SECOND EDITION

MUNICIPAL SOLID WASTE

Engineering Principles and Management

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TO OUR STUDENTS

PREFACE TO THE FIRST EDITION

The subject of solid waste management is gaining importance with the rising environmental awareness of general public as well as the government. This book is a humble effort to take a brief view of this vast subject. This is the first local book on solid waste management in Pakistan.

Book is divided into eleven chapters. Chapter 1 gives a brief introduction of the term solid waste and the scope of the discipline of solid waste management and its basic functional elements. Chapter 2 discusses in details the sources and types of municipal solid waste, its basic characteristics and methods to calculate the quantities of solid waste. Various statistical tools applied to the bulk of solid waste data have been presented in details with solved examples. Onsite handling, storage and processing has been briefly reviewed in Chapter 3. Chapter 4 deals with various methods of collection and their comparison under different field conditions. Application of data to analyze a collection system has been illustrated with solved examples. Transfer stations hold an important position in the overall solid waste management system. An introduction to the need, types and use of transfer stations can be found in chapter 5. Processing techniques are finding excessive application in solid waste management systems. Purpose and description of different processing techniques are discussed in chapter 6.

Composting of organic components of solid waste is dealt in Chapter 7. It describes the process, environmental requirements and microbiology involved in composting process. Chapter 8 presents in details the most widely used disposal method i.e. sanitary landfilling. Methods of landfilling, various control measures exercised, design and operation of landfill are discussed in this chapter. Chapter 9 suggests a proposed solid waste management law. Solid waste management projects can only be successfully implemented by active community participation and awareness. Chapter 10 briefly describes how community may be involved in solid waste management operation. Privatization of solid waste management services is becoming popular and is being practiced in many parts of the world. Chapter 11 presents guidelines for the privatization of solid waste management services in Pakistan.

For easy reference, design data and other useful information, selected from a variety of sources or developed specially for this text are presented in more than 18 tables and 70 figures. To increase the usefulness of this text for both teachers and students, more than 15 worked examples are included. The example problems are worked out in step-by-step format. To test and further extend the student's knowledge numerous discussion topics and problems are included in the exercises given at the end of each chapter. We are thankful to Miss Seher Wasim for making correction and improving subject index. Help of Mr. Manzoor Ahmad in composing this book is highly acknowledged.

Prof. Shaukat Hayat
Prof. Dr. Sajjad H. Sheikh

PREFACE TO THE SECOND EDITION

When the first edition of this book was published in 2010, Solid Waste Management (SWM) was a neglected sector in Pakistan. In the last 6 years that have intervened between the publication of first edition and the preparation of the second edition; SWM sector has achieved a little maturity and is achieving value with rising awareness among masses and the government institutions. Open dumping practices are gradually declining with the introduction of modern solid waste management practices such as, landfilling, recycling and resources recovery at provincial and local levels. Steady advances are being made to adopt international best practices and innovative technologies necessary to handle the solid waste safely and economically.

In the 1st edition, major focus was on engineering principles of SWM. However, SWM is not only to understand the engineering principles but their application using management rules. In fact, the engineering principles and management are intertwined in such a way that without a working knowledge of management; solid waste engineer is unable to design an efficient SWM system.

The purpose of the 2nd edition of this book is to equip the students of relevant disciplines with the necessary knowledge; workable in local conditions for effective management of the solid waste and to update the waste managers on what innovations have been made in SWM at international and local level and how waste can be managed efficiently and cost effectively. In addition to updating all chapters, this editions has been improved by dividing the book into two parts. Part-1 deals with the engineering principles (design of storage, transfer, transportation, treatment, recovery and disposal of waste) and Part-2 deals with the management issues; making this book equally useful for both SWM engineers and managers.

Part-1 has been slightly reorganized maintaining the original sequence of topics beginning with the introduction to SWM in Chapter 1. Waste sources, types and characteristics are discussed in Chapter 2. Onsite storage, collection, transfer and transportation are discussed in Chapter 3, 4 and 5 respectively. Methods and techniques for waste processing are dealt in Chapter 6. Composting and landfilling are discussed in Chapter 7 and 8 respectively. Chapters 9 and 10 are new additions; Chapter 9 deals with a very important and current topic of waste to energy. Five special wastes are considered in Chapter 10 with sections on management of (i) healthcare waste (ii) electronic waste (iii) packaging waste (iv) slaughter-house waste, and (v) industrial wastes.

Part-2 deals with the planning and managerial aspects of SWM. Planning for effective SWM, procurement management, human resource management, financial management, applications of GIS in SWM planning, legal and regulatory framework, community participation and public – private partnerships has been discussed from Chapter11 through 18. Chapter 19 presents a case study of Lahore Waste Management Company (LWMC) and briefly enumerates the latest intervention made by the LWMC to manage solid waste on modern grounds and improve the service delivery standards in Lahore.

Professionals involved in the preparation of feasibility studies and design of SWM system for small to intermediate cities have a good news. A solved example on complete designing steps with detailed cost estimates has been made part of this edition as Annexure-1. To increase the usefulness of this book for students and waste managers many worked examples are included. To further extend the students' knowledge; numerous discussion topics and problems are included in the exercises given at the end of each chapter. Many new photographs have been added in this edition to provide the reader with visual insights into various engineering designs and management strategies for better planning and decision making.

Prof.Shaukat Hayat

Prof. Dr. Sajjad Haidar Sheikh

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Dr. Nasir Javed dedicated one staff member, Mr. Tahir Qureshi, Research Analyst, for the preparation of the first draft of all the chapters in Part-2. These chapters were then reviewed by the authors. Mr. Tahir worked hard to prepare and then further improve the chapters. Mr. Tahir proceeded on higher studies abroad. Afterwards, Mr. Kashif Nadeem, Research Associate, SWM was designated to take over the responsibility. He worked really hard, not only to further improve the chapters in Part-2, but also gave very useful input to improve the chapters in Part-1. Many new useful figures, photographs and write ups were added by him. He greatly helped in proof reading, editing and review of almost the entire book.

The authors are grateful to other contributors from the Urban Unit for their support in writing and reviewing some sections of part-2 such as GIS applications in SWM, procurement and financial management as well as the communication team who played a key role in designing of this book.

Authors are also thankful to Ms. Misbah Afaq and Ms. Gul-e-Hina, both lecturers at the Institute of Environmental Engineering & Research, UET, Lahore for their useful input in some sections of this book.

PART 1

PART 2

PART I

ENGINEERING PRINCIPLES

1. INTRODUCTION

Increasing population, industrialization, urbanization, economic growth and improved standard of living has resulted increase in solid waste generation [1]. Management of these huge quantities of municipal solid waste has become a serious concern for government departments, environmental protection agencies and regulatory bodies. If the waste is not properly managed, the time is not far when our planet will be filled with waste. Besides, waste contains materials that can be recovered, reused and recycled conserving resources and land required for the disposal.

US, EPA defines solid waste as, "any discarded, rejected, abandoned, unwanted or surplus matter, whether or not intended for sale or for recycling, reprocessing, recovery or purification by a separate operation from that which produced the matter; or anything declared by regulation or by an environment protection policy to be waste" [2]. It can also be defined as anything non- liquid and non-gaseous in terms of by-product that is produced because of any human activity and can produce any detrimental impact on environment [3].The term solid waste used in this context encompasses the heterogeneous mass discarded by the urban community, as well as more homogeneous accumulations of agricultural, industrial and mineral waste.

1.1 Impacts of Solid Waste

Solid waste is being produced since the inception of human history. In early history, human being used to throw their waste in open land because of small population and few environmental hazards. But with the passage of time; population grew, human activities expanded, resource utilization increased, so the waste production increased too. These expanded human activities have posed challenges to the waste managers. If these wastes are not handled properly, these can pollute air, water and also canresult in epidemic diseases. Solid waste manag-ement is a real challenge for developing countries due to shortage of resources and inadequate institutional set up.

The solid waste, when not taken care properly becomes the reason of spreading diseases, environmental pollution and occupational hazards. Almost more than 50% of the environmental pollution in Pakistani urban areas can safely be attributed to the inadequate solid waste management practices. Littering of food and other solid waste on the streets, roads, and vacant lots lead to the breeding of rats, with their attendant fleas carrying the germs of disease and the outbreak of plague, as lately happened in India. The plague, called the Black Death, killed half of the Europeans in the fourteenth century and caused many subsequent epidemics and high death tolls. The United States Public Health Service (USPHS) has published the results of a study tracing the relationship of 22 human diseases to improper solid waste management.

Data are also available to show that the illness-accident rate for sanitation workers is several times higher than that of industrial employees [4].

1.2 Solid Waste Management

Solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and recovery and disposal of solid waste in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations and that is also responsive to the public attitude.

If solid waste management is to be accomplished in an efficient manner, the functional aspects and relationships involved must be identified and understood clearly. In this context, the activities associated with the management of solid waste from point of generation to final disposal may be grouped into six functional elements.

1.2.1 Functional Elements of SWM

The functional elements of SWM are shown in a simplified flow diagram in Fig.1.1 [3]. The first functional element "waste generation" includes both the quantities and qualities of the waste. Reduction of SW at source, although not controlled by solid waste managers, is now included in system evaluations as a method of limiting the quantity of waste generated.

The second of the six functional elements of the solid waste management system is waste handling, separation, storage and processing at the source. Waste handling and separation involves the activities associated with management of waste until it is placed in storage container for collection. Handling also encompasses the movement of loaded containers to the point of collection. Separation of waste components is an important step in the handling and storage of solid waste at the source.

For example, from the standpoint of material specification and revenues from the sales of recovered materials, the best place to separate waste materials for reuse and recycling is at the source of generation. Onsite storage in proper containers is important because of public health concerns and aesthetic considerations.

They provide cover, containment and convenience in handling. Processing at source involves activities such as household composting and compaction.

The third functional element is "collection". It includes not only gathering of waste but also their transportation to a point where collection vehicle is emptied.

The fourth functional element "transfer and transport" involves two steps:

(i) Transfer of waste from smaller collection vehicles to larger transport equipment, and

(ii) Subsequent transport of waste to disposal site or a processing facility.

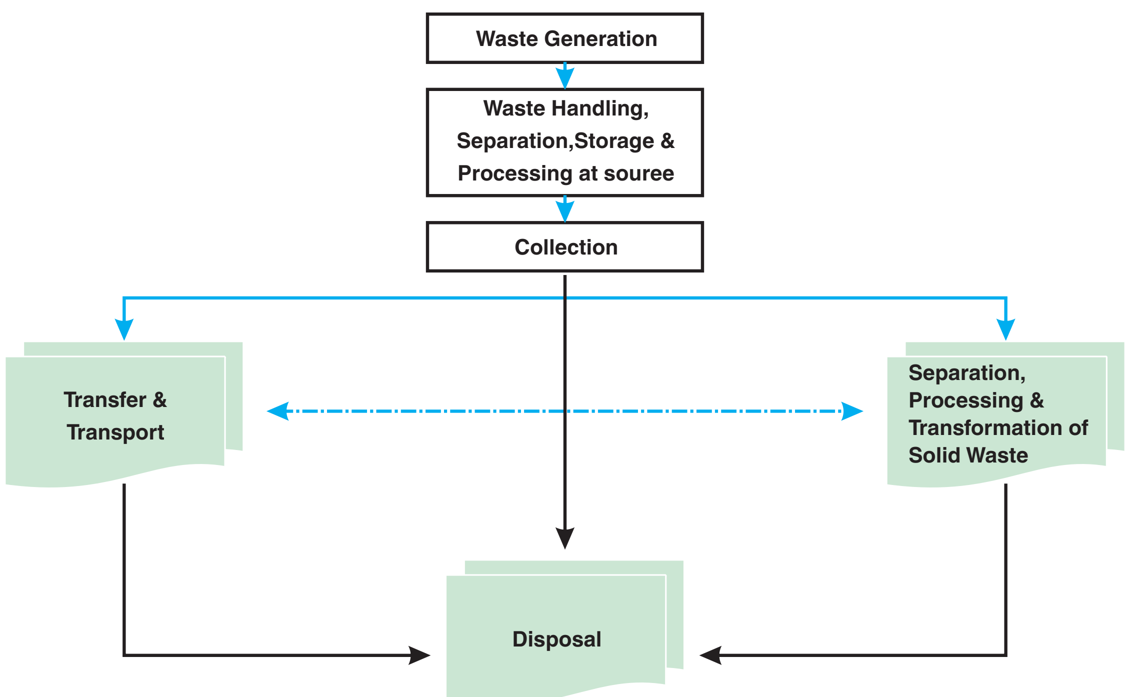

Figure 1.1: Interrelationships between the functional elements of MSWM system

The fifth functional element is "separation, processing and transformation" of solid waste. Separation involves separating the reusable and recyclable materials. Processing and transformation involves transformation of waste to other products which can be beneficial in one form or the other. For example, processed solid waste can be further used for incineration and composting.

The last functional element is "disposal". This refers to disposal of solid waste by landfilling or land spreading, which is the ultimate fate of all solid waste in contemporary practice.

1.3 Integrated Solid Waste Management

Integrated Solid Waste Management (ISWM) is a comprehensive waste prevention, recycling, composting, and disposal program. An effective ISWM system considers how to prevent, recycle, and manage solid waste in ways that most effectively protect human health and the environment. ISWM involves evaluating local needs and conditions, and then selecting and combining the most appropriate waste management activities for those conditions. The major ISWM activities are waste prevention (source reduction), recycling, reusing, waste transformation (composting and combustion) and disposal in properly designed, constructed, and managed landfill [5,6].

The ISWM aims to manage the waste in an environmentally and economically sustainable way [7]. Accordingly, the twin goals of ISWM are:

(i) To recover maximum possible amount of reusable materials and energy from the municipal solid waste stream through best available practices, and

(ii) To avoid releasing the energy or matter into the environment as a pollutant [8]. ISWM provides a hierarchy (an order from most preferred to least preferred) of approaches and technologies for managing solid waste in order to meet the goal of sustainability.

1.3.1 Hierarchy of Integrated Solid Waste Management

The ISWM hierarchy is based upon the material and energy that is embodied in solid waste and that is associated with its recycling and disposal. The solid waste management hierarchy as proposed by USEPA is shown in Fig. 1.2. The higher an option in the hierarchy, the more benefits it has in terms of economic value. These options are briefly discussed below.

The waste management hierarchy is a widespread element of national and regional policy of various developed countries and is often considered as the most fundamental approach of modern management operations according to their environmental or economic benefits.

The hierarchy is a useful policy tool for conserving resources, for dealing with landfill shortages, for minimizing air and water pollution and for protecting public health. In many develop-

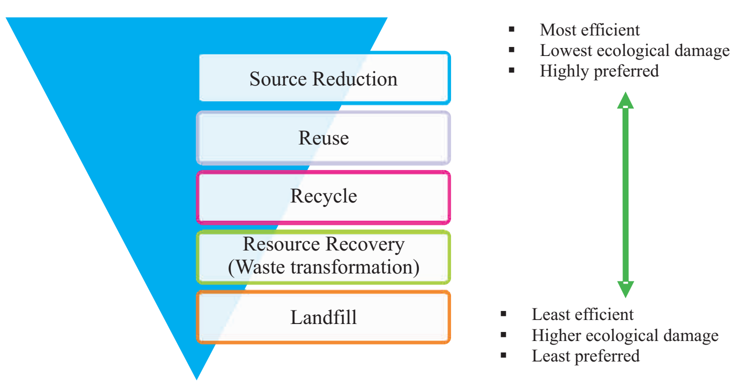

Figure 1.2: Hierarchy of solid waste management

ing countries, some aspects of this hierarchy are already in place, since traditional practices revolving around waste prevention reuse, and recycling are prevalent.

At the same time, keeping in view the regional conditions, it should be recognised that all waste management practices have financial implications as well as benefits. This means the hierarchy cannot be followed rigidly because in particular situations the cost of a prescribed activity may exceed the benefits when all financial, social, and environmental considerations are taken into account [9,10].

In recent years, after the establishment of Lahore Waste Management Company(LWMC), the concept of integrated waste management is being introduced especially in Punjab.

1.3.1.1 Waste Reduction

The highest priority option in ISWM hierarchy is to avoid or reduce the solid waste generation at the source. It involves reducing the amount and/or toxicity of the waste generated. Waste reduction may occur through the designing, manufacturing, and packaging of products with minimum toxic content, minimum volume of material, or a longer useful life. Waste reduction may also occur at the household, commercial, or industrial facility through selective buying patterns and the reuse of products and materials.

1.3.1.2 Reusing

Municipal solid waste generation could be reduced through reusing the items that are no longer required by someone. Most of our daily use products are reusable. For example, plastic bags obtained from the market are often used to pack the household waste and transport it from the house to the waste bin. Newspapers are rolled up to make fireplace logs, and coffee cans are used to hold bolts and screws. All of these are examples of reuse. Reusing is thus about extending the life or giving a second life to something that we previously considered as "garbage". In this way, the garbage we are sending to the landfill sites will be reduced and the operational life span of the landfill site will extend.

1.3.1.3 Recycling

The third option in the ISWM hierarchy is recycling, which involves (1) the separation and collection of waste materials; (2) the preparation of these materials for reuse, reprocessing, and remanufacture; and (3) the reuse, reprocessing, and remanufacture of these materials. Recycling is an important factor in helping to reduce the demand of resources and the amount of waste requiring disposal by landfilling.

1.3.1.4 Resource Recovery

The fourth option in the ISWM hierarchy, resource recovery (waste transformation), involves the physical, chemical, or biological alteration of waste. The transformation of waste materials usually results in the reduced use of landfill capacity. The reduction in waste volume through combustion is a well-known example.

1.3.1.5 Landfilling

Landfilling is the last and least preferred option of the ISWM hierarchy. It involves the controlled disposal of waste on or in the earth's mantle, and it is by far the most common method of ultimate disposal for waste residuals.

EXERCISES

1. Define solid waste.
2. What is meant by solid waste management?
3. What is meant by integrated solid waste management?
4. Arrange functional elements of SWM in a flow diagram.
5. What is meant by '4R' in SWM?
6. Give down three examples of waste reduction that you might be able to implement in your routine life.

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2. WASTE GENERATION QUANTIFICATION AND CHARACTERIZATION

Knowledge of the sources and types of solid waste, along with data on the composition and rates of generation, is basic requirement for the design and operation of the functional elements associated with the management of solid waste.

2.1 Sources of Solid Waste Generation

Sources of solid waste are, in general, related to land use and zoning. Although any number of source classifications can be developed. Table 2.1 depicts the main sources of the solid waste. definitions of "solid waste" term vary greatly in literature.

There are different types of solid waste originating from different resources, with varying quantities, characteristics and different methods of handling. Some type of waste are toxic, carcinogens, and malicious and require special care for its management and disposal. That is why there is a need to classify waste according to their source of origin and quantity of production.

Table 2.1: Sources of solid waste generation [1]

Sr No.	Waste Source	Typical facilities, activities or locations where wastes are generated
1	**Residential**	Includes single and multi-story houses and high density apartments. Type of solid waste includes: food waste, rubbish, ashes and special wastes.
2	**Commercial**	Includes stores, restaurants, markets, office building, hotels, auto repair shops, medical facilities etc. Type of waste includes food waste, rubbish, ashes, demolition and construction wastes, occasionally hazardous wastes.
3	**Institutional**	School, universities, hospitals, prisons, governmental centers etc. Waste similar to residential and commercial is produced in these institutions.
4	**Municipal**	The term “municipal” normally is assumed to include both the residential and commercial solid wastes generated in the community. It is thus a combination of both sources at serial no. 1 and 2 as given above. In this book, the major focus will be on the municipal solid waste.
5	**Industrial**	Generated from construction, fabrication, light and heavy manufacturing, refineries, chemical plants, mining, power plants, demolition etc. Type of waste includes food waste, rubbish, ashes, demolition and construction waste, special wastes, hazardous waste etc.
6	**Open Areas**	Includes streets, parks, vacant lots, play grounds, beaches, highways, recreational areas etc. Type of waste includes special waste, rubbish etc.
7	**Treatment Plant Sites**	It includes water and wastewater treatment plants. Waste is principally composed of residual sludge and other minor components.
8	**Agriculture**	It comes from field and row crops, orchards, dairies, farms, feedlots etc. Types of waste include spoiled food waste, agricultural waste, rubbish etc.SWM systems in Pakistan deal with wastes at Sr. No. 4 and 6 only.

2.2 Types of Solid Waste

The term solid waste is all-inclusive and encompasses all sources, types of classifi-cations, compositions and specifications. The Various Investigators from the field of environmental sciences and engineering had classified the solid waste into the following categories:

2.2.1 Garbage

This refers to the component of solid wastes that consists of animal, fruit, or vegetable residues. It normally results from the handling, preparation, cooking and eating foods. It is also called 'food waste'. It is highly putrescible and will decompose rapidly. Often, decomposition will lead to the development of offensive odor. It can originate from residences, restaurants, hospitals and prisons etc.

2.2.2 Rubbish

Rubbish consists of combustible and non-combustible solid wastes of households, institutions, commercial activities, etc. excluding food waste or other highly purtrescible items. Typically combustible rubbish include paper, cardboard, plastics, textiles, rubber, leather, wood, furniture and garden trimmings, timber, unused furniture, dressed timber. Non-combustible rubbish consists of items as glass, crockery, tin cans, aluminum cans, ferrous and other non-ferrous metals and dirt.

2.2.3 Ashes and Residues

Materials remaining from the burning of wood, coal, and other combustible waste in homes, institutions, industrial and municipal facilities for purposes of heating, cooking and disposing of combustible wastes are categorized as “ashes and residues”. It is composed of fine powdery materials and small amounts of burned and partially burned materials.

2.2.4 Demolition and Construction Waste

Waste from razed buildings and other structures are classified as demolition waste. Whereas, waste from construction, remodeling and repairing of individual residences and other buildings are classified as construction waste. These include dirt, stones, concrete, bricks, plaster, timber, plumbing, heating and electrical parts.

2.2.5 Treatment Plant Waste

The solid and semi-solid wastes from water, wastewater and industrial waste treatment facilities are included in this classification.

2.2.6 Agricultural Waste

Waste and residues resulting from diverse agricultural activities-including planting and harvesting of crops, production of milk, production of animals for slaughtering and operation of feedlots-are collectively called agricultural waste.

2.2.7 Hazardous Waste

Chemical, biological, flammable, explosive or radio-active wastes, that pose a substantial danger, immediately or over time, to human, plant or animal life are classified as “hazardous”. Due to immense danger associated with them, this waste must be handled and disposed of with great care and caution.

2.3 Characterization of Solid Waste

The solid waste is a mixture of heterogeneous matter, and its composition differs with the origin, i.e., residential waste are different from commercial waste and industrial waste are different from agricultural waste.

In order to decide about the handling of solid waste at all the stages of solid waste management, i.e., storage, collection, processing and recovery and disposal, it is necessary to know the exact nature of wastes. In this respect, the knowledge of the following parameters is essential:

i. Physical composition of solid waste
ii. Chemical composition of solid waste
iii. Energy content of solid waste
iv. Moisture content of solid waste
v. Density of solid waste

2.3.1 Physical Composition Analysis

Physical analysis is used to determine the composition of household waste and the estimation of its recycling and scientific waste treatment options.

Physical composition of solid waste is determined with respect (a) sources (b) characteristics, and (c) individual components.

a) With respect to sources the solid wastes may be:

- Residential waste.
- Commercial waste
- Industrial waste
- Institutional waste
- Agricultural Waste

b) With respect to characteristics, the solid waste can be categorized as:

- Organic and inorganic
- Putrescible and non-putrescible.
- Combustible and non-combustible.
- Hazardous and non-hazardous.

c) And with respect to individual components, the major types are

- Food wastes,
- Paper and cardboard
- Polyethylene bags
- Other plastics
- Garden trimmings
- Rags
- Glass
- Metals
- Debris (dust, stones etc.)

Physical composition describes the individual components of solid waste stream and their relative distribution, usually based on percentage by weight. Data on the physical composition of municipal solid waste (MSW) of Lahore were collected in 2011 by Istanbul Environmental Management Industry and Trading Company (ISTAC) Average values of different components in percentage by weight, are presented in Table 2.2.

Table 2 2: Average physical composition of MSW of Lahore

Components of the Municiapal Waste	Classification according to waste source					
	Low Income	Middle Income	High Income	Commercial	Institutional	Over All
	Percentage by weight					
Combustible waste	1.25	1.94	1.26	1.86	15.25	3.83
Diaper	5.75	7.64	7.10	3.56	0.96	5.35
Electronic waste	0.03	0.09	0.04	0.06	0.02	0.05
Glass	0.16	0.56	0.22	0.26	1.09	0.43
Hazaduous waste	0.11	0.45	0.14	0.04	0.10	0.18
Biodegradeable waste	76.15	71.63	77.26	73.78	62.59	72.76
Metals	0.03	0.05	0.02	0.00	0.17	0.04
Non-combustible waste	4.13	2.92	2.68	5.02	2.67	3.42
Paper-Card	0.78	2.67	1.16	1.74	6.14	2.34
PET	0.02	0.08	0.03	0.05	0.24	0.08
Nylon	4.93	6.26	5.32	6.29	5.27	5.58
Plastics	0.34	0.84	0.35	0.20	0.44	0.45
Tetrapack	0.26	0.49	0.33	0.37	2.84	0.77
Inert Waste	6.06	4.38	4.09	6.77	2.22	4.72

Source: Consulting services project for integrated solid waste management of Lahore city of the state of Punjab in Pakistan", ISTAC, 2011

Physical composition of solid waste can be determined by either using input method or output method [1]

On national level, Input method can be used to estimate the waste production through collecting data from the production industries. The accuracy of this method depends upon the data collection and the refuse rate. For example, if the national glass production is 10,000,000 tons annually, and we can safely assume that all this will end up (sooner or later) in waste that would be dumped to the sanitary landfilled, recycled or recovered. In this method, data are obtained from specialized agencies or institutions that regularly collect and publish data. This system provides regular updates about the current and future waste production estimates. However, this method is expensive because of the data collection.

For local level, reliable, accurate and most acceptable is output method of analysis and to perform sampling studies. This method requires less effort and finance as compared to input method. Sample size and method of characterizing the refuse are the most important variable for this method, which should be carefully chosen before initiating the composition analysis of any waste stream.

2.3.1.1 Measuring Waste Composition by Load Count Analysis

The procedure involves unloading and analyzing a quantity of wastes in a controlled area of a disposal site, that is isolated from winds. A representative sample may be a truck load resulting from a typical week day collection route in residential area. For analysis, a sample size of 100-200 kg is sufficient from a truck load. American Society for Testing Materials (ASTM) has named this method as ASTM-D5231-92 standard method for composition analysis of the municipal solid waste.

To obtain this 100 kg sample, coning and quartering method is utilized (Fig: 2.1). First of all, the large pieces of the waste items are converted to smaller ones to homogenously mix the waste. Then waste heap is converted to a conical shape with pile diameter 4 to 8 times the pile height (approximately 0.8 m high) [2,3]. The cone is then flattened and is divided into four quarters using straight lines, perpendicular to each other. The opposite quarters are discarded and again rests of the two quarters are mixed. The above procedure is repeated to get a sample size of approximately 100-200 kg (minimum 100 kg). This sample is then segregated in different components like food waste, paper, plastics, rags, garden trimmings, glass, metals and debris etc., and percentage of each is calculated on weight basis. The extra two quarters from the last reduction are utilized for moisture content analysis and bulk density computations.

The instruments and equipment required for physical analysis of the municipal waste are; gloves, face mask, safety shoes, weighing balance, polythene bags, polyurethane sheet, scissors, string, sieve, buckets with labels(such as recyclable plastic, non-recyclable plastic leather, food waste, textile, bones, stones, hairs, wood, grass, ferrous metals, non-ferrous metals, hazardous waste, diapers, miscellaneous) and spade.

The number of waste categories should be decided early in the sampling program before initiating the composition study. This is usually decided depending upon where the data are to be utilized.

For commercial and industrial MSW the field procedure for component identification for commercial and non-process industrial solid wastes involves the analysis of representative waste samples taken directly from the source and not from a mixed waste load in a collection vehicle.

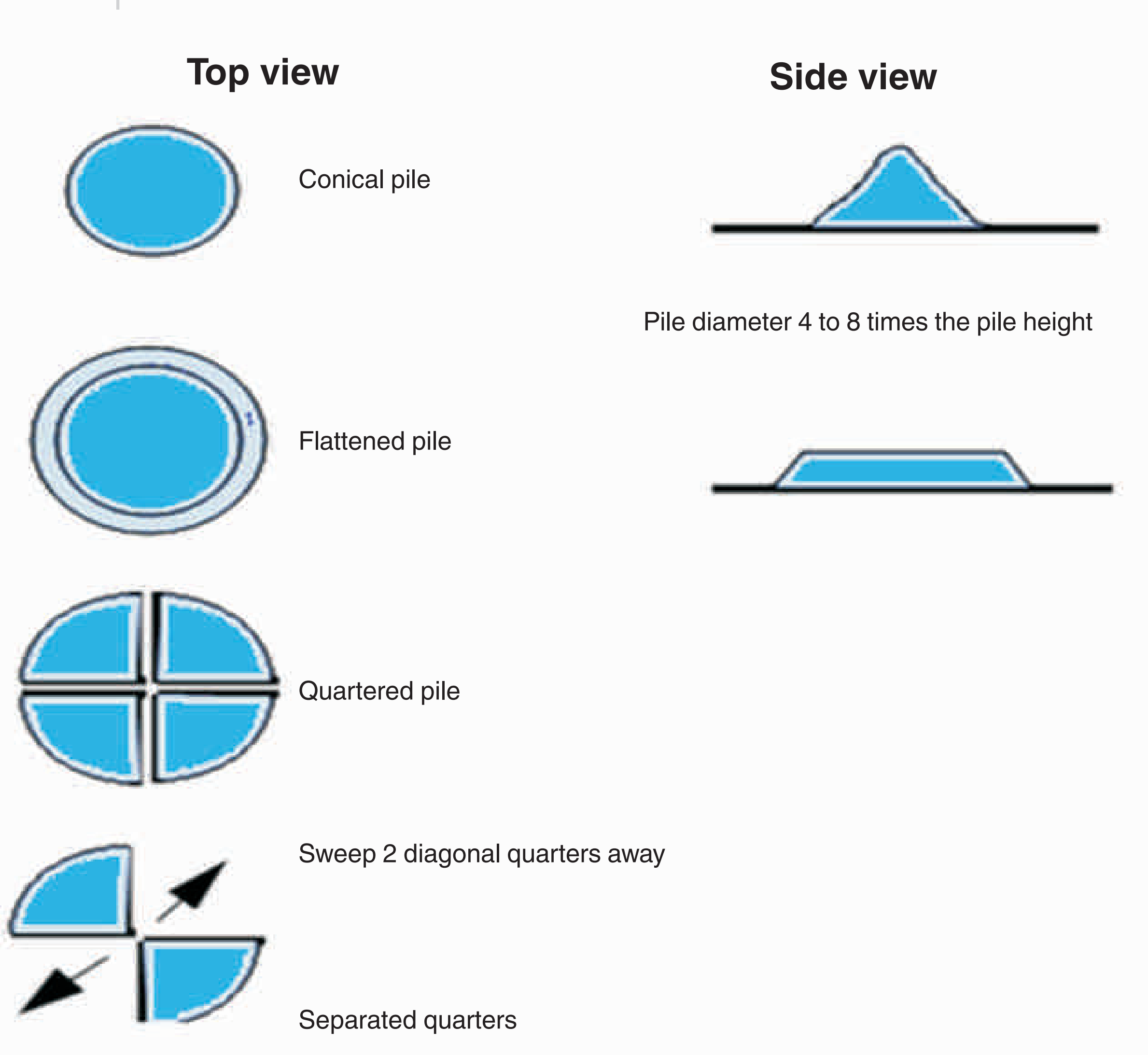


Figure 2.1: Coning & quartering method [3]

2.3.1.2 Measuring Composition by Photogrammetry

Photogrammetry is an alternative of the manual sampling and characterizing the refuse in order to save time and to make the characterization of solid waste safer. In this method, the representative portion of the solid waste (refuse) is photographed and is analyzed.

