24	6	9190	10258
3	Bangladesh	2	1	9	40	1	2882	2898
4	Belgium	30	5.3	8	40	5	8534	9779
5	Bulgaria	10	1.7	1.6	54	1.7	5136	5447
6	Burma	1	3	6	80	4	6024	5962
7	Colombia	22	1	2	56	5	7773	9095
8	Czechoslovakia	13.4	6.2	6.6	41.8	4.2	6134	6380
9	Denmark	32.9	4.1	6.1	44	6.8	9506	11221
10	England	37	8	8	23	2	8406	9369
11	Finland	55	5	6	20	6	11269	13896
12	France	30	4	4	30	1	6776	7755
13	Gabon	6	5	9	77	3	6569	6392
14	Germany	20	5	10	21	2	5203	5720
15	Hong Kong	32	2	10	9	11	8364	10739
16	India	3	1	8	36	1	2835	2875
17	Indonesia	10	2	1	72	6	7294	8011
18	Iran	17.2	1.8	2.1	69.8	3.8	8625	8462
19	Italy	31	7	3	36	7	9176	10502
20	Japan	21	5.7	3.9	50	6.2	8141	9027
20	Kenya	12.2	2.7	1.3	42.6	1	4740	5001
22	Netherlands	22.2	3.2	11.9	50	6.2	8276	9702
23	New Zealand	28	6	7	48	0.1	7487	7999
24	Nigeria	15.5	4.5	2.5	51.5	2	6166	6485
25	Norway	38.2	2	7.5	30.4	6.5	9195	11402
26	Pakistan	2.2	2.2	1.75	52.5	1.2	3661	3680
27	Philippines	17	2	5	43	4	6162	7064
28	Saudi Arabia	24	9	8	53	2	8085	8201
29	Singapore	43	3	1	5	6	8467	10781
30	Spain	18	4	3	50	4	5943	6452
31	Sri Lanka	8	1	6	80	1	6036	6192
32	Sudan	4	3	-	30	2.6	3298	3342
33	Sweden	50	7	8	15	8	11146	13409
34	Taiwan	8	1	3	25	2	3205	3622
35	U.S.A.	28.9	9.3	10.4	17.8	3.4	7183	7783

2.3.3.5 Estimation of Percentage of Carbon

Laboratory analysis for nitrogen, phosphorus, and potash are more precise and require more elaborate equipment, but are relatively by simple chemical determination to make. The determination of the C/N ratio, which is so important in regard to nitrogen conservation and for estimating the quantity of the finished compost, is more of a problem, because the quantitative analysis of carbon is difficult, time consuming, and expensive [8]. It has been suggested in a New Zealand report that, for composting work, the percentage of carbon can be estimated satisfactorily from the percentage of ash- a much simpler test - by the equation $C = \frac{(100 - \%ash)}{(1.8)}$

. The University of California group on checking this simpler method, found the results to be within 2%-10%of the more accurate carbon determination.

The total amount of mineral matter, usually called ash, can be determined by igniting a known weight of dry sample to drive off all compostible organic matter and again weighing after cooling. The percentage of ash, on a dry basis, is:

$$\frac{100 \times (dry\ weight\ before\ ignition - weight\ after\ ignition)}{(dry\ weight\ before\ ignition)}$$

2.3.4 Biological Properties of MSW

Excluding plastic, rubber, and leather components, the organic fraction of most MSW can be classified as follows [13]:

1. Water soluble constituents, such as sugars, starches, amino acids, and various organic acids,
2. Hemicellulose, a condensation product of five- and six- carbon sugars,
3. Cellulose, a condensation product of the six-carbon sugar glucose,
4. Fats, oils, and waxes, which are esters of alcohols and long chain fatty acids,

5. Lignin, a polymeric material containing aromatic rings with methoxyl groups (OCH_3), the chemical nature of which is still not known (present in some paper products such as newsprint and fiberboard),
6. Lignocellulose, a combination of lignin and cellulose,
7. Proteins, which are composed of chains of amino acids

Perhaps the most important biological characteristic of the organic fraction of MSW is that almost all of the organic components can be converted biologically to gases and relatively inert organic and inorganic solids. These transformations may be accomplished either aerobically or anaerobically depending on the availability of oxygen. The principal differences between the aerobic and anaerobic conversion reactions are the nature of the end products and the fact oxygen must be provided to accomplish the aerobic conversion. The detail of these processes is given in later sections. The production of odors and the generation of flies are also related to the putrescible nature of the organic materials found in MSW.

2.4 Treatment and Disposal Options

The most common forms of treatment are:

2.4.1 Open Dumping

Some components of refuse are suitable for open dumping. These include street sweepings, ashes, and some rubbish. However, serious nuisances and hazards will result if garbage or mixed refuse is disposed of in this manner. Low areas which may be brought up to grade by filling are generally chosen for the dump. Ashes and street sweepings, though dusty, enable the construction of a fairly stable fill. Carefully selected rubbish may also be utilized, although fires often occur and some settling of the filled areas will result. Dump locations must be carefully chosen, so that there will be a minimum chance of complaint from near by residents.

While some municipal ordinances prohibit the placing of garbage and some rubbish, i.e. paper, food cartons, cans, etc, on open dumps, most dumps invariably receive some of these materials because the difficulties of inspection make rigid enforcement impossible. This, together with lack of adequate supervision of open dumps, has resulted in unsatisfactory conditions in many cities.

2.4.2 Integrated Sustainable Waste Management System (ISWM)

The concept of Integrated Sustainable Waste Management (ISWM), which is presented in Figure 2.1, recognizes three important dimensions in waste management [20]:

(1) The stakeholders involved in and affected by waste management,

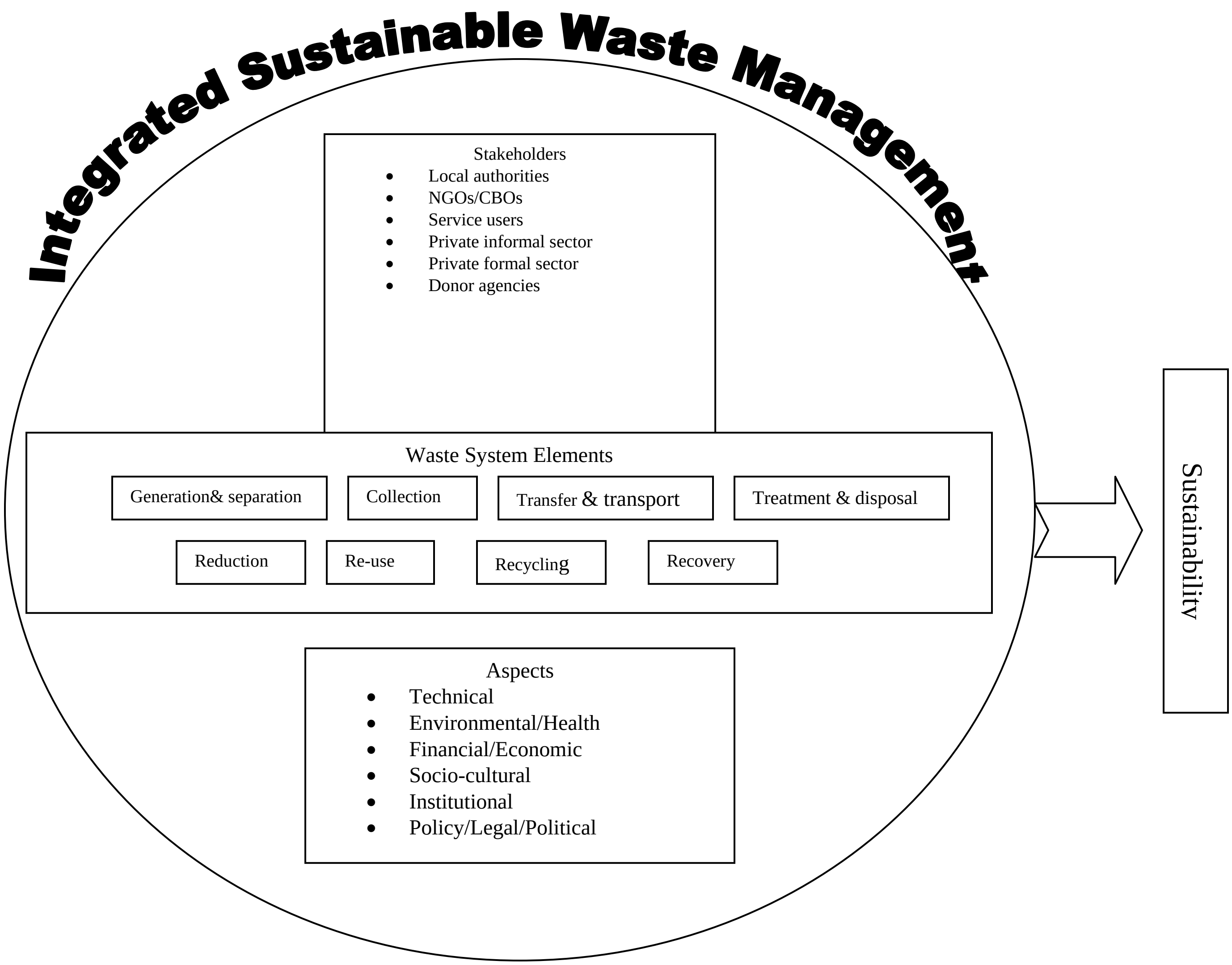


Figure 2.1: The integrated Sustainable Waste management Model

(2) The (practical and technical) elements of the waste system and

(3) The sustainability aspects of the local context that should be taken into account when assessing and planning a waste management system.

2.4.3 Landfilling:

There is no form of treatment that can entirely avoid the need for land for final deposit [8]. Treatment often enables a proportion of the wastes to be utilized in some way, but there are residues from all forms of treatment, thus sanitary landfilling is usually necessary, although on a reduced scale, whatever form of treatment may be needed. Hence the basis of a good solid waste management system is the municipal solid waste (MSW) landfill. MSW landfills provide for the environmentally sound disposal of waste that cannot be reduced, recycled, composted, combusted, or processed in some other manner. A landfill is needed for disposing of residues from recycling, composting, combustion, or other processing facilities and can be used if the alternative facilities break down. A properly designed MSW landfill includes provisions for leachate management and the possible collection of landfill gas and its potential use as an energy source.

Innovative planning may also facilitate productive use of the landfill property after the landfill is closed.

Sanitary landfill differs from ordinary dumping in that the materials are placed in a trench or other prepared areas and adequately compacted and covered with earth at the end of the working day. The procedure has been defined as a method of disposal wherein each day's accumulation of refuse is thoroughly compacted and covered. The term " modified Sanitary Landfill" has been applied to those operations where compaction and covering are accomplished once or twice each week.

As in other methods of disposal, satisfactory sanitary landfill operation demands careful preliminary evaluation of local conditions. As opposed to other methods, sanitary landfills are designed to care for the complete disposal of all refuse produced, with the possible exception of bulky building wastes and the like. For this reason, sanitary land fill capacities usually are designed for the total refuse produced. Where compacted refuse is placed in the fill to a depth of 2 meters, it is estimated that 1 ha of land per year will be required per 25,000 population.

Prospective landfill sites should be evaluated with respect to type of soil available, drainage, prevailing winds, availability of access roads, the underground water situation, and the haul distance involved. Sandy loam is considered the most ideally suited landfill soil, although other soils can be utilized. Poor surface drainage may hinder the operation and care should be exercised to prevent interpretation of an underground water stratum in constructing the fill.

A schematic of a typical MSW landfill is shown in Figure 2-2. Note that in the completed landfill, the waste is enclosed by cover material at the top and by a liner system at the bottom. Appropriate systems are in place to control contaminated water and gas emissions and reduce adverse impacts on the environment. Key terms used in MSW landfill design include the following [14]:

- **Waste management boundary:** The waste management unit boundary is the boundary around the area occupied by the waste in a landfill. It is measured in square meters or in acres.
- **Liner:** The liner is a system of clay layers and/or geosynthetic membranes used to collect leachate and reduce or prevent contaminant flow to groundwater.
- **Cover:** A typical MSW landfill has two forms of cover consisting of soil and geosynthetic materials: (1) a daily cover placed over the waste at the close of each day’s operations and (2) a final cover, or cap, which is the material placed over the completed landfill to control infiltration of water, gas emission to the atmosphere, and erosion. It also protects the waste from long-term contact with the environment.

- **Leachate:** Leachate is a liquid that has passed through or emerged from solid waste and contains soluble, suspended, or miscible materials removed from such waste. Leachate typically flows downward in the landfill but may also flow laterally and escape through the side of the landfill.
- **Leachate collection system:** Pipes are placed at the low areas of the liner to collect leachate for storage and eventual treatment and discharge. Leachate flow over the liner to the pipes is facilitated by placing a drainage blanket of soil or plastic netting over the liner. An alternative to collection pipes is a special configuration of geosynthetic materials that will hydraulically transmit leachate to collection points for removal.
- **Landfill gas:** Generated by the anaerobic decomposition of the organic wastes, landfill gas is a mixture of methane and carbon dioxide, plus trace gas constituents.
- **Gas control and recovery system:** A series of vertical wells or horizontal trenches containing permeable materials and perforated piping is placed in the landfill to collect gas for treatment or productive use as an energy source.
- **Gas monitoring probe system:** Probes placed in the soil surrounding the landfill above the groundwater table to detect any gas migrating from the landfill.
- **Groundwater monitoring well system:** Wells placed at an appropriate location and depth for taking water samples that are representative of groundwater quality.

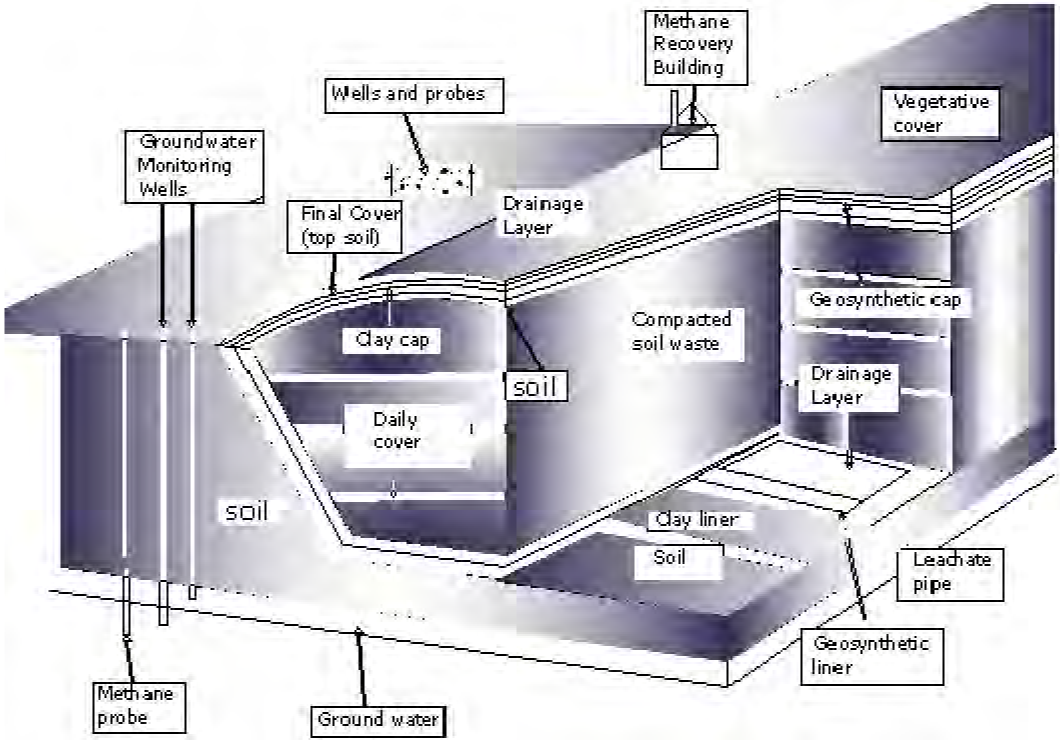


Figure 2.2: Schematic for a typical MSW landfill

The quantity of methane emission is influenced by the quantity and the composition of solid waste disposed to the disposal sites and the depth of waste in the site. The methane emissions have been found to increase or decrease with the increase or decrease of MSW disposed to the disposal sites. The variation of the amount of methane emitted in each year continues to vary with the variation of the amount of MSW land filled.

The net annual methane emitted from A.A. land fill has been estimated for period of 1994 - 2030 as shown below.