The photograph of the selected refuse is taken directly from the above (90^0 with the substrate surface) and the picture is then projected on a large screen that is divided into about 10×10 grid blocks. The waste components such as paper, plastic, food items, textile, leather, drink can, PET bottles, glass are identified and tabulated. Using already known bulk densities (which include interior space, e.g., in a beverage can), percentage of each component is then calculated [1].

(a)Bulk sample

(b)Representative sample

(c)Training staff to carry out segregation

(d)Segregation process

(e) weighing each component

(f) Recording weighing results

Figure 2.2: Physical composition analysis of Lahore waste

Most commonly used method in Pakistan is load count or coning and quartering method. In the recent study for Lahore, ISTAC used the same method for analysis of the physical composition of Lahore waste as shown in the Fig. 2.2 [4].

2.3.2 Chemical Composition

Determination of chemical composition of solid waste is important in evaluating alternative processing and recovery facilities. For example carbon / nitrogen ratio of solid waste shows whether it is suitable for composting or not. Besides that, determination of carbon, hydrogen, oxygen, nitrogen and sulfur helps in estimating the potential of the waste to produce biogas. Furthermore, energy contents of solid waste can also be evaluated from this information.

Average chemical composition i.e., percent by weight of carbon, hydrogen, oxygen, nitrogen and sulfur of different components of residential MSW is shown in Table 2.3. Example 2.1 illustrates the use of this information in determining approximate chemical formula.

Table 2.3: Typical data on the ultimate analysis of the combustible components in residential MSW [5]

Component	Percent by weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Organic						
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	-	-	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard Wastes	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Inorganic						
Glass	0.5	0.1	0.4	<0.1	-	98.9
Metals	4.5	0.6	4.3	<0.1	-	90.5
Dirt, ash, etc.	26.3	3.0	2.0	0.5	0.2	68.0

Solved Example 2.1

Estimation of the chemical composition of a solid waste Sample

Determine the approximate chemical formula of the residential solid waste with the typical composition shown in the table below and ultimate analysis given in Table 2.3. Typical physical composition and moisture content in residential MSW.

Component	Percentage by weight	Moisture Content (%)
Food waste	15	70
Paper	35	6
Cardboard	7	5
Plastic	5	2
Textiles	3	10
Rubber	3	2
Leather	2	10
Garden Trimmings	20	60
Wood	2	20
Glass	4	2
Tin Cans	3	3
Aluminum	0.5	2
Other metals	1	3
Dirt, ashes etc.	105	8

Solution:

Set up a computation table as shown on page 15 to determine the total weight of the major elements i.e., carbon, hydrogen, oxygen, nitrogen and sulfur in different components of the waste according to the percentages of each element given in Table 2.3. The steps for finding out the chemical formula are shown in the computation table, on page 14.

Key for various columns in the computational table (on page 14) is as follows.

Col. 1 = Copied from table 2.3
Col. 2 = Copied from table 2.3
Col. 3 = Dry weight = Col.1 × (100 Col.2)÷100
Col. 4 = Copied from table 2.3
Col. 5 = Col.4 × Col.3 ÷100
Col. 6 = Copied from table 2.3
Col. 7 = Col.6 x Col.3÷ 100
Col. 8 = Copied from table 2.3
Col. 9 = Col.8 x Col.3÷100
Col. 10 = Copied from table 2.3
Col. 11 = Col.10 x Col.3÷100
Col. 12 = Copied from table 2.3
Col. 13 = Col.12 x Col.3÷100

Computation Table for Solved Example 2.1

Col No.		1	2	3	4	5	6	7	8	9	10	11	12	13
					Carbon [C]		Hydrogen [H]		Oxygen [O]		Nitrogen [N]		Sulphur [S]	
Sr. No.	Components	% age by weight	Moisture Content	Dry weight	% age by weight	Total weight	% age by weight	Total Weight	% age by weight	Total Weight	% age by weight	Total Weight	% age by weight	Total Weight
			%	kg		kg		kg		kg		kg		kg
1	Food waste	15	70	4.50	48.00	2.16	6.40	0.29	37.60	1.69	2.60	0.12	0.40	0.02
2	Paper	35	6	32.90	43.50	14.31	6.00	1.97	44.00	14.48	0.30	0.10	0.20	0.07
3	Cardboard	7	5	6.65	44.00	2.93	5.90	0.39	44.60	2.97	0.30	0.02	0.20	0.01
4	Plastic	5	2	4.90	60.00	2.94	7.20	0.35	22.80	1.12	0.00	0.00	0.00	0.00
5	Textiles	3	10	2.70	55.00	1.49	6.60	0.18	31.20	0.84	4.60	0.12	0.15	0.00
6	Rubber	3	2	2.94	78.00	2.29	10.00	0.29	0.00	0.00	2.00	0.06	0.00	0.00
7	Leather	2	10	1.80	60.00	1.08	8.00	0.14	11.60	0.21	10.00	0.18	0.40	0.01
8	Garden Trimmings	20	60	8.00	47.80	34082	6.00	0.48	38.00	3.04	3.40	0.27	0.30	0.02
9	Wood	10	20	8.00	49.50	3.96	6.00	0.48	42.70	3.42	0.20	0.02	0.10	0.01
					Total	**34.98**		**4.58**		**27.76**		**0.89**		**0.14**
						A=34.98		B=4.58		C=27.76		D=0.89		E=0.14

Finding Chemical Formula

$C_{A/12}H_{B/1}O_{C/16}N_{D/14}S_{E/32}$

$C_{34.98/12}H_{4.58/1}O_{27.76/16}N_{0.89/14}S_{0.14/32}$

$C_{2.91}H_{4.58}O_{1.73}N_{0.06}S_{0.0044}$

Dividing all by 0.0044, which is the lowest value

$C_{2.91/0.0044}H_{4.58/0.0044}O_{1.73/0.0044}N_{0.06/.0044}S_{0.0044/.0044}$

$C_{665}H_{1045}O_{369}N_{14}S$ (Chemical formula of the solid waste components shown in Table 2.3)

2.3.3 Energy Content

Energy content of solid waste can be determined in two different ways (1) in the laboratory by using Bomb Calorimeter or (2) by using the data from the literature if the elemental composition of solid waste is known.

A bomb calorimeter is a device used to measure the energy contents of solid waste in the laboratory. A diagram of a bomb calorimeter has been shown in Fig. 2.3. It consists of a thermometer attached to an insulated container. Solid waste and fuel is placed in the crucible and ignited with electric energy. The initial and final temperatures (after ignition) are noted. This temperature change is used to find out the energy content.

The other method of finding energy content is using the data on elemental composition. This data may be available in the literature. Typical data for energy content of residential MSW are given in Table 2.4 and the use of these data to calculate energy content of solid waste has been illustrated in Solved Example 2.2.

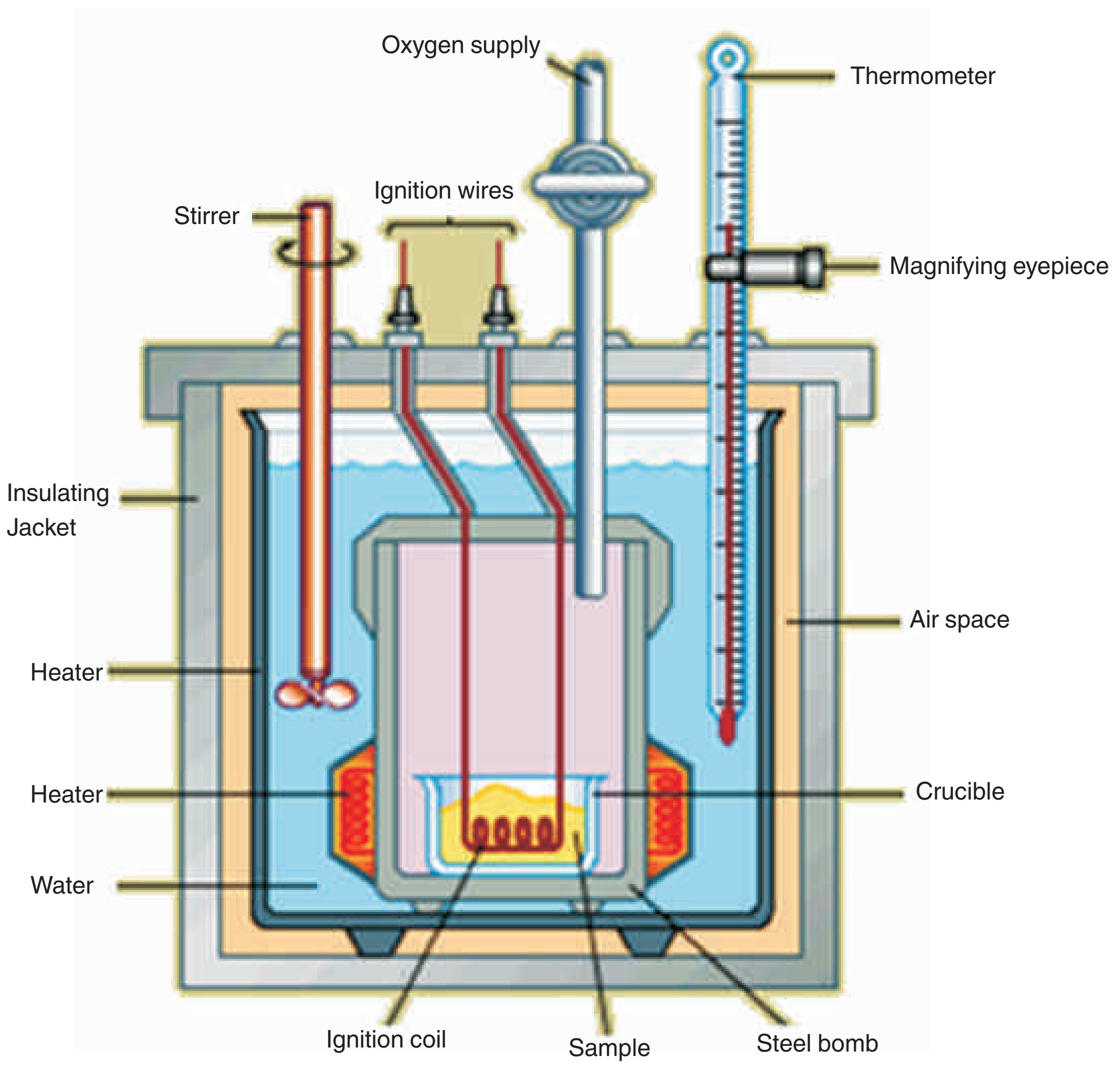


Figure 2.3: Bomb calorimeter [6]

Table 2.4: Typical data on energy content of residential MSW [5]

Component	Energy, Btu/lb	
	Range	Typical
Organic		
Food wastes	1500–3000	2000
Paper	5000–8000	7200
Cardboard	6000–7500	7000
Plastics	12000–16000	14000
Textiles	6500–8000	7500
Rubber	9000–12000	10000
Leather	6500–8500	7500
Yard Wastes	1000–8000	2800
Wood	7500–8500	8000
Inorganic		
Glass	50 – 100	60
Tin cans	100 – 500	300
Aluminum	--	-
Other metal	100 – 500	300
Dirt, ashes, etc.	1000 – 5000	3000
Municipal solid waste	4000 – 6000	5000

Note 1: British thermal unit (BTU) is a unit of energy. It is defined as the energy required raising the temperature of 1 lb of water from 63°F to 64°F.

Note 2: Btu/lb x 2.326 = K Joul/Kg.

Solved Example 2.2

Estimation of energy content of typical residential MSW [5]

Determine the energy content of a typical residential MSW with the average composition shown in Table 2.4. Take quantities of different components of solid waste from Table 2.3.

Solution:

1. Assume the heating value will be computed on as discarded basis.
2. Determine the total energy content using the data given in Table 2.4. The necessary computations are presented in the following

Component	Solid Waste,[1] lb (1)	Energy,[2] Btu/lb (2)	Total Energy, Btu (1)(2)
Organic			
Food wastes	15.0	2000	30,000
Paper	35.0	7200	232,000
Cardboard	7.0	7000	49,000
Plastics	5.0	14000	70,000
Textiles	3.0	7500	22,500
Rubber	3.0	10000	30,000
Leather	2.0	7500	5,000
Yard Wastes	20.0	2800	56,000
Wood	2.0	8000	16,000
Inorganic			
Glass	4.0	60	240
Tin cans	3.0	300	900
Aluminum	0.5	-	---
Other metal	1.0	300	300
Dirt, ashes, etc.	1.0	3000	3000
Total	١٠٠,٠		544.440

(1) Quantities of organic components derived from Table 2.3

(2) Adopted from Table 2.4.

Energy content =

$$\frac{544{,}440\ Btu}{100\,lb} = \frac{5444\ Btu}{lb} = \frac{12{,}674\ kJ}{kg}$$

$$(Btu/lb \times 2.326 = kJ/kg)$$

The computed value compares well with the typical value of 5000 Btu/lb given in Table 2.4.

2.3.4 Moisture Content

The moisture content of solid waste is usually expressed in two ways. (1) Either the moisture content in a sample is expressed as a percentage of the wet weight of the material, or (2) as a percentage of the dry weight of the material. Mostly, the wet-weight method is used in the field of solid waste management. The wet-weight moisture content can be expressed as follows:

$$M = \left(\frac{w - d}{w}\right)100 \qquad (2.1)$$

Where M = Moisture content, %
w = Initial weight of sample as delivered, lb (or kg).
d = Weight of sample after drying at 105°C, lb (or kg).

Typical data on the moisture content of the solid waste components has been presented in Solved Example 2.1. For most MSW, the moisture content will depend on the composition of the wastes, the season of the year, and the humidity and weather conditions, particularly rain. The use of data in Table 2.3 to estimate the overall moisture content of solid waste is illustrated in example 2.3.

Solved Example 2.3:

Estimation of moisture content of typical MSW [5]

Estimate the overall moisture content of a sample of as collected MSW with the typical composition given in Example 2.1.

Component	Percent by weight (1)	Moisture content, %(2)	Dry weight* (%) (1)-(1x2)
Organic			
Food wastes	9.0	70	2.7
Paper	34.0	6	32.0
Cardboard	6.0	5	5.7
Plastics	7.0	2	6.9
Textiles	2.0	10	1.8
Rubber	0.5	2	0.5
Leather	0.5	10	0.4
Yard Wastes	18.5	60	7.4
Wood	2.0	20	1.6
Misc organics	-	-	-
Inorganic			
Glass	8.0	2	7.8
Tin cans	6.0	3	5.8
Aluminum	0.5	2	0.5
Other metal	3.0	3	2.9
Dirt, ashes, etc.	3.0	8	2.8
Total	100.0		78.8

* Based on an as delivered sample weight of 100 lb

Solution:

Determine the moisture content of the solid waste sample using Eq. (2.1) i.e.

Moisture content (%) = $\left(\frac{100 - 78.8}{100}\right)100 = 21.2\%$

2.3.5 Bulk Density

Density or specific weight is defined as the weight of a material per unit volume e.g., kg/m3. Since the density varies markedly with geographic location, season of the year and length of time in storage, great care should be used in selecting typical value. However average values of density of MSW at different stages are given in Table 2.5. These values relate to local conditions in Pakistan. Sand replacement method can be used to determine the density in landfills.

Table 2.5: Density of solid waste at different stages under local conditions in Pakistan [7]

Stage of Collection	Bulk density kg/m³	
	Range	Average
Filth depots	150 – 250	200
Hand Carts	150 – 250	200
Donkey Carts	250 – 350	300
Dumpers	500 – 600	550
Tractor carrier	400 – 500	450
Hoist trucks	400 – 500	450
Tractor – Trolleys	400 – 500	450
Disposal (Open dumps after natural compaction)	1000 – 1300	1200

2.4 Quantification of Solid Waste

Generation of solid wastes is a diffused process and takes place in every nook and corner of the society. The prominent sectors include residential, commercial, industrial and agricultural areas. Furthermore, it varies with season, geographical location and prosperity difference within the residential areas. Generally the quantities generated are calculated on the basis of generation per capita per day basis.

Knowledge of generation rates is very important for designing a solid waste management system and to determine the total amount of waste to be managed. Different measuring methods and waste classifications adopted have caused confusion. Nevertheless, the goals must clearly be established before collection of such data.

Four topics are discussed in this regard.

1. Expression for unit generation rates
2. Methods to determine generation rates
3. Factors that affect generation rates.
4. Statistical analysis of generation rates.

2.4.1 Expression for Unit Generation Rate

Generation rates can be measured either on volume or weight basis i.e., how much of volume or weight of solid waste is generated by one person per day. Use of volume as a measure of quantity can be extremely misleading. For example, a cubic meter of loose waste represents different quantity than a cubic meter of compacted waste and each of these is different from a cubic meter of waste that has been compacted in a landfill.

To avoid confusion, solid waste quantities should be expressed in terms of weight. Weight is the only accurate basis for records because tonnages can be measured directly, regardless of the degree of compaction.

The use of weight records is also important in the transport of solid wastes because the quantity that can be hauled is restricted by highway weight limits rather than by volume. The general expression for residential areas is kg per capita per day, and due to lack of more rational data the same unit is being applied to industrial and agricultural wastes. The more rational units for these should be:

- Industrial waste: kg/repeatable unit of production, e.g., kg per automobile.
- Agricultural: kg/ton of raw product

The average generation rate of municipal solid waste in Pakistan varies from 0.3 to 0.6 kg/capita/day.

2.4.2 Methods Used to Determine Generation Rate

Most solid waste generation rates, reported in the literature are actually collection rates and not generation rates. This is because many factors affect collecting all generated waste data. Commonly used methods are: (i) Load count analysis; and (ii) Material balances analysis.

2.4.2.1 Load Count Analysis for Solid Waste Generation Rate Computations

In this method, the number of individual loads is counted. The method is illustrated in Solved Example 2.4.

Solved Example 2.4

Estimate the unit generation rate for 1600 homes from the following data collected from a transfer station for one week.

1. Number of compactor trucks = 10
2. Average size of compactor truck = 20 m^3
3. Density of solid waste in compactor truck = 170 kg/m^3
4. Number of flat bed trucks = 10
5. Density of solid waste in flat bed truck = 70 kg/m^3
6. Average flat bed truck volume = 1.5 m^3
7. Number of loads of private vehicles = 20
8. Estimated volume per private vehicle = 0.3 m^3
9. Density of solid waste in private vehicle = 50 kg/m^3

Determine the unit waste generation rate based on the assumption that each household is comprised of 6 people.

$$\text{Unit rate} = \frac{35350\,\text{kg/wk}}{(1600\times 6)\times 7\,\text{days/wk}}$$

= 0.53 kg per capita per day

Solution:

Set up the computation Table as shown below:

Item	Number of loads	Average volume (m^3)	Total volume (m^3) (1)	Density (kg/m^3) (2)	Total weight (kg) (1)X(2)
Compactor truck	10	20.00	200	170	3400
Flatbed truck	10	1.50	15	70	1050
Private vehicle	20	0.30	6	50	300
Total kg/wk					35350

2.4.2.2 Materials Balance Analysis

As compared to load count analysis, this method gives relatively accurate value of generation rates. However, high expenses and large amount of work is involved as compared to load count analysis. This method should be used only in special circumstances. Under majority of situations, load count analysis will serve the purpose.

In this method, a detailed material balance analysis for each generation source, such as an individual home or a commercial and industrial activity is made. Following steps can be followed for material balance analysis. These steps are also pictorially presented in Fig. 2.4.

1. Draw a system boundary around the unit to be studied.
2. Identify all activities that cross or occur within the boundary and affect generation rate.
3. Give generation rate in each activity.
4. Determine the quantities of waste generated, collected and stored by using a material balance.

A simplified material balance analysis is illustrated in Example 2.5 [5].

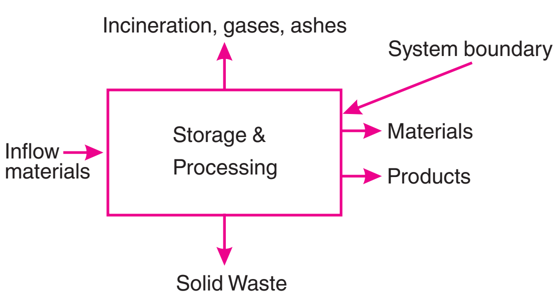


Figure 2.4: Material balance analysis sketch

Solved Example 2.5

1. A cannery (where food/fruits are canned) receives on a given day.
   i) 12 tons of raw produce
   ii) 5 tons of cans
   iii) 0.5 tons of cartons
   iv) 0.3 tons of miscellaneous materials

2. As a result of internal activity
   i. 10 tons of product are produced, remainder discharged to sewer
   ii. 4 tons of cans are stored, remainder used
   iii) 3% of cans used are damaged and incinerated, remainder used.
   iv) 75% of miscellaneous materials become paper waste and incinerated, remainder is disposed of.

3. Determine the generation rate of wastes.

Solution:

Cans used in product = (1 – 0.03) ton
= 0.97 ton

Cartons incinerated = (0.03) (0.5 ton)
= 0.015 ton

Cartons used in product = (0.5–0.015)ton
= 0.485 ton

Miscellaneous incinerated = (0.75) (0.3 ton)
= 0.225 ton

Miscellaneous disposed of = (0.3 – 0.225) ton
= 0.075 ton

Total incinerated = (0.015+0.225)ton
= 0.240 ton

Total produce = (10+0.97+0.485) tons
= 11.455 tons

Neglecting the amount of materials discharged in the incinerator stack gases, a materials flow diagram is shown in Fig. 2.5.

Comment: This simple example was presented to illustrate some of the computations involved in the preparation of a materials-balance analysis. If the internal processing activities are more complex, the amount of work involved in arriving at a materials balance obviously could become prohibitively expensive.

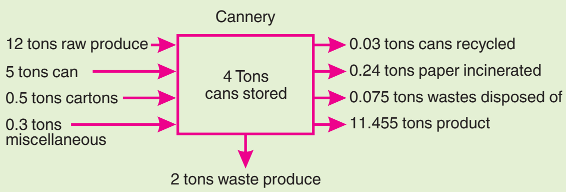


Figure 2.5: Materials balance flow diagram sketch for example 2.5

2.4.2.3 Sampling from Representative Generation Units

In these method representative houses, shops etc are selected and sampling made for a definite period, which may be one week, one month or one year. The method is illustrated in the Solved Example 2.6.

2.4.3 Factors Affecting Generation Rate

Factors that influence the quantity of wastes generated include geographic location, frequency of collection, the habits and economic status of the people, the extent of salvage and recycle operations, legislation, and public attitudes [5]. All these factors are important in planning for solid waste management. Broad generalizations are of little or no value. However, the impact of several factors must be evaluated separately in each situation. The above mentioned factors have been briefly discussed below [5].

Solved Example 2.6

A number of houses were selected in different areas of Lahore showing the poor middle and rich population of the city. The generation thus obtained was 0.2 kg/capita/day as calculated in the table below.

Solution:

Residential waste generation rate (kg/capita/day)

Sample No.	Sample Area	Income Level	Average Population Sampled (No.)	No. of Houses (No.)	Duration of Sample (Days)	Total Wt. of sample (Kg)	Generation Rate (Kg/Capita/day)
1	Gulberg	High	21	4	10	69.3	0.33
2	Ichhra	Middle	40	5	10	56	0.14
3	Sanda	Middle	50	5	12	126	0.21
4	Walled City	Middle	45	5	8	97	0.27
5	Mustafa Abad	Low	46	5	10	79	0.17
6	Begumpura	Low	65	6	10	71.5	0.11
						Average	0.2

2.4.3.1 Geographic Location

The influence of geographic location is related primarily to the different climates that can influence both the amount of certain types of solid waste generated and the collection operation. Substantial variations in the amount of yard and garden waste generated in various parts of the country are also related to climates. For example, in the warmer areas where the growing season is considerably longer than in the colder areas, yard waste are collected not only in considerably greater amounts but also over a longer period of time.

Because of the variation in the quantities of certain types of solid waste generated under varying climates, special studies should be conducted when such information will have a significant impact on the system. Often, the necessary information can be obtained from a load-count analysis.

2.4.3.2 Frequency of Collection

In general, it has been observed that where unlimited collection service is provided, more waste is collected. This observation should not be used to infer that more waste is generated. For example, if a homeowner is limited to one or two containers per week, he or she may, because of limited container capacity, store newspaper or other materials in the garage or storage area. With unlimited service, the homeowner would tend to throw them away. In this situation the quantity of waste generated may actually be the same, but the quantity collected is considerably different. Thus the fundamental question of the effect of collection frequency on waste generation remains unanswered.

2.4.3.3 Characteristics of Population

It has been observed that the characteristics of the population influence the quantity of solid waste generated. For example, the quantity of yard waste generated on a per capita basis are considerably greater in many of the wealthier neighborhoods than in other parts of the town.

2.4.3.4 Extent of Salvage and Recycling

The existence of salvage and recycling operations within a community definitely affects the quantity of waste collected. Whether such operations affect the quantity generated is another question.

2.4.3.5 Legislation

Perhaps the most important factor affecting the generation of certain types of waste is the existence of local, provincial and federal regulations concerning the use and disposal of specific materials. For example, in United States a legislation popularly called 'Bottle Bill' was passed in 1971. It requires carbonated soft drink and beer container to be returned. [8] This law reduced the road side litter from 40 to 60% and increased containers recycling in USA. With the return rates averaging 90%, another major benefit was in waste reduction and resource conservation, particularly for aluminum [9].

2.4.3.6 Public Attitudes

Significant reductions in the quantity of solid waste generated will occur when and if people are willing to change their habits and lifestyles to conserve national resources. It will also reduce the economic burdens associated with the management of solid waste.

2.4.4 Statistical Analysis of Generation Rate

In developing solid waste management systems, it is often necessary to determine the statistical characteristics of solid waste generation. For example, for many large industrial activities, it would be impracticable to provide container capacity to handle the largest conceivable quantity of solid waste to be generated at a given day. The container capacity to be provided must be based on statistical analysis of the generation rates [3].

The statistical measures that must be considered include the frequency, mean, mode, median, standard deviation and coefficient of variation. These statistical measures combined with some graphical representation of the bulk of data (normally collected in solid waste studies) helps in obtaining necessary information from such data. The above mentioned statistical terms are defined below.

2.4.4.1 Frequency

The frequency of occurrence represents the number of times a given value occurs in a set of observations.

2.4.4.2 Mean

The mean is defined as the arithmetic average of a number of individual measurements and is given by:

$$\overline{x} = \frac{x_1 + x_2 + x_3 + x_4 + \ldots\ x_n}{n} \text{ or } \frac{\sum_{i=1}^{i=n} x_i}{n} \quad ..(2.2)$$

Where

x_i = i^{th} observation

n = total no. of observations

2.4.4.3 Median

If a series of observations are arranged in order of increasing value, then the middle-most observation (if observations are in odd numbers) or the arithmetic mean of two middle-most observations (if observations are in even numbers), in a series is known as median.

e.g. 1) Odd number of observations e.g. 3, 8, 9, 11, 16 (Median = 9)

2) Even number of observations

e.g. 3, 8, 9, 11, 16, 22 (Median = $\frac{9+11}{2}$ = 10)

2.4.4.4 Mode

The value occurring with the greatest frequency in a set of observations is known as mode. Set of observations = 1, 3, 5, 5, 5, 6, 6, 7, 7, 9 (Mode = 5).

2.4.4.5 Standard Deviation (S.D)

There is uncertainty in any set of measurement. The precision of a set of measurement can be assessed in a number of different ways. Most commonly, the error of an individual measurement in a set is defined as the difference between the arithmetic mean and the value of measurement. Mathematically;

$$\text{S. D} = \sqrt{\frac{\sum f_i (x_i - \bar{x})^2}{n-1}} \quad ....(2.3)$$

Where

n = no. of observations

x_i = for grouped data it is mid-point of ith data range; for ungrouped data x_i = ith observation

$\overline{x}$ = Mean value

f_i = *for grouped data it is frequency; for ungrouped data f_i = 1 (See example 2.7 for grouped data and 2.8 for ungrouped data)*

S.D shows scatter in a set of measurements. The larger the scatter in a set of measurements, the greater will be S.D. Conversely, as the precision in a set of measurement improves, the value of S.D will decrease.

2.4.4.6 Coefficient of Variation (CV)

Although, the S.D can be used as an indication of the absolute dispersion of a set of measured values, in itself it provides little or no information as to whether the value is large or small. To overcome this difficulty, the coefficient of variation (CV), as given below, is used as a relative measure of dispersion.

$$CV = \frac{S.D}{\bar{x}} \times 100 \qquad ....(2.4)$$

Consider the following two data sets

	Data Set 1	Data Set 2
	2200	19
	2000	32
	1500	36
Mean	1900	29
S.D	360	8.8
C.V	19%	30.6%

As can be seen from the above two data sets that numerically the S.D of data set 1 is larger i.e. 360 than the S.D of data set 2 i.e. 8.8 and it appears that scatter is more in data set 1. However, C.V for data set 1 is 19% while for data set 2 it is 30.6% which shows that scatter is more in data set 2. Thus while comparing scatter in two different data sets, C.V is more useful than the S.D. Typically, the C.V for solid waste generation rates will vary from 10 to 60 percent. For measurements in biological field C.V will vary from 10 to 30 percent. For chemical analysis C.V varies from 2 to 10 percent.

2.4.5 Pattern of Variations

Variation seems inevitable in nature. It is necessary to have some simple method of describing pattern of variation. The graphical presentations and analysis of observed data can be used to depict and evaluate trends and to determine the reliability of conclusions made from a limited set of observations. Time series, histograms or frequency plots and cumulative frequency curves are extensively used for the presentation and analysis of data.

2.4.5.1 Time Series

Observations arranged in the order of occurrence in time are often called time series. It shows trends, cycles or periodicities and fluctuations that may be of value in understanding the basic nature of phenomenon under evaluation.

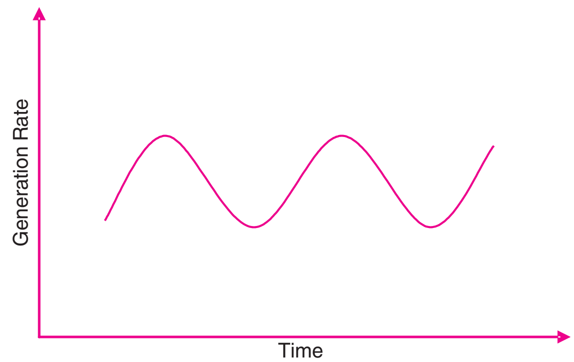


Figure 2.6: Graph showing time series

2.4.5.2 Frequency Plots/Histogram

Observations arranged in order of magnitude form an array. If whole numbers are assigned to a magnitude range, then the frequency of occurrence of whole numbers can be plotted against the magnitude ranges. The resulting plot is called histogram.

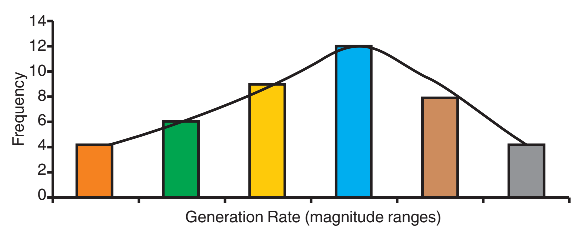


Figure 2.7: A typical histogram

2.4.5.3 Cumulative Frequency Curves

It is sometimes advantageous to tabulate magnitude ranges against cumulative frequency to find the Percentage age of time a particular magnitude is exceeded or less than.

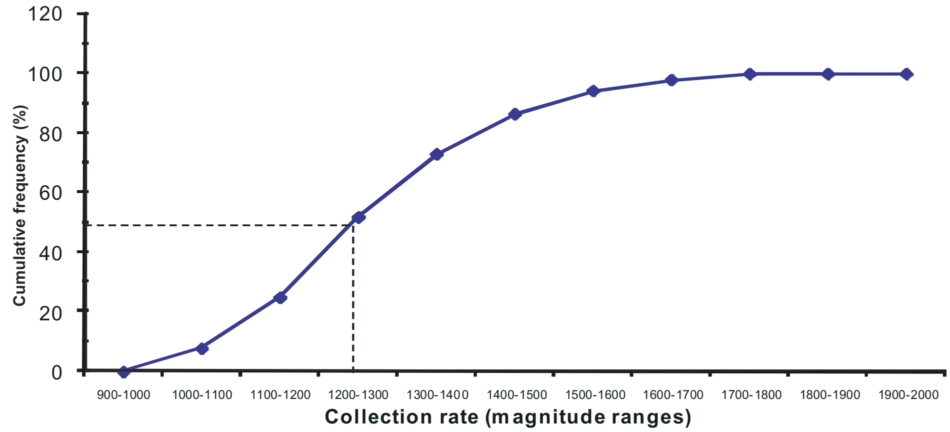


Figure 2.8: Cumulative frequency curve

From Fig. 2.8, it can be seen that 50% of the time the generation rate is more than 1200-1300.

2.4.6 Types of Frequency Plots

There are two types of frequency plots (1) Normal and (2) Skewed.

2.4.6.1 Normal Curve

Many frequency distributions found in nature, do correspond roughly to the curve shown in Fig. 2.9.

The above curve is called 'normal' or Gaussian curve. In normal distribution, about 2/3 (66%) of the occurrences fall within one S.D. on either side of the average or mean. Curve is symmetric about mean/average value.

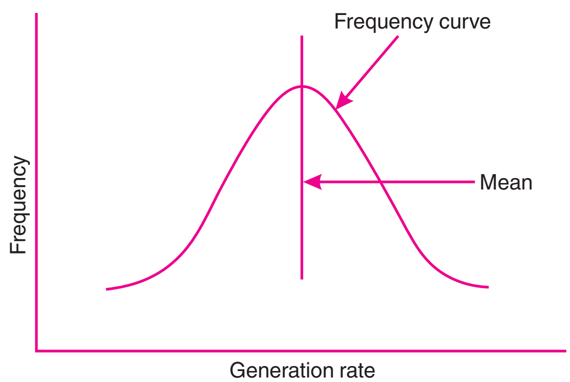


Figure 2.9: Normal frequency distribution

2.4.6.2 Skewed Curves

There are many other frequency patterns, which are like the normal in that frequency decrease continuously from center to the extreme values but – unlike normal are not symmetric about the mean. In skewed curves, extreme values occur more frequently in one direction from the center than the other as shown in Fig. 2.10.

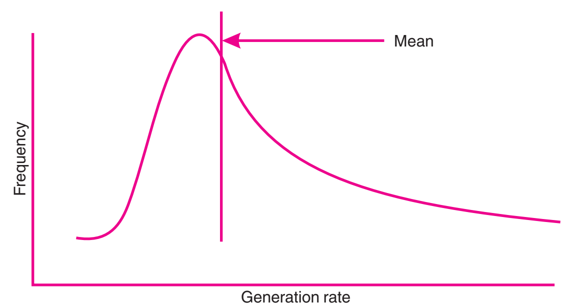


Figure 2.10: Skewed frequency distribution (skewed to right)

The above frequency curve is skewed to the right i.e.extreme variation occurs more frequently above the mean than below it. Similarly Fig. 2.11 shows a frequency distribution which is skewed to the left i.e. extreme values occur more frequently below the mean than above it. Most frequency distributions in SWM are skewed.

2.4.7 Comparison of Mean, Median & Mode

The arithmetic mean is the most widely used measure of the central tendency. It is usually preferred over median and mode. The reason being, it is easy to manipulate mathematically. It is the most reliable, provided there are no extreme values in the data because all the values in the data are used in calculating mean unlike the mode and the median. Whenever, a set of data contain extreme values, the median and the mode will, probably, be a better indicator of central tendency of the whole set of data because they are not influenced by extreme values.

The median may be a preferred measure of central tendency for describing economic, sociological and educational data. It is therefore popular in the study of social sciences because much of data contain extreme values.

The mode is more useful in business planning as a measure of popularity that reflects central tendency or opinion. Examples include the drink seller wanting to know the most popular brand of drinks, manufacturers who want to know the most popular size of shoe, shirt etc.

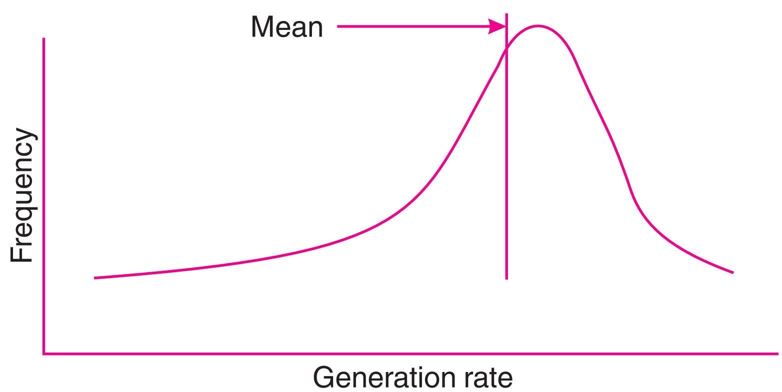


Figure 2.11: Skewed frequency distribution (skewed to left)

Solved Example 2.7

(Grouped Data) [3]

The residential and commercial solid waste of a city with 25,000 people is collected on Tuesday and Saturday morning. The volume of waste collected has been recorded for 1 year and the data for Tuesday is given below. Prepare a frequency histogram and cumulative frequency distribution curve for Tuesday. Find the mean, median, mode, standard deviation and coefficient of variation for the data given. Discuss briefly the nature of the distribution and its significance. (In grouped data, instead of mentioning individual readings, a magnitude range is defined for a set of reading falling within a specific range e.g. 1000-1100 and number of reading falling within that range is shown as a frequency i.e. 4 in this case).

Generation Rate (m^3/collection day)	Frequency (Weeks)	Generation Rate (m^3/collection day)	Frequency (Weeks)
800-900	0	1400-1500	7
900-1000	0	1500-1600	4
1000-1100	4	1600-1700	2
1100-1200	9	1700-180	0
1200-1300	14	1800-1900	1
1300-1400	11	1900-2000	0
		Total	52

Solution:

Set up a computational table as shown below:

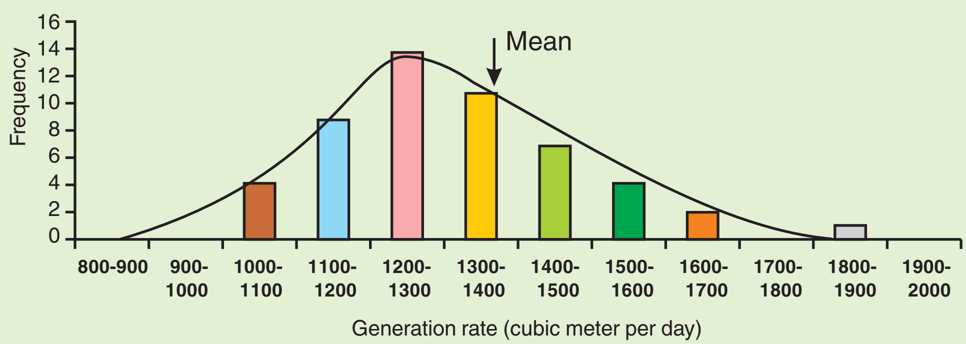
Generation Rate (m^3/collection day)	Frequency f_i	Cumulative Frequency		x_i	$f_i x_i$	$(x_i - \bar{x})$*	$f_i (x_i - \bar{x})^2$
		Total	% w.r.t total (52)				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
800-900	0	0	0	850	0	-465	0
900-1000	0	0	0	950	0	-365	0
1000-1100	4	4	7.7	1050	4200	-265	280900
1100-1200	9	13	25	1150	1036	-165	245025
1200-1300	14	27	51.9	1250	117500	-65	59150
1300-1400	11	38	73	1350	14850	35	13475
1400-1500	7	45	86.5	1450	10150	135	127575
1500-1600	4	49	94.2	1550	6200	235	220900
1600-1700	2	51	98.1	1650	3300	335	224450
1700-1800	0	51	98.1	1750	0	435	0
1800-1900	1	52	100	1850	1850	535	286225
1900-2000	0	52	100	1950	0	635	0
				Σ	68400		1457700

* $\bar{x}$ mean = 1315 m^3/day as calculated on the next page.

Column 1 shows the generation rate in m^3/collection day i.e. on Tuesday. Column 2 shows the frequency. Column 3 shows the cumulative frequency and column 4 shows percentage of cumulative frequency in 52 which are the total number of Tuesday in a year. Column 5 shows x_i which is the middle of a magnitude range i.e. for 800-900 range, it is 850. Column 6 shows the product $f_i x_i$. Column 7 gives the difference between mean value of the magnitude range x_i and mean value of the entire data i.e., $\bar{x}$.

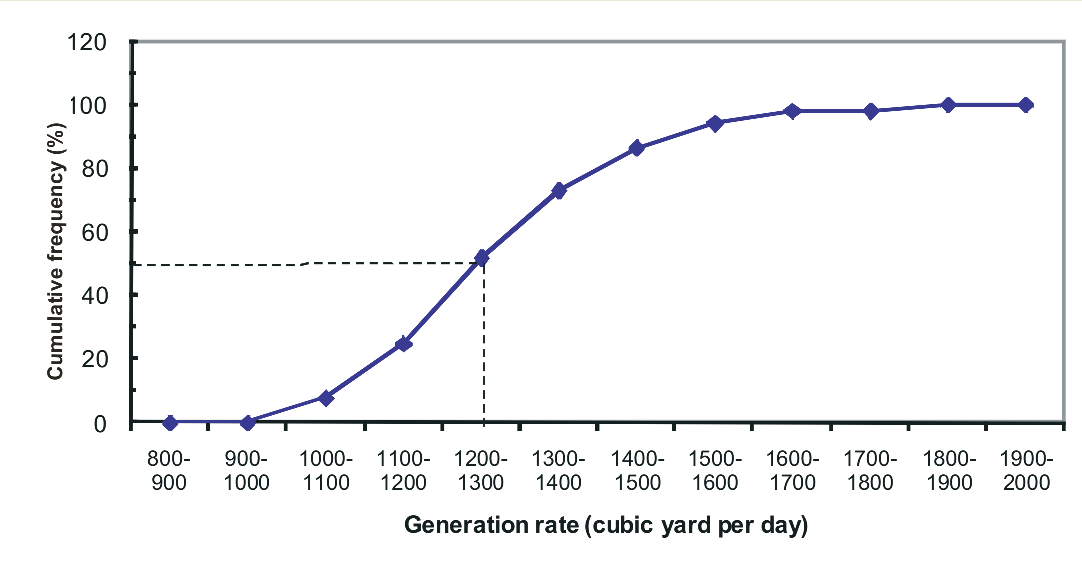
a) Histogram

Histogram can be drawn by plotting values of generation rates (col. 1) along x-axis and frequency (Col. 2) along y-axis as shown below.



b) Cumulative frequency curve

Cumulative frequency curve can be drawn by plotting generation rates (col. 1) along x-axis and cumulative frequency in percentage (Col. 4) along y-axis.



The above figure shows that for 50% of the time the collection rate lies below 1200-1300 m^3/day and 50% of the time it lies above 1200-1300 m^3/day. Therefore, we can conclude that 50% of the time the generation rate lies in a range of 800-1200 m^3/day and 50% of the time it lies in a range of 1200-2000 m^3/day.

c) Mean

$$Mean = \frac{\sum f_i x_i}{n} = \frac{68400}{52} = 1315.38 \frac{m^3}{day}$$

From the value of mean, it can be seen that the curve is not symmetric about the mean; hence the frequency curve is skewed.

d) Median

$$Median = \frac{26^{th}\ observation + 27^{th}\ observation}{2}$$

$$= \frac{1250+1250}{2} = 1250 \frac{m^3}{day}$$

e) Mode

$$\text{Mode} = 1250 \frac{m^3}{day}$$

f) Standard Deviation

$$S.D = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{145770}{52-1}} = 169 \frac{m^3}{day}$$

g) Coefficient of variation

$$CV = \frac{S.D}{\bar{x}} \times 100$$

$$= \frac{169}{1315.38} \times 100$$

$$= 12.84\,\%$$

Solved Example 2.8

Ungrouped Data

Determine the mean, standard deviation and coefficient of variation for the following solid waste generation data for a period of 10 days.

Generation rate (m^3/day)	
34	170
48	120
290	75
61	110
205	90

Solution:

This example refers to ungrouped data. In such data, f_i is unity. Set up a computational table as shown below.

Sr. No	x_i	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
1	34	-86.3	7447.69
2	48	-72.3	5227.29
3	290	169.7	28798.09
4	61	-59.3	3516.49
5	205	84.7	7174.09
6	170	49.7	2470.09
7	120	-0.3	009
8	75	-45.3	2052.09
9	110	-10.3	106.09
10	90	-30.3	918.09
Σ	1203		57716.1

a) Mean

$$Mean = \frac{\sum x_i}{n} = \frac{1203}{10} = 120.3 \quad \frac{m^3}{day}$$

b) Standard deviation

$$S.D = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{577161}{10-1}} = 80 \quad \frac{m^3}{day}$$

c) Coefficient of variation

$$CV = \frac{S.D}{\bar{x}} \times 100 = \frac{80}{120.3} \times 100 = 66.5\%$$

EXERCISES

1. Differentiate between garbage, rubbish, refuse and trash based on their composition and source.
2. What are the different types of solid wastes produced? What are different characteristics of Municipal solid waste?
3. What do you understand by unit generation rate?
4. What are typical generation rates in different countries? What do you derive from such data?
5. Describe the method devised by the ASTM for the physical composition analysis of the unprocessed municipal solid waste.
6. Population of Lahore is 8 million. Daily generation of special wastes is 400 metric tons. Average generation rate from all other sources is 0.45 kg/capita/day. Estimate the overall generation rate. Domestic component of overall generation is 20% and animals dung 25%. Calculate the daily generation of these components.
7. What are different methods for determining generation rates? Comment on their merits and demerits.
8. How does the density vary from point of generation to point of disposal for solid wastes? Comment on its importance in designing an efficient system.
9. How can you calculate the moisture content, and what is its significance?
10. It is normally very difficult to sort out the wastes at open dumps in our cities. How will you proceed to know the physical composition of the wastes keeping this constraint in view?
11. In a solid waste sample, food wastes are 25%. Carbon content in the dry food wastes is 50% and moisture content in the sample is 30%. Calculate the overall percentage of food waste carbon in the sample.
12. What future changes you expect in the composition and generation rate of Lahore solid wastes. Discuss different factors.

13. As a municipal engineer how would you go about to estimate the generation rate and composition of solid wastes for various sources of your community. If these data were needed within a month, how would you estimate the seasonal effect?

14. One hundred grams of dried refuse was found to consist of 25 grams ash, 34 grams carbon, 36 grams oxygen, 4 grams hydrogen and one gram nitrogen. Determine the empirical chemical formula.

15. How do you categorize the solid wastes on the basis of their physical composition, characteristics and chemical composition? How does this information help you in deciding about their disposal?

16. Determine the arithmetic mean, median, mode, standard deviation, coefficient of variation for the solid waste generation data for a community. Also draw the frequency histogram and cumulative frequency curve.

Generation rate (m^3/day)	Frequency (days/year)
800-900	0
900-1000	0
1000-1100	1
1100-1200	3
1200-1300	4
1300-1400	9
1400-1500	11
1500-1600	10
1600-1700	7
1700-1800	4
1800-1900	2
1900-2000	1

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3. ONSITE HANDLING STORAGE AND PROCESSING OF SOLID WASTE

The second important element in the solid waste management is the onsite handling, storage and processing. Onsite handling means the activities associated with the handling of solid waste until it is placed in the containers used for its storage before collection. It also includes the moving of loaded containers to the collection point and to return the empty containers after collection to the storage locations. Storage means the temporary storage of waste while awaiting collection. Processing involves grinding, sorting, compaction; shredding, composting and incineration etc used to (i) reduce the volume (ii) alter the physical form, or (iii) recover usable materials from solid waste [1].

The above functions have a significant effect on public health, on subsequent functional elements, and on public attitudes. Therefore, it is important to understand them. For this purpose, this chapter includes the details of each function with reasonable details.

3.1 Onsite Handling

The onsite handling methods used at residential and commercial sources are described in the following sections. The auxiliary equipments and facilities that are normally used in the industrialized countries are listed in Table 3.1.

3.1.1 Residential Waste

Household compactors are used to reduce the volume and small wheeled handcarts are used to transport containers to the pickup points in low-rise and medium rise buildings. While for high rise buildings gravity chutes, service elevators, and pneumatic conveyors are used in the industrialized countries.

Where kitchen grinders are used, food waste and other grind-able materials are discharged to the wastewater collection system after grinding.

Table 3.1: Typical equipment used for the onsite handling of solids waste

Source	Auxiliary equipment and facilities
Residential Low-rise	Household compactors, small-wheeled handcarts.
Residential Medium-rise	Gravity chutes, service elevators, collection carts, pneumatic conveyors.
Residential High-rise	Gravity chutes, service elevators, collection carts, pneumatic conveyors.
Commercial	Wheeled or castor collection carts, container trains, burlap drop cloths, service elevators, conveyors, pneumatic conveyors.
Industrial	Wheeled or castor collection carts, container trains, service elevators, conveyors.
Open areas	Vandal-proof containers
Treatment plant sites	Various conveyors and other manually operated equipment and facilities
Agricultural	Varies with the individual commodity.

Chutes, for use in apartment buildings, are available in diameters from 30 to 90 cm; the most common size is 60 cm. They are furnished with suitable intake doors, draft baffles at the intakes, door locks, sprinklers, disinfection systems, sound insulation and roof vents. Components of

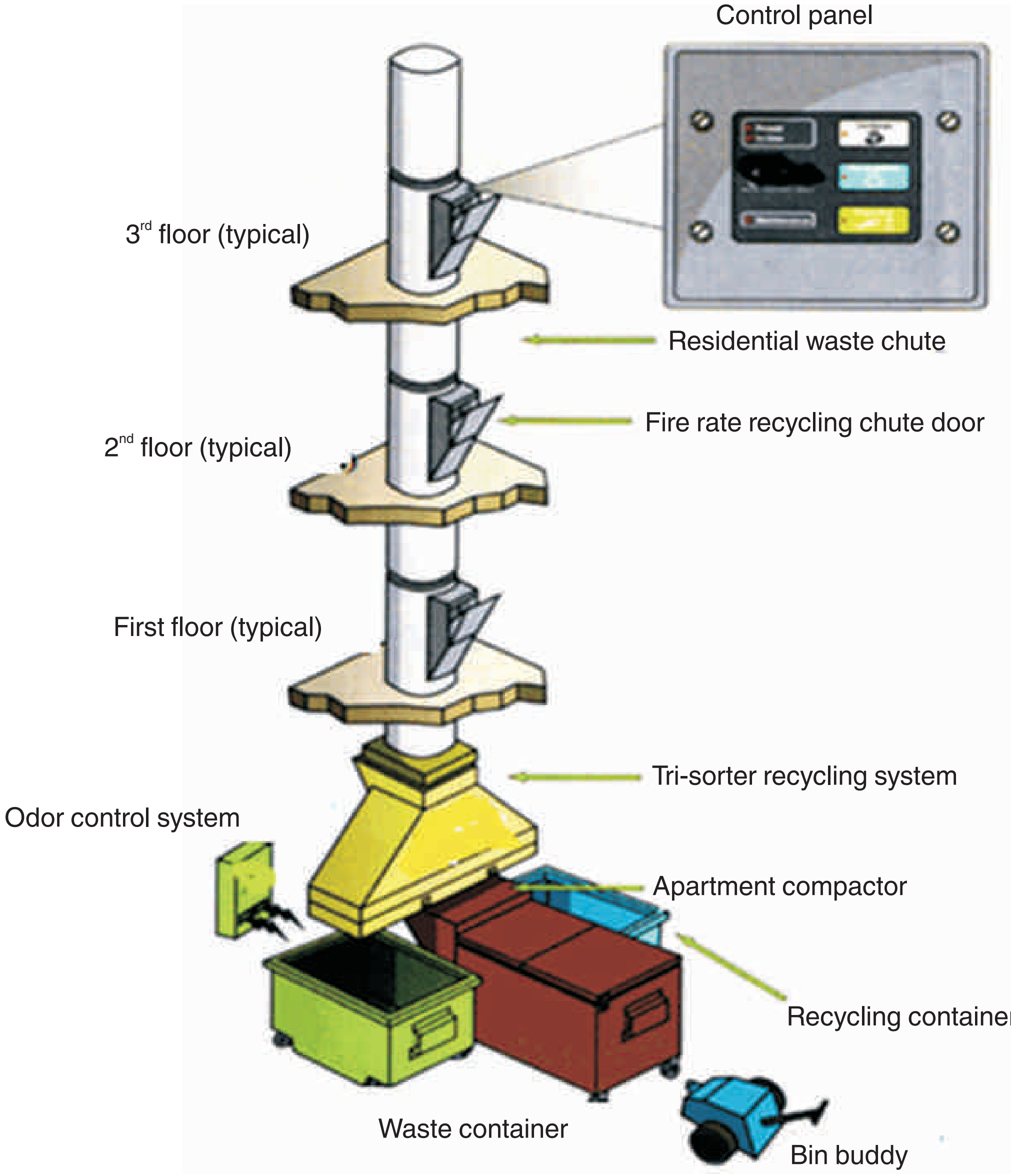


Figure 3.1: Chute system for solid waste collection in high rise buildings [1]

the chute feed system are shown in the Fig 3.1.

3.1.2 Commercial Waste

Wheeled or castor collection carts, container trains, burlap drop cloths, service elevators, mechanical conveyors and pneumatic conveyors have been used in industrialized countries according to the situation.

Manual separation of recyclables is extensively resorted to in developing countries at source, during storage and while transferring the waste to communal storage locations by using hand carts. Handcarts are, otherwise the most favorable means of handling the waste.

3.1.3 Industrial Waste

Wheeled or castor collection carts, container trains, service elevators and mechanical conveyors are the normal means used in industrialized countries for handling the waste.

3.1.4 Source Separation

Source separation is becoming increasingly successful throughout the world. It allows efficient recovery of materials, such as papers, plastics, glass, metals. In some countries source separation is accomplished by having two containers; one for "wet" waste and one for "dry" waste. Wet waste refer to the organic portion of solid waste like food waste etc. and dry waste normally refer to paper, plastics, metals etc. In Pakistan three-bin system can be used especially for the collection of recyclables: one bin for "drink cans" second for "glass and plastic bottles" and the third for "paper" waste as shown in the Fig. 3.2 below.

Figure 3.2: Three bin system for recyclable waste collection

The programs for multi-bin system, which are succeeding in different parts of the world, attribute their success to public education, reliable collection service, and an economic incentive – whereby costs of collection are shown to be lowered by the cooperative citizens' efforts. Color coding schemes are also used for the onsite segregation of the municipal solid waste as shown in the Fig 3.3.

Figure. 3.3: Color coding for onsite solid waste segregation

3.2 Onsite Storage

A golden rule of solid waste management is "containerization" that states "once picked up solid waste should never be thrown again on the ground; always put it in the container and from small container into bigger container or a collection vehicle". In one word it can be expressed as "containerization".

The factors which need to be considered for onsite storage of solid waste are (i) type of container (ii) container locations, and (iii) public health and aesthetics [1].

3.2.1 Types of Containers

The storage containers may be divided on the basis of their uses as individual units or communal units. And on the basis of their size they may be small, medium and large containers.

Separate or individual units are mostly small size containers with size up to 200 liters. They may be either non-standardized or standardized by the collection agency. Non-standardized containers range from temporary containers such as cartons, plastic bags, baskets, wooden crates to regular containers such as plastic or metal bins. The non-standardized units are those which are not originally designed for use in solid waste management, and are also called make-shift type containers. Their advantage is that they do not cost the owner or collection agency. However, their disadvantage is that, the containers may be flimsy and otherwise difficult or dangerous to handle. Standardized containers with lids are usually plastic or metal bins specifically made for use in SWM and should carry the name and address of the owner in standardized format. They are proven to improve collection productivity, being conveniently handled by the collectors. Standardized containers, have one major disadvantage that they are costly and it is needed to keep them clean regularly.

Communal storage units may be either stationary or lift-able. Stationary units include masonry or concrete structures of different shapes or large mild steel containers with or without doors as shown in the Fig. 3.4, 3.5 and 3.6.

Figure 3.4: Locally used solid waste collection containers

The stationary units are being used locally but none of them is recommendable due to the following disadvantages.

i) Waste is typically strewn about the site by scavenging activities of animals, people and winds.

ii) Waste is thrown around and not inside these units.

iii) The collection vehicle's time is wasted due to manual lifting of wastes.

Liftable units are large steel drums or containers. They can be lifted mechanically by collection vehicles. They may be (a) medium size or (b) large size containers.

(a) Medium size containers are used for multi-storey buildings, densely populated areas, commercial and industrial establishments. Their size varies from 0.5 to 4 m^3.

Figure 3.5: Medium sized lift-able waste collection containers

(b) Large size containers are employed in multi storey buildings, large industrial establishments and for demolition and construction waste. Their size ranges from 6 to 40 m^3.

Figure 3.6: Large sized lift-able waste collection containers

3.2.2 Capacity of Containers

Based on per week (7 days) service, at least 50% excess capacity should be allowed. And in case of 6 days per week service at least 100% excess capacity needs to be provided. Capacity should be chosen on the basis of peak loading periods, of the year.

3.2.3 Storage Locations

For effective collection of the solid waste from the households, institutions, commercial centers, industries, and newly developing colonies, placing the storage bins or container is an important aspect as the collection is the major component of the solid waste management system. Typical locations are given in Table 3.2.

Table 3.2: Planning for temporary storage locations of solid waste collection

Residences Area	On the side of the main entrance, garage or lawn, at rear of the house or other designated places
Commercial Area	For commercial areas and high-rise buildings, specially built platforms or enclosures to be provided in the plans
Industries Area	For convenient pickup, a place to be fixed in consultation with the collection agency.
New Colonies/ Development Plans	In such plans the places should be fixed for provision of Communal Storage units on the roadsides at convenient locations in accordance with the principles of aesthetics and sanitation.

3.2.4 Public Health and Aesthetics

Infestation of areas used for the storage with vermin and insects need proper sanitation. This requires use of lids, periodic washing of containers and storage areas and efficient removal of the biodegradable materials in warm climate.

Production of odor and unsightly conditions can also be controlled by reasonable collection efficiency, tight lids on the containers, scrubbing the containers and by periodic washing of the containers.

3.2.5 Litter Bins for Primary Collection

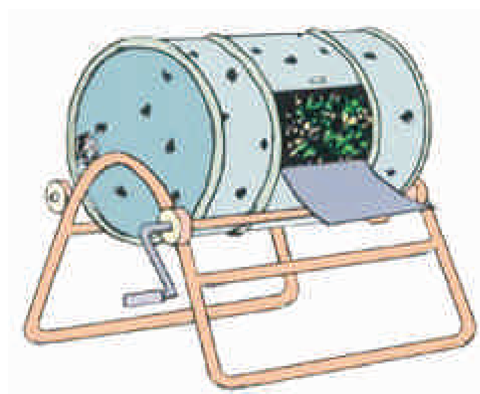
Besides the containers, litter bins with a capacity of 20-25 kg are to be provided on sides of streets for pedestrian's convenience throughout the city. Lahore waste management company has placed 2,650 litter bins alongside the roads in urban areas of Lahore.

This will help in keeping the streets clean and litter free. They are mounted on a pole or pedestal. It has hinged connection with the poles (Fig. 3.7). Hinged connection makes their turning easy and while being mounted these can be emptied in a hand cart.

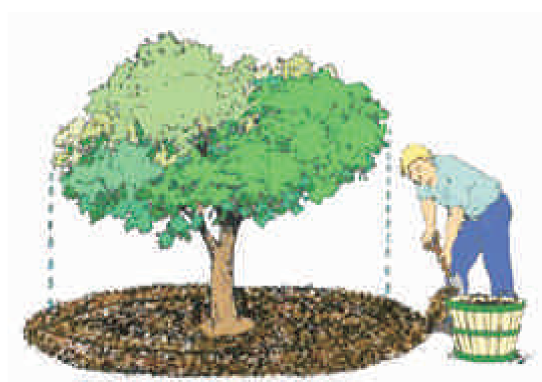
Figure 3.7: Road side litter bins in Lahore

3.3 Processing of Solid Waste at Residences

Solid waste processing at site reduces the volume, helps in recovery of usable materials and alters physical form of the waste. The most common processes used for the purpose include food waste grinding, component separation, compaction, incineration and composting.



(a) Rotating barrel composter



(b)Lawn Mulching

Figure 3.8: Household composting system

Backyard incineration is no longer allowed in most urban areas of industrialized countries. Composts at the backyard can be quickly made by using a barrel [2] as shown in Fig. 3.8 (a). Such structures can be rotated.

Lawn mulching is another type of composting which involves leaving grass clippings from newly mowed lawn where they were cut (Fig.3.8 b). In time, the grass clippings will be composted and incorporated into the humus.

EXERCISES

1. What are the functions of the following w.r.t. solid wastes? Indicate the situations where they are employed with general sizes (i) Gravity chute (ii) Service elevator (iii) Pneumatic conveyors (iv) Burlap drops (v) Vandal-proof containers.
2. What aesthetic and public health considerations are important for onsite storage?
3. What are the different types of onsite storage facilities used in advanced countries, and what types you recommend for different areas of Lahore?
4. What types of onsite storage facilities exist in our urban setups? What improvements you propose in them?
5. List the advantages gained by an efficient storage system.
6. What are the different types of onsite processing facilities available in advanced countries? Discuss their utility in different situations in Pakistan.
7. What do you mean by onsite handling? Name the appliances used and discuss their utility in different situations in Pakistan.

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4. COLLECTION OF SOLID WASTE

The term "collection" includes not only the gathering or picking up of solid waste from the various sources, but also hauling of these wastes to the disposal site or transfer station and unloading there.

4.1 Phases of Solid Waste Collection

Solid waste collection is a multiphase process having at least five distinct phases as shown in the Fig 4.1[1].