Table 2.3: Methane emitted from A.A landfill

Year	Total Annual MSW disposed to SWDS (Gg MSW)	Net annual Methane Emissions, Gg CH_4
1994	75.41	4.65
2000	158.14	9.74
2010	211.49	13.03
2020	269.92	16.63
2030	323.27	19.91

Source: Fikru Tesama [2]

Table 2.4: The net annual methane emitted from landfills of other urban centers in the country

Year	Total Annual MSW disposed to SWDS (Gg MSW)	Net annual Methane Emissions, Gg CH_4
1994	382.42	23.56
2000	760.29	46.83
2010	1478.31	91.06
2020	2734.76	168.46

Source: Fikru Tesama [2]

The goal of MSW landfilling is to place residuals in the land according to a coordinated plan designed to minimize environmental impacts, maximize benefits, and keep the resource and financial cost as low as possible. To achieve these ends, the solid waste manager and the landfill owner and operator must carefully plan the development of new facilities and optimize the performance of existing facilities.

2.4.4 Composting

It is a system for controlling the natural decomposition process to produce a humus. The wastes of most developing countries are often ideal for conversion in to organic fertilizer because of their high vegetable putrescible content and the compost should be used for fertilizer only when it is appropriate type of waste. Economic forces also favour composting in those countries where high food production is of great importance, and fertilizer imports are limited by foreign exchange constraints [8]. Composting involves the aerobic biological decomposition of organic materials to produce a stable humus-like product (Figure 2-3). Biodegradation is a natural, ongoing biological process that is a common occurrence in both human-made and natural environments. Grass clippings left on the lawn to decompose or food scraps rotting in a trash can are examples of uncontrolled decomposition. To derive the most benefit from this natural, but typically slow, decomposition process, it is necessary to control the environmental conditions during the composting process. Doing so plays a significant role in increasing and controlling the rate of decomposition and determining the quality of the resulting compost.

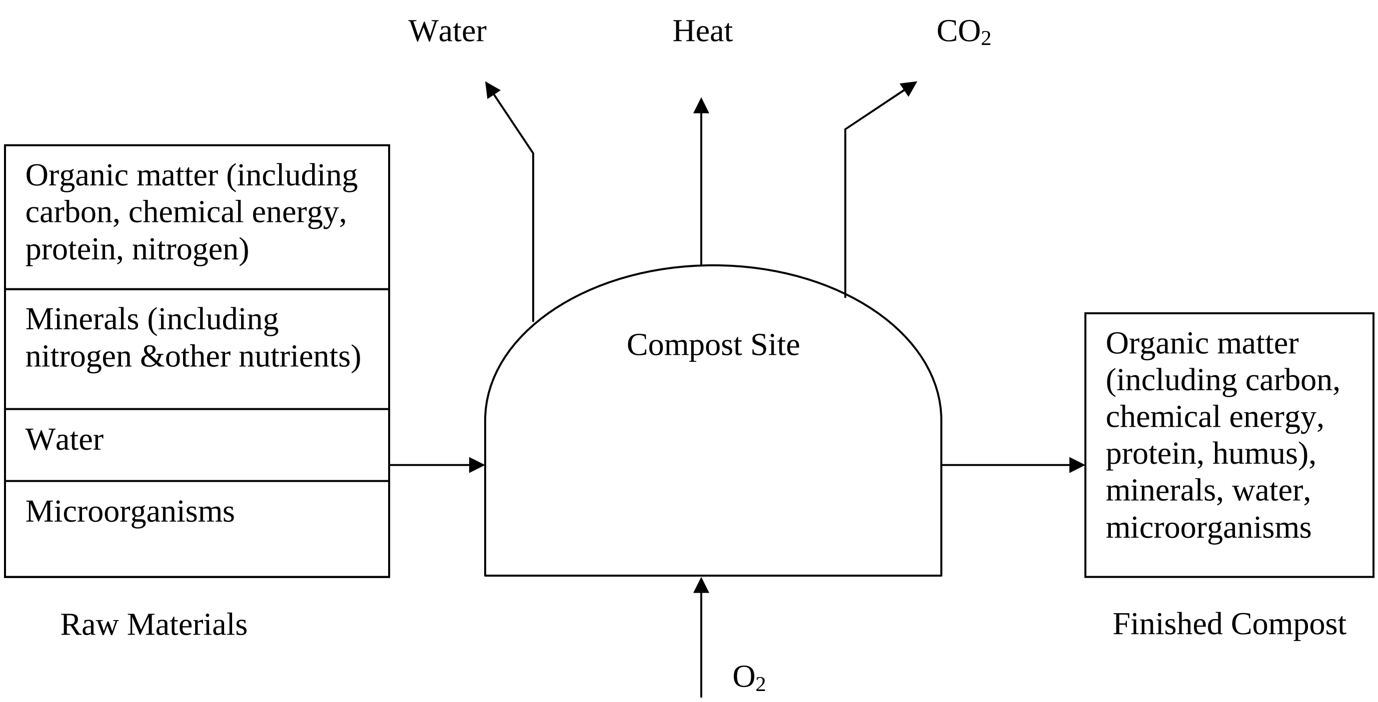


Figure 2.3: Aerobic composting process for organic wastes

The carbon, chemical energy, protein, and water in the finished compost is less than that in the row materials. The finished compost has more humus. The volume of the finished compost is 50% or less of the volume of row material.

Compost is the end product of the composting process, which also produces carbon dioxide and water as by-products. Composts are humus, which is dark in color, peat-like, has a crumbly texture and an earthy odor, and resembles rich topsoil. The final product has no resemblance in physical form to the original waste from which the compost was made. Good-quality compost is devoid of weed seeds and organisms that may be pathogenic to humans, animals, or plants. Cured compost is also relatively stable and resistant to further rapid decomposition by microorganisms.

Composting and co-composting are two commonly used terms. Composting is a broader term that includes co-composting. While composting refers to the decomposition of any organic materials (also referred to as "feedstocks"), co-composting is the composting of two or more feedstocks with different characteristics—for example, the co-composting of biosolids in liquid/ dewatered form with yard trimmings and leaves.

It is important to view compostable materials as usable, *not* as waste requiring disposal. When developing and promoting a composting program and when marketing the resulting compost, program planners and managers should stress that the composting process is an environmentally sound and beneficial means of recycling organic materials, *not* a means of waste disposal.

In the broadest sense, any organic material that can be biologically decomposed is "compostable." In fact, humans have used this naturally occurring process for centuries to stabilize and recycle agricultural and human wastes. Today, composting is a diverse practice that includes a variety of approaches, depending on the types of organic materials being composted and the desired properties of the final product.

2.4.4.1 The Benefits of Composting

Municipal solid wastes contain up to 70 percent by weight of organic materials. Yard trimmings, which constitute 20 percent of the MSW stream, may contain even larger proportions of organic materials. In addition, certain industrial by-products—those from the food processing, agricultural, and paper industries—are mostly composed of organic

materials. Composting organic materials, therefore, can significantly reduce waste stream volume. Diverting such materials from the waste stream frees up landfill space needed for materials that cannot be composted or otherwise diverted from the waste stream.
Composting owes its current popularity to several factors, including increased landfill tipping fees, shortage of landfill capacity, and increasingly restrictive measures imposed by regulatory agencies. In addition, composting is indirectly encouraged by states with recycling mandates that include composting as an acceptable strategy for achieving mandated goals, some of which reach 50-60 percent [21]. Consequently, the number of existing or planned composting programs and facilities has increased significantly in recent years.

Composting may also offer an attractive economic advantage for communities in which the costs of using other options are high. Composting is frequently considered a viable option only when the compost can be mar-keted—that is, either sold or given away. In some cases, however, the benefits of reducing disposal needs through composting may be adequate to justify choosing this option even if the compost is used for landfill cover.

Composts, because of their high organic matter content, make a valuable soil amendment and are used to provide nutrients for plants. When mixed into the soil, compost promotes proper balance between air and water in the resulting mixture, helps reduce soil erosion, and serves as a slow-release fertilizer.

Generally there are a number of preconditions for successful composting:

1) Suitability of the wastes;
2) A market for the product;
3) Price for the product which is acceptable to farmers;
4) A net disposal cost (plant costs minus income from sales which can be sustained by the local authority).

2.4.4.2 Composting Challenges

Despite the growing popularity of composting, communities face several significant challenges in developing and operating successful composting programs. These include the following:

- Developing markets and new end uses
- Inadequate or non-existing standards for finished composts
- Inadequate design data for composting facilities
- Lack of experienced designers, vendors, and technical staff available to many municipalities.
- Potential problems with odors
- Problems controlling contaminants
- Inadequate understanding of the biology and mathematics of composting
- Inadequate financial planning.

2.4.4.3 The Biological, Chemical, and Physical Composting Processes

Many factors contribute to the success of the composting process. Understanding these processes is necessary for making informed decisions when developing and operating a composting program.

2.4.4.3.1 Biological Processes

The treatment of organic wastes through the biological process is one of the commonest and relatively less expensive methods in practice. Here, unstable, decomposable organic wastes are converted into simpler compounds, and finally stabilized by the action of microorganisms.

In the biological process of organic wastes, this phenomenon is brought about under scientifically designed and controlled conditions. The essential part of the process centers on the activity of various forms of microorganisms, which are grouped in to three categories, according to their oxygen intake requirement:

Aerobic - those which grow and live in the presence of free oxygen:
Anaerobic - those which live and thrive only in the absence of free oxygen:
Facultative - those which live in the presence or absence of free oxygen

The following microbes are involved in the degradation process:

- Aerobic and facultative anaerobic bacteria (primarily rod-shaped and endos pore formers)
- Actinomycetes
- Mold fungi, and
- Algae and Protozoa

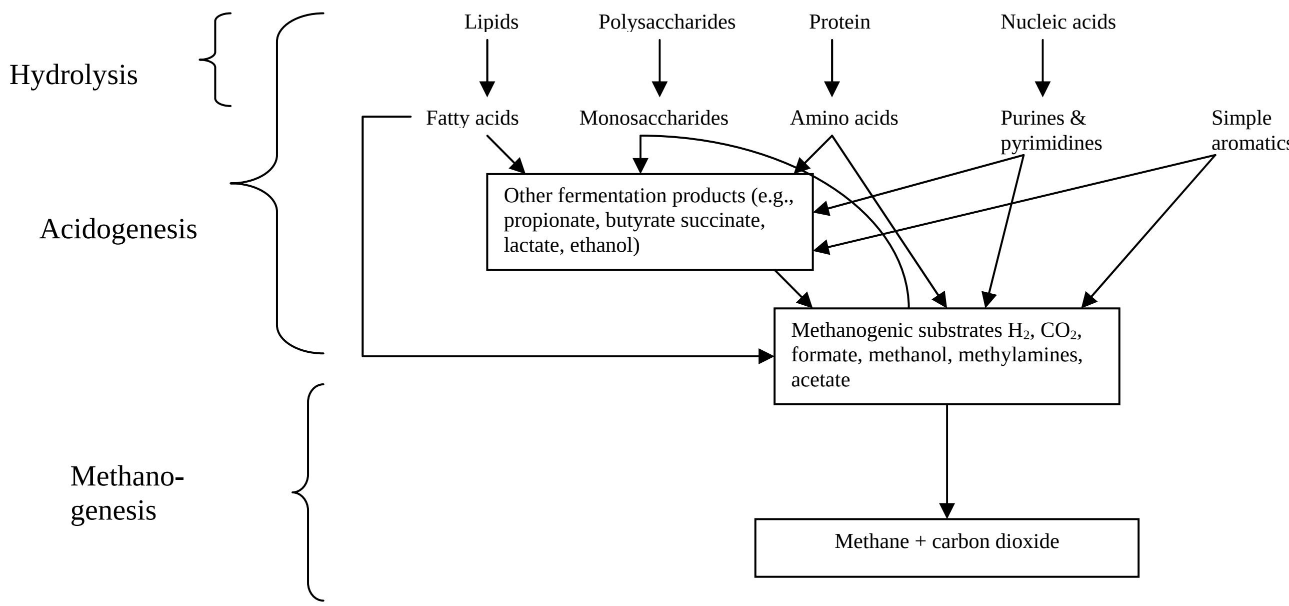
Aerobic and anaerobic processes both have a place in solid waste management. Each process offers different advantages. In general, the operation of anaerobic process is more complex than that of the aerobic processes. However, anaerobic processes offer the benefit of energy recovery in the form of methane gas and thus are net energy producers. Aerobic processes on the other hand are net energy users because oxygen must be supplied for waste conversion; but they offer the advantage of relatively simple operation and, if properly operated, can significantly reduce the volume of the organic portion of MSW.

Aerobic composting is the most commonly used biological process for the conversion of the organic portion of MSW to a stable humus like material known as compost.
Applications of aerobic composting include yard waste, separated MSW and co-composting with waste water sludge.

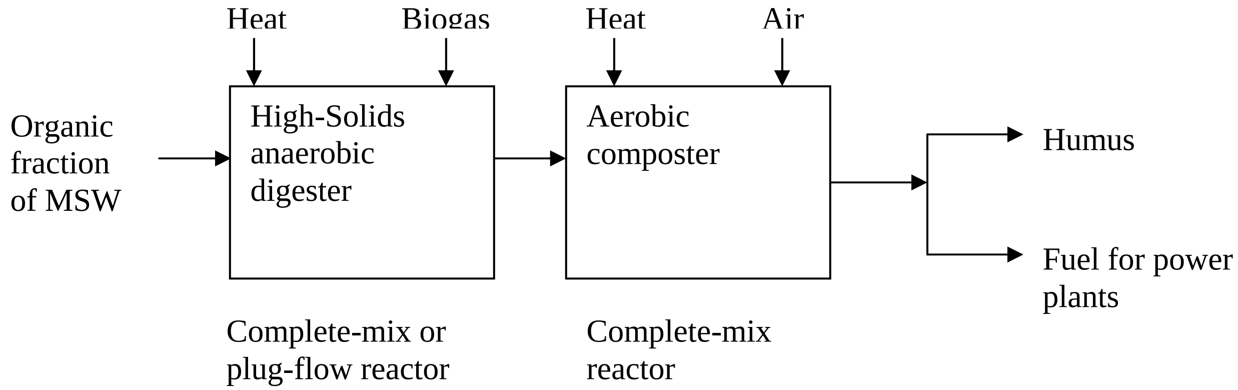
The general aerobic transformation of solid waste can be described by means of the following equation:

$$Organic matter + O_2 + nutrients \xrightarrow{Bacteria} newcells + resistant\ organic\ matter + CO_2 + H_2O + NH_3 + SO4^{2-} + ... + heat$$

The biological conversion of the organic fraction of municipal solid waste under anaerobic conditions is thought to occur in three steps as shown in figure below. The first step in the process involves the enzyme-mediated transformation (hydrolysis) of higher-molecular-mass compounds into compounds suitable for use as a source of energy and cell tissue. The second step involves the bacterial conversion of the compounds resulting from the first step into identifiable lower- molecular-mass- intermediate compounds. The third step involves the bacterial conversion of the intermediate compounds into simpler end products, principally methane and carbon dioxide [7].



The facultative process combines the high solids anaerobic digestion and aerobic composting processes. The major advantage of this process is the complete stabilization of the organic waste with a net energy recovery and with out the need for major dewatering equipment. Other advantages include pathogen control and volume reduction. The process is a two stage process as shown below:



Peak performance by microorganisms requires that their biological, chemical, and physical needs be maintained at ideal levels throughout all stages of composting. Microorganisms such as bacteria, fungi, and actinomycetes play an active role in decomposing the organic materials. Larger organisms such as insects and earthworms are also involved in the composting process, but they play a less significant role compared to the microorganisms.

As microorganisms begin to decompose the organic material, the carbon in it is converted to by-products like carbon dioxide and water, and a humic end product—compost. Some of the carbon is consumed by the microorganisms to form new microbial cells as they increase their population. Heat is released during the decomposition process.

Microorganisms have preferences for the type of organic material they consume. When the organic molecules they require are not available, they may become dormant or die. In this process, the humic end products resulting from the metabolic activity of one generation or type of microorganism may be used as a food or energy source by another generation or type of microorganism. This chain of succession of different types of microbes continues until there is little decomposable organic material remaining. At this point, the organic material remaining is termed compost. It is made up largely of microbial cells, microbial skeletons and by-products of microbial decomposition and undecomposed particles of organic and inorganic origin. Decomposition may proceed slowly at first because of smaller microbial populations, but as populations grow in the first few hours or days, they rapidly consume the organic materials present in the feedstock.

The number and kind of microorganisms are generally not a limiting environmental factor in composting nontoxic agricultural materials, yard trimmings, or municipal solid wastes, all of which usually contain an adequate diversity of microorganisms. However, a lack of microbial populations could be a limiting factor if the feedstock is generated in a sterile environment or is unique in chemical composition and lacks a diversity of microorganisms. In such situations it may be necessary to add an inoculums of specially selected microbes. While inocula speed the composting process by bringing in a large population of active microbes, adding inocula is generally not needed for composting yard trimmings or municipal solid wastes. Sometimes, partially or totally composted materials (composts) may be added as an inoculum to get the process off to a good start. It is not necessary to buy "inoculum" from outside sources. A more important consideration is the carbon: nitrogen ratio, which is described in a later section.

Microorganisms are the key in the composting process. If all conditions are ideal for a given microbial population to perform at its maximum potential, composting will occur rapidly. The composting process, therefore, should cater to the needs of the microorganisms and promote conditions that will lead to rapid stabilization of the organic materials.

While several of the microorganisms are beneficial to the composting process and may be present in the final product, there are some microbes that are potential pathogens to animals, plants, or humans. These pathogenic organisms must be destroyed in the composting process and before the compost is distributed in the market place. Most of this destruction takes place by controlling the composting operation's temperature, a physical process that is described below in section 2.4.4.3.3.

2.4.4.3.2 Chemical processes

Chemical transformation processes include a number of hydrolysis processes, which are used recover compounds such as glucose and furfural, and a variety of other chemical conversion processes used to recover compounds such as synthetic oil, gas, and cellulose acetate. Methanol, an alternative liquid fuel, can also be produced. These chemical processes are not used routinely for the transformation of the organic fraction of MSW, because these compounds can also be manufactured from other cellulose-containing wastes.

Acid hydrolysis, used to recover glucose from cellulose, involves treating a finely divided suspension of cellulose containing waste with a weak acid. The suspension is then heated to between 180 and 230 ^{o}C and slight pressure is applied [2]. Under these conditions, the cellulose in the waste is converted in to glucose and other sugars. The amount of glucose recovered depends on the characteristics of the waste. It is estimated that upwards of 80 percent of the weight of Kraft paper may be recovered as sugar [2].

$$(C_6H_{10}O_5)n + H_2O \xrightarrow{acid} nC_6H_{12}O_6$$

Cellulose glucose

Lignin is not affected by the process. The sugar and glucose extracted from the cellulose can be converted by other chemical and biological processes into alcohols and other industrial chemicals.

The chemical environment is largely determined by the composition of material to be composted. In addition, several modifications can be made during the composting process to create an ideal chemical environment for rapid decomposition of organic materials. Several factors determine the chemical environment for composting, especially:

a) The presence of an adequate carbon (food)/energy source,
b) A balanced amount of nutrients,

c) The correct amount of water/moisture,

d) Adequate oxygen,

e) Appropriate pH, and

f) The absence of toxic constituents that could inhibit microbial activity.

Carbon/Energy Source

Microorganisms in the compost process are like microscopic plants: they have more or less the same nutritional needs (nitrogen, phosphorus, potassium, and other trace elements) as the larger plants. There is one important exception, however: compost microorganisms rely on the carbon in organic material as their carbon/energy source instead of carbon dioxide and sunlight, which is used by higher plants.

The carbon contained in natural or human-made organic materials may or may not be biodegradable. The relative ease with which a material is biodegraded depends on the genetic makeup of the microorganism present and the makeup of the organic molecules that the organism decomposes. For example, many types of microorganisms can decompose the carbon in sugars, but far fewer types can decompose the carbon in lignins (present wood fibers), and the carbon in plastics may not be biodegradable by any microorganisms. Because most municipal and agricultural organics and yard trimmings contain adequate amounts of biodegradable forms of carbon, carbon is typically not a limiting factor in the composting process.

As the more easily degradable forms of carbon are decomposed, a small portion of the carbon is converted to microbial cells, and a significant portion of this carbon is converted to carbon dioxide and lost to the atmosphere. As the composting process progresses, the loss of carbon results in a decrease in weight and volume of the feedstock. The less-easily decomposed forms of carbon will form the matrix for the physical structure of the final product—compost.

Nutrients

Among the plant nutrients (nitrogen, phosphorus, and potassium), nitrogen is of greatest concern because it is lacking in some materials. The other nutrients are usually not a limiting factor in municipal solid waste or yard trimmings feedstocks. The ratio of carbon to nitrogen is considered critical in determining the rate of decomposition. Carbon to nitrogen ratios, however, can often be misleading. The ratio must be established on the basis of *available* carbon rather than *total* carbon. In general, an initial ratio of 30:1-50:1 carbon: nitrogen is considered ideal [10]. Higher ratios tend to retard the process of decomposition, while ratios below 20:1 may result in odor problems. Typically, carbon to nitrogen ratios for yard trimmings range from 20 to 80:1, wood chips 400 to 700:1, manure 15 to 20:1, and municipal solid wastes 15 to 50:1. As the composting process proceeds and carbon is lost to the atmosphere, this ratio narrows. Finished compost should have ratios of 15 to 20:1 [10].

To lower the carbon: nitrogen ratios, nitrogen-rich materials such as yard trimmings, animal manures, or biosolids are often added. Adding partially decomposed or composted materials (with a lower carbon: nitrogen ratio) as inoculum may also lower the ratio. Attempts to supplement the nitrogen by using commercial fertilizers often create additional problems by modifying salt concentrations in the compost pile, which in turn impedes microbial activity. As temperatures in the compost pile rise and the carbon: nitrogen ratio falls below 20:1, the nitrogen in the fertilizer is lost in a gas form (ammonia) to the atmosphere. This ammonia is also a source of odors.

Moisture

Water is an essential part of all forms of life and the microorganisms living in a compost pile are no exception. Because most compostable materials have a lower-than-ideal water content, the composting process may be slower than desired if water is not added. However, moisture-rich solids have also been used. A moisture content of 50 to 60 percent of total weight is considered ideal [12]. The moisture content should not be great enough, however, to create excessive free flow of water and movement caused by gravity. Excessive moisture and flowing water form leachate, which creates a potential liquid management problem and potential water pollution and odor problems. Excess moisture also impedes oxygen transfer to the microbial cells. Excessive moisture can increase the possibility of anaerobic conditions developing and may lead to rotting and obnoxious odors.

Microbial processes contribute moisture to the compost pile during decomposition. While moisture is being added, however, it is also being lost through evaporation. Since the amount of water evaporated usually exceeds the input of moisture from the decomposition processes, there is generally a net loss of moisture from the compost pile. In such cases, adding moisture may be necessary to keep the composting process performing at its peak. Evaporation from compost piles can be minimized by controlling the size of piles. Piles with larger volumes have less evaporating surface/unit volume than smaller piles. The water added must be thoroughly mixed so all portions of the organic fraction in the bulk of the material are uniformly wetted and composted under ideal conditions. Properly wetted compost has the consistency of a wet sponge. Systems that facilitate the uniform addition of water at any point in the composting process are preferable.

Oxygen

Composting is considered an *aerobic* process, that is, one requiring oxygen. *Anaerobic* conditions, those lacking oxygen, can produce offensive odors. While decomposition will occur under both aerobic and anaerobic conditions, aerobic decomposition occurs at a much faster rate. The compost pile should have enough void space to allow free air movement so that oxygen from the atmosphere can enter the pile and the carbon dioxide and other gases emitted can be exhausted to the atmosphere. In some composting operations, air may be mechanically forced into or pulled from the piles to maintain adequate oxygen levels. In other situations, the pile is turned frequently to expose the microbes to the atmosphere and also to create more air spaces by fluffing up the pile.

A 10 to 15 percent oxygen concentration is considered adequate, although a concentration as low as 5 percent may be sufficient for leaves [10]. While higher concentrations of oxygen will not negatively affect the composting process, they may indicate that an excessive amount of air is circulating, which can cause problems. For example, excess air removes heat, which cools the pile. Too much air can also promote excess evaporation, which slows the rate of composting. Excess aeration is also an added expense that increases production costs.

pH

A pH between 6 and 8 is considered optimum [9]. pH affects the amount of nutrients available to the microorganisms, the solubility of heavy metals, and the overall metabolic activity of the microorganisms. While the pH can be adjusted upward by addition of lime or downward with sulfur, such additions are normally not necessary. The composting process itself produces carbon dioxide, which, when combined with water, produces carbonic acid. The carbonic acid could lower the pH of the compost. As the composting process progresses, the final pH varies depending on the specific type of feedstocks used and operating conditions. Wide variations in pH are unusual. Because organic materials are naturally well-buffered with respect to pH changes, significant decrease in pH during composting usually do not occur.

2.4.4.3.3 Physical Processes

The physical environment in the compost process includes such factors as temperature, particle size, mixing, and pile size. Each of these is essential for the composting process to proceed in an efficient manner.

Particle Size

The particle size of the material being composted is critical. As composting progresses, there is a natural process of size reduction. Because smaller particles usually have more surface per unit of weight, they facilitate more microbial activity on their surfaces, which leads to rapid decomposition. However, if all of the particles are ground up, they pack closely together and allow few open spaces for air to circulate. This is especially important when the material being composted has high moisture content. The most desirable particle size for composting is less than 5 cm, but larger particles can be composted [20]. The particle size of the material being composted is governed to some extent by the finished-product requirements and by economic considerations. The optimum particle size has enough surface area for rapid microbial activity, but also enough void space to allow air to circulate for microbial respiration. The feedstock composition can be manipulated to create the desired mix of particle size and void space. For yard trimmings or municipal solid wastes, the desired combination of void space and surface area can be achieved by particle size reduction. Particle size reduction is sometimes done after the composting process is completed to improve the aesthetic appeal of finished composts destined for specific markets.

Temperature

All microorganisms have an optimum temperature range. For composting this range is between 32° and 60° C [7]. For each group of organisms, as the temperature increases above the ideal maximum, thermal destruction of cell proteins kills the organisms. Likewise, temperatures below the minimum required for a group of organisms affects the metabolic regulatory machinery of the cells. Although composting can occur at a range of temperatures, the optimum temperature range for thermophilic microorganisms is preferred, for two reasons: to promote rapid composting and to destroy pathogens and weed seeds. Larger piles build up and conserve heat better than smaller piles. Temperatures above 60° C are not ideal for composting. Temperatures can be lowered if needed by increasing the frequency of mechanical agitation, or using blowers controlled with timers, temperature feedback control, or air flow throttling. Mixing or mechanical aeration also provides air for the microbes.

Ambient air temperatures have little effect on the composting process, provided the mass of the material being composted can retain the heat generated by the microorganisms. Adding feedstock in cold weather can be a problem especially if the feedstock is allowed to freeze. If the feedstock is less than 5° C, and the temperature is below freezing, it may be very difficult to start a new pile. A better approach is to mix cold feedstock into warm piles. Once adequate heat has built up, which may be delayed until warmer weather, the processes should proceed at a normal rate.

Pathogen destruction is achieved when compost is at a temperature of greater than 55° C and PH of less than 5 for at least three days. It is important that all portions of the compost material be exposed to such temperatures and PH to ensure pathogen destruction throughout the compost. At these temperatures and PH, weed seeds are also destroyed. After the pathogen destruction is complete, temperatures may be lowered and maintained at slightly lower levels (51° to 55° C) [19].

Attaining and maintaining 55° C temperatures for three days is not difficult for in-vessel composting systems. However, to achieve pathogen destruction with windrow composting systems, the 55° C temperature must be maintained for a minimum of 15 days, during which time the windrows must be turned at least five times [7]. The longer duration and increased turning are necessary to achieve uniform pathogen destruction throughout the entire pile.

Mixing and agitation distribute moisture and air evenly.

Care should be taken to avoid contact between materials that have achieved these minimum temperatures and materials that have not. Such contact could recontaminate the compost.

Compost containing municipal wastewater treatment plant biosolids must meet United State Environmental Protection Authority (USEPA) standards applicable to biosolids pathogen destruction. This process of pathogen destruction is termed “process to further reduce pathogens” (PFRP). States may have their own minimum criteria regulated through permits issued to composting facilities. A state’s pathogen destruction requirement may be limited to compost containing biosolids or it may apply to all MSW compost.

Mixing

Mixing feedstocks, water, and inoculants (if used) is important. Piles can be turned or mixed after composting has begun. Mixing and agitation distribute moisture and air evenly and promote the breakdown of compost clumps. Excessive agitation of open vessels or piles, however, can cool the piles and retard microbial activity.

2.4.5 Incineration:

Well designed and properly operated incineration plants efficiently handle the disposal of combustible refuse. Bacteria and insects are destroyed in the process, and the non combustible ashes, metal, etc cause only minor sanitation problems if properly handled. On the credit side also is the fact that by proper design the incinerator may produce steam that can be sold to near by industries or utilized in some other municipal enterprise requiring steam

At the present time high construction and operating costs limit wide utilization of municipal incinerators, although a number of large cities, where landfill sites are not conveniently available, are formulating long-range plans for the construction of increased incinerator capacity.

The primary purpose of which is to render the waste inert, and may sometimes provide a source of energy. For most developing countries incineration can be dismissed firmly as a rational solution to the problems of wastes disposal on the following ground:

a) Wastes are too low in calorific value
b) They are probably too high in moisture content

2.4.6 Recycling

Recycling, the process by which materials otherwise destined for disposal are collected, processed, and remanufactured or reused, is increasingly being adopted by communities as a method of managing municipal waste. Whether publicly or privately operated, a well-run recycling program can divert a significant percentage of municipal, institutional, and business waste from disposal and can help to control waste management costs by generating revenue through the sale of recyclable materials. Public support for establishing recycling programs continues to grow and some states now require communities to recycle. Successful recycling is not guaranteed, however. Program managers must give special attention to making the program economically efficient and maximizing public participation.

Establishing an effective recycling program presents a major administrative and political challenge to a community. In successful programs, procedures are continually reviewed and adjusted according to changing conditions.

Program managers should continually strive to provide a consistent stream of high-quality (free of contaminants) recovered materials that meet the standards of the marketplace.

2.5 Environmental Aspects

The process of selection of the right solid waste management system is a complex one due the heterogeneity of the waste, but an appropriate method can save money and avoid future problems for the surrounding community.

The disposal methods should used in such away that the present requirements are fulfilled and future situations are anticipated. The method should also provide opportunities for recycling of materials, if possible, and should not pollute the air, the ground water, the surface water or the land.

An introduction to these environmental aspects for the main management systems is presented in this section.

Sanitary landfilling:

Correctly managed sanitary landfills remove or at least control the environment problems associated with crude dumping - vermin, flies, and ground water pollution. The use of solid wastes to reclaim landscape which has say resulted from mineral extraction is finding increasing interest in the waste and its deposit is in this instance seen to have social benefit.

Composting:

The possible economic importance of composting to most developing countries has already been stressed. There may also been significant advantages to public health because it is often the custom for farmers to collect crude wastes and to use them as fertilizers without any proper treatment or control, thus causing risks which would be avoided if the waste were processed into a hygienic product by the local authority.

Incineration:

Incineration has a few environmental advantages and invariably presents environmental problems. No doubt as a direct disposal system, incineration offers the highest efficiency with volumetric reductions exceeding 90% [16]. However, the financial costs, both capital and operational, are considerably higher than any other disposal methods. Furthermore social and environmental costs are high, the atmospheric pollution problems being typical.

CHAPTER THREE

3.0 EXISTING SOLID WASTE MANAGEMENT SYSTEM OF A.A.U.

Addis Ababa University has a better infrastructure than Addis Ababa city with an accommodation of few houses of domestic residences.

The University has about 38,000 undergraduate, 8,000 postgraduate and few PhD students.

Solid waste management (SWM) is one of the infrastructures of the University. The overall existing condition of the SWM in the university integrated with Addis Ababa city is presented below.

3.1 Organizational Set-Up

SWM is a part of sanitary works which is headed by executive construction division in each campuses.

Inspectors are assigned for each campus to control sweepers. Totally there are more than 50 sweepers in the university.