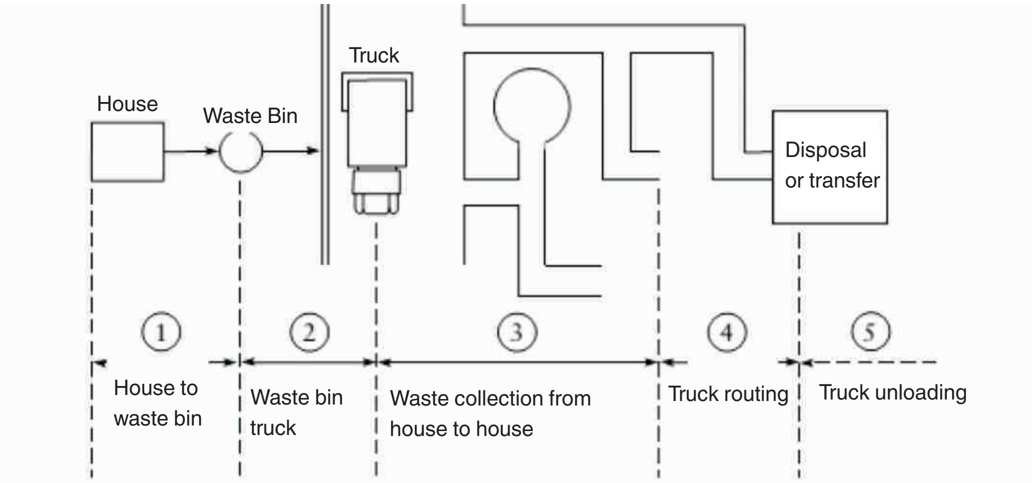

Figure.4.1: Different phases of municipal solid waste collection

Phase I: Transferring the solid waste to the waste collection bins placed inside or outside the home by the individual house owner.

Phase II: Transfer the refuse from bins to collection truck, which is generally done by the collection crew of the solid waste management department.

Phase III: Collection of the solid waste from several homes, commercial and business centers, educational institutions etc.

Phase IV: Transfer of the collected waste on the planed routes in order to maximize the collection efficiency, reducing the fuel consumption and reducing the haul distance. The route is planned in such a way that the last collection point is at minimum distance from the waste disposal or processing facility.

Phase V: Last phase of the solid waste collection system is the transfer to the disposal or processing facility as planned during the siting stage of the landfill or processing facility.

While hauling and unloading are similar for most collection systems, the collection or picking of waste varies with facilities and locations. The collection operation is considered with respect to:

a) Types of pick-up services
b) Types of collection systems
c) Analysis of collection systems
d) Setting up of collection routes

4.2 Type of Pick-Up Services

Types of pick up services are different for non-separated (commingled) and separated waste. These services further vary with respect to types of residential areas or commercial/industrial activities.

4.2.1 Pick-Up Services for Low-Rise Detached Dwellings

Five different types of services are provided for such areas in western countries (a) Curbside service (b) Alley service (c) Set out and setback service (d) Setout service. (e) Backyard carry service.

a) Curbside Service

The residents put their loaded containers on the curbside of the street on the specified days, and after being emptied by the collection crew, take back the empty containers inside the premises.

b) Alley service

In alley service the containers are placed by the residents in the alleys instead of at the curbsides. Rest of the process is the same as above in the curbside service. This is just to keep the strees tidy.

c) Set out and setback service

The collection crew of the agency is responsible to bring out the loaded containers from within the premises and put them back inside the premises.

d) Setout service

In this service the collection crew is responsible to bring out the loaded containers from within the dwellings, but the empty containers will be left on the curbside. The residents will take back the empty containers.

e) Backyard carry service

The collection vehicle is driven to the backyard of large bungalows for the service to be performed by the crew.

These services are performed manually as well as mechanically. The manual methods include (i) direct lifting and emptying into collection vehicle (ii) rolling of loaded containers on their rims up to the vehicle and emptying (iii) using small lifts for rolling loaded containers and (iv) using tote containers or drop cloths (Fig. 4.2).

Figure 4.2: Use of tote containers in San Francisco [1].

4.2.2 Pick-Up Services for Low and Medium Rise Apartments

Curbside pick-up service is common in such areas. The containers will be rolled on to the collection vehicle where they will be emptied manually or mechanically (Fig. 4.3).

(a) Manual emptying

(b) Mechanical emptying

Figure. 4.3: Collection of wastes containers placed at curb by homeowner

4.2.3 Pick-Up Services for High Rise Apartments

Depending on the size and type of containers used, the waste from the containers is emptied into the collection vehicle by mechanical system available with the vehicle. The mechanical system can be attached to front or rear end of the vehicles (Fig. 4.4).

4.2.4 Pick-Up Services for Commercial / Industrial Areas

Depending on the size and type of container used, the contents of the containers may be emptied manually or mechanically into the collection vehicle. To minimize the difficulty due to traffic congestion, mechanized collection can also be performed during the early morning or late evening hours.

(a)

(b)

Figure 4.4: Self-loading collection vehicle equipped with internal compactor: (a) front loader (b) rear loader [2].

4.3 Types of Collection Systems

Collection systems used in the industrialized countries may be categorized with respect to their mode of operation, the equipment used and the type of waste collected. With respect to mode of operation, the collection systems are of two types: (1) Hauled Container System (HCS) and (2) Stationary Container System (SCS). These two systems with their equipment and personnel requirements are described below:

4.3.1 Hauled Container System

In this system, the loaded containers are taken to the disposal site or transfer facility for unloading, and empty containers are returned to their original location or any other location. Advantages and disadvantages of HCS are given in Table 4.1 [2].

Table 4.1: Advantages and disadvantages of HCS

Advantages of HCS	Disadvantages of HCS
It is ideally suited for sources with high generation rate,	Use of very large containers may reduce their utilization factor.
The use of large containers reduces handling time as well as unsightly accumulations in numerous small containers.	Each container requires a round trip, which increases the haul distance and thus the cost, if the disposal site is located at longer distance
Flexible i.e., containers of many different sizes and shapes can be used for different sources.	

HCS is further of two types: i.e.

A. Hauled container system (conventional mode)

In this system the emptied containers are brought back at the same locations, from where they were picked up. The working is shown by the schematic in Fig. 4.5(a).

B. Hauled container system (exchange container mode)

In this system the collection vehicle carries one extra empty container, puts the empty container at first pick-up location, picks the loaded container, hauls the loaded container to the disposal site, and returns the empty container to the next pick up location and so on. At the end of the day's work, the last container, emptied by the vehicle is taken to the garage. The working is shown by the schematic in Fig. 4.5(b).

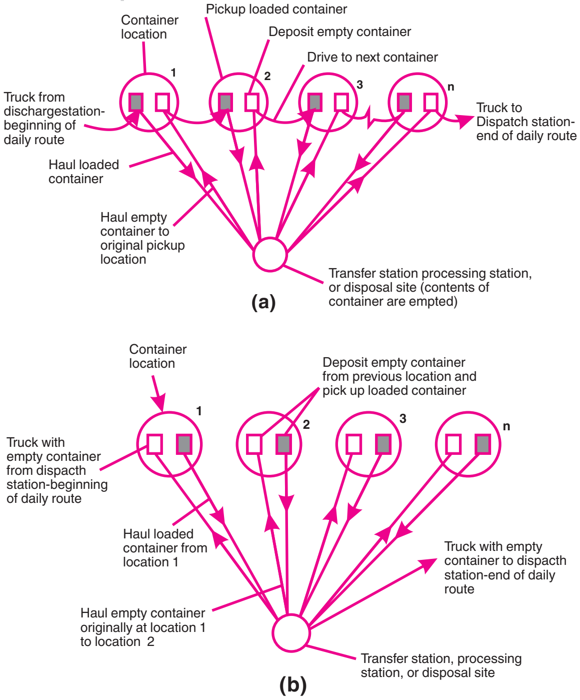

Figure 4.5: Schematic of operational sequence for hauled container system (a) Conventional mode (b) exchange container mode [2].

4.3.1.1 Types of Collection Vehicles Used in HCS

Three different vehicles are used in HCS i.e., hoist truck, tilt-frame truck and trash-trailer.

a) Hoist truck systems

These systems are useful for demolition and construction waste or industrial rubbish or for pick up from a few places with large accumulations as shown in Fig. 4.6.

Figure. 4.6: Collection vehicle used to haul and empty large containers (2 to 10 m^3). Container hoist and unloading mechanism is mounted on truck frame [2].

2) Tilt frame container systems

These systems, also known as drop or debris boxes, are suitable for sites where generation rate warrants the use of large containers. Such large containers, in conjunction with stationary compactors are finding widespread use in apartment complexes, commercial services and transfer stations in advanced countries (Fig. 4.7 (a) and (b)).

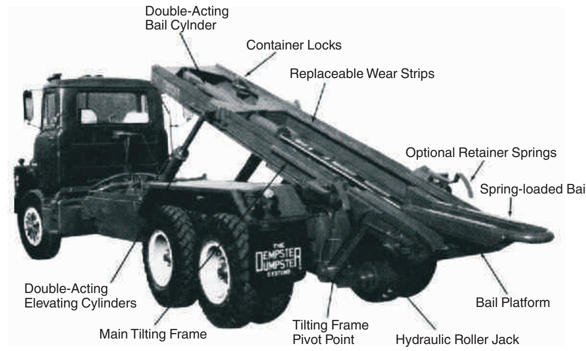

Figure 4.7 (a): Truck with tilt-frame loading mechanism [2].

Figure 4.7 (b): Contents of large tilt-frame loaded container being emptied at landfill [2].

c) Trash-trailer systems

Such systems are used especially for heavy rubbish such as sand and metal scrap and for collection of demolition waste (Fig. 4.8).

Figure 4.8: Contents of trash-trailer used for demolition waste being unloaded at landfill [2].

4.3.1.2 Comparison of Conventional Mode and Exchange Container Modes

Comparison between the two modes is shown in the Table 4.2 below.

Table 4.2: Comparison of conventional and exchange modes of HCS.

HCS Mode	Advantages	Disadvantages
Conventional	No need of extra container. No need for extra space for placing storage containers	Needs more time, as distance required to be covered per trip is more.
Exchange container	Time for returning back to first container site and driving time between containers is saved	One extra container is required. Double space is required for placement of storage container at each site.

4.3.2 Stationary Container System

In this system the loaded containers are emptied into the body of the collection vehicle, while the containers are put back at their places. A number of containers can thus be emptied per trip of collection vehicle. The loaded vehicle then moves to the disposal site or transfer station, is unloaded there and starts its next trip. The schematic of the operation is shown in Fig. 4.9. The collection vehicles used are usually compactor trucks.

These systems may be used for all types of wastes. These are of two types (i) with mechanically loaded vehicles (ii) with manually loaded vehicles.

A) SCS with mechanically loaded vehicles

A variety of container sizes may be used with these systems as shown in Fig. 4.10. These systems are very commonly used for collection of residential waste. They are not suitable for industrial or construction and demolition wastes.

Figure 4.10: Mobile mechanical waste compactor for waste collection [3].

B) SCS with manually loaded vehicles

These systems are also normally employed for collection of residential wastes (along with litter). This system can compete with mechanically loaded vehicles, because in many residential areas many individual pick up points may be

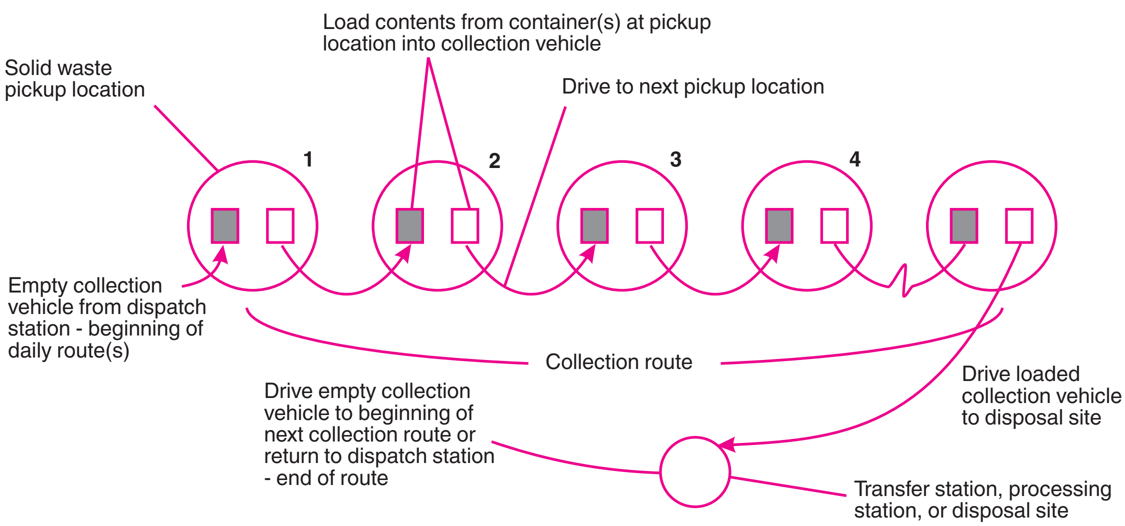

Figure 4.9: Schematic of operational sequence for stationary container system [2].

inaccessible to mechanized self-loading collection vehicles. Examples of such systems are given in Fig. 4.11, which are normally rear loaded.

Figure 4.11: Manually loaded vehicles

4.3.2.1 Types of Vehicles used in SCS

Stationary container systems may be used for the collection of all types of wastes. The types of vehicles used vary according to the type and quantity of wastes to be handled. Self-loading compactors and manually loaded compactors are the two main types. Manually loaded compactors are used for residential collection because many individual pick-up points are inaccessible for the self-loading compactors.

4.3.3 Comparison of HCS and SCS

Comparison of hauled containers system and stationary containers system is given in Table 4.3.

Table 4.3: Comparison of the HCS & SCS

Hauled container system	Stationary container system
Container size and utilization factor are important in HCS	Container size and utilization factor are not important in SCS.
Trips to the MRF*, transfer station or disposal site is made with container.	Trips to the MRF, transfer station or disposal site are made after filling the collection vehicle by emptying a number of containers.
The utilization of the driver and vehicle is not optimized in HCS.	The utilization of the driver and the vehicle in terms of the quantities of wastes hauled is considerably greater than HCS.

*MRF – Material recovery facility.

4.4 Analysis of Collection Systems

Analysis refers to finding out number and capacity of vehicles, labor required, time required and cost involved in a particular collection system. For the purpose of analysis, the collection activities may be broken down into different unit operations as given below [4].

a) Pick-up

It is denoted by 'P'. It is the time spent in pickup of container.

b) Haul

It is denoted by 'h'. It is time for transporting solid waste to disposal site and coming back.

c) At Site

It is denoted by's'. It is time spent on disposal site. It includes time spent waiting to unload as well as time spent for unloading.

d) Off-Route

It is denoted by 'W'. It is time spent on activities that are non-productive from the point of view of the overall collection operation. They may be (a) necessary and (b) unnecessary.

- **Necessary off-route time includes**
  - i) Time spent checking in and out in the morning and at the end of day.
  - ii) Time spent driving to the first pick-up point.
  - iii) Time lost due to unavoidable traffic congestion.
  - iv) Time spent on equipment repair and maintenance.

- **Unnecessary off-route time includes**
  - i) Time spent on lunch in access of the stated lunch period.
  - ii) Time spent on taking un-authorized tea breaks.
  - iii) Time spent in talking to friends.

The off-route time factor varies from 0.1 to 0.25; average of 0.15 is representative of most operations.

e) Time per Trip

It is denoted by 'T'. It is time taken for one trip from container location to disposal site and back to the next container location. It is equal to the sum of all above unit operations (From 1 $\longrightarrow$ 4).

4.4.1 Analysis of Hauled Container Collection System

Refer to Fig. 4.4 which shows the schematic of hauled container system with conventional mode. For one day's work, an empty truck comes from the garage to the work area, picks up the loaded container from the first location, goes to the disposal site or transfer station or MRF, unloads the wastes and hauls back the empty container to the original location, deposits the empty container and moves on to the second location. It repeats this process by performing a number of trips until at the end of the day's work it goes back to the garage.

For the purpose of the system's analysis, the time spent in various activities will be counted as shown in Fig. 4.12.

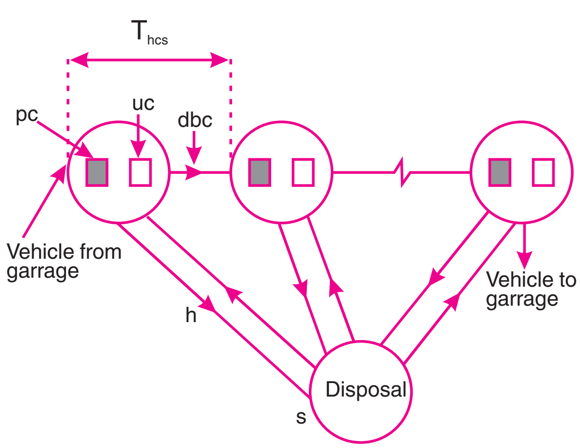

Figure. 4.12: Time spent in various activities

Let

T_{hcs} = Average total time spent per trip (hrs) to serve one container.

(i.e. time taken by the vehicle from start of picking up of one container to the starting of pick up of next container).

pc = Average time spent in pick up of filled container (hrs)

h = Average haul time to disposal site and back (hours per trip).

s = Average time spent at disposal site (hours per trip)

uc = Average time spent in redeposit/unloading of the emptied container (hours/trip).

dbc = Average haul time spent in driving between two container locations.

Then,

$$T_{hcs} = pc + uc + dbc + h + s$$

Due to human factors involved, some allowance is to be given for off-route activities, like traffic jams tea breaks etc. Let W be the fraction of time spent in off-route activities then:

$$T_{hcs} = \frac{pc + uc + dbc + h + s}{1 - W}$$

Now if

t_1 = Time to travel from garage to work area.

t_2 = Time to travel from work area to garage.

H = Total working hours per day.

N_d = Number of trips per day.

Then

$$N_d = \frac{[H(1 - W) - (t_1 + t_2)]}{T_{hcs}}$$

Also haul time to disposal site depends upon the speed and distance traveled. It can be expressed as:

$h = a + bx$
= Haul time (hours per trip).
x = Round trip distance (km).
a = Haul constant (Hours per trip).
b = Haul constant (Hours per km).

$$T_{hcs} = \frac{pc + uc + dbc + h + s}{1 - W}$$

Similarly,

$dbc = \acute{a} + \acute{b}x$

When $\acute{a}, \acute{b}$ = Haul constants. (For travel between container locations.)

x = Average distance traveled between two container locations.

The use of these equations is illustrated in Examples 4.1 & 4.2.

Solved Example 4.1

Analysis of a hauled container system

Solid waste from a new industrial park is to be collected in large containers (drop boxes), some of which will be used in conjunction with stationary compactors. Based on traffic studies at similar parks, it is estimated that the average time to drive from the garage to the first container location (t_1) and from the last container location (t_2) to the garage each day will be 15 and 20 min, respectively. If the average time required to drive between containers is 6 min and the one-way distance to the disposal site is 25 km (speed limit: 90 km/h), determine the number of containers that can be emptied per day, based on an 8-hour workday. Assume the off-route factor, W, is equal to 0.15. The missing data may be assumed.

Data given:

$pc + uc$ = 0.4 h/trip (assumed)
dbc = 0.1 h/trip
a = 0.016 h/trip (assumed)
b = 0.018 hours/km (assumed)
x = 50 km
W = 0.15
s = 0.133 hours/trip (assumed)
$t_1 + t_2$ = 0.25 + 0.35 = 0.6 hours
H = 8 hours

Required Nd (Number of Containers/day) = ?

Solution:

$$\text{Time/trip} = T_{hcs} = \frac{pc + uc + dbc + a + bx + s}{1 - W}$$

$$\text{h/trip} = \frac{0.4 + 0.1 + 0.016 + 0.018 \times 50 + 0.133}{1 - 0.15} = 1.8$$

It is evident that:

$H = t_1 + t_2 + N_d \times T_{hcs}$
$8 = 0.6 + N_d \times 1.8$
$Nd = 7.4 / 1.8 = 4.02 \times 4 = 16.08$

Solved Example 4.2 [2]

Because of a difference of opinion among city staff members, you have been retained as an outside consultant to evaluate the collection operation of the city. The basic question centers around the amount of time spent on off-route activities by the collectors. The collectors say that they spend less than 15 percent of each 8-hour workday on off-route activities; management claims that the amount of time spent is more than 15 percent. You are given the following information that has been verified by both the collectors and management:

(a) A hauled container system, without container exchange, is used.
(b) The average time spent driving from yard to the first container is 20 min, and no off-route activities occur.
(c) The average pickup time per container is 6 min.
(d) The average time to drive between containers is 6 min.
(e) The average time required to empty the container at the disposal site is 6 min.
(f) The average round-trip distance to the disposal site is 10 km/trip, and the haul equation ($h = a + bx$) constants are a = 0.004 h/trip and b= 0.02 h/km.
(g) The time required to redeposit a container after it has been emptied is 6 min.
(h) The average time spent driving from the last container to the corporation yard is 15 min, and no off-route activities occur.
(i) The number of containers emptied per day is 10.

From this information, determine whether the truth is on the side of the collectors or the management.

Solution:

Data given:

H	=	8 hours	a	=	0.004h/trip
pc	=	6 min = 0.1 h	b	=	0.02 h/km
uc	=	6 min = 0.1 h	x	=	10 km
dbc	=	6 min = 0.1 h	t_1+t_2	=	35 min
	=	0.58 h.			
s	=	6 min = 0.1 h	N_d	=	10
W	=	?			

While serving 10 container locations, 9 trips will involve dbc and one trip i.e., last trip will be without dbc. Accordingly,

$$H = t_1 + t_2 + 9 \times \frac{pc + uc + dbc + a + bx + s}{1 - W} + \frac{pc + uc + a + bx + s}{1 - W}$$

$$8 = 0.58 + 9 \times \frac{0.1+0.1+0.1+0.004+0.02\times10+0.1}{1 - W} + \frac{0.1+0.1+0.004+0.02\times10+0.1}{1 - W}$$

or W = 0.199 = 19.9 %.

Since W > 15%, therefore, management is right in pointing out that more than 15% time is spent on off-route activities.

4.4.2 Analysis of Stationary Container Collection System

As the loading process in mechanically loaded and manually loaded vehicles differs, both the systems are dealt separately:

A) Mechanically loaded collection vehicles

For these systems the time per trip may be expressed as:

$$T_{scs} = \frac{P_{scs} + h + s}{1 - W} = \frac{P_{scs} + a + bx + s}{1 - W}$$

Where

P_{scs} = Pick-up time per trip.

P_{scs} = C_t (uc) + (N_p – 1) (dbc)

Where

C_t = Number of containers emptied per trip.

uc = Average unloading time per container

N_p = Number of pick up locations per tip.

dbc = Average drive time between two container locations.

The use of this formula is illustrated in Example 4.3.

Solved Example 4.3

Comparison of solid waste collection systems [2]

A private solid waste collector wishes to locate a disposal site near a commercial area. The collector would like to use a hauled container system but fears that the haul costs might be prohibitive. What is the maximum distance away from the commercial area that the disposal site can be located so that the weekly costs of the hauled container system do not exceed those of a stationary container system? Assume that one collector-driver will be used with each system and that the following data are applicable.

i. Hauled container system

a) Quantity of solid wastes = 300 m^3/wk
b) Container size = 8 m^3/trip
c) Container utilization factor = 0.67
d) Container pickup time = 0.033 h/trip
e) Container unloading time = 0.033h/trip
f) At-site time = 0.053 h/trip
g) Overhead costs = Rs. 400/wk
h) Operational costs = Rs. 15/h of operation.

ii. Stationary container system

a) Quantity of solid wastes = 300 m^3/wk
b) Container size = 8 m^3/location
c) Container utilization factor = f= 0.67
d) Collection vehicle capacity = 30 m^3/trip
e) Collection vehicle compaction ratio = r = 2
f) Container unloading time = 0.05h/container
g) Overhead costs = Rs. 750/wk
h) Operational costs = Rs. 15/h

i) At site time = 0.1 h/trip

Average Distance between containers

= 0.1 km

a' = 0.06 h/trip

b' = 0.067 h/km

a = 0.022 h/trip

b = 0.022 h/km

Solution:

Here we need to compare the weekly costs of both the systems, assuming that with a round trip distance of x km, the cost of both the systems will be the same. We take up each system separately.

a) Hauled container system

Total cost per week = Overhead cost per week + operational Cost per week. (i)

Overhead cost/week = Rs. 400 (given)

Operational cost = Cost per hour x No. of trips/week x Time/trip (hrs) (ii)

Cost per hour = Rs. 15

$$\text{No. of trips/week} = \frac{\text{Amount of Waste / week}}{\text{Amount / Container}}$$

$$= \frac{300\,m^3}{\text{Container Size} \times \text{Utilization Factor}}$$

$$= \frac{V}{cf} = \frac{300\ m^3}{8\,m^3 \times 0.67} = 56$$

$$\text{Time/Trip} = T_{hcs} = \frac{pc + uc + dbc + a + bx + s}{1 - W}$$

$$= \frac{0.033 + 0.033 + (0.06 + 0.067 \times 0.1) + 0.022 + 0.022x + 0.057}{1 - 0.15}$$

$$= \frac{0.208 + 0.022\,x}{0.85} = 0.245 + 0.026x$$

Putting the values in equation (ii)

Operational cost = 15x56 (0.245 + 0.026x)

= 206 + 21.74x

Total Cost/Week = Y_{hcs} = Overhead Cost

+ Operational Cost

= 400 + 206 + 21.74 x

= 606 + 21.74 x (iii)

b) Stationary Container System

Total cost/week = Y_{scs} = Overhead cost/week

+ Operational cost/week (iv)

Overhead cost/week = Rs. 750

Operational cost/week = Cost/hr x No. of trips/week x time/trip (hrs)

Cost per hour = Rs. 15

No. of trips/week

$$= \frac{\text{Amount of Waste/ Week}}{\text{Capacity of Compactor Truck} \times \text{Compaction Ratio}}$$

$$= \frac{V}{vr} = \frac{300\,m^3}{30\,m^3 \times 2} = 5$$

$$\text{Time per trip} = T_{SCS} = \frac{P_{scs} + a + bx + s}{1 - W}$$

Where P_{scs} = $C_t(uc) + (N_p - 1)\,dbc$

$$\text{Where } C_t = \frac{\text{Vol. carried / trip}}{\text{Vol. / Container}} = \frac{vr}{cf} = \frac{30 \times 2}{8 \times 0.67} = 11$$

N_p = Number of pick-up locations/trip = 11

So P_{scs} = 11(0.05) + (11-1) [0.06 + 0.067x 0.1]

= 1.22 hr/trip

$$\text{and time/trip} = T_{scs} = \frac{1.22 + 0.022 + 0.022\,x + 0.1}{1 - 0.15}$$

= 1.579 + 0.0259x

So,

Total cost/week = Y_{scs} = Overhead cost

+ Operational cost

= 750 + 15 5 (1.579 + 0.0259x)

= 750 + 114.4 + 1.94x

= 864.4 + 1.94x

c) Equating the two costs

Y_{hcs} = Y_{scs}

606 + 21.7x = 864.4 + 1.94x

or x = 13.4 km

So that one way distance = 13.4/2 = 6.7 km

By plotting the weekly costs against the round trip distance, shows that HCS is economical for shorter distances and SCS is economical for longer distances (See Fig. 4.13).

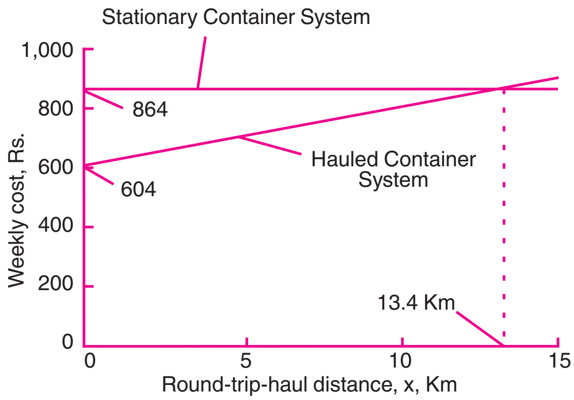

Figure 4.13: Weekly cost versus round-trip-haul distance for example 4.3.

B) Manually loaded vehicles

In this system, the pick-up time per location t_p depends on the time required to drive between the container locations and the number of containers per pick up location.

This can be represented by

t_p = $dbc + 0.18\,C_n + 0.014\,PRH$ ...(vi)

Where t_p = Average pick up time per pick-up location.

dbc = average time spent to drive between two pick-up locations

C_n = Number of containers served/location.

PRH = Percent rear of the house.

If N_p = Pick-up locations served per trip.

P_{scs} = total pick-up time per trip.

n = Number of collectors used per vehicle

Then $$P_{scs} = \frac{N_p \times t_p}{60 \times n}$$

and $$T_{scs} = \frac{P_{scs} + a + bx + s}{1 - W}$$

The size of the vehicle can also be determined, if N_p is known by using the equation.

$$v = \frac{N_p \times V_p}{r}$$

Where v = Volume of the collection vehicle.

r = Compaction ratio.

N_p = Number of pick-up locations per trip.

V_p = Volume of waste / pick-up location.

The use of these equations is illustrated in Example 4.4.

Solved Example 4.4

Analysis of SCS with manual loading vehicle [2]

The agency responsible for the collection of solid wastes presently allows two containers per service, picked up at the backyard. Consideration is being given to limiting backyard service to one container only; the remaining services would be allowed two containers at curbside. About 10 percent of all services would be expected to ask for the backyard service. How many additional containers can be collected per day? At present there are 300 collection stops per day. Assume that the average pickup time per service can be estimated using Eq. (vi).

Solution:

1. For the present system determine the collection time using Eq. (vi).

Collection time

= [(0.72 + 0.18(2) + 0.014(100)] min/service x (300 services)

= (0.72 + 0.36 + 1.40) (300)

= 744 min

2. For the new system determine the total number of pickup locations Tp that can be picked up if the proposed new service is instituted. 90% (0.9) services are from curb side and 10% (0.1) from rear of house.

Collection time

= [(0.72 + 0.18(2) + 0.014(0)] min/service x (0.9 Tp) + (0.72 + 0.18(1) + 0.014 (100)] min/service x (0.1 Tp)

744 = (0.72 + 0.36) (0.9 Tp) + (0.72 + 0.18 + 1.40) (0.1 Tp)

744 min = 1.20 Tp

$$Tp = \frac{744}{1.20} = 620 \text{ services}$$

3. Determine number of additional containers that can be collected.

Containers collected at present

= (2 containers / service) (300 services)

= 600 containers

Containers collected, proposed

= (2 containers / service) (0.90) (620 services)

+ (1 container/service) (0.10) (620 services)

= 1116 + 62 = 1178 containers

Additional containers collected per day = 1178 – 600 = 578 containers.

4.5 Design of Collection Routes

Analysis of collection system provides vehicle and labor requirements information. The next step is to laydown/decide the collection routes. This exercise, i.e. chalking out of the best collection routes, is necessary to use both work force and equipment in the best possible way. This exercise is actually a trial and error process. There are no fixed rules that can be applied to all situations. Following guidelines/factors should be kept in mind while laying out routes.

4.5.1 Guidelines and Considerations

For efficient use of collection vehicles and the staff, design of collection routes is very necessary. A few general guidelines for this exercise are as follows:

i) Existing policies, regulations regarding S.W.M. must be identified.

ii) Existing system conditions such as crew sizes, vehicle types must be coordinated.

iii) All the vehicles should almost travel equal distances, and carry equal amount of loads.

iv) When possible, routes should begin and end near arterial streets of the city.

v) The first container should be served from the farthest end and the last container from nearest to the disposal site.

vi) In hilly areas the route should start from the top of the grade and proceed downward as the vehicle becomes loaded.

vii) Wastes generated at the traffic congested locations should be collected in early hours of the day.

4.5.2 Procedure for Developing Layout of Collection Routes

The procedure of layout of collection routes involves four steps:

Step 1: Preparation of location map showing the pickup locations and the peculiar data for HCS or SCS.

Step 2: Data analysis, and preparation of information summary table.

Step 3: Preliminary layout of routes.

Step 4: Evaluation of preliminary routes and development of balanced routes by hit and trial. The application of this procedure is illustrated as follows:

Step 1 is general for both hauled container system and stationary container system, while steps 2, 3 and 4 are different for the two systems.

Following is the procedure for these four steps.

Step 1: Preparation of location map

Prepare a map showing the commercial, industrial, or housing area. Plot the following data for each solid waste pickup point location i.e., number of containers, collection frequency and the estimated quantity of wastes to be collected per trip. The use of following symbols will help.

HCS	SCS Mechanical Loading
F/N	$\frac{SW}{N/F}$

Where F = Collection Frequency
N = Number of containers.
SW = Solid waste/container/trip.

Depending on the size of the area and the number of pick up points, the area should be sub-divided into rectangular and square areas-corresponding roughly to functional land use area.

Steps 2, 3 & 4 for Hauled Container Systems

Fig. 4.14 shows a hypothetical functional use area with pick up locations marked with additional data as following.

Collection operation = 5 days per weak
Average number of trips per day = 9

Step 2: Data analysis

From Fig. 4.14 count the number of pickup locations, each of which receives the same collection frequency and fill these numbers in column 1 and 2 of Table 4.4 as shown. Next determine the number of containers receiving the same collection frequency to be collected each day, as shown in column 4 through 8 of the same table. This distribution should be done, so that almost equal numbers of trips are made by all the vehicles. With this information the collection routes can be laid out.

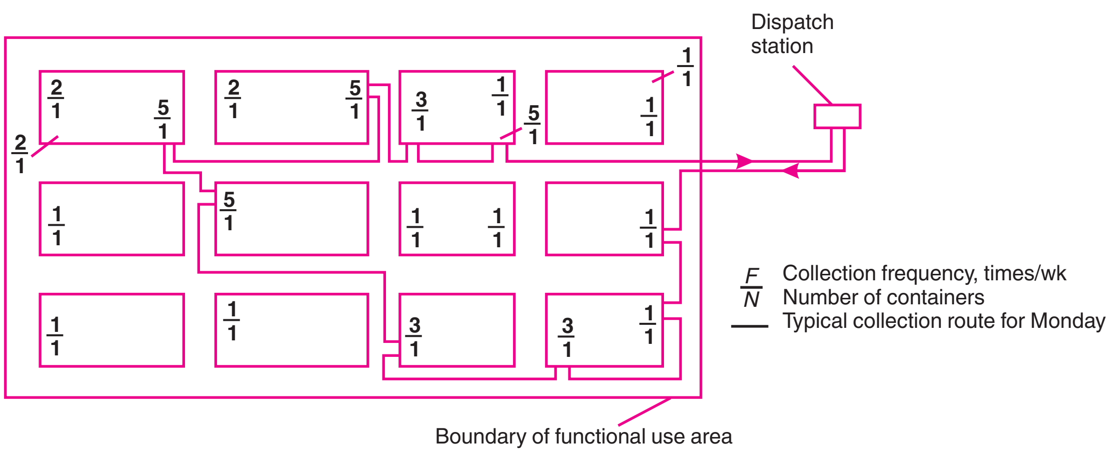

Figure 4.14: Plan of a typical functional use area with HCS [2].

Table 4.4: Summary Data on a typical functional-use Area shown in Fig.4.14

Collections/wk (1)	No. of Pickup points (2)	Trips/wk (1) x (2) (3)	No. of containers (receiving the same collection frequency) emptied per day				
			Mon. (4)	Tues. (5)	Wed. (6)	Thurs. (7)	Fri. (8)
1	10	10	2	2	2	2	2
2	3	6	0	3	0	3	0
3	3	9	3	0	3	0	3
4	0	0	0	0	0	0	0
5	4	20	4	4	4	4	4
		-	-	-	-	-	-
Total		45	9	9	9	9	9

Step 3: Preliminary layout of routes

Starting from the dispatch station or where the vehicles are parked lay out the collection routes for each day so that they begin and end near the dispatch station. A typical route for Monday is shown in Fig. 4.14. The collection operation should proceed in a logical manner, taking into account factors such as traffic conditions, type of activity, etc.

Step 4: Development of balanced routes

When five preliminary routes have been laid out, the average distance to be traveled between containers should be computed. If the routes are unbalanced, they should be redesigned so that each route covers approximately the same distance. In general, a number of collection routes must be tried before the final ones are selected. When more than one collection vehicle is required, collection routes for each functional-use area must be laid out, and the workloads for each driver must be balanced.

Steps 2, 3 & 4 for Stationary Container Systems (With self-loading compactors)

Assume that collection routes are to be laid out for the area shown in Fig. 4.15 and that the following data are known in addition to the data shown in Fig. 4.15 prepared in Step 1.

Collection vehicle = 30 m^3 self-loading compactor with compaction ratio 3.

Number of trips per day = 1

Working days per week = 3 (Monday, Wednesday, Saturday)

Step 2: Data analysis

Estimate the quantity of wastes collected each working day. From Fig. 4.15, it is clear that there are eight locations to be serviced during each collection day and that the quantity of wastes to be collected is 64 m^3. There are two locations with 16 m^3 wastes each day and there are eight locations with frequency of once/day. The data is then summarized in Table 4.5.

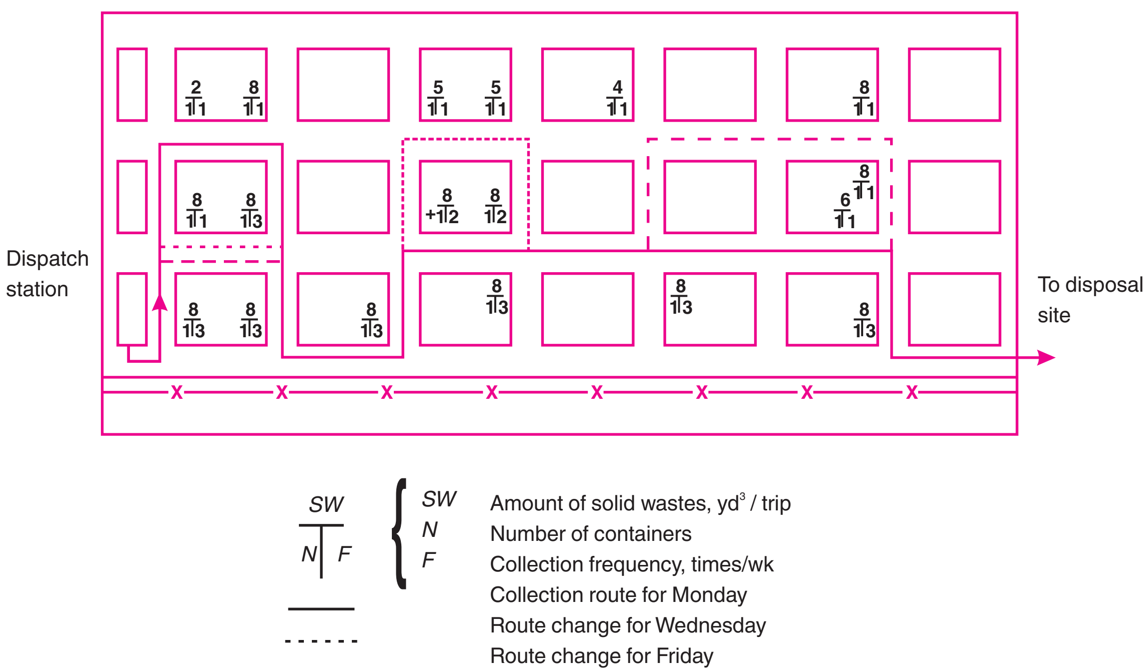

Figure 4.15: A typical functional use area with SCS [2].

Table 4.5: Summary Data on functional area shown in Fig. 4.15

Collections frequency (Times/week)	Number of Pick-up Locations (No.)	Total Waste (m^3/day)	Quantity of Waste Collected per day (m^3)		
			Monday	Wednesday	Saturday
3	8	192	64	64	64
2	2	32	16	16	-
1	8	46	10	10	26
Total		270	90	90	90

Step 3: Preliminary layout of routes

Once the data summery table is prepared the layout of routes can proceed as shown in Fig. 4.15 on preliminary basis.

Step 4: Development of balanced routes

After establishing the preliminary routes, these are balanced equalizing the amount of waste collected per day and the distance to be traveled each day.

4.5.3 Schedule

A master schedule for each collection route should be prepared for use by the engineering department and the transportation dispatcher. A schedule for each route, on which can be found the location and order of each pickup point to be serviced, should be prepared for the driver. In addition a route book should be maintained by each truck driver. The driver uses the route book to check the location and status of accounts. It is also a convenient place in which to record any problems with the accounts [2].

EXERCISES

1. What are different collection services for low-rise and high-rise buildings used in advanced countries? What types you propose for different localities of Lahore?
2. What is the most practicable system to be employed in Lahore for collection?
3. Sketch the conventional and exchange hauled container systems and SCS. What advantage one has over the other in different situations.
4. What is off-route factor and how it is used in determining the actual round-trip time.
5. What are pickup, haul, at site times for different collection systems.
6. Calculate the number of containers and collection vehicles required for solid waste management of a city with the following data. Population = 1,000,000, Generation rate = 0.4 kg/c/d, size of container 1 m^3, density in container = 200 kg/m^3, container utilization factor = 0.8; size of collection vehicle = 10 m^3; density in collection vehicle = 400 kg/m^3, Trips / veh. / day = 4. Daily service is provided. Use SCS.
7. The agency responsible for collection of solid wastes presently allows two containers to be picked up from the backyard for 100% of services. What percentage savings will be made in collection time, if the service is provided to 60% of the population at curbside and for 40% at the backyard? The number of containers per service in each case is two.
8 Determine the operational cost of a stationary container system which is to be provided to 40 homes with 2 containers served at the curbside and 20 homes with 2 containers served at the rear of the homes. Capacity of each container is 0.2 m^2. The size of the collection truck is 12 m^3 which has a compaction ratio of 2. The collection frequency is twice per week, and the crew size is 2. Haul time data is as below.

    x = 40 km   s = 0.06 hr/trip
    a = 0.06 hr/trip   b = 0.02 hr/km

9. A section of a community has 30 houses. Calculate the time required to serve this community section using the following data:

i) Each house has two containers to be picked-up from the backyard per week. The size of each container is 150 liters.
ii) The size of the collection vehicle is 4.5 m^3. No compaction takes place in the collection vehicle.
iii) The distance to disposal site is 30 km. Time spent at disposal is 0.2 hours.
iv) The haul constants are: 'a' = 0.08 hours/trip, 'b' = 0.025 hours/km.
v) $t_p = 0.018 + 0.18\,C_n + 0.014\,PRH$.

10. What are the important considerations for laying collection routes?

11. Construct a data summary table for devising collection routes for a stationary container system with following data. The service is to be provided 5 days/week.

$$\frac{6}{1/3}, \frac{4}{1/2}, \frac{3}{1/1}, \frac{8}{1/3}, \frac{8}{1/2}, \frac{8}{1/1}, \frac{7}{1/2}, \frac{5}{1/1}, \frac{4}{1/1}, \frac{8}{1/1}, \frac{8}{1/3}, \frac{5}{1/1}, \frac{3}{1/2}.$$

12. How will you proceed to develop haul constants, pickup, on-site times and time spent at each location in situations in Lahore.

13. You have been requested to submit a proposal to evaluate the solid waste collection operation for the city of Lahore. Prepare a proposal in an outline form to be submitted to the City district Government, Lahore (CDGL). Indicate clearly the major divisions or tasks in which the work would be divided.

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5. TRANSFER AND TRANSPORT OF SOLID WASTE

Transfer and transport refers to the means, facilities and appurtenances used to affect the transfer of waste from one location to another (usually to more distant location). Typically, the waste from relatively small collection vehicle is transferred to larger vehicle and is transported to distant location for safe disposal or further processing.

5.1 Transfer Station

Solid waste collection zone expands with the spread of the urban population. This produces the problem in collection of the solid waste from the scattered households and colonies. This issue could be addressed through setting up a waste transfer station, where collected waste from the small and medium sized vehicles is transferred to large containers. Transfer station reduces the fuel consumption per unit volume of the solid waste and improves the transportation efficiency.

According to Texas administration code (TAC), transfer station is defined as "a facility used for transferring solid waste from collection vehicles to long-haul vehicles. It is not a storage facility such as one where individual residents can dispose their wastes [1].

Transfer station provides a link between the community's solid waste collection program and waste disposal or processing facility as shown in the Fig.5.1.

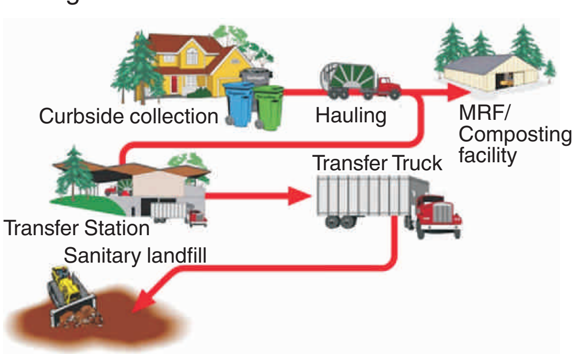


Figure 5.1: The concept of solid waste transfer [2]

Transfer station should not be mixed with citizen's communal containers. Communal container means a container in which all the adjoining houses has a right to dispose waste. It is specially designed for the exclusive use of the residents of the specific area and it should not be used for industrial or commercial vehicles.

5.2 Need of a Transfer Station

The decision to establish a transfer station is based on economics. When the haul distances increase, it becomes uneconomical to transport waste by the collection vehicles which are necessarily small capacity and have mechanisms to pick-up waste. In case of long haul, their collection mechanism remains idle for long time, which is uneconomical too. Besides this, the transfer stations are required when waste disposal or processing facilities are not directly accessible. For example, transportation of waste from Islands is not possible through conventional highway transportation. Alternate means, like ocean-going barges are required to transport the wastes to the processing facilities or disposal sites. In such cases provision of transfer stations becomes necessary.

In congested areas of the cities, like the walled city in Lahore and similar other areas, small capacity vehicles like donkey carts, tri-wheelers etc., are used for collection of solid waste as shown in the Fig.5.2. Such vehicles cannot go to distant disposal sites for unloading. Transfer stations are to be provided near the service areas in such cases.

(a)Riksaf used in urban areas of Sindh (b) donkey carts for solid waste collection

Figure. 5.2: Small capacity waste collection vehicles

Transfer stations are also required when waste processing and disposal facilities are located in remote areas and are not directly accessible though highways. As a rule of thumb the transfer station would be feasible if landfill or waste processing facility is 20-30 miles or more (one way) [3].

Transfer of waste components is an integral part of the operation of a material recovery facility (MRF). In an MRF great reduction of the final weight takes place. Thus, if MRF facility is provided then size of transfer station tend to be much smaller.

While planning to construct a transfer station, hauling cost must be compared with the cost of transfer station in order to establish a relationship for breakeven analysis. Based on the routing scheme, if the one way hauling distance from the last collection point to the waste processing or disposal facility is short, transfer station will not be required. If the processing or disposal facility if far away from the last collection point, transfer station will be required. In addition, transfer station is a must, where the haul distance to final disposal is large and size of collection vehicle is small.

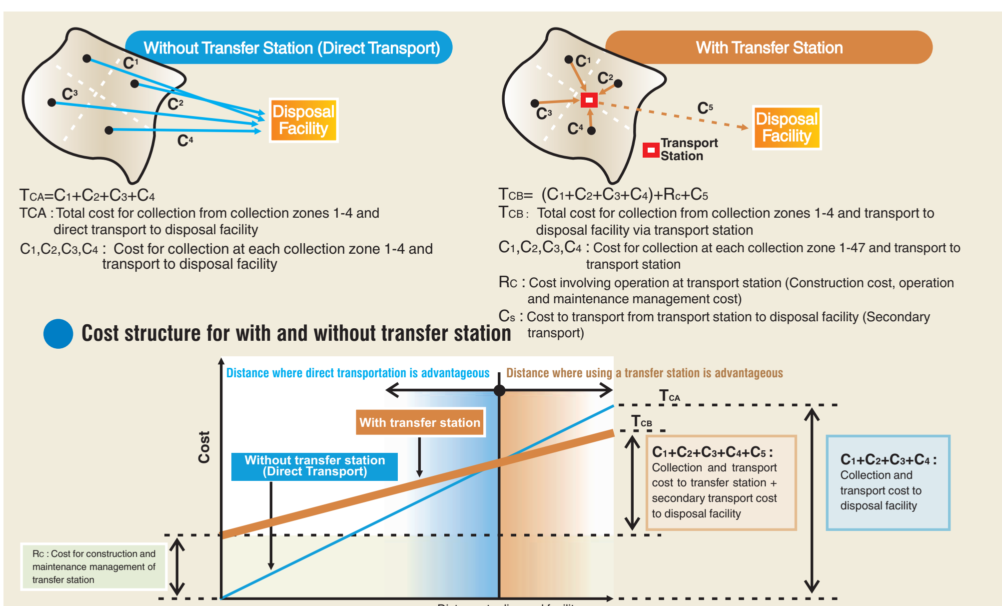


Figure 5.3: Cost comparison with and without transfer station [4]

The Solved Example 4.3 (chapter 4), illustrates the time and economic advantages of stationary container system over the hauled container system in case of long distance. The economic advantage of a transfer station when compared with SCS in case of long haul distance is illustrated in the example 5.1.

Solved Example 5.1

Determine the break-even time for a hauled container system and a stationary container system as compared to a system using transfer and transport operations, when the following data are applicable [5].

1. Transportation costs.

a) HCS using a hoist truck with 8-m^3 container = Rs. 8/-hr.

b) SCS using 20-m^3 compactor = Rs. 12/hr.

c) Tractor-trailer transport unit 120-m^3 capacity = Rs. 16/hr.

2. Transfer station costs

Amortization and operation Costs = Rs. 0.35/m^3

Solution:

Find unit cost Rs./m^3/min

A. Hauled container system

8m^3 @ Rs 8/hr

1 m^3 cost $= \frac{8}{8}$ = Rs 1/m^3/hr

= Rs $\frac{1}{60}$ /m^3/min

= Rs 0.0167/m^3/min

B. Stationary container system

20 m^3 @ Rs 12/hr

For 1 m^3 Cost = Rs $\frac{12}{20x60}$ /m^3/min

= Rs 0.01/m^3/min

Tractor-trailer

120 m^3 @ Rs 16/hr

for 1 m^3 Cost = $\frac{16}{120x60}$

= Rs 0.0022 /m^3/min

Find unit costs for different haul times as shown in table below and plot them.

System	Haul Time (Min)						
	0	1	10	20	30	40	50
HCS	-	0.0167	0.167	0.334	0.501	0.668	0.835
SCS	-	0.01	0.1	0.2	0.3	0.4	0.5
Transfer & Transport	0.35	0.35 + 0.0022 0.3522	0.35 + 0.022 = 0.372	0.35 + 0.044 = 0.394	0.35 + 0.066 = 0.416	0.35 + 0.088 = 0.438	0.35 + 0.11 = 0.46

Determine break-even time (t) for HCS and SCS with transfer & transport (T&T)

Cost of HCS = cost of T & T, at time 't_1'

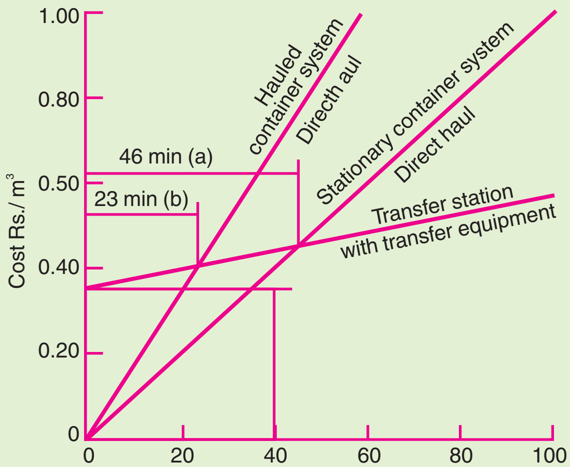
$0.0167\, t_1 = 0.35 + 0.0022 t_1$

t_1 = 24 min

Also cost of SCS = Cost of T & T, at time 't_2'

$0.01 t_2 = 0.35 + 0.0022 t_2$

t_2 = 45 min



Comments

In this particular example, if we are using HCS and round trip to disposal site is less than 24 min, and then no T & T facility is required because it would be uneconomical in this case. But if t > 24 minutes, then it is justified to provide T & T facility. Similarly, if SCS is used and round trip time to disposal site is 45 min then no T & T facility is required. However, if round trip time to disposal site is > 45 min, then construction; of T&T facility will save cost.

5.3 Types of Transfer Stations

Based on the mode used to load the transport vehicles, transfer stations are classified into three general types:

a) Direct discharge
b) Storage discharge
c) Combination of direct and storage discharge types.

5.3.1 Direct Discharge Transfer Station

In this type of transfer station, the waste in the collection vehicles is emptied directly into the large transport vehicles as shown in Fig. 5.4. Figures 5.5 and 5.6 show these facilities as constructed in USA.

The waste from small collection vehicles may also be directly loaded into stationary compactors which compact the wastes into transport vehicles or into waste bales that are transported to the disposal site. According to the size such transfer stations may be called.

i) Large capacity direct load transfer stations (for more than 500tons/day)
ii) Medium capacity direct load transfer stations (for 100-500 tons/day), and
iii) Small capacity direct load transfer stations (for less than 100 tons/ day).

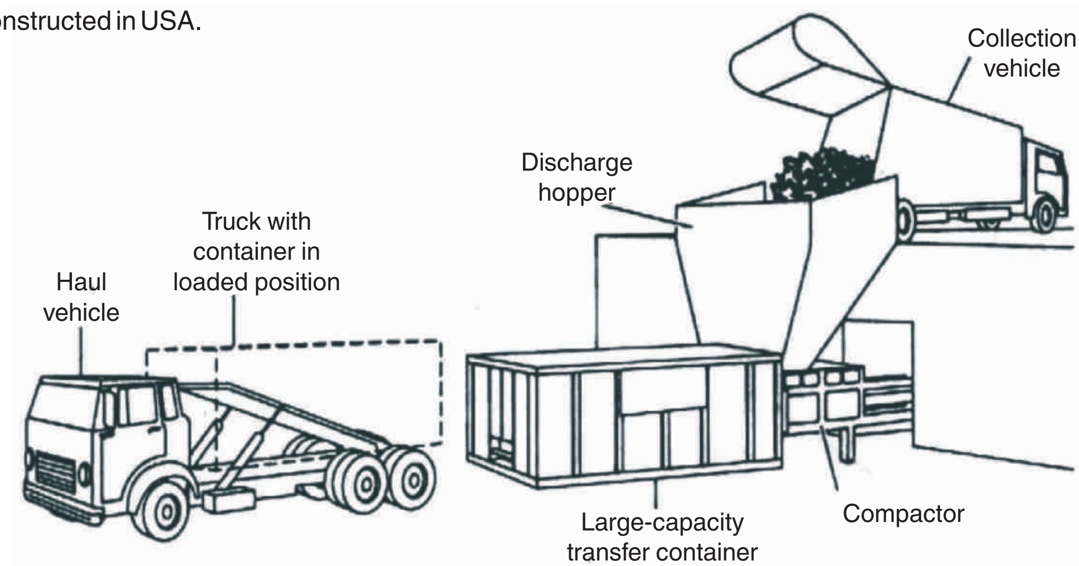


Figure 5.4: Small-capacity direct-discharge transfer station equipped with a stationary compactor. (Adapted from Schindler Waggon AG, Prattein, USA)

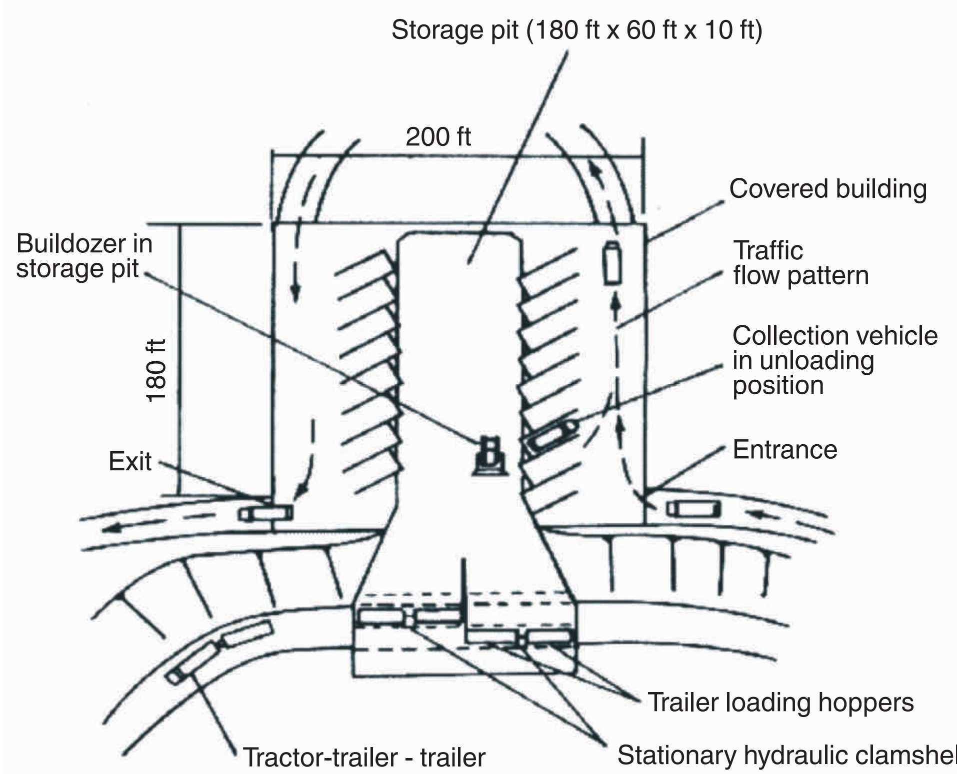


Figure 5.5: Large capacity direct load transfer station [5]

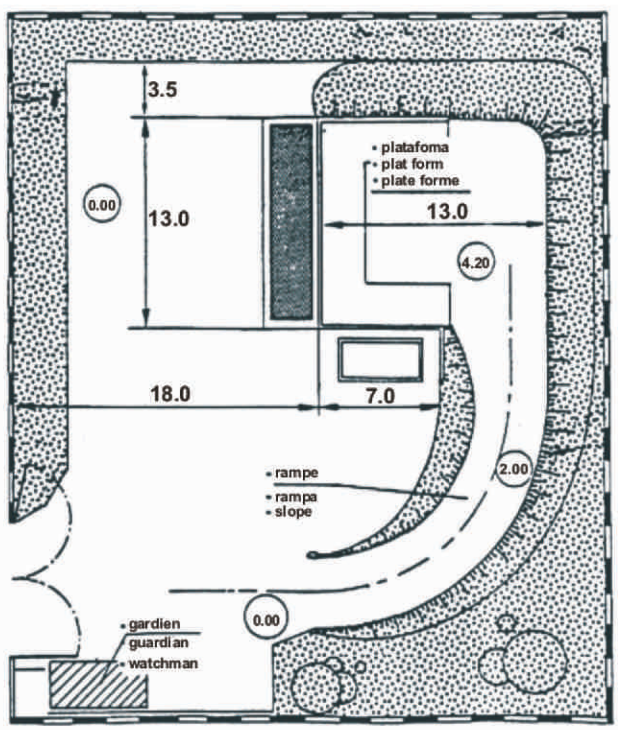


Fig. 5.6: Medium capacity direct load transfer station [5]

5.3.2 Storage Discharge Transfer Station

In storage discharge transfer station waste collection vehicles unload into a storage pit, from where the wastes are loaded into transport vehicles by various types of auxiliary equipment. The storage capacity varies between 1 to 3 days. They may be large capacity storage discharge transfer stations or medium capacity storage discharge transfer stations.

5.3.3 Combined Transfer Station

These are multipurpose facilities that serve a broader range of users. They can also house a material salvage operation.

The wastes which require segregation will be deposited at storage discharge transfer facility and the wastes not requiring salvage can be served at the direct discharge section. Commonly used transfer station method in Japan is compactor-container transfer station as shown in the Fig 5.7(a). Garbage collected by the mini transport vehicles is dropped into the hopper and is compressed using a stationary compactor. The compacted waste is then transferred to large capacity container and is transported to an incineration facility or disposal site [4].

Fig. 5.7(b): stationary compactor-container transfer station

5.4 Comparison of Transfer Stations

The two main types of the transfer stations i.e. direct discharge and storage discharge transfer stations are compared in Table 5.1

Table 5.1: Comparison of transfer stations

Direct discharge transfer station	Storage discharge transfer station
This type of transfer station is used when: • Waste is not to be sorted at transfer station, or • Sufficient number of transport trailers are available, So that the collection vehicles have not to wait for longer durations for unloading.	This type of transfer station is used when: • When waste is to be sorted out at the transfer station, or • Sufficient number of transport vehicles are not available, so that the collection vehicles have to wait for longer durations for un-loading.

5.5 Transport Means and Methods

The principle transport means and methods used to transport solid wastes include motor vehicles, railways and ocean-going vessels (barges).

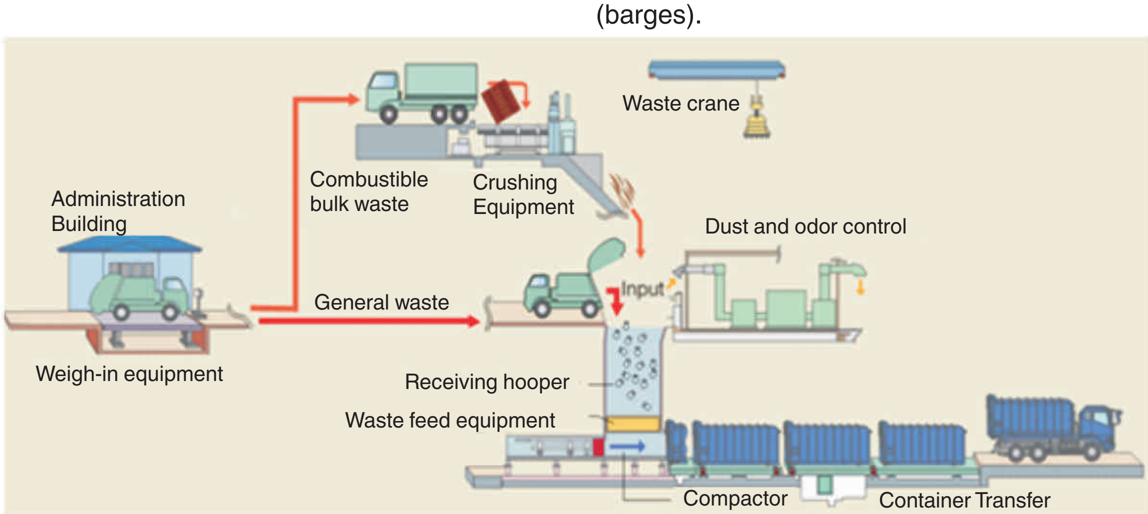


Fig. 5.7(a): Typical waste transfer station in Japan

5.5.1 Conventional Means for Transportation of MSW

All types of motor vehicles to be used to transport solid wastes should satisfy the following requirements.

i) Minimum hauling costs.
ii) Covering of wastes during haulage.
iii) Designed according to highway traffic rules.
iv) Allowable volume and weight limits not to be exceeded.
v) Unloading methods should be simple and dependable.

Fig. 5.8 shows some of the principle types of vehicles used at transfer stations. These are:

a) Trucks.
b) Truck-trailer combination.
c) Tractor semi-trailer combination.
d) Tractor semi-trailer - pull trailer combination.