Generally, in order to have integrated solid waste management system, the university should have, sufficient number of SWM professionals, as represented by figure 3.1

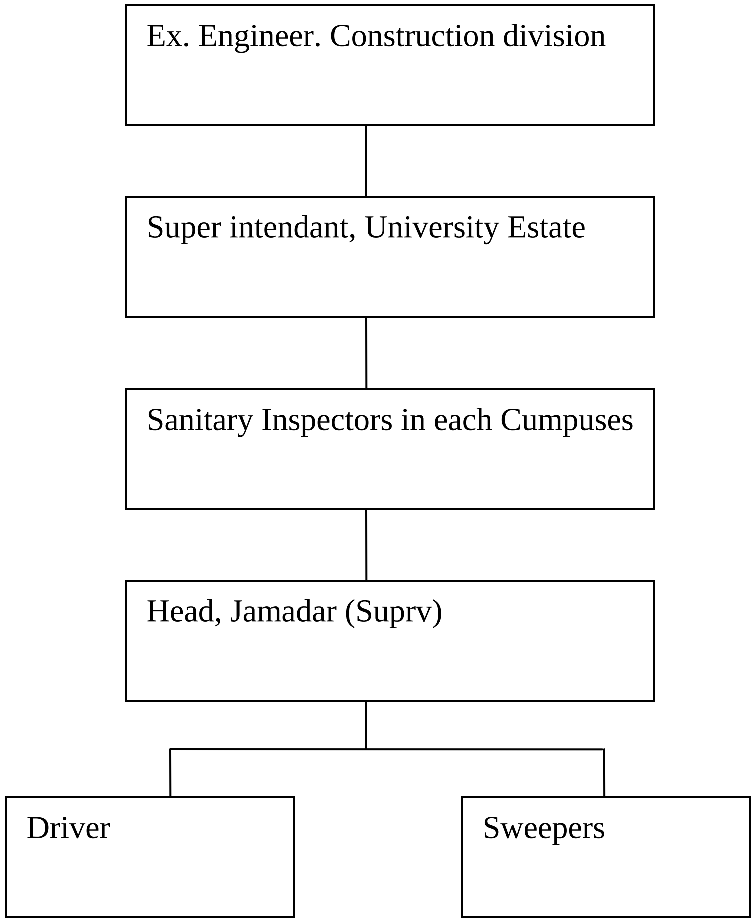


Figure 3.1: Typical recommended Organizational Set up of Solid Waste Management System in A.A.U

3.2 SWM System

Integrated with A.A City, the university SWM system comprises functional elements of waste generation, storage at the source, collection, hauling and disposal.

3.2.1 Generation of Refuse

Solid waste is generated from students' residential areas, students mess, and from offices.

There is no reliable data about the generation rate, as well as the nature of the waste. But from the total annual consumption of ingredients like 'karya', carrot, tomato, cabbage, meat, egg, red & white onion, potato, etc. for students mess in all the campuses of the university and from the estimation of the sanitary inspectors, a total of 10 ton/day during summer and 12 ton/day during winter would be collected.

It was observed that the food left from students meal in almost all of the campuses is taken by scavengers on a timely basis for their diet. And the other not used for this purpose is collected in a container.

3.2.2 Storage and Collection

Removable type community collection containers unevenly distributed in the city are used for storage at the source in the campuses of the university.

Wheel barrows for street sweepings and small baskets and plastic bags for the generated wastes in the campuses are used to store and discharge solid wastes to containers in the near-by area of each campuses from where it is taken to the respective Addis Ababa sub city containers

Currently, out of the total generated waste per day in the university, a large portion of the solid waste is left uncollected or disposed off in open spaces, in ditches and rivers or improperly burned. This waste pollutes water and soil, necessarily causing great sanitary and environmental impact.

3.2.3 Hauling and Disposal

Except the food wastes that are left from the scavengers and some unburned items all the other waste types from students hostels and offices are collected in each campuses and improperly burned.

The rest that is collected in the containers at different campuses of the university is directly hauled to the respective sub city nearby containers by small and micro enterprise groups. And from there it is transported and damped to the city disposal site by trucks.

Considering the cost of fuel, manpower and overhead costs for transportation per single trip, the system is inefficient and not economical.

Thus, it is necessary to thoroughly analyse the characteristics of the waste, in order to select a better disposal technique.

CHAPTER FOUR

4.0 METHODOLOGY OF THE STUDY

4.1 Introduction

Prior to sample collection for the analysis, preliminary site visits were made to observe the physical nature of the solid wastes in dust bins at different localities of the university, and sites were selected for sample collection.

Based on the above investigation, the university was categorized into three major groups.

Group I included students' mess. For the purpose of sampling 3 sites were selected for sample collection:

- Technology Faculty students mess;
- Science Faculty students' mess; and
- Main Campus students' mess

Group II Student hostels with three sites:

i. Technology students hostels;
ii. Science students' hostels; and
iii. Main campus students hostels

Group III categorized for offices, and this also sub-grouped into 2 sites.

i. Offices in the main campus; and
ii. Offices in technology campus

4.2 Sampling Procedure and Analysis

Following stratified random sampling technique [5] and using preliminary site investigation, a total number of 8 sites were selected to get representative sample for the whole university.

During sample collection, the solid waste inside the dust bin was completely mixed with shovel and roughly divided into four. One shovelful waste was taken from each division and brought to the laboratory for analyses.

4.2.1 Physical Composition

Based on literature review [4] and practical observations, the physical Compositions were determined by immediate sorting of the wet sample into various components.
The various components used for this purpose were;

1) Leaves, Food waste, Grass
2) Paper
3) Plastics, Rubber
4) Rags
5) Glass, Ceramics
6) Metals (all types)
7) Bricks, Stones, Dirt, Ashes
8) Wood

Each component was weighted individually and percentage was found out by the following equation.

$$\%\,Component = \frac{weight\ of\ components}{Total\ weight\ of\ components} \times 100 \tag{4.1}$$

In addition to the above parameters, the density of samples was determined by weighing the wet sample and measuring the volume occupied by the loose sample in a container of known dimensions. Therefore, density of each sample was found out by

$$Density, {kg}/{m^3} = \frac{Weight\ of\ wet\ sample, kg}{Volume\ of\ loose\ sample, m^3} \quad (4.2)$$

In this analysis, the volume was measured by pouring the sample into a container and jerking the container three times back and forth [7] from which the dimension occupied by the sample was measured.

Moisture Determination

Principle:

The amount of water present in a sample is considered to be equal to the loss of weight after drying the sample to constant weight at a temperature near the boiling of water. The method is applicable to all putricible products except those that may contain volatile compounds other compounds other than water or those reliable to decompose at 100 ^{o}C.

Apparatus:

- Oven, 100-102^{o}C
- Dishes, Nickel, stainless steel, aluminum, or porcelain.
- Desiccator. With phosphorus pentoxide, calcium chloride, granular silica gel.

Procedure:

1. Dry the empty dish and lid in the oven for 15 min & transfer to the dessicator to cool
2. Weigh the empty dishes and lid to the nearest mg.
3. Mix the prepared sample thoroughly and transfer about 5 g to the dish. Replace the lid and weigh the dish and the contents, as rapidly as possible, to the nearest mg.

4. Remove the lid and place the dish and lid in the oven, avoiding contact of the dish with thee walls. Dry for 6 hours. For products that do not decompose during the long periods of drying, it is permissible to dry overnight, i.e., about 16 hrs.
5. Remove the dish from the oven, replace the lid, cool in the dessicator, and reweigh when cooled.
6. Dry for further hour to ensure that the constant weight has been achieved.

Calculation:

$$\%moisture = \left(W_2 / W_1 \right) \times 100$$

$$\%Total \quad solids \quad \left(W_3 / W_1 \right) \times 100$$

Where: W1 = Weight of wet sample

W2 = Loss of Weight

W3 = Weight of dry sample

Organic/Volatile matter

Loss of weight on ignition at 600 to 650^{o}C for 2 hrs in muffle furnace

4.2.2 Chemical Analysis

Chemical analysis was done to determine selected parameters, which were considered relevant for selection of appropriate solid waste disposal method. The quantity of waste as shown in table below from each site were used for each parameters .

Sampling site	Quantity of waste taken to laboratory for chemical analysis (g)
Office	
Technology faculty	110
Main campus	100
Students Hostel	
Technology Faculty	120
Main Campus	130
Science Faculty	100
Students Mess	
Technology Faculty	100
Main Campus	100
Science Faculty	100

Parameters included in the analysis and methods employed are presented below in detail and in summarized form in Table 4.1

1. Nitrogen

Principle

All nitrogen is converted to ammonia by digestion with a mixture of conc. Sulfuric acid and conc. Orthophosphoric acid containining potassium sulfate at a boiling point as raising agent and selenium as a catalyst. The ammonia released after alkalization with sodium hydroxide is steam distilled into boric acid and titrated with sulfuric acid.

Reagents

1. Acid mixture. Mix 5 parts of conc. Orthophosphoric acid with 100 parts of conc. Sulfuric acid.
2. Selenium catalyst. Ground 0.5 g of selenium metal with 100 g of potassium sulfate.

3. Hydrogen peroxide, 30%
4. Sodium hydroxide 40% (W/V). Dissolve 400 g NaOH in water and make up to 1L.
5. Boric acid – indicator solution.

    A. Dissolve 75 mg bromocresol green and 50 mg methyl red in 100 mL of 99% ethanol.
    B. Dissolve 50 g boric acid (H_3BO_3) in liter of water (saturated solution).
    C. To 25 mL of B add 10 drops of A.

6. H_2SO_4 0.1 N or 1 N. prepare from Titrasol or an equal commercial reagent accumulation to the prescription. Check the normality once a week.
7. Standard ammonium chloride. Dissolve 4 g NH_4Cl in water and make up to 1L. Store in the refrigerator. Keep as stable for a month

Apparatus Used:

- Digestion apparatus (aluminum block, tubes, etc)
- Tecator distillation apparatus
- Radiometer pH Stat. apparatus

Procedure:

Digestion:

I. Weigh accurately 0.5-1.5 g dried sample, depending on expected nitrogen content, in a Tacator tube.
II. Add 6 mL of the acid mixture from a pipette and mix carefully.
III. Add step by step 3.5 mL of hydrogen peroxide. Watch out for violent reactions. As soon as the most violent reaction has cease shake the tube a few times and put it back into the rack.
IV. Add 3 g of the catalyst mixture. Let stand for 5 – 15 min before digestion.
V. With the temperature of the digester at 370 ^{o}C lower the tubes (in the rack) into the digester. Locate the exhaust Manifold the top of the tubes and continue the

digestion until a clear solution is obtained, about 1h. During this step excessive foaming may occur.

VI. Transfer the tubes in the rack into the fume hood for cooling

VII. Add 50 mL of water. Shake to avoid precipitation of sulfate in to the solution.

Distillation:

1. Place a 250 mL conical flask containing 25 mL of the boric acid-indicator solution under the condenser of the distiller with its tips immersed into the solution.
2. Transfer the digested and diluted solution into the sample compartment of the distiller. Rinse the tubes with two portions of about 5 mL water and add the rinses.
3. Add 25 mL of the 40% sodium hydroxide solution in to the compartement and rinse it down with a small amount of water. Stopper and switch on the steam.
4. Distill 100 mL, and then lower the receiver so that the tip of the condenser is above the surface of the distillate. Continue the distillation until a total volume of 150 mL is collected. Rinse the tip with a few mL of water before the receiver is removed.

Titration

Alternative 1. Titrate with 0.1*N sulfuric acid to a reddish color.

Alternative 2. Titrate with 1*N sulfuric acid using the Radio meter pH stat.

Settings: End point pH 5.2
Down scale, proportional band 1. pH
Delay shut off 15 Sec., Speed 1.25

Calculation:

$$Mg\ nitrogen\ in\ the\ sample = V \times N \times 14$$

$$\frac{G\ nitrogen}{100\,g\ sample} = \frac{mg\ of\ nitrogen \times 100}{mg\ sample}$$

$$Total\ nitrogen\,(\%) = \frac{(V \times N \times 1.4)}{W}$$

Where: V = volume of sulfuric acid consumed

W = weight of sample

N = normality of the acid

14 = Eq.wt of nitrogen

2. Ash

Principle

The ash content is determined from the loss in weight that occur during incineration of the sample at a temperature high enough to allow all organic matter to be burnt off without allowing appreciable decomposition of the ash constituents or loss by volatilization.

Procedure

1. Clean a porcelain crucible and dry it in an oven at 105 ^{o}C (30 min.)
2. Let the crucible cool in a desiccator for 30 min or more and weigh it (W_1).
3. Weigh at least 2.5 gm of sample to an accuracy of 4 decimal places and transfer it quantitatively to the crucible. (A sample with high moisture content i.e. greater than 20%, should be dried before ashing).
4. Char at low temperature in an open oven or over a Bunsen flame.
5. Ash the sample in the muffle furnance at 550 ^{o}C for 1 hour. Take out the crucible from the furnance, let it cool, and moisten the ash with a few drops of de-ionized water. Evaporate the water on a sandbath (app. 15 min).

6. Ash once more for 30 min at 550°C. Cool the crucible; add some drops of de-ionized water and 5 drops of conc. HNO_3. Evaporate on a sandbath for app. 15 min. as above.
7. Finally, ash the sample as above for 30 min. at the same temperature as previously. Let the crucible cool in a desiccator for app. 45-60 min. then weigh it. (W_2).

Calculation:

$$\% \, Ash = \frac{W_2 - W_1}{W_3} \times 100$$

Where W_3 = weight of fresh sample

3. Phosphorous

Principle:

The phosphorous is converted to phosphomolybdate, which is reduced to a blue molybdenum compound by aminonaphtolsulphonic acid to give a blue molybdenum compound.

Procedure:

1. Dissolve and digest the total ash of Wf gm of fresh sample with 20% iron – free Hcl and wash it quantitatively with de-ionized water into a 50 ml volumetric flask.
2. Take 1 ml of the clear extract and dilute it to 100ml with de-ionized water.
3. Add into a test tube ;

    - 5.0 ml (duplicates) of the sample(dilution)
    - 0.5 ml molybdate mix

- 0.2 ml aminonaphtholsulphonic acid mixture

4. Let stand for 10 min.
5. Read absorbance (A) in Beckman B at 660 nm against dist. Water.

With each daily set of analysis do simultaneously

- Standard: As above but 5.00 ml of working standard in place of the sample dilution (reading A_s).
- Blank: As above but 5 ml de-ionized water in place of the sample dilution (reading A_B).

Calculation:

First subtract A_B from all other readings

$$P \quad {}^{mg}\!/_{100\ g} = {}^{A}\!/_{A_S} \times {}^{1000}\!/_{W_F}$$

4. Potassium

Principle

After wet digestion, the potassium content is measured flame photometrically.

Reagents

- Nitric acid. Dilute nitric acid (sp.gr. 1.42) 1:1 with water
- Distilled water (or deionized).
- Acid washing liquid for glassware. Dilute nitric acid (sp.gr.1.42) to 100 mL with distilled water.

- Potassium stock standard, 100 mg of potassium with 1L water. Dry some potassium chloride at 105^0C for 2 hrs. weigh 190.7 mg of the dried product in water and make up to 1000 mL. Keep this solution in a polyethylene bottle.
- Potassium diluting solutions. Weigh 3.8 g of KCI, dissolve in water, and dilute to 1L.
- Filter paper. Diameter 9 and 12.5 cm, Schleicher and Schull No. 589-1.
- Working standard solutions. Pipette 0, 5, 10, 15, 20 mL of NaCl diluting solution to NaCl standards. Dilute to the marks. These solutions contain 0, 0.5, 1.0, 1.5 and 1.0 mg K/ 100 mL respectively.

Apparatus:

- Flame filter photometer of flame emission spectrophotometer.
- Glassware for metal analysis. All glasswares should be cleaned with dilute nitric acid and distilled water.

Procedure:

Preparation of the sample:

1. Weigh to the nearest mg, 2g of the sample on a filter paper (diameter 9 cm).
2. Fold up the filter paper and transfer into a 250 mL Kjeldahl flask.
3. Add 20 mL of 1:1 dilute nitric acid.
4. Boil gently for about 10 min and cool to room temperature.
5. Filter the digested solution through a filter paper (diameter 12.5 cm) in to 100 mL graduated flask. Wash the kjeldahl flask and the filter paper 3- times each with a 10 mL of water.
6. Make up to 100 mL and mix and take it as solution A.
7. Prepare a blank starting from instruction 1 to 6 above and take it as solution B.

Dilution of solutions:

Pipette 5 mL of solution A and B in to a 100 mL graduated flask, make up to the mark and mix (take them as solutions C and D respectively).

Calculation:

- Prepare a calibration graph for K
- Read the concentrations (mg/100 mL) of solutions C and D from the calibration graph.