Figure 5.8: Vehicles used for the transportation of solid waste

5.5.2 Unconventional Means for Transportation of MSW

For transporting the solid wastes to remote landfill sites, use of railways is ideally suitable, where such facility exists. Rail transfer stations are more expensive due to huge capital requirements for the construction of rail lines, installation of equipment to remove or replace rail roof for loading and unloading of the solid wastes. In England Japan, Malaysia, barges are used to transport wastes for Islands.

(a)Transport of waste through rail

(b) transport of waste through barges

Figure 5.9: Transportation of waste through unconventional means

5.6 Methods used to Unload Waste Containers

One of the following methods could be used for unloading of the transfer vehicles or containers at the transfer station, landfill or waste processing facility [6]:

a) Live bottom or walking floor

The longitudinal floor of the transfer vehicles is vibrated back and forth. This movement pushes the solid waste out of the transfer vehicle or the bottom surface of the vehicle is equipped with moving conveyor.

b) Push blade

A telescoping rod connected with the blade, pushes the solid waste from the front of the containers toward back similar to the compactors.

c) Drag chain

Some transfer vehicles are equipped with chains on sprockets that can extend from the front of the vehicles to the rear and through pulling the chain, the solid waste is dragged out of the container.

d) Tipper

Some transfer vehicles are not equipped with any unloading mechanism. At the landfill site, the transfer vehicles is simply lifted at an angle causing the door to open and solid waste to slide out.

5.7 Requirements for Efficient Transfer Station

5.7.1 Capacity Requirements

In direct discharge type transfer stations sufficient number of transfer vehicles should be housed at the transfer station with proper size so that collection vehicles will not have to wait for long. Of course it should not be designed for peak hours. Ideally an economic trade off analysis should be made. For example, the annual cost of the time spent by the collection vehicle waiting to unload must be traded off against the incremental annual cost of the use of more transport equipment.

In case of storage discharge type transfer stations, the storage capacity varies from one-half to one day's volume of waste. Seldom will the nominal storage capacity exceed two day's volume of waste [5].

5.7.2 Equipment and Accessory Requirements

This depends upon the use of the transfer station. The types and number of equipment requirement vary with the capacity. Scales are required for monitoring the operation and to develop meaningful data. They also help in levying the charges, based on weight. Offices should be equipped with telephone and two way speaker system.

For direct load transfer station some type of rigs are required to push and equalize the wastes in transfer vehicles. In a pit type storage load transfer station, one or more tractors are required to break up the wastes and to push them into the loading hopper [5].

5.7.3 Environmental Requirements

Following are the environmental requirements for a solid waste transfer station [7]:

i) Construction material should be such that it can be maintained and cleaned easily. It should also be fire-proof.

ii) To eliminate inadvertent emissions, enclosed facilities should have air-handling equipment that creates a negative pressure within the facility.

iii) Proper barriers need to be provided to restrict the blowing of paper and bags.

iv) Spilled solid wastes should be immediately picked up.

v) Overhead water sprays are used to keep the dust down, and workers should wear masks.

vi) For safety reasons, the public should not be allowed to discharge wastes directly into pits at large storage discharge type transfer stations.

5.7.4 Location of Transfer Stations

Whenever possible, transfer stations should be located [5]:

i) As near as possible to the weighted center of the individual solid waste production areas to be served,

ii) Within easy access of major arterial highway routes as well as near secondary or supplemental means of transportation,

iii) Where there will be a minimum of public and environmental objection to the transfer operations, and

iv) Where construction and operation will be most economical.

Additionally, if the transfer station site is to be used for processing operations involving materials recovery and/or energy production, the requirements for those operations must also be assessed. In some cases, these latter requirements may be major controlling factors.

5.8 Pneumatic Waste Collection Systems

Pneumatic collection systems uses negative pressure of air to pull the municipal solid waste (might be segregated streams such as paper, plastic, PET bottles, drink cans etc). It is then deposited through chutes or outdoor litter bins through a network of pipes connecting the terminal where the collected waste is compacted, baled and transported to the waste disposal or processing facility.

At the terminal, air separator removes the particles heavier than air from the waste stream and sends it to the compactor for volume reduction. The air, in which waste was separated, passes through the fabric filter where dust particles are retained and is circulated through exhausters and out through the stacks.

There are two kinds of pneumatic waste collection systems: stationary pneumatic collection system and mobile pneumatic collection system.

Stationary pneumatic waste collection system is shown in Fig. 5.10 (a, b)

Figure 5.10 (a): Stationary pneumatic collection system [8]

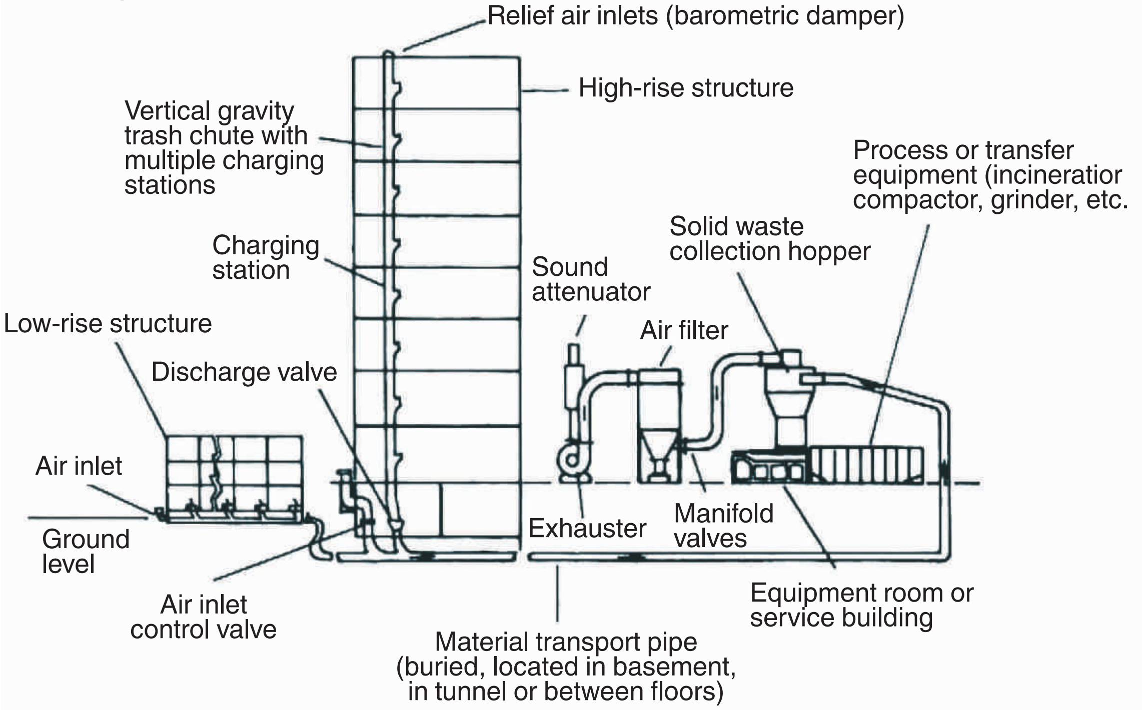


Figure 5.10 (b): Pneumatic transport system for solid wastes [5]

For the mobile pneumatic waste collection system, high capacity vacuum truck is required to suck the waste deposited at the disposal points connected to the piping network. The truck is also equipped with compaction mechanism which compacts the waste and transports it to the waste processing or disposal facility, as shown in the Fig.5.11.

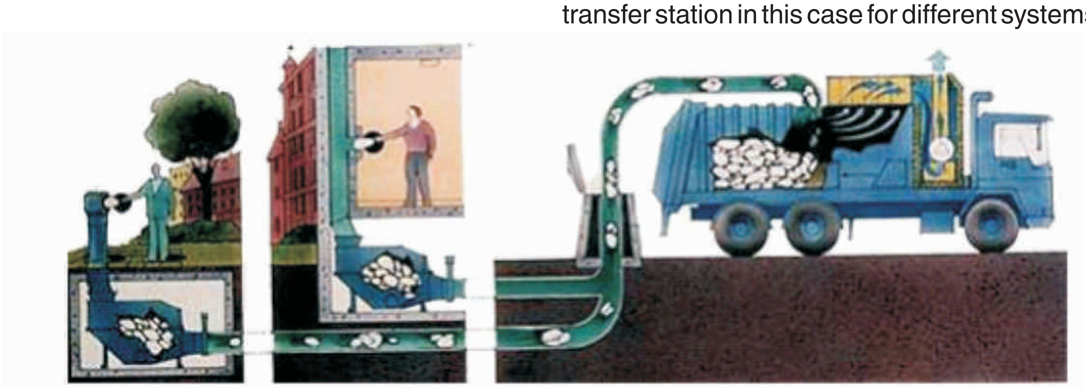


Fig. 5.11: Mobile pneumatic waste collection system

Such facility is quite costly and has been tried in the industrialized countries for multi-story buildings and requires the provision of transfer station. It is not recommended for developing countries.

EXERCISES

1. What are the different situations under which transfer operation becomes mandatory?
2. How excessive haul distance to disposal site affects a collection system? Discuss the utility of transfer station in this case for different systems.
3. What are different types of transfer stations? Give their merits and demerits in different applications.

4. What are the different unloading mechanisms for waste transfer vehicles?
5. How pneumatic waste collection system works?
6. Give capacity requirements, equipment and accessory requirements and environmental requirements for different types of transfer stations.
7. What type of transfer stations you propose for Lahore? Make a hand-drawn sketch of the facility with rough dimensions.
8. What types of transportation facilities are available for solid wastes? Give the unloading/tipping techniques for the motor vehicles used for transportation of solid wastes.
9. What is break-even time? Illustrate its importance with respect to provision of transfer and transport system as against direct haul by collection vehicles used in stationary container system.
10. Assume, it costs Rs. 30 per ton per Km to operate a garbage truck and Rs.10 per ton per Km to operate a transfer truck. A transfer station also has a fixed cost of Rs.1000 per ton. If it is 30 Km to the landfill, what would be your least expensive transportation alternative (show your calculations)?

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6. PROCESSING TECHNIQUES AND EQUIPMENTS

6.1 Purpose of Processing Solid Waste

Processing techniques are employed for three different purposes, as elaborated below:

6.1.1 Efficiency Improvement

Processing of the solid waste is done to improve the efficiency of the solid waste collection, transportation and disposal. Examples include:

i) Reduction in storage requirements at high-rise buildings, both incineration and baling are used.
ii) To reduce transfer and transportation costs.
iii) Before waste paper is reused, it is usually baled to reduce shipping and storage volume requirements.
iv) In some cases waste is baled to reduce haul cost to the disposal site.
v) At disposal site, solid waste is compacted to use the available land effectively.
vi) Shredding reduces the size of the waste ingredients and improves the bulk density of the waste. In this way, it reduces the land requirements for disposal.

6.1.2 Materials Recovery

Usually components that are most amenable to recovery are those for which markets exist and which are present in the waste in sufficient quantity to justify their separation. Materials that can be recovered from MSW include paper, cardboard, plastic, glass, ferrous metal, aluminum etc.

6.1.3 Conversion and Transformation

Combustible organic matter can be converted to energy in a number of ways, including (i) incineration (ii) pyrolysis and (iii) bio-digestion. For this purpose, combustible organic matter is first separated from the MSW. Afterwards shredding and drying is performed before incineration or using shredded solid waste for co-firing in cement industries. Segregated organic waste can be transformed to compost or biogas.

6.2 Processing Techniques

Techniques such as (1) densification, (2) Chemical volume reduction (3) Mechanical Shredding (4) Component separation and (5) Drying and dewatering (Moisture reduction) are used to achieve the above mentioned goals.

6.2.1 Densification

Densification (also called volume reduction or compaction) of solid waste is an important factor in the development and operation of all solid waste systems. Compaction is extensively used in developed countries to reduce landfill requirements and haul costs. Vehicles equipped with compaction mechanism are used for the collection of solid waste. To increase the useful life and capacity of landfills, wastes are compacted before being covered. Paper for recycling is baled (through compaction) for shipping to processing centers.

6.2.1.1 Types of Compaction Equipment

Based on mobility, there are two types of compaction equipment i.e. (1) stationary compactors and (2) mobile compactors.

A) Stationary compactors

Stationary compactors are those which remain at their place while the wastes are being fed to them for compaction e.g. compactors used at storage locations and transfer stations (Fig. 6.1). In fact, compaction mechanism installed in waste collection vehicles itself is a stationary compactor.

Figure. 6.1: Stationary compactors

According to their applicability, stationary compactors can be classified as:

i) Light duty(for residential area)
ii) Commercial or light industrial
iii) Heavy industrial, and
iv) Transfer station compactors

B) Mobile compactors

Mobile compactors are those which traverse over the dumped solid wastes. The example is bulldozers as used at the disposal sites. Different kinds of the mobile compactors used in developed and under-develoed countries are shown in the Fig. 6.2.

Figure: 6.2: Mobile compactors

Compactors may also be classified as low-pressure (up to 690 KN/m^2 or 100 psi) and high pressure (above 690 KN/m^2 or 100 psi and up to 34,500 KN/m^2 or 5000 psi).

Table 6.1: Types and applicability of different compaction equipment [1]

Location of Application	Type of the Compactor
Solid waste generation points	Vertical compaction unit, rotary compactors, bag or extruder, and under counter.
Collection	Vehicles equipped with compaction mechanism (packer).
Transfer and/or processing station	Stationary/transfer trailer, stationary low pressure and stationary high pressure compactors.
Disposal sites	Bulldozers, movable wheeled or tracted equipment and track mounted compactors.

6.2.1.2 Selection of the Compaction Equipment

Factors to be considered while selecting an appropriate compactor are:

i) Characteristics of wastes to be compacted like; size, composition, moisture content and bulk density.
ii) Methods of transferring and feeding wastes to the compactor.
iii) Handling methods and uses for compacted wastes.
iv) Compactor design and operational characteristics.
v) Site considerations including space and height, access, noise etc.

6.2.1.3 Relationship between Compaction ratio and Volume Reduction

Two terms are worthy of mention here i.e. compaction ratio and % volume reduction.

The relationship between the compaction ratio and the percent of volume reduction is shown in Fig. 6.3 and is explained by calculations [2].

(a) Compaction Ratio $= \frac{\text{Initial Vol}}{\text{Final Vol}} = \frac{V_i}{V_f}$	= 1	2	3	4	5
(b) Vol. reduction (%) $= \frac{V_i - V_f}{V_i} \times 100$	=0%	50%	66.7%	75%	80%
Difference in volume reduction %	=0%	50%	16.7%	8.3%	5%

It can be noted from above that volume reduces by 50% as compaction ratio increases to 2. Similarly, when compaction ratio increases to 3, the corresponding increase in volume reduction is 16.7%. Therefore, as the compaction ratio increases the corresponding increase in volume reduction decreases. Thus very high compaction ratios are not very beneficial in terms of corresponding volume reduction, hence should be avoided.

It can be concluded from above graph that very high compaction ratios are not desirable as no appreciable volume reduction is achieved. As can be seen that for a volume reduction of only 10% (80% 90%), the corresponding compaction ratio has to be increased from 5 to 10. Thus high compaction ratios are normally uneconomical due to high cost of compactors for achieving them.

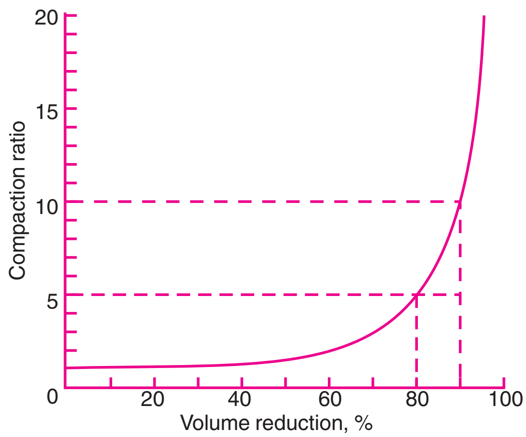


Figure 6.3: Compaction ratio versus percent volume reduction [2]

Whenever high compaction ratios are used, cost of compactor is first compared with corresponding reduction in transportation cost. If justified only then such equipment is used. Normally a compaction ratio from 2 ⟶ 3 is used.

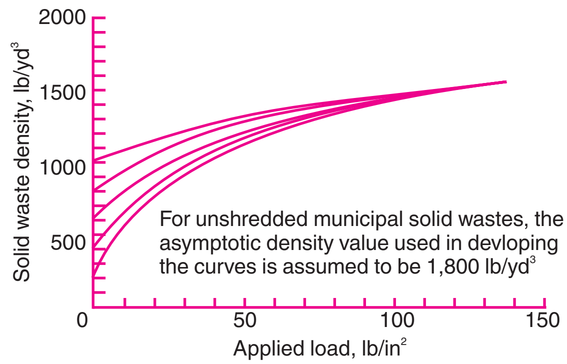


Figure 6.4: Density of solid wastes versus applied pressure [2]

It can be clearly seen from the graph that the increase in density, brought about by the application of pressure, is highly dependent on initial density of waste to be compacted. Another variable that significantly affects degree of compaction is moisture content. In some stationary compactors, water is added during compaction process.

Despite of several benefits of compaction, following are the demerits:

i) Biodegradable organic wastes such as vegetable and fruit waste, leftover food from the households and commercial restaurants, on compaction destroy the market value of the recyclable commodities such as plastic, paper, aluminum, cardboard etc.

ii) Due to compaction, it becomes difficult to sort out the recyclable items at the

MRF facility as the waste is mixed and compacted into the lumps.

6.2.2 Chemical Volume Reduction

Open burning, incineration and pyrolysis are methods for chemical volume reduction. Incineration is both used for volume reduction and power production. As design and operation of the modern municipal incinerators are highly specialized undertaking; only introduction of the subject will be dealt here.

One of the most attractive features of the incineration process is that 80 to 90 % reduction in volume of the combustible waste can be achieved and in some newer incinerators the reduction is possible up to 95%. Air pollution control is the major hindrance in wide utilization of the technology of incineration.

Onsite incinerators are also employed at residences, apartments and stores in some parts of the developed countries. Different features of an incinerator are illustrated in Fig. 6.5. Trucks are unloaded into a storage bin. Width of unloading platform and storage bin is dependent upon the number of trucks which must be unloaded simultaneously. Volume of the storage bin is usually equal to volume to be received for one day. Overhead crane batches the loads into charging hopper and the operator maintains the moisture content percentage by selecting the mix from storage bin. Incombustible items are removed from the waste before feeding into the incinerator at most installations. Different types of grates are utilized for drying and burning of the wastes. Air may be introduced from below (under fire air) or above (over fire air) the grates to control burning rates and furnace temperatures. Because most of the organic waste is thermally unstable, various gases are driven off in the combustion process taking place in the furnace at 1400°F. These gases along with small particles pass to secondary chamber known as "Combustion Chamber" and burn at temperatures above 1600°F.

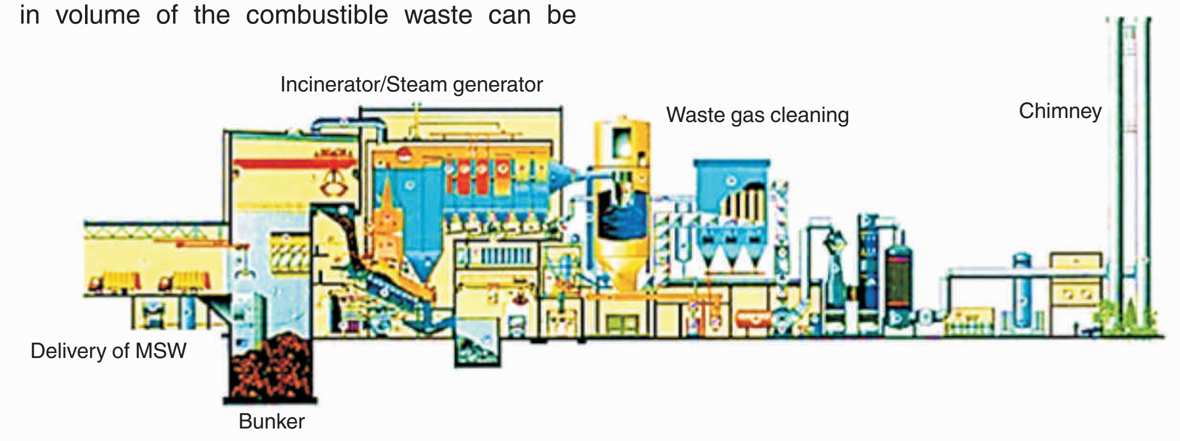


Figure 6.5: Section through a typical continuous-feed mass-fired municipal incinerator [3]

Odor producing compounds are usually destroyed at 1400 – 1600°F. Air cleaning equipment is necessary for meeting local regulations. Induced draft fan is used for adequate air flows. Flue gases leave through the stack while the ashes and un-burnt residues go to the residue hopper and from there are transported to disposal site. A modern incinerator with air pollution control equipment and generation of electricity is shown in Fig. 6.6.

During incineration the primary concern in air pollution control is with particulate emissions rather than with gases and odors. To control these particulate emissions various types of control equipments like settling chambers, baffled collectors, scrubbers, cyclone separators, electrostatic precipitators and fabric filters are employed.

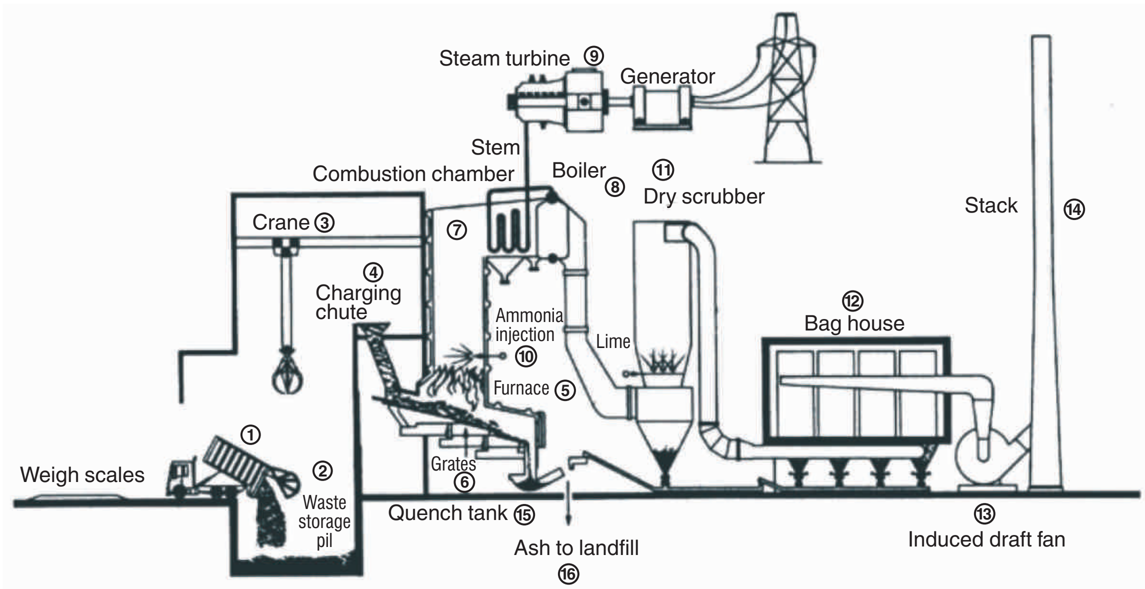


Figure 6.6: Section through a typical continuous-feed mass-fired municipal combustor used for the production of energy from MSW.

6.2.3 Mechanical Size Reduction

Size reflection is important in the design and operation of solid waste management systems, in the recovery of materials for reuse and

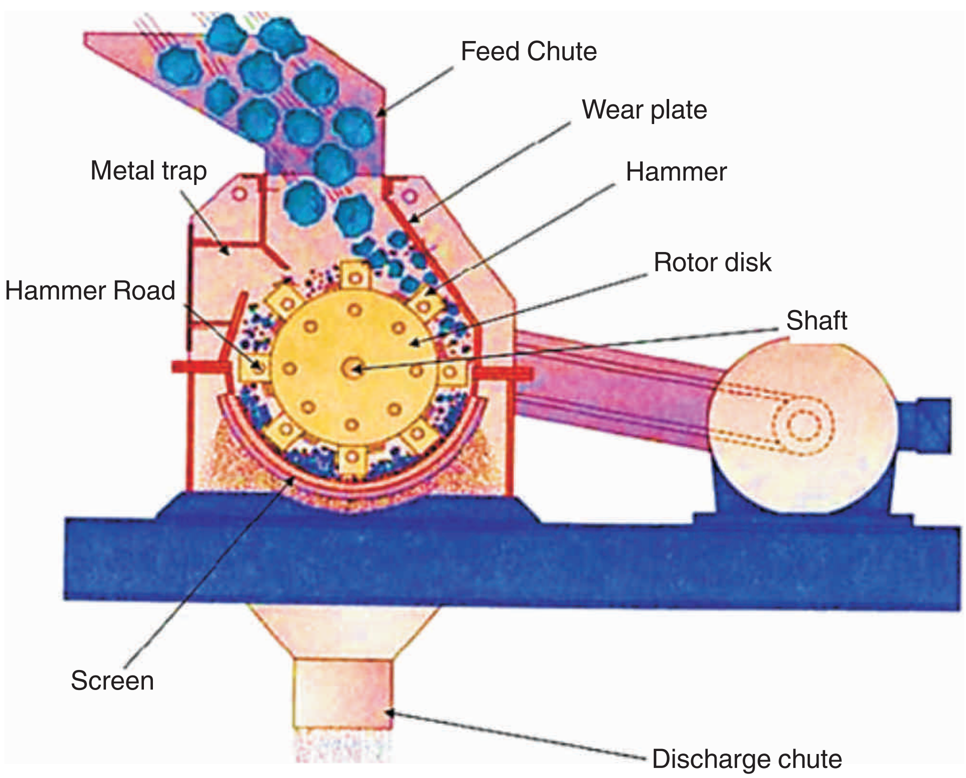


Figure 6.7: Vertical hammer mills used for the size reduction of solid waste

conversion to energy. The terms shredding, grinding and milling are used interchangeably for mechanical size reduction. Fig.6.7 shows a hammer mill, which is used for shredding wastes [2]. The benefits of shredding include:

i) Higher density at lower compaction pressure in bailing.
ii) Recovery of materials and energy becomes easier.
iii) Sanitary landfilling no more requires daily covers if waste is shredded. Grinders, clippers, jaw crushers, rasp mills, shredders, cutters, clippers, hammer mills, and hydro-pulpers are the types of equipment employed. Their mode of action and application are summarized in the Table 6.1.

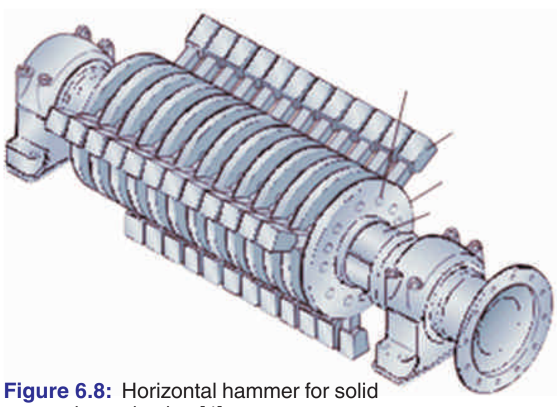


Figure 6.8: Horizontal hammer for solid waste size reduction [4]

6.2.4 Component Separation

Component separation is performed to optimize the resource recovery process and recycling activities. It is performed through adopting different means including hand sorting air-separation etc. Details are given in the following sections.

6.2.4.1 Hand Sorting

The manual separation of solid wastes can be accomplished at the source, the transfer station, processing station or at the disposal site. Examples are the separation of newspapers, metals, glass, cans, wood etc. A conveyor belt can facilitate the process at the recovery centers as shown in Fig.6.8(a & b).

Figure 6.9: (a) Conveyer assisted sorting

Table 6.1: Size reduction equipments [1]

Sr. No.	Type of equipments	Functions	Applications
1.	Small grinders	Grinding, mashing	Organic residential solid wastes.
2.	Chippers	Cutting, slicing	Paper, cardboard, tree trimmings, yard wastes, wood, plastics.
3.	Large grinders	Grinding, mashing	Brittle and friable materials. Used mostly in industrial operations.
4.	Jaw crushers	Crushing, breaking	Large solids
5.	Rasp mills	Shredding, tearing	Moistened solid wastes. Most commonly used in Europe.
6.	Shredders	Shearing, tearing	All types of municipal wastes.
7.	Cutters, clippers	Shearing, tearing	All types of municipal wastes.
8.	Hammer mills	Breaking, tearing, cutting, crushing	All types of municipal wastes. Most commonly used equipment for reducing size and homogenizing composition of wastes

Figure 6.9: (b) Manual sorting

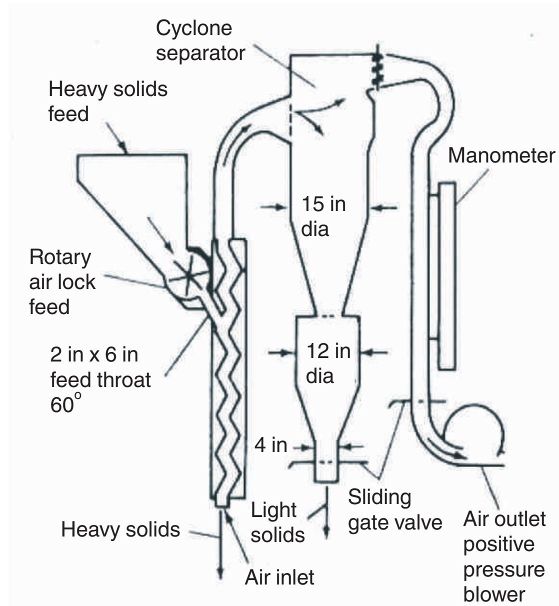


Figure 6.10(b): Experimental zigzag type air separator [5]

6.2.4.2 Air Separation

It is used to separate organic material "light fraction" from the inorganic material "heavy fraction". Practically speaking, papers, plastic and other light organic materials are separated from shredded waste stream [1].

Conventional vertical chute type and zigzag air classifier are generally used in industrial processes and may be employed in solid wastes as shown in Fig. 6.10 [5].

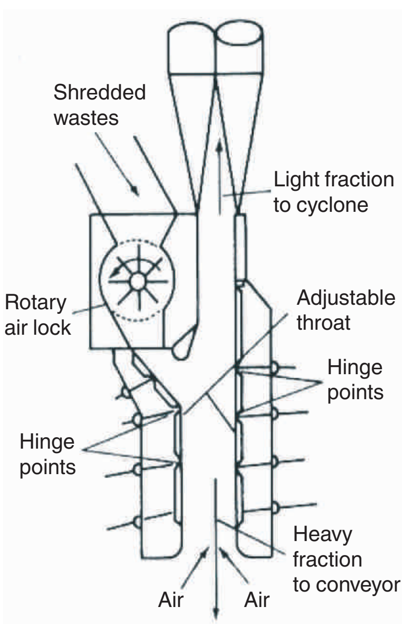


Figure 6.10(a): Conventional chute type air separator [5]

For horizontal ducts $V = 500 \dfrac{S}{S+1} \times d^{2/5}$

and for vertical ducts $V = 600 \dfrac{S}{S+1} \times d^{3/5}$

Where; V = Air velocity (m/min.), S = Specific gravity of material being transported (fraction), and d = Dia. of longest particle to be moved, (mm).

Solved Example 6.1

If an air velocity of 600 m/min is to be used to transport finally ground material with a specific gravity of 0.75 in a horizontal duct, estimate the maximum particle size that can be transported.