Let: The concentrations (mg/100 mL) be c and d

Weight (g) of the sample = W

Then: K content (mg/100g product) = [(c-d) x 200]/W

Table 4.1: Summary of Analytical Methods

S.No.	Parameter	Principle/Methods	Instrument/Technique
1	Moisture content	Gravimetry	Evaporation at 75^{o}C for 48 hours in oven
2	Organic/volatile matter	Gravimetry	Evaporation at 600 to 650^{o}C for 2 hours in Muffle furnace
3	Nitrogen (Ammoniacal and organic)	Volumetric	Digestion, distillation then titration
4	Phosphorus as P_2O_5	Colorimetric	Spectrophotometer at 660 nm
5	Potassium as K_2O	Computerized flame photometry	Digestion followed by flame photometry
6	Calorific value (Gross)	Combustion	- Bomb- calorimeter
7	PH	Electro Metric	- Digital PH meter
8	Carbon: Because of the difficulty of quantitative analysis of carbon in the laboratory, the method discussed in item 2.3.3.5 of chapter Two is used to estimate this parameter. Therefore, $\% \, Carbon = \frac{(100 - \% \, Ash)}{(1.8)}$		

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

The waste characteristics for selected physical and chemical parameters and the composition of refuse was determined for various groups, and then by taking average of these values, characteristics for the entire university were calculated.

Tables and figures of the results are presented at the end of this chapter. (Table 5.9 to Table 5.12 and Fig. 5.1 to Fig 5.10 respectively.)

The characteristic of the refuse from the university, both physical and chemical, as determined for the various categories are presented below.

5.1 Composition of Refuse

The results of the composition of wastes were determined by a wet-weight method and are given in the following section as organic and inorganic wastes. These values are averaged values of two days samples for the various components as they existed in the sample. (Fig.5.10 a to h gives the pie-chart of the composition of the waste from different stations)

5.1.1 Organic Waste

The residential and commercial solid wastes, excluding special and hazardous wastes, consist of organic and inorganic solid wastes from residential areas and commercial establishments. Typically organic wastes include compostable materials, paper, plastics, textiles, wood, yard wastes etc…

5.1.1.1 Food waste, Leaves, Grass

This categories of waste components was made to represent compostable materials available in each sample, and the recorded values as averaged for each group are as follows:

Table 5.1: Category of combustible matter from AAU

Group	Minimum	Maximum	Average
I – Students Mess	32.7%	48%	40.3%
II – Students Hostels	14.7%	35.3%	25.6%
III - Offices	2.9%	12.2%	7.55%

Higher value for this category of waste component was recorded for students mess, and it is generally observed from literatures that, this category is higher in high income residential areas than low income residential areas. Therefore, when the values of this category in students mess were considered, lower value, i.e. 32.7% was recorded at technology faculty students mess and maximum percentage, i.e. 48% was recorded at Social Science Faculty students mess mainly due to the discharge of drain cleanings which comprises wet decomposable materials, such as leaves and grass.

It was obvious to obtain minimum percentage of this category at offices (Social science campus 2.9% and technology campus 12.2%)

5.1.1.2 Paper

The percentage of paper from group I (students mess) range from 7.8% to 11.8% (Table 5.1) with an average value of 9.5%.

The percentage of paper in group II (students hostels) are 14.4% for science students, 25.6% for technology and 12.8% for the main campus making an average of 17.6%, showing a higher value than the students mess.

The percentage of paper in social and technology faculty offices are 40.1% and 23.5%, respectively, giving an average of 31.8%, higher than other groups. This is mainly because, in offices, paper is one of the most constituent of solid waste. The higher value social science faculty can be attributed to the location of dumping site, which is unapproachable to the scavengers as compared to other offices.

The paper content in general, shows an increase in value for group II and Group III, since the groups include office and students residence.

The average value as calculated for the entire university was found to be 18.11% and this value is almost at higher range of most Ethiopian cities.

5.1.1.3 Plastics and Rubber

The values recorded for this category in each group are as follows:

Table 5.2: Category of Plastics & rubber from AAU

Group	Minimum	Maximum	Average
I – Students Mess	2.3%	7.6%	4.3%
II – Students Hostels	4.9%	11.3%	7.2%
III - Offices	1.3%	4.5%	2.9%

The plastic component has increased since last few years as an index of development. The plastic contents show a clear tendency of an increase in the standard of living of the university community, as the values recorded in most of the sites were comparable with that of western cities (Table 5.13), despite the informal scavenging activity.

In group II, higher values (Table 5.1) can be attributed to the use of sanitary pads thrown out and covered with plastics, apart from the use of plastic bags as containers for the purchases in higher income group. The lower values in offices are self- explanatory.

Generally, the values recorded in the university ranges between 1.3% to 11.3% (Fig.5.3), with an average value of 5.04%.

5.1.1.4 Rags

For this category, a value as low as 0.6% to a maximum of 14.7% was recorded (Fig.5.4). When values are put in various groups look like as follows:

Table 5.3: Category of rags from AAU

Group	Minimum	Maximum	Average
I – Students Mess	0.6%	14.7%	9.6%
II – Students Hostels	1.6%	3.2%	2.2%
III - Offices	4.3%	7.8%	6.1%

The average value for the whole university found to be 5.95%.

Generally, higher average values were recorded at students mess (group I), while lower values were recorded at students hostels (group II).

5.1.1.5 Wood

This category was not found in all dust bins except in main campus and Technology Faculty offices, during sampling. This is due to its high recycling rate for using as fuel. The only value recorded was 2.3% and 2.4 % respectively at the aforementioned sites and when distributed to the entire university the percentage reduced to 0.59%.

5.1.2 Inorganic Waste

The materials that are collected and dispose of under the term inorganic fraction includes glass & ceramics, metals, bricks, stones, dirt and ash.

5.1.2.1 Glass and Ceramics

Group wise analysis showed the following results,

Table 5.4: Category of Glass & ceramics from A.A.U

Group	Minimum	Maximum	Average
I – Students Mess	2.1%	5.5%	3.6%
II – Students Hostels	6.6%	7.8%	7.1%
III - Offices	2.7%	3.7%	3.2%

The values in this category were highly affected by scavenging activity in which the waste collectors of the university also observed participating in collecting recyclable bottles/glass. Due to this fact, no such component was observed significantly in most of the sites, a higher value was recorded at technology students hostel, may be not approachable to the scavengers.

The average value for the entire university found to be 4.83%, which approaches to the lower limit of those cities in developed countries (Table 2.3). However, it is a highest value as compared to the value of Ethiopian cities (Table 2.1).

5.1.2.2 Metals

In this case, as such no useful item was observed except a few rusted nails and wires, and almost all sites have values less than 0.5%. This is essentially due to the recycling and reuse of this material at the source of generation. The highest value recorded during sampling was 1.4 %(Fig.5.6) at technology faculty (Group III), and the calculated average for the campuses were 0.34%. As compared to most Ethiopian cities, the value in the university is towards the lower limit of the range.

5.1.2.3 Bricks, Stones, Dirt, Ashes

In this category, except items resulted from cooking and construction activities, street sweepings and on-site incineration, which are discharged in to the dust bins, it was not possible to quantify all the items essentially due to uncontrolled disposal of construction and demolishing wastes.

The values for this category as recorded for each group are as follows:

Table 5.5: Category of Bricks, stones, dirt & ashes from AAU

Group	Minimum	Maximum	Average
I – Students Mess	29.8%	34.8%	32.4%
II – Students Hostels	31%	45.2%	40.3%
III - Offices	38.7%	52.2%	45.5%

The values recorded showed an increasing order from students messes to offices, this is because of the fact that corridors of offices and students hostels are swept regularly on a daily basis.

The averaged value for the entire university was 38.6%, and this is within the range of the Ethiopian cities (Table 5.13) as the roads nature in the campuses is almost similar in both cases.

It was also obvious that dust bins nearer to roads are receiving higher percentage of this category, since street sweepings are directly discharged into them, compared to other bins away from street. Sometimes, on-site incineration is taking place inside the dust bins, which also increase the percentage of ash.

5.2 Physical characteristics

5.2.1 Density

The density of solid waste is mainly affected by its constituents.
The group wise values of these parameters are given below:

Table 5.6: Category of density of wastes from AAU

Group	Minimum (kg/m^3)	Maximum (kg/m^3)	Average (kg/m^3)
I – Students Mess	197	342	256.67
II – Students Hostels	271	456	339.67
III - Offices	159	316	237.5

5.2.2 Moisture Content

The moisture in the samples, which was measured in wet-weight method, was found to vary from 17 to 63 percent, depending on the composition of the waste and other factors.

The values recorded for this parameter for the various groups in the campuses are given below:

Table 5.7: Category of Moisture Content of wastes from AAU

Group	Minimum	Maximum	Average
I – Students Mess	54%	63%	59.3%
II – Students Hostels	38.5%	52%	46.2%
III - Offices	17.3%	22%	19.65%

Higher value was recorded at group I (Students Mess) due to the fact of higher percentage of food wastes in the sample of this group, while minimum value was recorded at Group III (offices) which may essentially be due to higher percentage of paper content in the sample.

Generally the values are in a decreasing order from group I to Group III, and an overall averaged value for the entire campus found to be 44.48%

5.3 Chemical characteristics

5.3.1 Carbon

The trend of this parameter, since it was determined from the organic content of the sample, was found to vary in direct proportion to the organic contents. Therefore as the organic matter content is higher in group II, higher value was recorded in this group, while lower value recorded in group III.

The calculated values of this component for the various groups are as follows:

Table 5.8: Category of carbon Content of wastes from A.A.U

Group	Minimum	Maximum	Average
I – Students Mess	33%	38%	35.3%
II – Students Hostels	26%	34%	28.67%
III - Offices	24%	32%	28%

The average value for the entire campus found to be 31%

5.3.2 Nitrogen, Phosphorus; and Potassium (NPK)

Since the decomposition of organic substances is performed by microorganisms, a balanced nutrient ratio is required.

Nutrient addition is necessary for the proper bacterial growth and for the subsequent degradation of the organic waste in composting process.

To continue to reproduce and function properly an organism must have a source of energy: carbon for the synthesis of new cell tissue, and inorganic nutrients such as nitrogen, phosphorus and potassium

The averaged values of these parameters as determined for the samples from the various groups in the university are as follows:

In Group I, NPK values found to be 0.6percent; 57.44mg/100g; and 1.13percent, respectively

In Group II, 0.56 percent; 60mg/100g; and 1.19percent, respectively.

In Group III, 0.445 percent; 50.84mg/100g; and 1.15percent respectively.

The over all averaged value for the entire campuses was found as 0.54 percent; 56.77mg/100g; and 1.16 percent, (N, P and K) respectively. No specific trend could be observed when the values put in the different groups.

5.3.3 Calorific Value

The calorific value, in general shows an increase in the value as the paper content increases. Due to this fact, maximum value of this parameter was recorded at social science campus office, as the paper content at this site was the maximum of all sites, and lesser calorific values recorded at sites where the paper content is relatively less.

Generally, the calorific values of the samples range from 6300KJ/Kg to 11,255KJ/Kg, and an averaged value of 7312 KJ/Kg was recorded.

When the averaged value is compared with the cases of different cities, the trend was found to be towards the cities in developed countries (Table 2.2)

5.3.4 Energy Content Estimation

Based on literature review [1] about estimation of energy content of MSW, as discussed in Chapter Two, it was tried to develop an equation based on the experimental values from the university and by modifying the Alikhan and Abu-Ghararah equation ($E = 53.5 [F + 3.6(CP)] + 372(PLR)$. However, the validity of the equation needs further study.

In the modification, the effect of rags on the energy content was considered along with the component of plastics, since this effect was not considered in the previous equation. For this purpose Least Square technique was used in order to obtain constants which give calculated values with minimum deviation from that of experimental ones. The modified equation is:

$$E = 75.13[F+3.1(P)] + 144.2(PRR)$$

Where E = Energy content of MSW in KJ/Kg

F = Percentage of food waste, leaves and grass

P = Percentage of paper; and

PRR = Percentage of plastic, rubber and rags.

Calculated and experimental values are given in table 5.4 for the purpose of comparison.

Using the data in Table 5.4, coefficient of correlation (r) was determined to observe how close the computed energy content values found by the proposed new equation and experimental values were. The coefficient of correlation (r) found to be 0.892, and as the number of data was so limited, this value is not far from good fitting.

5.3.5 C/N Ratio

The values of this parameter range from 33 at Technology Faculty Students Hostel to 61.9 at main campus offices. Depending on the particular waste material, the C/N ratio computed on the total weights of carbon and nitrogen could be quite misleading, especially in those cases where all of the available nitrogen is biodegradable, but only a portion of organic carbon is biodegradable.

In this case, the higher value recorded at main campus office essentially could be from the higher percentage of paper which contributed to get high carbon content with lesser percentage of nitrogen.

Generally the averaged value of C/N ratio for the entire campus found to be 45.74, which could be comparable value with that of the optimum values of ranging from 30 to 50 for composting [22]

5.2 Quantity of Refuse

It was rather difficult to obtain an exact idea of the amount of refuse produced in the university mainly due to salvage of reusable components at source and inefficient collection. All of the wastes produced does not reach the disposal site. Hence, it was possible to estimate the quantity only reaching the disposal site. This was obtained from the quantity collected on a daily basis as the information obtained from the concerned office.

As discussed in item 4.2.3 of chapter four, the total and per capital quantity was estimated as follows:

8 trolleys of 1.5 m^3 capacity working once a day
Total volume collected = 8 x 1.5 = 12 m^3
Density range of collected waste = 197 Kg/m^3 to 456 Kg/m^3
(The value from offices and most of the waste from students hostels are excluded because collection from these sites is not taking place rather the wastes are collected at a place in each campuses and improperly burned)

$$\begin{aligned}&\textit{Total weight of waste collected per day} = \textit{Density} \times \textit{Volume}\\&= 197 \times 12 \textit{ to } 456 \times 12\\&= 2364 \textit{ kg to } 5472 \textit{ kg}\end{aligned}$$

Contributing Population (students using Mess and leaving in dormitory) = 15,000
Hence per capital solid waste generation:

$$= \frac{2364}{15,000} kg \ \ to \ \ \frac{5472}{15,000} kg$$

$$= 0.16 \ kg / cap / day \ to \ 0.37 \ kg / cap / day$$

As per the sanitary division of the university campuses:

Daily collection = 16,000Kg to 20,000Kg (seasonal variation)

Contributing population = nearly 20,000

Per capital contribution = 0.8 Kg to 1 Kg

Generally the per capital generation from the university indicates a trend towards developed countries (Table 5.13)

Table 5.9: Composition of Municipal Solid Waste from AAU

	Group I Students Mess			Group II Students Hostels			Group III Offices		Average Value
Item	**Technology (North)**	**Social (Main campus)**	**Science**	**Technology (North)**	**Social (Main campus)**	**Science**	**Social (Main campus)**	**Technology (North)**	
Organic Waste									
Leaves, Food Waste, Grass	32.7	48	40.2	14.7	35.3	26.8	2.9	12.2	26.6
Paper	8.9	11.8	7.8	25.6	12.8	14.4	40.1	23.5	18.11
Plastics, Rubber	3	7.6	2.3	4.9	11.3	5.4	4.5	1.3	5.04
Rags	14.7	0.6	13.6	1.6	3.2	1.8	7.8	4.3	5.95
Wood	-	-	-	-	-	-	2.3	2.4	0.59
Inorganic Waste									
Glass, Ceramics	5.5	2.1	3.3	7.8	6.6	6.9	3.7	2.7	4.83
Metals	0.4	0.1	0.3	0.2	0.2	0.1	-	1.4	0.34
Bricks, Stones, Dirt, Ashes	34.8	29.8	32.5	45.2	31	44.6	38.7	52.2	38.6

(Note: All values are given in percentage of Wet-weight)

Table 5.10: Physical characteristics of Municipal Solid Waste from AAU

Item	Group I Students Mess			Group II Students Hostels			Group III Offices		Average Value
	Technology (North)	Social (Main campus)	Science	Technology (North)	Social (Main campus)	Science	Social (Main campus)	Technology (North)	
Density, Kg/m^3	231	197	342	271	456	292	159	316	283
Moisture, %	61	54	63	48	52	38.5	22	17.3	44.48
PH	6.72	6.7	6.68	6.6	6.65	6.55	7.63	7.77	6.92

Relative and absolute fluctuations in waste composition change the density and moisture content of waste.

Table 5.2 presents the measured fluctuations in density and moisture content of the waste in A.A.U

The main reason for the variation of moisture content and density in the above table is the local weather condition during sampling and the daily variation of the composition of the wastes.