Solution:

$V = 500 \dfrac{S}{S+1} d^{2/5}$

$V = 600$ m/min.

$S = 0.75$

$d = ?$

$d^{2/5} = \dfrac{600}{500} \times \dfrac{1.75}{0.75} = 2.8$

$d = 13$ mm

6.2.4.3 Inertial Separation

Inertial methods rely on ballistic or gravity separation principles to separate shredded solid wastes into light and heavy fraction. Ballistic separator (BS) classify the MSW into three fractions i.e. (1) fine, (2) light weight and (3) heavy (Fig.6.11). The main working component of the BS is moveable, inclined and perforated screen. The screen consists of several vibrating elements which allow the fraction of MSW up or down based on gravity and form of the each component. The heavy components of MSW moves to the lower side of the screen, lighter particles such as plastic bottles moves in the opposite direction toward the upper side of the screen and the fine particles pass through the perforation.

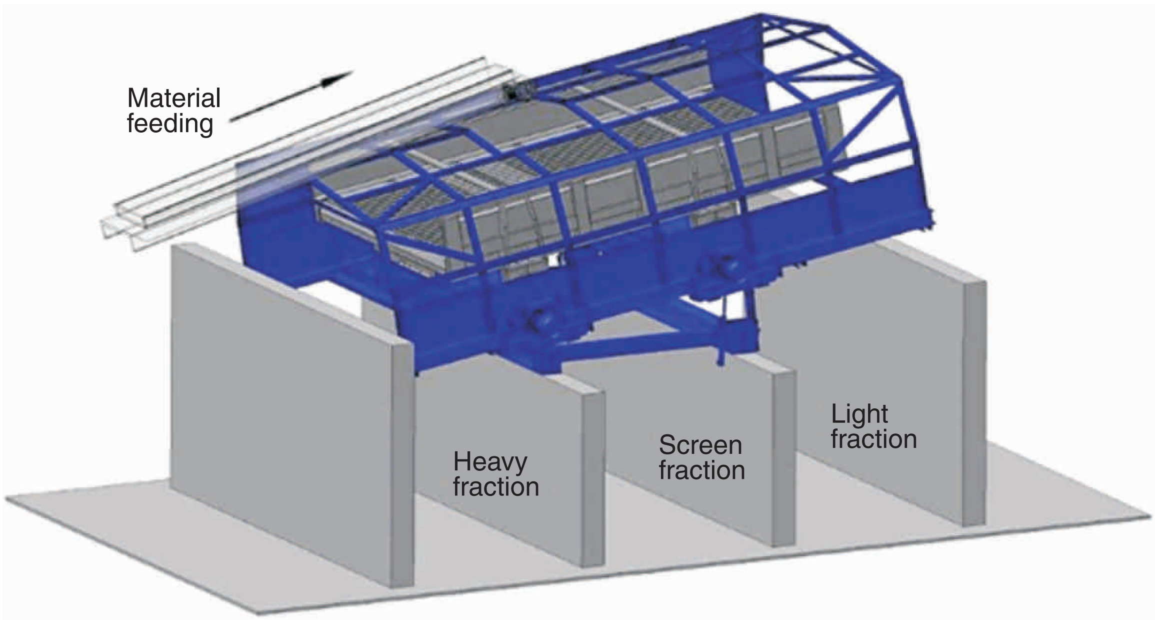
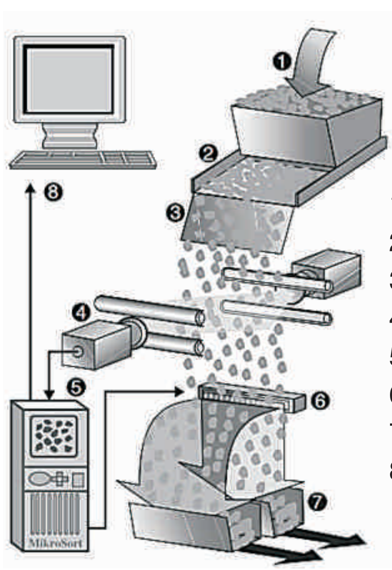


Figure 6.11: working principle of ballistic separator

6.2.4.4 Optical Sorting

Glass is separated from opaque particles through optical sorting. Different glass colors can



1. Feed preparation
2. Vibratory feeder
3. Particles in free fall
4. Scanning by optional system
5. Processor
6. Compressed-air impulse jets
7. Separated products
8. Field-bus network interface

Figure 6.12: Operating principle of electronic sorting

also be separated from each other. Four basic operations involved in the optical soring process are: (a) Particles are fed mechanically, (b) Particles are inspected optically; (c)Inspection results are evaluated electronically (d) and Pre-determined types of particles are removed by a precisely timed air blast. The working principle of opt-electronic sorter is explained in the Fig.6.12 [6].

6.2.4.5 Magnetic Separation

Ferrous materials are recovered after shredding and before air classification or after air classification by this method. Most common types of equipment are suspended magnet, magnetic pulley and the suspended magnetic drum as shown in Fig. 6.13.

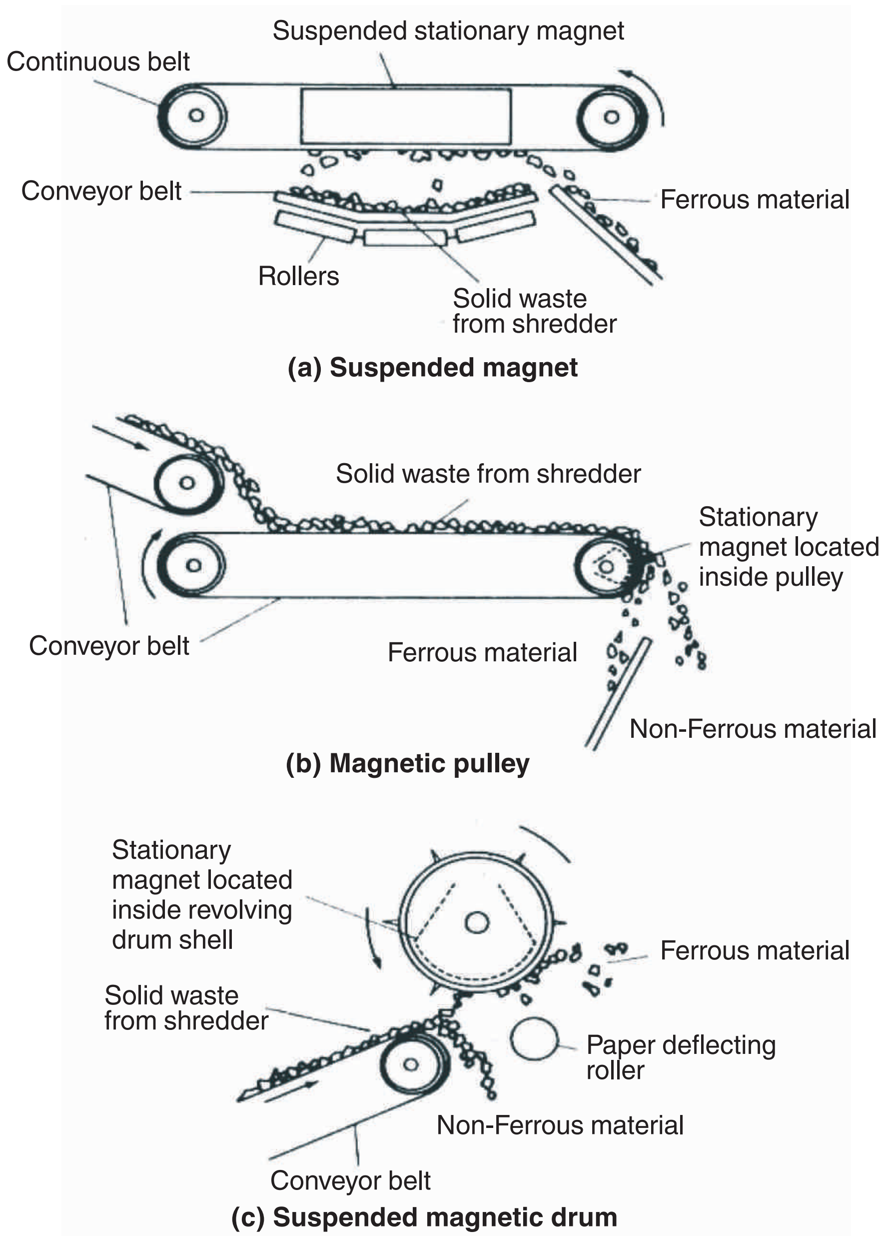


Figure 6.13: Typical magnet separators (Eriez Magnetics.) [6]

6.2.4.6 Screening

Screening involves separation into two or more size ranges using one or more screens. The process may be wet or dry, later being common and for solid wastes. Both vibrating and rotary drum screens are commonly employed as shown in Fig. 6.14. Typically screens are used for the removal, of glass and related materials from shredded solid waste.

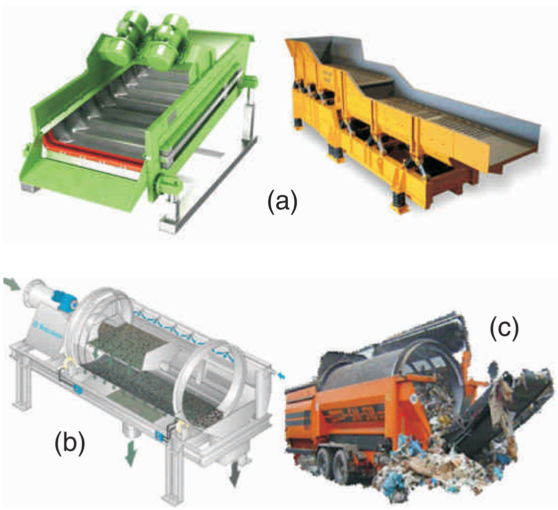


Figure 6.14: Typical screens used for the separation of solid wastes (a) Vibrating screen (Universal Vibrating Screen Company). (b) Rotary drum screen, and (c) Trommel Screen

6.2.5 Drying and Dewatering

It is used to reduce the water content of sludge produced at water and wastewater treatment plants. Sludge contains 94 – 99% water. Reduction in its water content and volume makes its subsequent handling and disposal easier. Centrifugation and filtration are two methods used to dewater sludge.

EXERCISES

1. What are the purposes of processing techniques and equipment?
2. Write short notes on the followings:
   (a) Mechanical volume reduction
   (b) Chemical volume reduction
   (c) Mechanical size reduction
   (d) Component separation.
3. Plot compaction ratio against volume reduction and solid waste densities against applied load and discuss the behaviors.
4. Draw rough sketch of an incinerator and explain the function of important parts.
5. Explain briefly the function of various air pollution control devices used on incinerator.
6. What are different types of size reduction equipment? Name them. What is the difference between their utility.
7. Component separation can be done both manually as well as mechanically. Discuss its application in different situations in Pakistan.
8. What are different modes of air separation, inertial separation magnetic separation and screening?
9. Devise the scheme for component separation dealt in the class.

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7. COMPOSTING

This chapter deals with the description of the process, laboratory tests needed to check the quality of compost, description of composting process, its environmental aspects, and comparison with other disposal methods and utility of compost as soil amendment. The microbiology of composting is another important area which is dealt in details separately at the end of the chapter.

7.1 Composting and Compost

The major component of the solid waste in Pakistan is generally organic in nature. This includes vegetable and fruit peelings, wasted food and garden trimmings (Fig. 7.1).

Composting is defined as, "biological decomposition of the biodegradable organic fraction of MSW under controlled conditions to a state sufficiently stable for nuisance-free storage and handling and for safe use in land applications" [1]. The term "controlled conditions" "differentiates the composting process from the simple organic waste decomposition that happens in open dumps and landfills.

During the composting process, heat, various gases and water vapors are released, greatly reducing the volume and mass of the pile. The composting process is explained in the Fig 7.2.

(a) Fruit vegetable peelings (b) Mixed organic waste (c) Garden trimmings

Figure 7.1: Organic solid waste

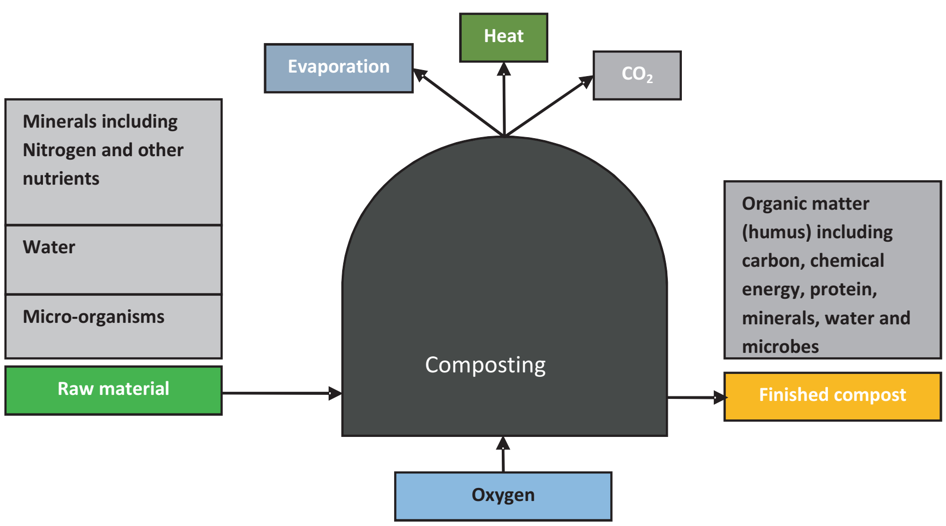


Figure 7.2: Composting process [2]

The end product remaining after bacterial activity is called "humus" or "compost" as shown in the Fig. 7.3

Figure 7.3: End product of the composting

Decomposition of solid waste may be accomplished aerobically or anaerobically. Anaerobic process however involves offensive odors and is extremely slow. Most composting operations are therefore aerobic. Characteristics of the compost are given in the following table [3].

Table 7.1: Characteristics of the compost

Parameter	Typical Range	Importance
pH	5.0 –8.5	Optimum plant health
Soluble salts	1 – 10 dS (mmhos/cm)	Phyto-toxicity
Nutrients	N (0.5-2.5%), P (0.2-2.0%), K (0.3-1.5%)	Plant vitalityNeed for fertilizers
Water holding capacity	75 - 200% dry weight basis	Irrigation requirements
Bulk density	415 - 711 l (Kg/m3)	Handling/Transportation
Moisture content	30 – 60%	Handling/Transportation
Organic matter	30 –70%	Application rates
Particle size	< 1" screen size	Porosity
Stability	Stable – highly table	Phyto-toxicity

7.2 Process Description

Composting process consists of four basic steps: (1) preparation; (2) digestion, (3) curing, and (4) finishing.

7.2.1 Preparation

The material delivered to the composting facility is removed from the container transfer vehicles or bags. The non-compostable materials such as plastics, textile, leather, bones, glass, metals etc are removed from the feed stock. This will prevent any damage to the machines during the subsequent operations. The compost quality will also improve due to the sorting of the non-compostable wastes from the organic waste stream.

A general process flow diagram of the municipal solid waste composting is shown in Fig. 7.4[4]

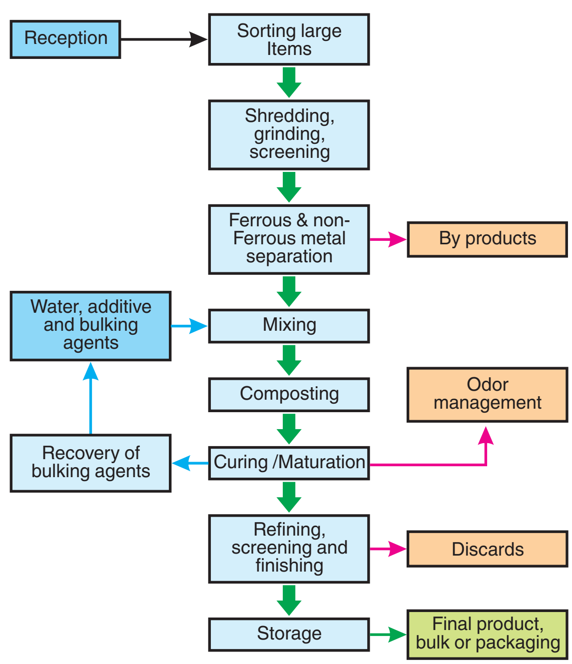


Figure 7.4: General process flow diagram for MSW composting facilities

Typical preparation steps include (a) sorting of salvageable material (b) removal of non-putrescibles (c) grinding (d) addition of wastewater sludge if necessary. Following conditions are essential for effective composting.

i) For optimum results, the size of the waste should lie between 2 and 8 cm. Size reduction is accomplished through shredding.
ii) Sufficient number of microorganisms to be present to perform digestion. Sewage sludge is added for this purpose.
iii) C/N ratio should be 30 to 50.
iv) C/P ratio should be 100 or less.
v) Moisture content should be 50 to 60%. Addition of water is done to raise moisture contents, if required.
vi) pH should vary between 5.5 to 8.5 throughout the process.
vii) Air should be thoroughly dispersed throughout the organic waste. This is done by frequently turning and mixing the wastes.
viii) Temperature should be maintained between 50 to 60°C for active composting period.

7.2.2 Digestion

In modern composting plants digestion takes place within windrows (area method) or in mechanical digesters (High rate digestion method).

Figure 7.5: Specially designed machines used to turn composting material placed in windrows

Windrow composting has been tried at various places and is successfully being used in Pakistan too, but entails many disadvantages e.g., operation is affected by local climate, may produce odors, time consumed is excessive (30 to 40 days) and amount of land required is more as compared to other technologies. Based on the aeration method, windrow system can be further classified as: (1) Turned windrows (2) Aerated static pile and (3) Passively aerated windrows.

Turned windrow: In this method prepared solid wastes are placed in windrows (long piles) in open field .The windrows are turned once or twice per week for a composting period of about 5 weeks with specially designed machines (Fig 7.5). The material is then cured for additional 2 to 4 weeks to ensure stabilization. Instead of turning, the windrows may also be aerated through forced aeration.

Aerated static pile: In this method of composting, the perforated pipes are inserted into the composting material piles and air is supplied through blower (suction fan or exhaust fan) as shown in the Fig.7.6. The perforated pipe run throughout the length of the pile and is also connected with the widthwise pipes.

In this method, no turning is required. If the adequate air is supplied to the compost pile and is uniformly distributed, it takes 3-5 weeks for the completion of the active composting. The required flow rate of the air can be controlled through running the blower intermittently or can be programmed based on the time or rise/ fall of temperature.

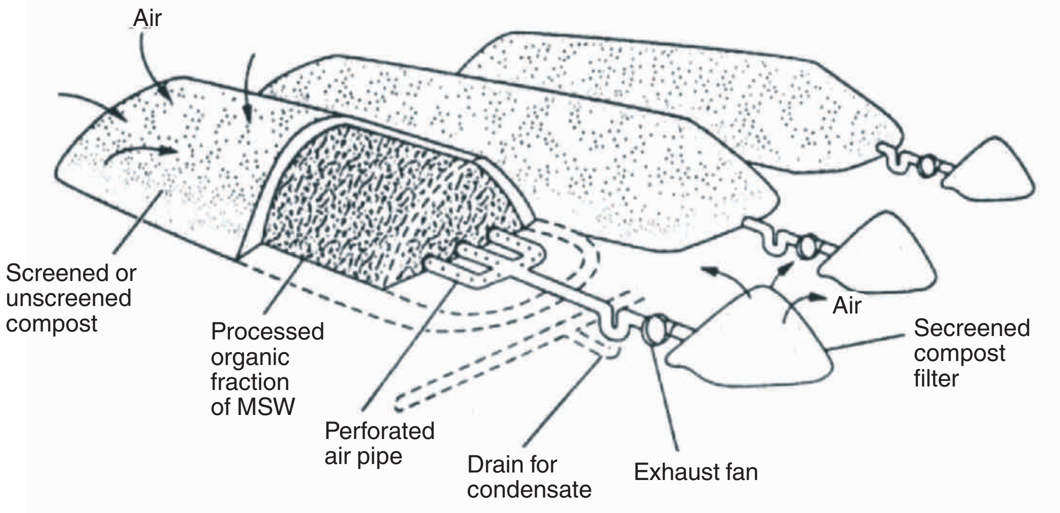


Figure 7.6: Schematic of aerated static pile composting system [1].

Passively aerated windrow: In order to reduce the forced aeration cost, the passive aeration is adopted. The base of the pile is prepared like aerated static pile using bulking agents and the perforated pipes (100mm dia.) are embedded in each windrow at a distance of 35-45 cm from each other and one end of the pipe is left open directing outward so that air can diffuse into the pile without using blower as shown in the Fig. 7.7 [5].Then, the organic waste mixture to be composted is placed in windrows and is not turned until the stable compost is achieved.

Figure 7.7: Passively aerated windrow

Mechanical digester: Digestion may also be carried out in a mechanical digesters. Air flow rate, moisture content and the temperature inside the enclosed digester are maintained using the principle of bioreactor. The air is fed into the reactor through forced aeration, tumbling, stirring or combinations, and the exhaust air is drawn through negative pressure followed by a bio-filter. Moisture is being continuously monitored through the probes installed inside the vessel and embedded into the mass to allow maintenance of the optimal aerobic conditions for successful composting. A simple schematic diagram of the mechanical digesters composting process is shown in the figure below [5].

All the modern composting system are a combination of mechanical digesters and windrows in which active phase of the composting is carried out in digesters and the curing and maturation phases are carried out in windrows. Some typical digesters include Dano system and Natuarizer system as shown in Figs. 7.9 & 7.10.

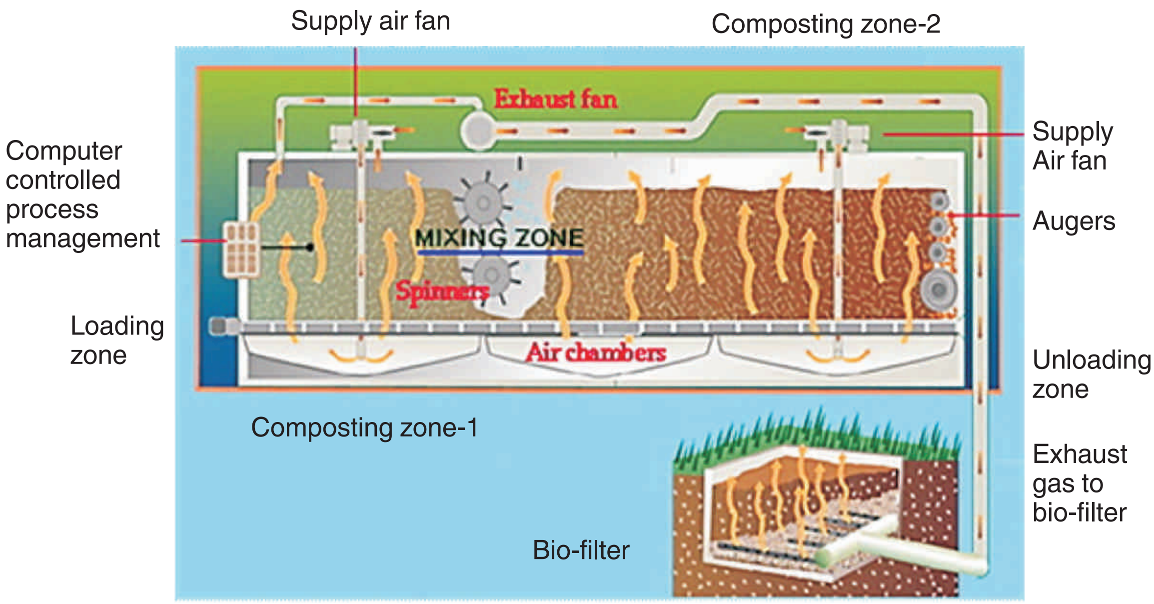


Figure 7.8: Working principle of mechanical digester

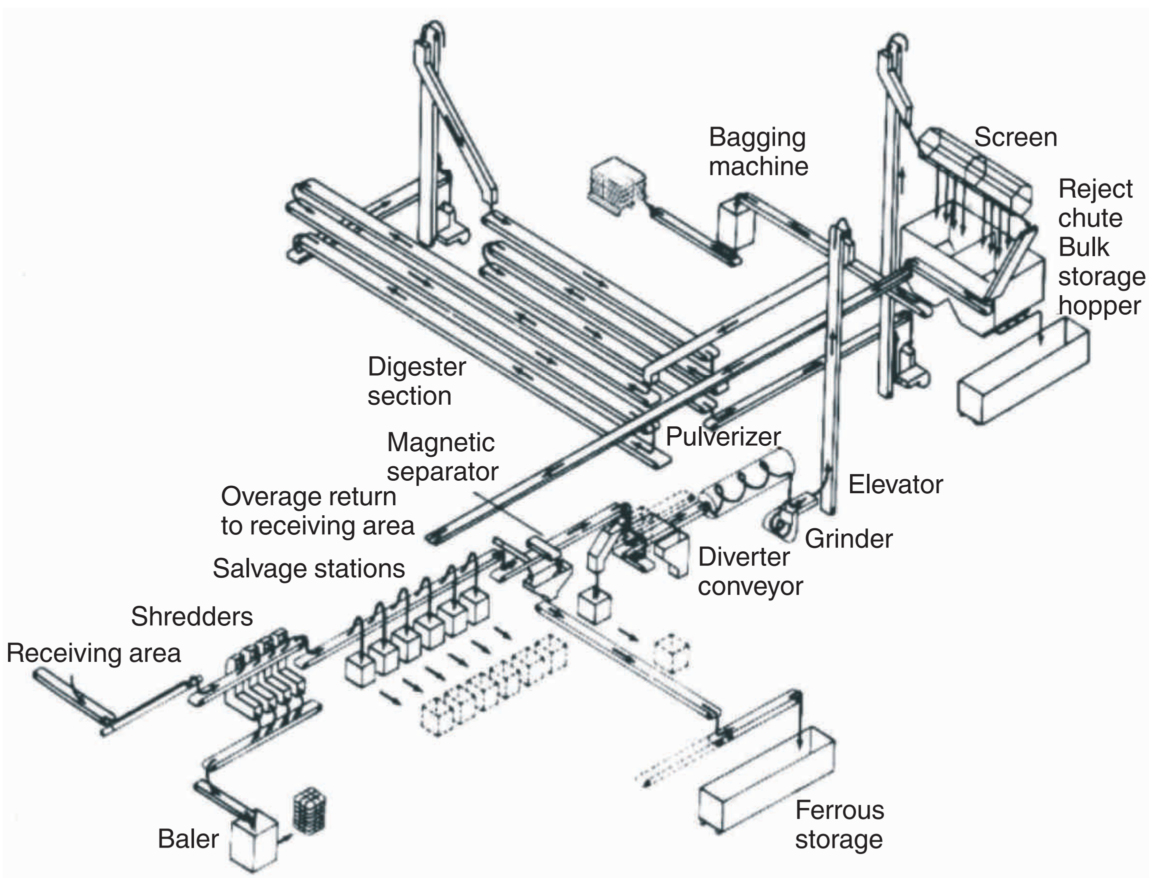


Figure 7.9: Flow sheet for IDC-naturizer compost system [6]

By controlling the operation carefully in a mechanical system, it is possible to produce compost within 5 to 7 days. The composted material is then removed and cured in open windrows for an additional period of at least 3 weeks to ensure complete biodegradation.

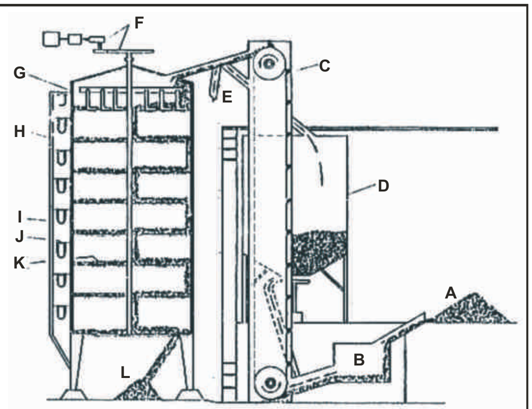
The process is performed under aerobic conditions. The products of aerobic digestion and the amount of oxygen required for the job are expressed by the following equation.

$C_aH_bO_cN_d + 0.5\,(ny+2s+r-c)\,O_2 \longrightarrow n\,C_wH_xO_yN_z + sCO_2 + r\,H_2O + (d-nx)\,NH_3 \ldots (7.1)$

Where $r = 0.5\,[b - nx - 3\,(d - nz)]$

$s = a - nw$

Computation of the amount of oxygen required for stabilization of prepared wastes is given in solved example 7.1.



A = Garbage-sorting unit	D = Storage tank	G = Ploughshares	J = Orifice plate
B = Grinder	E = By-pass	H = Air pipe	K = Deck
C = Bucket conveyor	F = Rotating mechanism	I = Manometer	L = Compost

The raw garbage is taken by bucket conveyor to and from the storage and dewatering tank to the top of the digester and is then slowly dropped down the decks of the unit

Figure 7.10: Dano system

7.2.3 Curing

In this step, carbon is further converted to carbon dioxide and humus and nitrogen into nitrates. Due to the successive consumption of the degradable material during the active composting process, the population of the micro-organisms decreases and the type of the organisms is changed too. This lowers the temperature of the compost pile. Curing is needed to ensure complete stabilization. The amount of curing depends upon the utilization of the material. Compost can be applied with little curing in fields which will not be planted for some months to come. However the material should be completely stabilized if it is to be used in a field ready for sowing so that stabilization may not rob the soil of nitrogen.

7.2.4 Finishing

In this step, the compost is passed through a 1 to 1.25cm fine screen to remove oversized materials, stones, metals, plastics and un-composted bulking agents. This improves the quality of the compost. In developed countries, there are established standards for the compost quality which are met before sending it to the market for sale. Therefore proper quality testing is required.

Finishing includes the operations of making pellets, granulation, regrinding, rescreening, blending with various additives and adjustment of moisture content and bagging etc., to facilitate handling if required. It also depends upon actual use of compost. If it is to be sold in bulk or landfilled, there is no need for finishing.

Solved Example 7.1

Determine the amount of oxygen required to compost 1000 kg of solid wastes. Assume that the initial composition of the material to be composted is given by $[C_6H_7O_2(OH)_3]_5$, that the final composition is estimated to be $[C_6H_7O_2(OH)_3]_2$, and that 400 kg of material remains after the composting process.

Solution:

1. Determine the moles of material present initially and at the end of the process. Moles present initially:

$$\frac{1000\,\text{kg}}{[(30\times12)+(50\times1)+(25\times16)]}=1.23$$

Moles present at end:

$$\frac{400\,\text{kg}}{[(12\times12)+(20\times1)+(10\times16)]}=1.23$$

2. Determine the moles of material leaving the process per mole of material entering the process.

$$n=\frac{1.23}{1.23}=1.0$$

3. Determine the values for a, b, c, d, w, x, y and z, and then determine the value of r and s in Eq. 7.1 For initial sample ($C_{30}H_{50}O_{25}$).

$a = 30,\ b = 50,\ c = 25 \quad d = 0$

For final product ($C_{12}H_{20}O_{10}$)

$w = 12 \quad x = 20 \quad y = 10 \quad z = 0$

The value for r is

$r = 0.5\,[b - nx - 3(d - nz)]$

$= 0.5\,[50 - 1.0(20)] = 15.0$

The value for s is

$s = a - nw$

$= 30 - 1.0(12) = 18$

4. Determine the amount of oxygen required.

$O_2/1000\text{ kg} = 0.5\,(ny + 2s + r - c)O_2$

$= 0.5\,[1.0\,(10) + 2(18) + 15 - 25]1.23(32)$

$= 708\text{ kg}$

7.3 Laboratory Tests and Control of Composting Process

Laboratory tests are necessary to determine the pre-requisites of the process as outlined in the methodology and also to control the degree and rate of composting. In the past, people have depended upon appearance, odor, and feel of the product to determine whether it has been properly composted.