Table 5.11: Chemical characteristics of Municipal Solid Waste from AAU

Item	Group I Students Mess			Group II Students Hostels			Group III Offices		Average Value
	Technology (North)	Social (Main campus)	Science	Technology (North)	Social (Main campus)	Science	Social (Main campus)	Technology (North)	
Organic Matter, %	59	68	64	47	63	48	58	44	56
Carbon, %	23	31	28	22	27	21	26	21	24.87
Nitrogen, %	0.58	0.59	0.62	0.66	0.45	0.56	0.42	0.47	0.54
Phosphorous mg/100g	64.75	63.74	43.85	55.25	62.38	62.53	41.43	60.25	56.77
Potassium as % K_2O	1.1	0.85	1.45	1.32	1.16	1.1	1.15	1.15	1.16
Calorific Value KJ/Kg	6300	6300	6300	7085	7085	7085	11255	7085	7312
C/N ratio	39.65	52.54	45.16	33.33	60	37.5	61.9	44.68	45.74

Table 5.12: Experimental and Calculated Energy Content Values of MSW from AAU

S.No	Name of Site	Experimental value KJ/Kg	Calculated value using previous new Eqn, KJ/Kg	Percent of Error/deviation	Calculated values using proposed New Eqn. KJ/Kg	Percent of Error/deviation
1	Technology Mess	6296	9665	55%	6617	6%
2	Main campus Mess	6296	7134	13%	5975	5%
3	Science campus mess	6296	9204	46%	7183	14%
4	Technology Hostel	7085	8136	15%	8004	13%
5	Main campus Hostel	7085	6729	5%	6941	2%
6	Science campus hostel	7085	9665	36%	6617	7%
7	Main campus office	11255	12456	11%	11330	0.7
8	Technology office	7085	5780	18%	5403	24%

Table 5.13: Patterns of municipal refuse quantities and characteristics for developed countries, Ethiopian cities, and A.A.U

	Developed Countries [21]	Ethiopian Cities [3]	A.A.U
Waste Generation (Kg/cap/day)	0.7-1.8	0.15-0.35	0.8-1
Waste Densities (Wet wt. basis-Kg/m^3)	100-170	330-560	197-456
Moisture Content (% wt weight)	20-30	20-40	17.3-63
Composition (% by wet weight)			
-Paper	15-40	3-7	7.8-40.1
-Glass, Ceramics	4-10	0.3-0.8	2.1-7.8
-Metals	3-13	1-5	0.1-1.4
-Plastics	2-10	1.6-2.2	1.3-11.3
-Textiles	2-10	-	0.6-17
-Vegetable/Putrescible	20-50	30-70	3-48
-`Miscellaneous inerts	1-20	2-32	30-53

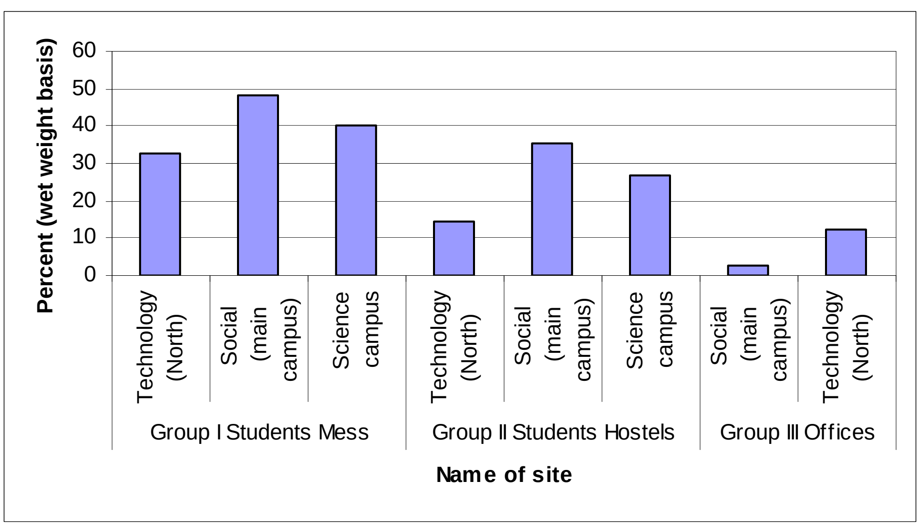


Figure 5.1: Percentage of Leaves, Grass and Food waste category

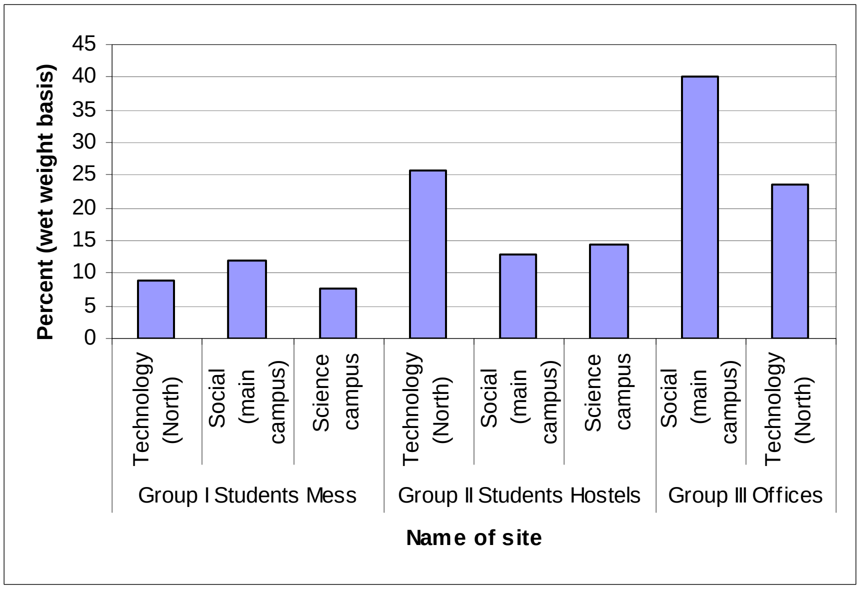


Figure 5.2: Percentage of Paper Category

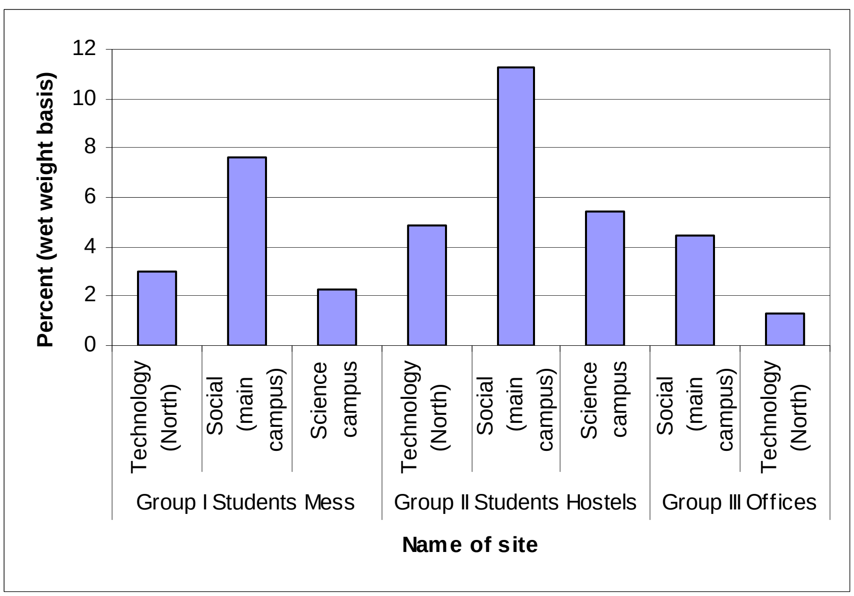


Figure 5.3: Percentage of plastic category

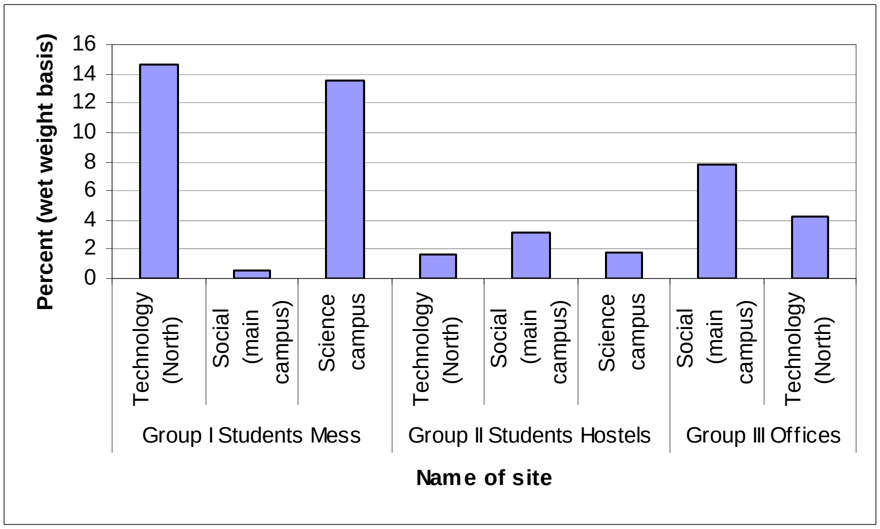


Figure 5.4: Percentage of Rags Category

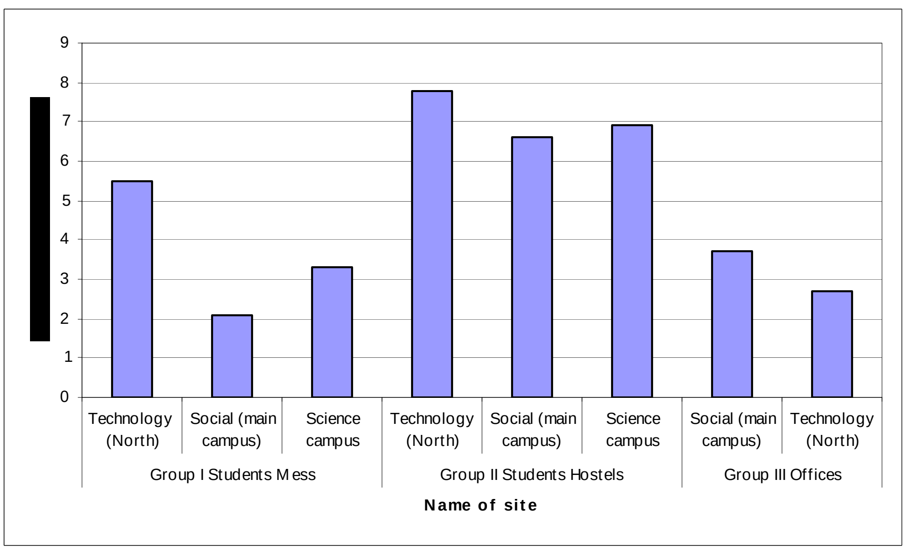


Figure 5.5: Percentage of Glass, Ceramics Category

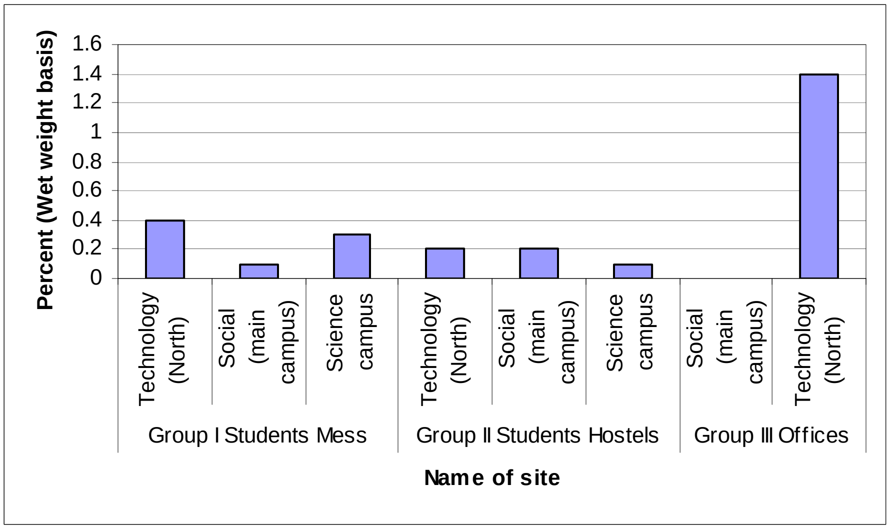


Figure 5.6: Percentage of Metals category

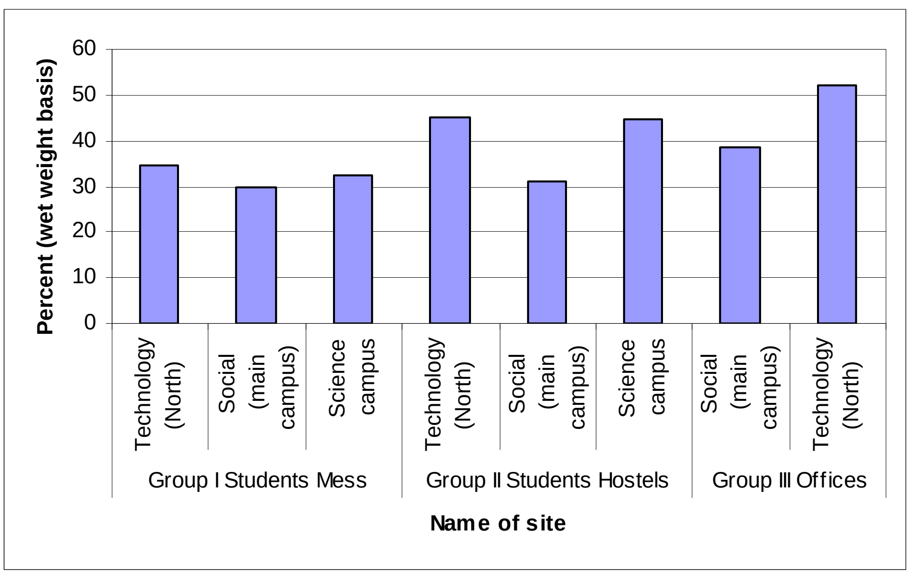


Figure 5.7: Percentage of Bricks, Stones, Dirt and Ashes

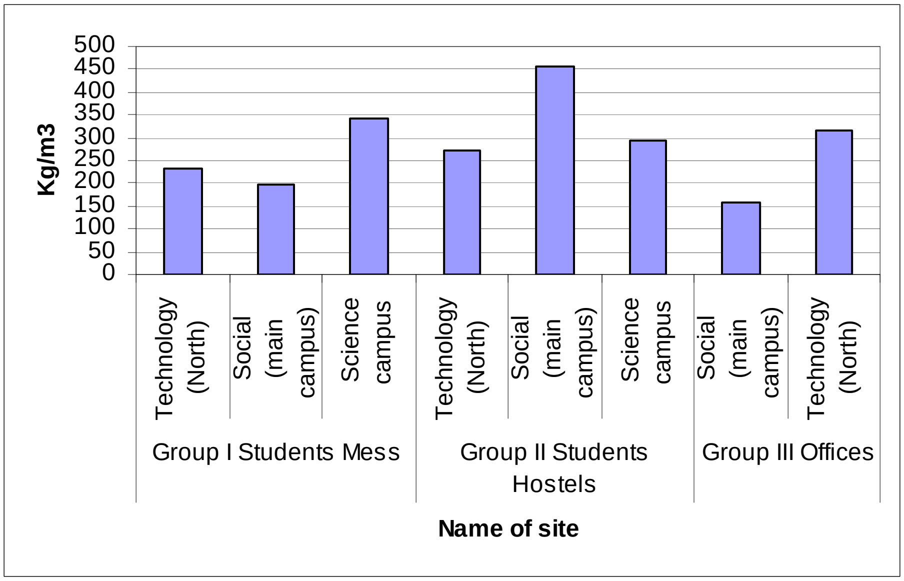


Figure 5.8: Wet Density

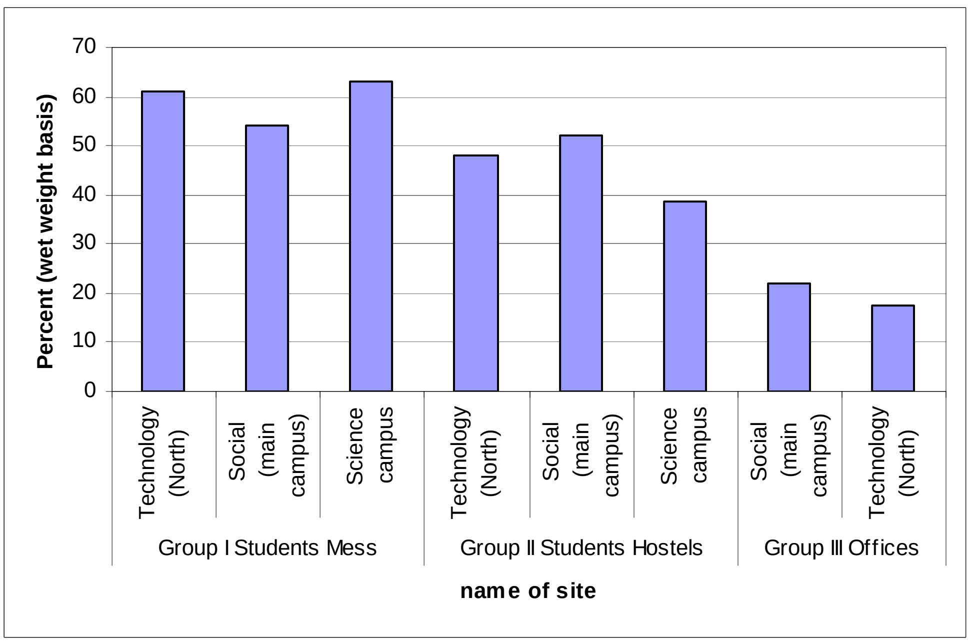


Figure 5.9: Percentage of Moisture content

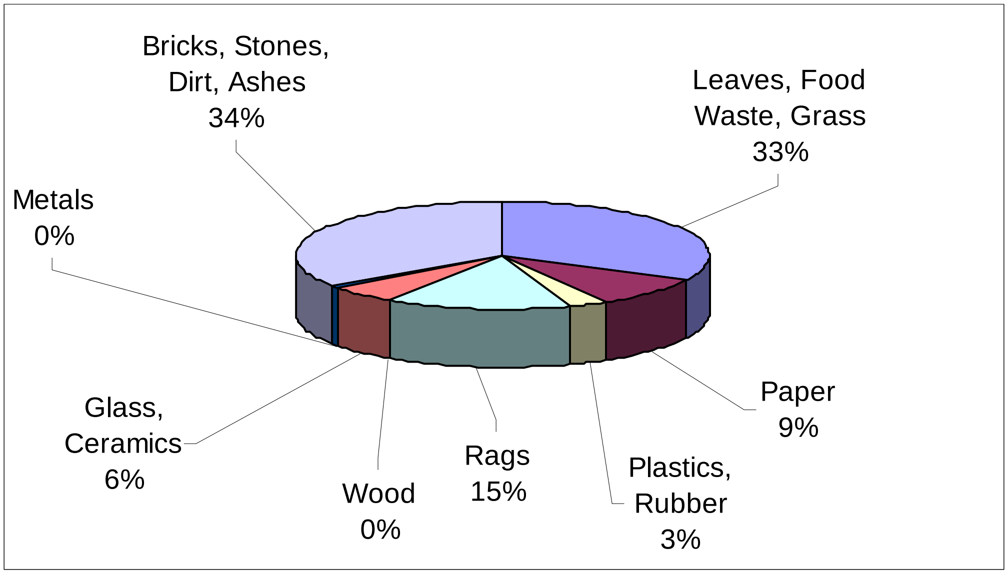


Figure 5.10a: Composition of MSW from Technology students Mess

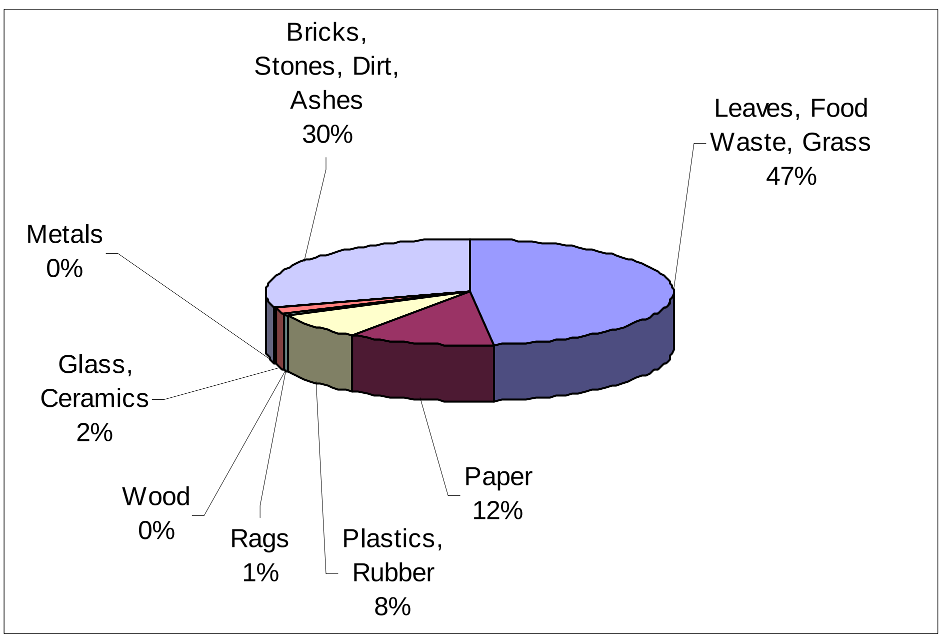


Figure 5.10b: Composition of MSW from main campus students Mess

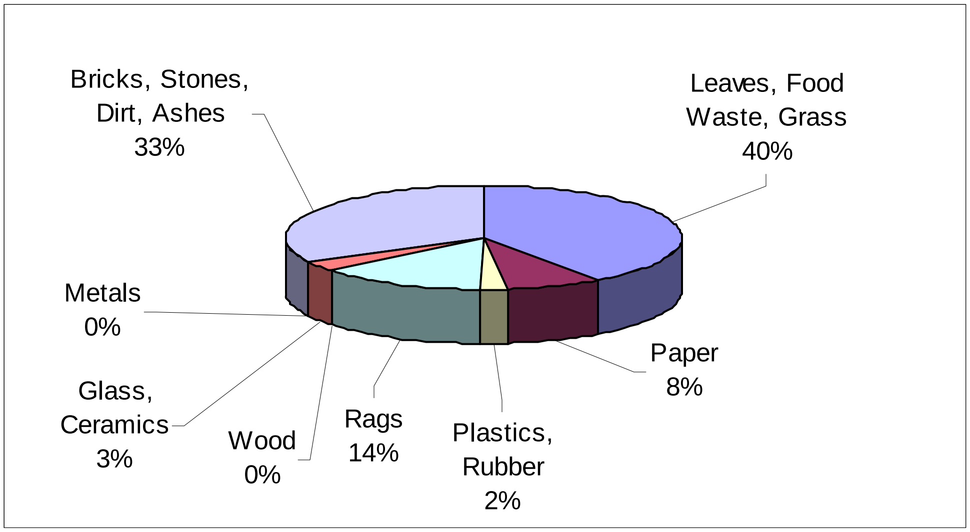


Figure 5.10c: Composition of MSW from Science faculty students Mess

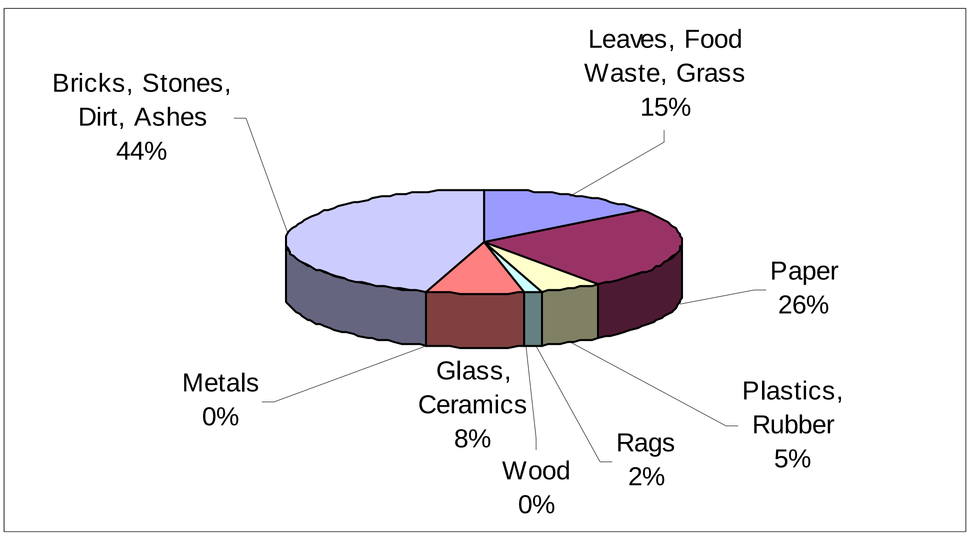


Figure 5.10d: Composition of MSW from technology faculty students Hostel

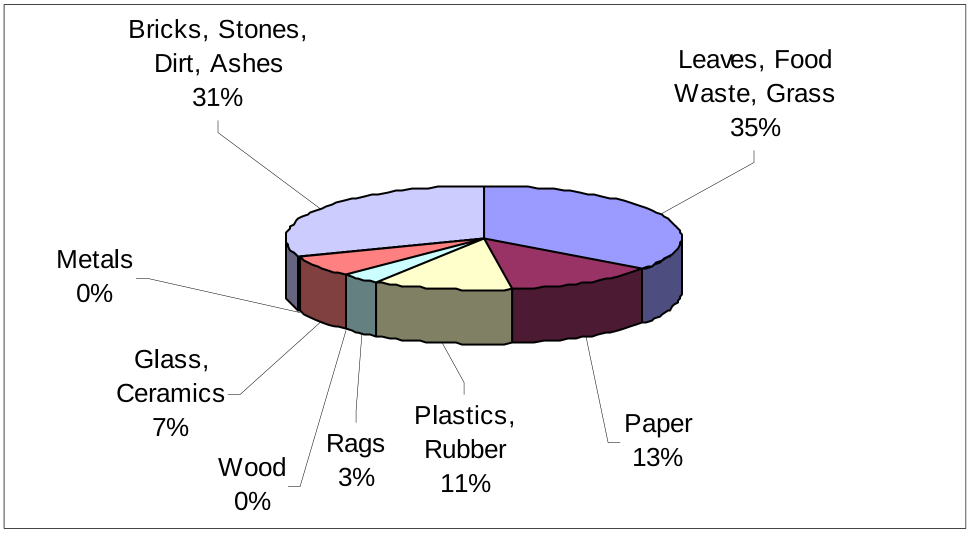


Figure 5.10e: Composition of MSW from main campus students Hostel

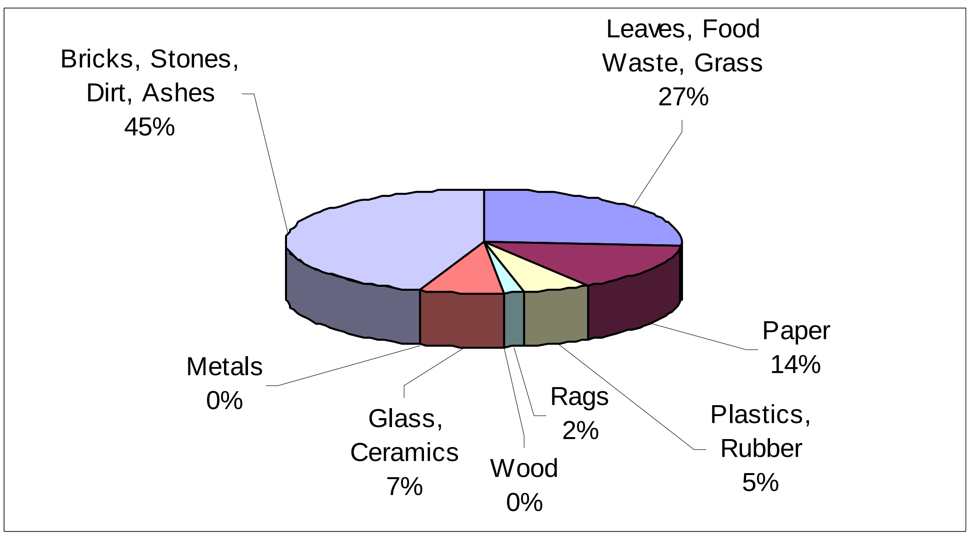


Figure 5.10f: Composition of MSW from Science faculty students Hostel

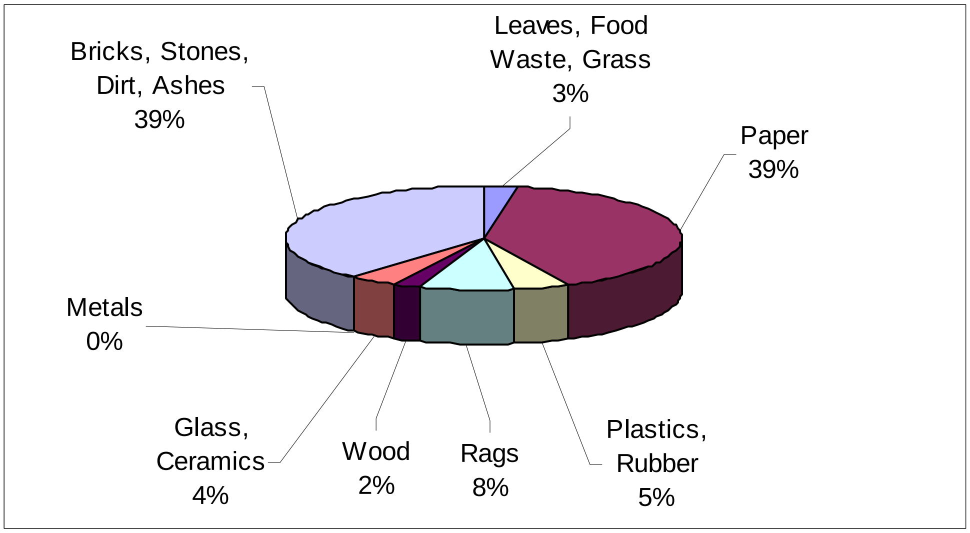


Figure 5.10g: Composition of MSW from main campus Office

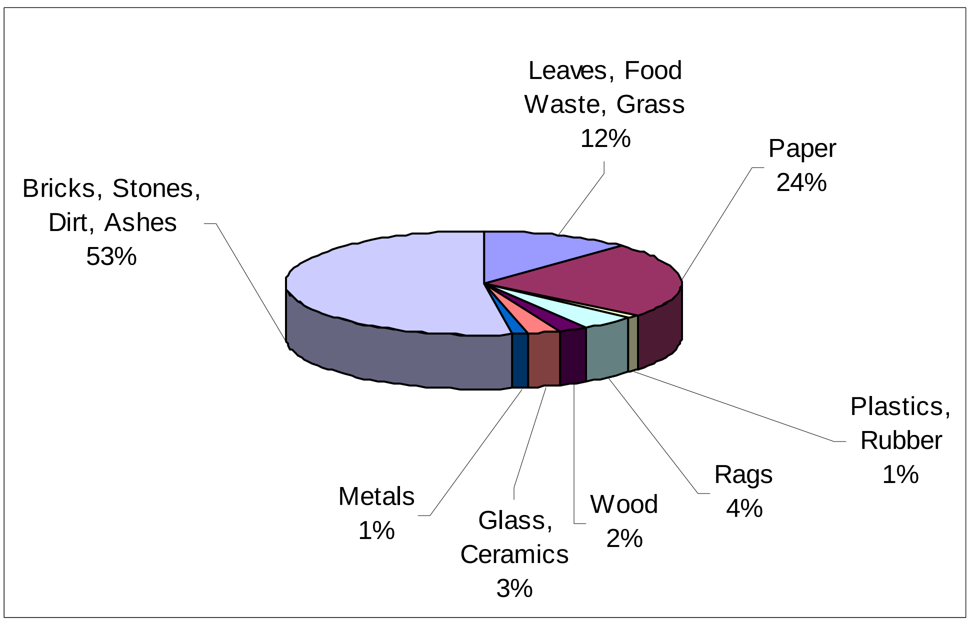


Figure 5.10h: Composition of MSW from Technology faculty Offices

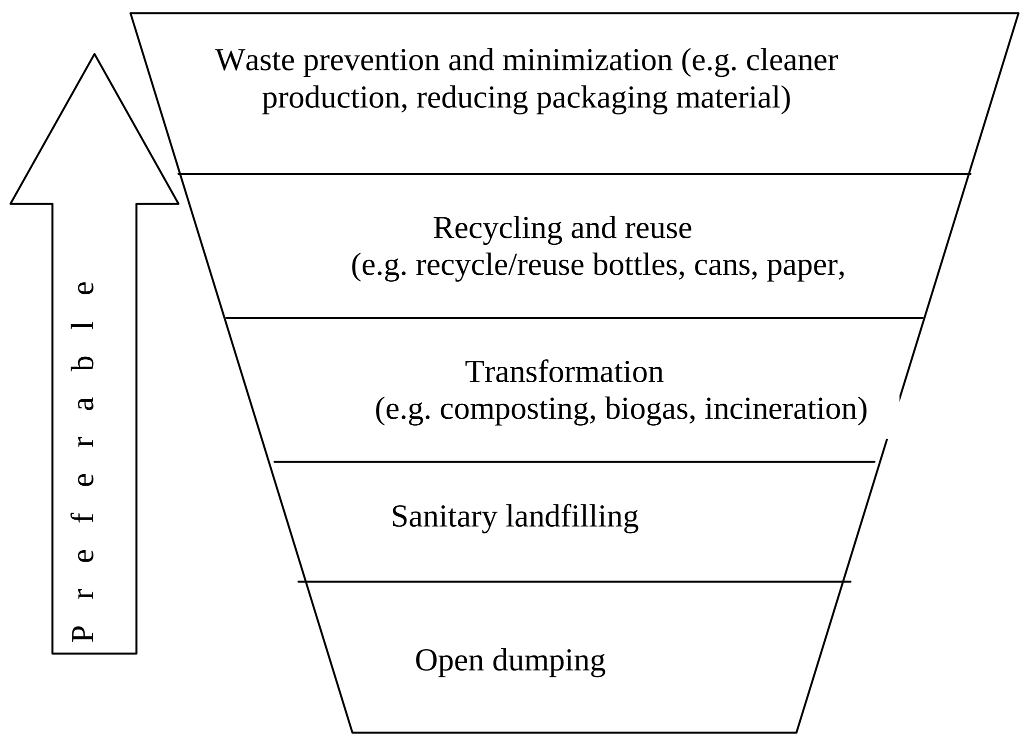
CHAPTER SIX

6.0 SOLID WASTE MANAGEMENT SYSTEM

6.1 Introduction

Environmentally sound waste management requires the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals.

The hierarchy of waste management policy options are shown in fig 6:1 [17]



Within any waste management system, the primary concern should be reduction of the quantities of waste material produced. Justifications in favor of waste reduction include:

- The generation of large volumes of waste correlates with the depletion of mostly non-renewable resources.
- The energy requirement for the transformation and upgrading of wastes is in proportion to the quantities treated and rises exponentially with increasing dilution of the waste.
- The increasing total costs for collection, segregation, intermediate storage, transport, treatment and final storage make waste minimization economically attractive.
- Increased public and legislative pressures seem likely to be mitigated only by waste reduction/minimization.
- Since waste equals inefficiency, reducing waste increases efficiency and hence profitability.

6.1.1 Waste segregation

The second most preferable waste management system is reuse/recycle and recovery.
Component segregation is a necessary operation in the recovery of resources from solid wastes and where energy and conversion products are to be recovered from processed wastes. The required segregation may be accomplished manually or mechanically.

To achieve a maximum recovery of all row materials from the university waste, the segregation process needs at least four streams

1. Compostable component of the waste (leaves, food waste & grass) which is about 27%
2. Combustible component (paper, plastics, and rags) 30%
3. Recyclable component (glass and metal) 6%
4. The rest inorganic waste 37 %

As can be seen from the composition of the waste from the university, it would be economical to separate manually.

In recycling/reuse process, resource recovery includes all activities of waste segregation, collection and processing which are carried out taking into consideration the economic viability of the material. Re-use and recycling provide an opportunity to capture some of the values from the waste. Of these two techniques, reuse is a simpler process involving reutilization of material in its end use form without the necessity of reprocessing. Recycling on the other hand, involves processing waste through remanufacture and conversion of parts in order to recover an original raw matter.

For recycling the paper produced in the university, in each cycle, the fibers will be shortened and the strength will be reduced .in addition ink and other materials (adhesives) may remain on the fiber resulting in worse quality and number of cycles is limited. Thus this component of waste should be mixed with the combustible matter for other type of treatment options.

The glass and metal component of the waste would be ideal for recycling.

Transformations of waste/treat and process, includes: incineration and composting and can occur through the intervention of people or by natural phenomena. Solid wastes can be transformed by physical, chemical and biological means [6].

Table 6.1: Transformation process in solid waste management [6]

Process	**Method**	**Principal conversion products**
Physical		
Separation	Manual and/or mechanical	Individual components found in commingled MSW
Volume reduction	Force or pressure	Original waste reduced in volume
Size reduction	Shredding, grinding, or milling	Altered in form and reduced in size
Chemical		
Combustion	Thermal oxidation	CO_2, SO_2, oxidation products, ash
Pyrolysis	Destructive distillation	A variety of gases, tar and/or oil
Gasification	Starved air combustion	Gases and inerts
Biological		
Aerobic compost	Aerobic biological conversion	Compost
Anaerobic digestion	Anaerobic biological conversion	Methane, CO_2, trace gases, humus

Anaerobic composting (in landfills)	Anaerobic biological conversion	Methane, CO_2, digested waste

Typically waste transformations are used to:

- improve the efficiency of solid waste management systems
- recover reusable and recyclable materials
- recover conversion products and energy

Once segregation activity is accomplished successfully;

6 % of the waste (glass and metal) can be recycled with technology which can be initiated in the university or sold to another firm involved in recycling business. And the 27 % compostable portion would go for composting. 30 % of the waste which is combustible can be incinerated.

The rest 37 % of the waste can be transported to the near by collection bins in the city.

Depending on the nature of solid waste, site for disposal, and economy, three main options for waste management would be considered

6.2 Incineration

Calorific value of the samples from different categories of the university campuses have shown value ranging from 6300 to 11250kJ/kg, in which the higher limit looks feasible to use incineration as a means of solid waste disposal. Since the combustible portion of the waste has got lower moisture content and higher calorific value especially the plastic it would be reasonable to take 11250kJ/kg.

Taking average total weight of waste collected per day = 3918 kg

The combustible portion = 0.3*3918 = 1175.4kg

Thus, total heat content per day = 1175.4*11250 = 13223250kJ = 13.22GJ

Since about 2560kJ/kg of heat is required to make the process self-sustaining [11], the remaining heat fraction become a valuable by product.

The daily heat consume for self-sustaining = 2560*1175.4 = 3009024kJ =3.01GJ

It can be seen from the above computation that the valuable heat is **10.21GJ/day**

An incinerator with a capacity of 1.2 ton/day should be designed for this category of waste.

One of the most common incinerator for this quantity of waste is an indirectly heated rotary kiln. The unit is cylindrical, slightly inclined, and rotates slowly which causes the refuse to move through the kiln to the discharge end. The retort is constructed of metal and the fire box is constructed of refractory material such as fire brick. (i.e. it can be designed as a pilot plant in the campus)

6.3 Composting

It must be known that the main objectives of solid waste treatment are

i. reduction of the volume and weight of material to be disposed of;
ii. reduction of emissions such as odours and leachates
iii. recovery of resources, with possible reduced disposal costs [14]

Composting is one system which may be used to achieve these objectives. The general objectives of composting are:

- To transform the biodegradable organic materials into a biologically stable material, and in the process reduce the organic volume of waste;
- To destroy pathogens, insect eggs, and other unwanted organisms and weed seeds that may be present in MSW;
- To retain the maximum nutrient (nitrogen, phosphorous, and potassium) content; and
- And to produce a product that can be used to support plant growth and as a soil amendment [15].

The solid waste from A.A.U have been found to contain 27% easily biodegradable matter. Apart from this, the C/N ratio of the waste (i.e. 45.74) on average is within the range required for composting i.e., 30 to 50 [15].

It was estimated that depending on locality and climate, some 350 to 500kg of compost can be produced from 1 tonne of waste [14]. Hence, the compostable portion, 1058 kg/day of the university's waste can produce equivalent amount. Approximately 150 to 250 kg are lost by evaporation and conversion to gas during the composting process.

Area required by a composting plant depends essentially on the process to be used. For simple plants, like the one required for the university, where fermentation takes place in heaps, area required ranges from 3 to 5 hectare for annual throughput of 50,000 tonne of waste [14], area required for the university, therefore, ranges from 0.2 to 0.3 ha which can be easily procured. Also, semi skilled personnel's can handle composting operations.
The final compost product can be sold to different organizations and institutes at birr 2.5-3.0 per kg. Hence daily sell of 875 to 1500 birr can be entertained.

6.4 Recycling

Recycling can be

- Direct recycling, the use of recovered material for the manufacture of identical or similar product
- Indirect recycling would imply the use of the recovered or salvage material for the manufacture or use of a product of less critical specification
- Thermal recycling implies the conversion of waste under conditions which generate either energy or chemical products or both.

Since the proportion of recyclable waste of the university is small, it won't be economical to construct a recycling pant it would rather be sold to processing mills like Addis Ababa Glass factory and Kotebe metal factory.

6.5 Sanitary Land Filling

Solid wastes may be used to improve natural features by raising the level of low-lying land to enable it to be used for cultivation or industrial development.

Described in this way, sanitary land filling has the virtue of being a method of solid waste disposal which confers environmental improvement by restoring dereliction or improving natural contours [7].

The percentage of inorganic and non-biodegradable organic matter present in the solid waste from A.A.U., give a value of 37%, and as far as this quantity is concerned, the use of sanitary land filling seems attractive to use as a means of disposal. This is 1450 kg/day of inorganic waste which should be transported to the city’s disposal facility. In addition to this slag and ash from the incinerator should also be disposed in the same way. It may incur 430-birr/ day for the university to transport such quantity of waste.

CHAPTER SEVEN

7.0 CONCLUSION AND RECOMMENDATIONS

Based on the studies conducted on characterization and management of Municipal Solid Waste generated in A.A.U. campuses from eight sites, the following conclusion & recommendations are drown.

1. Physical characterization of waste indicates that the decomposable matter (comprising of food waste, leaves, grass, etc.) range from 7.6% from offices to 40.3% from students mess, for obvious reasons.

2. The paper contents in the wastes are in the range of 12.8% to 25.6% for students' hostels, whereas the same is around 31.8% for offices. This can be attributed to the practice of reusing of paper and collection and sorting by scavengers in bins of students residential areas. A higher value from offices is self-explanatory.

3. Plastics and rubbers have percentage contents ranging from 2.9% to 7.2%. These are comparable with that of western cities, indicating a clear tendency of an increase in standard of living of university community vis-à-vis other towns in developing countries.

4. The recorded percentage contents of glass and ceramics as well as metal are lower (average 4.83% and 0.34% respectively). This can be attributed to the unorganized recycling operations, so common in Ethiopia.

5. Bricks, stones, dirt and ashes have higher contents (average around 39%) in MSW of the campuses mainly comprising of dirt and ash. This can be attributed to the practice of on-site incineration of MSW at most of the bins by waste collectors. A higher percentage of ash from office and hostel bins than that in student messes clearly indicate the regular street sweepings at the formers and random at the latter.

6. The wet density of MSW has been found to vary from 159 kg/m3 to 456 kg/m3 with an average value of 283 kg/m3, which is in the higher range of that of cities in developed countries. This can be attributed to the higher contents of inorganics i.e. dirt and ash.

7. The chemical analyses of waste indicate that the moisture contents as well as organic matter was recorded higher (max. 63 % and 60% respectively) at bins near residential areas compared to the offices (52 and 29%). This self explanatory, as the waste from residential areas have higher amount of food rejects.

8. Average C/N ratio of the waste from the campuses was found to be around 45.74%, showing it is amenable to composting process (range 30-50)

9. Energy contents of the waste range from around 6300 KJ/kg to 11,250 KJ/kg averaging to 7300 KJ/kg. An energy content equation based on the percentages of combustible material in the waste is proposed as

$$E = 75.13[F+3.1(P)] + 144.2(PRR)$$

Where E = Energy content of MSW in KJ/Kg

F = Percentage of food waste, leaves and grass

P = Percentage of paper; and

PRR = Percentage of plastic, rubber and rags.

10. Based on the characterization of MSW of A.A.U campuses, incineration can yield 118.1 KW of energy
11. The money which can be obtained from sell of compost can compensate transport cost of the inorganic waste.

Suggestions for Further Research

a. Characterization of MSW from A.A.U. campuses through different seasons.
b. Feasibility studies on composting of the waste
c. Studies related to design and implementation of incineration plant for A.A.U waste.
d. Studies on efficient management of off gasses from incinerator.
e. Cost analysis of the solid waste management of A.A.U.

References

1. Ali Khan. M.Z. and Ziad H. Abu – ghararah, *"New approach for estimating energy content of Municipal Solid Waste"*, Journal of Environmental Engineering. Vol. 117.No. 3, 1991.

2. Methane Emissions Estimation and Mitigation Assessment for solid waste sector, Ethiopia, by Fikru Tessema, A.A. Health Bureau, Oct.2001.

3. The strategic action plan within the Municipal waste management sector, the Five-year development plan (2000/01-2004/05), by Fikru Tessema, A.A. Health Bureau, Oct.2001.

4. Bond, Richard G. and Conrad P.Straub,eds. Handbook of Environmental Control, Vol. II: Solid Waste, U.S.A.: The Chemical Rubber Co.,1973.

5. Brock. E. and N.Y. Kirov, "The Planning of a Solid Waste Evaluation Survey", Solid Waste Treatment and Disposal, the int. ed. of the 1971 Australian waste disposal conference, held at University of New South Wales. Michgan;Ann arbor, 1972.

6. Brock. E. and N.Y. Kirov, "The Characterization of Municipal Solid Wastes", Solid Waste Treatment and Disposal, the int. ed. of the 1971 Australian waste disposal conference, held at University of New South Wales. Michgan;Ann arbor, 1972.

7. Cointreau. Sandra J., Environmental Management of Urban Solid Wastes in Developing Countries. A Project Guide. The World Bank, Urban Development Technical Paper No. 5, 1982.

8. Holmes. John R.,ed.,Practical Waste Management , John Wiley & Sons, 1983.

9. Holmes. John R.,ed., Managing Solid Waste in Developing Countries , John Wiley & Sons, 1984.

10. Roy. G.K., “Municipal Solid Waste Recycle – An Economic Proposition for a developing Nation”, Chemical Age of India (1987), Vol. 38, No.11.

11. Municipal and Rural Sanitation, 5th. Edition by Ehlers and Steel, 1958.

12. Sewerage Disposal and Air Pollution Engineering, 16th Revised Edition, by S.K Garg, 2004.

13. Environmental Pollution Control Engineering, 1st Edition, by C.S Rao, 1991.

14. Standard Methods for the examination of Water and Waste Water, 16th Edition. Washington, 1985.

15. Office for Revision of Addis Ababa Master Plan (ORAAMP). Project Proposal for Addis Ababa Municipal Solid Waste Management Programme, October, 2002.

16. Egyptian Environmental Affairs Agency. The National Strategy for Integrated Municipal Solid Waste Management, June 2002.

17. A Network for the Improvement of Addis Ababa City Solid Waste Management System. Dec. 2002.

18. Study Document on Existing Condition of Sanitation, Beautification and Parks Services, SBPDA, June 1995 E. C.

19. Markos Ezra and Dilnesaw Asrat. Population, Environment, Resources and Sustainable Development in Ethiopia. Addis Ababa University, Nov. 1997.

20. Ministry of Water Resources/National Meteorological Services Agency. The First National Communication of Ethiopia to the United Nations Framework Convention on Climate Change, October 2000.

21. Suess,Micheal J., ed. Solid Waste management : Selected topics. WHO Rigional Office for Europe. Copenhagen, 1985.

22. Tchobanoglous. George. et al. Integrated solid waste management: Engineering principles and Management Issues. McGraw-Hill. inc., 1993.

Signed Declaration

I declare that the thesis for the M.Sc. degree at the University of Addis Ababa, hereby submitted by me, is my original work and has not previously been submitted for a degree at this or any other university, and that all reference materials contained therein have been duly acknowledged.

Name: Kassahun Seyoum

Signature: --------------

Advisors:

Ato Teshome Worku

Signature: ----------------

Dr. Tassisa Kaba

Signature: ----------------