More scientific yard sticks are now available. A small laboratory, where routine tests are carried out, is essential for the efficient technical operation of a compost plant. Frequent rapid determination of pH, temperature and moisture content are needed. In large plants methods for determining oxygen uptake or carbon dioxide production should be used. Determinations of nitrogen, potassium, phosphorus, crude fiber and volatile solids are also desirable for medium and large plants or arrangements can be made to have some of these tests run elsewhere as the need arises. In a small plant, routine tests can be made by the supervisor; in a large plant a chemist should be employed [7].

Oxygen consumed, ash, % of total organic solids, and especially total organic solids less crude fiber, are considered the best yardsticks to measure degree of digestion, although pH, and transmittance are good, quick and indirect methods for the material and digestion process used. COD is a useful yardstick but is more time consuming and causes problems in the lab.

Tests for carbon (C), nitrogen (N), potassium (K) and phosphorus (P) are necessary to determine C/N, C/P ratios and amount of nutrients present. C/N ratio of compost prepared from most municipal wastes will fall between 10 and 20.

7.4 Area required for Composting

A number of parameters combine to determine the total areas required for composting especially composting pad such as total volume of the waste to be composted, space required for the equipment for handling and maneuvering and the aeration system which can either be forced or passive. Following steps are involved for the calculation of the area required for the composting pad [1].

A) Total volume of the feedstock (shredded organic material)

Total volume of the feedstock to be composted can be computed as follows:

$$TVF_s = \frac{R_t \times Rf_s}{BD} \quad \text{...........(7.2)}$$

Where;

TVF_s = Total Volume of Feedstock (m^3)

R_t = Retention time (days)

Rf_s = Rate of feed stock delivery (kg/day)

BD = Bulk density (kg/m^3)

B) Areas occupied by the windrows

Calculating the volume of each windrow depending upon its shape. The shape of the windrow can be anyone shown in the Fig 7.11.

Cross section areas of the compost pile will change depending upon the shape of the pile as shown the Fig. 7.11. The general formula for the computation of the cross section areas is as follows:

$$A = B \times H \quad \text{...........(7.4)}$$

Where;

A = Cross section Area(m^2)

B = Base (m)

H = Height (m)

After calculating the total volume of the feedstock and the volume of each windrow, the number of windrows can be computed as follows:

$$N_W = \frac{VF_s}{V_w} \quad \text{...........(7.5)}$$

Where;

N_W = Number of windrows

VF_s = Total Volume of the feedstock(m^3)

V_w = Volume of each windrow(m^3)

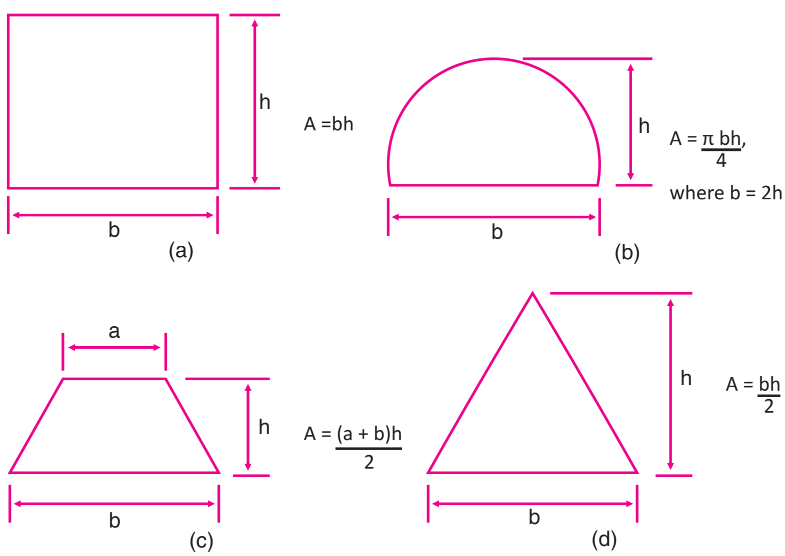


Figure 7.11: Area of potential compost piles

$$V = A \times L \quad \text{...........(7.3)}$$

V = Volume of the compost pile (m^3)

A = Cross section area of the pile (m^3)

L = length of the windrow

After knowing the number of windrows, area covered by the windrows will be computed as follows:

$W_a = N_W \times A_W$ ....(7.6)

Where;

W_a = Total windrow area (m^2)

N_W = Number of windrows

A_W = area per window (m^2)

C) Maneuvering area

Maneuvering area is required for the turning of the windrows. Two such spaces are provided on either side of the compost pile. The area required for each such space can be calculated by the following equation:

$A = L_W \times W_s$ ....(7.7)

A = Area of the space(m^2)

L_W = windrow length(m)

W_s = Width of the space(m)

Width of the space depends upon the type and size of the turning machine. For example with self-propelled turner space width might be 0.9 to 1.5 m.

D) Total area of the pad

Total area of the compost pad will be the sum of the area required by the windrows and for maneuvering.

7.5 Functions Performed by Composting

Following function are performed by the composting process:

a) Stabilizes the putrescible organic matter.

b) Kills pathogens and weed seeds.

c) Conserves N, P, K, and resistant organic matter found in the raw material.

d) Produces uniform, relatively dry end product free from objectionable and harmful objects.

e) Conducts the process in a sanitary manner. If conditions are controlled well then it is free from insects, rodents and odors.

7.6 Environmental Aspects

Composting plants may affect environment as these are potential sources of odors, breading places for flies and rodents. However, good management can minimize these problems. For this purpose:

a) Un-ground refuse is not to be held longer than one day.

b) Application of insecticides around unloading apron and on walls of receiving building can kill the larvae and flies brought by collecting vehicles.

c) Grinding destroys larvae and pupae.

d) Flies on fresh ground refuse can be controlled by maintaining proper conditions.

e) Maintaining high temperature during aerobic digestion controls fly larvae and eggs. Judicious use of insecticide may also help here.

f) Rodents can be controlled by poisons and denying them hiding places.

g) Hammer mills mice may be controlled by dampening materials.

7.7 Advantages & Disadvantages of Composting

It has been said that under favorable circumstances composting of organic wastes can be competitive with sanitary landfill and incineration even if the end product is not given away. However, the real economy of composting comes if the end product can be sold for a fair price.

7.7.1 Advantages

a) Composting is the only presently operational technology which provides for the recycling of organic residuals.

b) Composting can be used to dispose of many organic industries' wastes which because of their non-fluid nature are not amendable to treatment by activated sludge or trickling filter process.

c) The process is used in many parts of the world to convert human and often animal excrement with plant trimmings and other organic refuse to soil conditioner.

d) Composting plants offer favorable conditions for salvage of paper, cans, metals, rags and glass.

e) A well located refuse composting plant may reduce the cost of hauling refuse to the points of disposal.

f) Flexibility of operation permits a 100-200% overload design capacity for several days by increasing the time, receiving bins and grinders' operation.

g) Weather does not affect an enclosed system.

h) There is no leachate control problems involved.

i) There are no air pollution control problems as involved in incineration.

j) Composting produces potentially useful end product, which is utilized as soil conditioner, helps soil conservation in sloppy area, replaces the organic content exhausted by the excessive use of lands, improves porosity of soil and thus water retaining property for nourishment of the crops.

k) Sludge addition saves disposal cost.

7.7.2 Disadvantages

a) Capital and operating costs apparently are relatively high. Cost/ton of refuse is about 400-500% that of sanitary landfill if the end product is not sold.

b) Uncertainty of the market for compost as a fertilizer or soil conditioner undermines the desirability of the system especially in large population centers.

c) Seasonal use of the end product may require special marketing procedure or outdoor storage.

d) Refuse that damages the grinders must be removed and disposed of separately e.g. pipes, heavy stones.

e) Trained personnel to operate composting plants are not readily available.

f) Site procurement is a problem as every kind of refuse disposal facility is considered a nuisance in most neighborhoods.

g) A secondary disposal is always required, working also as alternate outlet in case of breakdown and for inorganic and non-recyclable materials.

Although this is a beneficial system of disposing the solid waste but it is more costly than landfilling method. It also needs final disposal into sanitary landfill which is the ultimate disposal method. But due to increase in the cost of land day by day and rising cost of manures and fertilizers, composting system has to be given due consideration.

7.8 Compost as Soil Conditioner

Concentrations of Nitrogen (N), Phosphorous (P) and Potassium (K) in compost are of course less as compared to those in commercial fertilizers. An estimate arrived is 11 kg of N, 60 kg of P and 120 kg of K per ton of compost. However, addition of compost adds organic matter to the soil, with several benefits.

Compost markedly improves the physical properties of the soil; makes it easier to till, more porous and easier to keep aerated. It helps the soil to absorb precipitation. Organic matter holds water like a sponge, so that in periods of drought, a field that contains a large amount of organic matter may be productive, when soil without it is valueless. Organic matter also supports earth worms which in turn keep the soil porous and improve aeration and percolation during heavy rains. This reduces run off and erosion.

According to test runs in California, organic matter in soil reduces the demand for chemical fertilizer as much as 40%. This is largely due to prevention of leaching i.e., water does not wash away chemical fertilizers as it does in barren soils.

Experiments also show that presence of organic matter is a pre-requisite to healthy biological activity of the soil, which stimulates growth. Roots have been known to grow 8 times as fast as in soil devoid of organic matter.

Healthy biological activity also helps in breaking down of insoluble mineral compounds such as phosphates which are required for plant growth.
Soluble N used as a fertilizer can be easily leached away. In the presence of organic matter and biological activity, a portion of this soluble N is converted into organic nitrogen of the micro-organisms bodies. As the micro-organisms die, the nitrogen again becomes available to the plant roots. In the interim period it is less likely to be looted by leaching or to the atmosphere as ammonia.

The same phenomenon occurs with phosphorus. Tests show that 95% of soluble phosphorus can be converted into organic bodies.

7.9 Anaerobic Digestion

Anaerobic digestion or anaerobic fermentation, as it is often called, is the process used for the production of methane from solid wastes. In most processes where methane is to be produced from solid wastes by anaerobic digestion, three basic steps are involved.

The first step involves preparation of the organic fraction of the solid wastes for anaerobic digestion and usually includes receiving, sorting separation and size reduction.

The second step involves the addition of moisture and nutrients, blending, pH adjustment to about 6.7, heating of the slurry between 55 and 60°C, and anaerobic digestion in a reactor with continuous flow, in which the contents are well mixed for 5to 6 days.
The third step involves capture, storage, and if necessary, separation of the gas components, evolved during the digestion process.

The specific organisms involved in the anaerobic fermentation of solid waste are not well defined. Therefore, it is common to see the term acid

Fig. 7.12: A typical biogas plant [8]

formers and methane formers used when referring to the organisms involved in the conversion of the liquified organic compounds into simpler acid and related intermediates and to carbon dioxide and methane. A typical biogas plant employing anaerobic digestion process is shown in Fig.7.12.

7.10 Microbiology of Composting Process

The oldest biological waste treatment system utilized by man involves the decomposition of solid waste in soil by micro-organisms. For centuries the wastes of man and other animals, including their bodies, and the tissues of plants have been disposed on or buried in the soil. Eventually all of these wastes have disappeared, being transferred into some of the substances that make up various soils. It is the soil micro-organisms that produce these changes by breaking down complex organic compounds into simple compounds, which in turn make up the nutrient material of the plant world. Currently there are at least two general categories of solid waste disposal accomplished by microbes: sanitary landfilling and composting. The following sections will briefly explain the specific microbial interactions which are responsible for solid waste disposal in soil [6].

7.10.1 The Soil Environment

The fertile soil environment provides an ideal habitat for a virtual microscopic menagerie, consisting of wide range of micro-organisms varying in number from a few per acre to billions per gram of soil (see Table 7.2).

Soil microorganisms may be thought of as those forms of life which generally cannot be seen without the aid of a microscope, including bacteria, protozoa, rickettsia, viruses, algae, and fungi. Simply stated, bacteria are typically single-celled vegetative organisms; protozoa are single-celled animals, rickettsia are similar to both bacteria and protozoa but are classified under a single genus; viruses are ultramicroscopic, considered by some to be proteins capable of multiplication; algae are microscopic plants containing chlorophyll; and fungi are microscopic plants devoid of chlorophyll.

Table 7.2: Soil population (number of organisms per gram in a fertile agricultural soil) [6]

Bacteria	Count/Population
Direct count	2,500,000,000
Dilution Plate	15,000,000
Actinomycetes	700,000
Fungi	400,000
Algae	50,000
Protozoa	30,000

7.10.2 Types of Micro-Organisms

The principal classes of microorganisms involved in the aerobic decomposition of solid wastes are;(1)bacteria, (2)fungi, (3) actinomycetes, (4) algae, (5)protozoa and (6) some larva[1].The general class of micro-organisms which play active role in the conversion of solid wastes to either cell mass or some by-product of cell metabolism are called “protists”.

Micro-organisms in this class may be unicellular or multicellular but without cell differentiation. Bacteria, fungi, yeasts and actinomycetes are of major concern. Protozoa and algae are also protists but are not of primary importance.

7.10.3 Process Microbiology

The principal microorganisms involved in the aerobic decomposition of solid wastes can be identified as bacteria, fungi, yeasts, and actinomycetes. While members of each of these groups can be found that are capable of decomposing all the raw materials in solid wastes, as a group they prefer different compounds. Typically, bacteria prefer simple water-soluble sugars, while fungi, yeasts, and actinomycetes are particularly effective in the decomposition of celluloses and hemicelluloses.

Aside from metabolic requirements, the predominance of microorganisms varies during the course of the composting process. One of the major factors contributing in composting process is the heat released as a result of the dissimilatory and assimilatory activities of the microorganisms in converting solid wastes to stabilized humus. In dissimilatory process, complex compounds are broken in simpler compounds with the release of energy. In assimilatory process simple compounds are converted to complex compounds and are accompanied with the production of biomass. These two processes can take place simultaneously.

7.10.4 Aerobic and Anaerobic Metabolism

Microorganisms that cannot grow or survive in the absence of oxygen are called obligate aerobes. Similarly, obligate anaerobes are those organisms that cannot survive or are inhibited in the presence of oxygen. Organisms capable of growth either in the presence or absence of oxygen are called facultative anaerobes. Many facultative organisms possess both aerobic and anaerobic metabolic systems and can change from one system to another in response to the presence of oxygen. Other facultative organisms have only an anaerobic metabolic system but are insensitive to the presence of oxygen.

7.10.5 Nutritional Requirements

To grow and function properly, microorganisms must have all the nutrients necessary to synthesize and maintain their cell tissue. This normally includes a source of carbon, hydrogen, oxygen, nitrogen, inorganic salts, and phosphorus, sulfur and trace amounts of assorted micronutrients.

7.10.6 Environmental Requirements

The most important environmental requirements for the microorganisms to work include: temperature, moisture content, pH, and the absence of toxicity. The temperature range over which microorganisms have been found to survive varies from -5 to 80°C. The lower limit is set by the freezing point of water, which is lowered by the contents of the cell. The upper limit is usually established by the characteristics of the constituents that make up the cell tissue.

For example, most proteins and nucleic acids are destroyed in the temperature range of 50 to 90°C. For most organisms used for the conversion of solid wastes, the temperature range for optimum growth is much smaller. Microorganisms that grow best in the temperature range of 20 to 40°C are called mesophiles and are the largest group found in nature. Those that grow best in the range below 20°C are called psychrophiles, and those that grow best above 45°C are called thermophiles. These distinctions are not very rigid, and many microorganisms have been identified that can adapt to all three temperature ranges.

Initially the material being composted heats up as a result of the release of energy accompanying the degradation of the readily convertible organic food wastes and simple sugars. When the temperature rises above 45 to 50°C, the thermophilic organisms begin to predominate. These organisms will predominate at about 55°C, which has been observed as the optimum temperature for these organisms. Certain types of bacteria and actinomycetes are common in this temperature range.

Under normal conditions, stabilization is more rapid in the thermophilic range than in the mesophilic range. Because water is essential for the growth of microorganisms, the moisture content of the wastes to be converted must be known, especially if a dry process, such as composting, is to be used. In many composting operations, it has been necessary to add water to obtain optimum bacterial activity. The optimum moisture content lies in the range of 50 – 60%. The right amount of the moisture content can be computed through simple mass balance as given below [4]:

$$M_p = \frac{M_a x X_a + 100 X_s}{X_s + X_a} \qquad \text{.............(7.8)}$$

Here,

M_p = Moisture content in the mixed pile

M_a = Moisture in the shredded and screed solid in terms of percentage

X_a = Wet mass of the solid (tons)

X_s = Mass of the sludge

Solved Example 7.2

Ten tons of a mixture of paper and other compostable materials has a moisture content of 7%. The intent is to make a mixture for composting of 50% moisture. How many tons of water or sludge must be added to the solids to achieve this required moisture concentration in the compost pile?

Solution:

M_a = 7%, X_a = 10 tons, M_p = 50% and X_s=?

Putting these values in 7.8;

$$50 = \frac{7\times10+100\times Xs}{Xs+10}$$

$$50(X_s+10) = 70+100X_s$$

$$50X_s+500 = 70+100X_s$$

$$50X_s = 430$$

$$X_s = 8.6 \text{ tons of water}$$

pH level is very important for the microbes to perform their activities while working on the organic waste to convert it into compost. Micro-organisms cannot survive in an environment where pH is too acidic (pH<5.5) or too basic (pH>9). When the pH of the compost feedstock is greater than 9, nitrogen is more readily converted to ammonia and becomes biologically unavailable. It increases the carbon content and an appropriate C:N is disturbed which impede the composting process. Generally, a pH range of 6.5-8 is acceptable for successful composting [9].

In order to measure the pH of the composting feedstock, slurry is prepared using waste sample and de-ionized water and is then measured using litmus paper or special probes.

7.11 Carbon and Nitrogen Cycles

The microbiology of solid waste composting can further be illustrated by the cyclic transformations of carbon, nitrogen, sulfur and compounds thereof. Only carbon and nitrogen cycles are considered here in detail.

7.11.1 The Carbon Cycle

Compounds of carbon are involved in a series of chemical changes of a cyclic nature. These biochemical events extend from reactions involving carbon dioxide to the complex polysaccharide constituents of solid wastes. Changes involve both degradation and synthesis. Solid wastes deposited in the soil contain carbon as a constituent of organic compounds, some of which is not available for plant growth. Thus carbon must be released, or returned as carbon dioxide, before it can again be utilized by plants. Microorganisms bring about this transformation.

The major organic carbon-containing substances present in solid waste include cellulose, starch, sugar, lignin, and pectin. Glycogen from dead animals, as well as the lipids and proteins of all animal cells, also contain carbon in complex organic organization. Through a variety of integrated microbial enzymatic reactions, the organically bound carbon in these substrates is ultimately released as carbon dioxide. Microbes capable of breaking down long chain cellulose molecules (cellulolytic microorganisms), including many species of bacteria and fungi, are common in landfill or compost systems. These organisms excrete an enzyme (cellulase) which hydrolyzes the long cellulose chain into smaller glucose molecules. This glucose is readily metabolized by a multitude of microbes via various biochemical pathways. Aerobic bacteria are likely to produce carbon dioxide and cell substance, whereas anaerobes produce methane gas, a variety of fatty acids, alcohols, and other neutral products.

Microorganisms are capable of synthesizing a variety of carbohydrates from simple carbon compounds, some of which are integral parts of the cell structure, capsular material, or products secreted into the soil environment as slime. The slimes released into the soil are beneficial in the formation of water-stable aggregates of soil particles, a desirable type of soil structure. A general summary of the carbon cycle is shown in Fig. 7.13.

about these changes, and not all the steps have been clearly elucidated. Some of the changes include:

(a) Proteolysis

The nitrogen present in proteins may be regarded as "unavailable", or "locked". In order to get this organically bound nitrogen free for

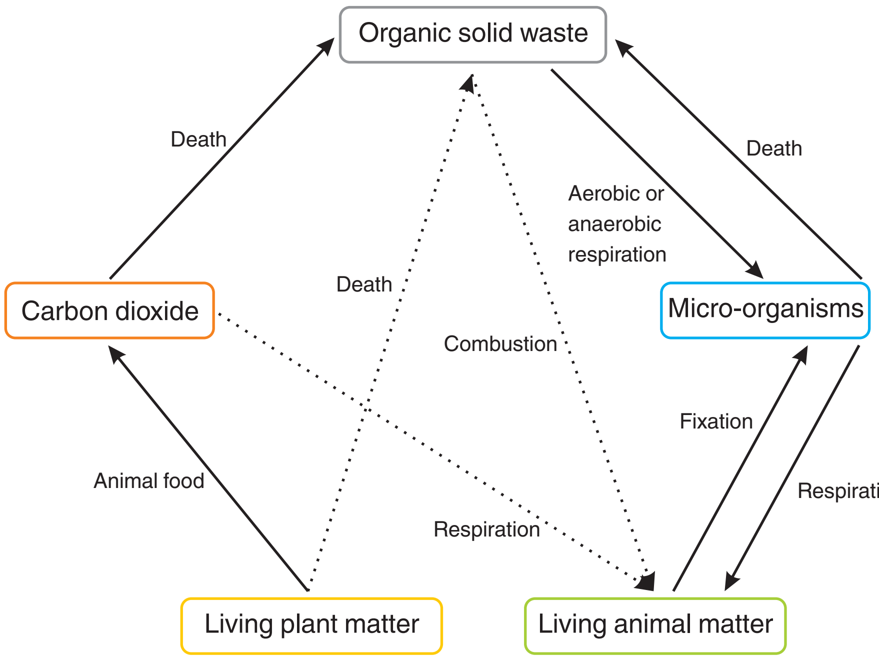


Figure 7.13: The carbon cycle

7.11.2 The Nitrogen Cycle

Nitrogenous substances are found in almost every type of organic solid waste. Proteins, a constituent of all living cells, are complex nitrogenous compounds having an average nitrogen content of approximately 16 percent. Other complex organic nitrogenous substances occurring in solid wastes include nucleic acids, purine and pyrimidine bases, and amino sugars. The simplest form of nitrogen involved in biological transformations is gaseous elementary nitrogen. The overall transformations in which microorganisms are involved range from nitrogen gas to protein and other complex organic nitrogenous compounds. Many intricate enzymatic reactions are involved in bringing

recirculation, the first process that must occur is the enzymatic breakdown of proteins, or proteolysis, to smaller units of amino acids (peptides). These peptides are then attacked by different enzymes (peptidases), resulting ultimately in the release of individual amino acids. Relatively few bacterial species possess large amounts of proteolytic enzymes. However, many fungi and soil actinomycetes are extremely proteolytic and consequently of great value in solid waste disposal systems.

(b) Amino acid breakdown

Amino acids are degraded by microbial attack through various metabolic pathways. The liberation of nitrogen from these compounds is accomplished by the removal of the amino group (deamination). One of the end products of these reactions is always ammonia (Nh_3).

(c) Nitrification

The oxidation of ammonia to nitrate is referred to as nitrification. It is carried out in two stages by specific bacteria, as shown below, and is one of the most important activities.

1. Oxidation of ammonia to nitrite by Nitrosomonas:

$$2NH_3 + 3O_2 \rightarrow 2HNO_2 + 2H_2O$$

2. Oxidation of nitrite to nitrate by Nitrobacter:

$$HNO_2 + 1/2O_2 \rightarrow HNO_3$$

Nitrosomonas and Nitrobacter are both obligate autotrophs and strict aerobes and will not grow upon the usual media employed for cultivation of heterotrophs. They grow only in a mineral salts medium containing ammonia or nitrite.

(d) Reduction of Nitrate to Ammonia

Several heterotrophic bacteria are capable of converting nitrates into nitrites or ammonia under anaerobic conditions. The oxygen of the nitrate serves as an acceptor for hydrogen. The process involves several reactions, and the overall result is as follows:

$$HNO_3 + 4H_2 \rightarrow NH_3 + 3H_2O$$

(e) Denitrification:

Certain microorganisms are capable of transforming nitrates to nitrogen gas or nitrous oxide. This process is called denitrification.

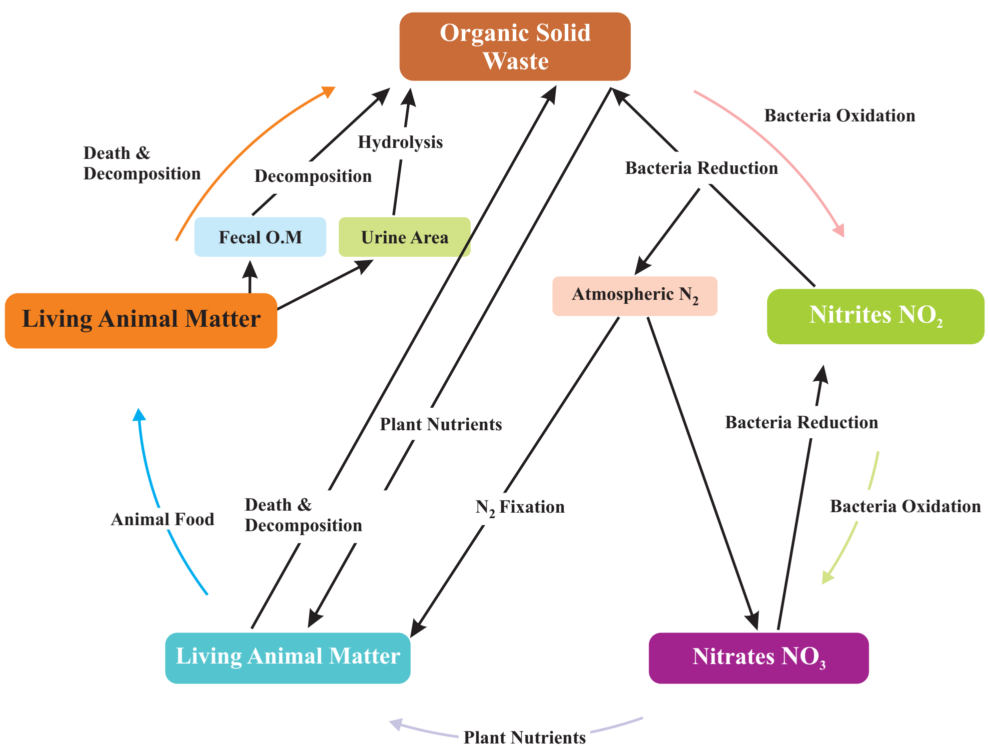


Figure 7.14: The nitrogen cycle

(f) Nitrogen Fixation

A number of microorganisms are capable to utilize molecular nitrogen in the atmosphere as their source of nitrogen. The conversion of molecular nitrogen into nitrogenous compounds is known as nitrogen fixation.

A summary of the various nitrogen transformations known as the nitrogen cycle is shown in Fig. 7.14.

EXERCISES

1. Briefly describe different types of microorganisms which play part in decomposition of organic wastes. Write a short note on assimilatory and dissimilatory processes.
2. What is meant by aerobes, anaerobes, facultative organisms?
3. Define composting and explain different steps involved in the process.
4. Explain the "Nitrogen and Carbon cycles" and discuss their importance with regards to composting.
5. What are the design considerations for composting process? Discuss their importance.
6. Delineate the importance of composting as a land conditioner.
7. What are the products of aerobic and anaerobic digestion?
8. What do you know about soil microorganisms? How do they help in biodegradation of solid wastes?
9. Composting is a viable disposal method for solid wastes in urban areas of Pakistan. Discuss and propose a proper methodology.
10. Discuss the various parameters with their importance in the preparation of solid wastes for composting. What should be done to put composting in practice locally?

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8. SANITARY LANDFILLING

This chapter deals with the safe disposal of the untreated municipal solid waste, rejected materials coming from the composting facilities, material recovery facilities (MRF) and incineration facilities etc. Rejected or residual materials are those which cannot be recycled. The major topics discussed in this chapter are (1) open dumping and landfilling (2) advantages and disadvantages of sanitary landfilling (3) different methods of landfilling (4) site selection criteria for landfill sites (5) chemical reaction occurring within the landfill site (6) generation, movement and management of landfill gases and leachate and (7) design aspects of the landfill site.

8.1 Disposal of the Solid Waste

Final disposal of the municipal solid waste can be accomplished in two ways i.e. (1) open dumping, and (2) sanitary landfilling.

8.1.1 Open Dumping

Open dumping refers to placing the solid waste, at a designated place, without any cover. Although a cheap disposal method, however, it is highly undesirable as it poses serious threats to the air, soil, ground water and human health (Fig. 8.1). It is mostly practiced in Pakistan.

Fig. 8.1: Open dumping of municipal solid waste

Open dumping results in littering of waste with wind. Rain water may result in dissolving organics and toxic matters, which may either infiltrate and join groundwater or may join surface water due to run off. Poor implementation of environmental regulations, lack of awareness, technical expertise and resources are the major factors for the use of this method in Pakistan.

8.1.2 Sanitary Landfill

Sanitary landfill is a scientific and an engineered method of final disposal of solid waste, in a manner that protects the public health and the environment. The process by which wastes are placed in the landfill is called landfilling. It includes the following activities:

- Monitoring of the incoming waste stream,
- Placement and volume reduction of the waste through mobile compactors such as bulldozers etc., and
- Installation of the landfill and environment control facilities.

In a sanitary landfill, waste is spread in thin layers, compacted to the smallest practical volume, and covered with the soil or other suitable material at the end of each day. When the disposal site reaches its ultimate capacity i.e., after all disposal operations are completed, a final layer of 0.6 meter thick or more of cover material is applied. A typical sustainable sanitary landfill site is show in Fig. 8.2.

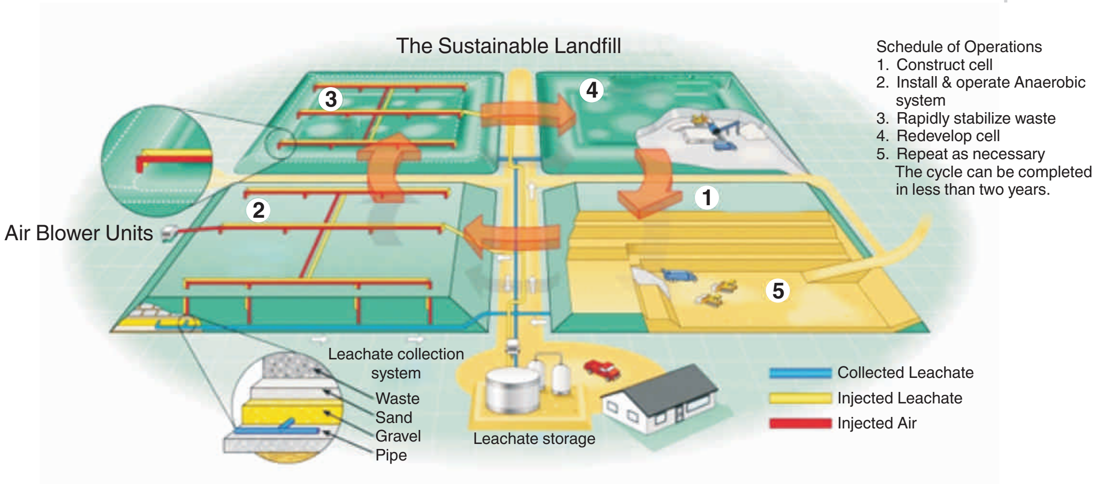


Figure 8.2: A typical sanitary landfill site design [1]

8.1.1.1 Advantages of Sanitary Landfill

Historically landfills have been the most economical and environmentally acceptable method for the disposal of solid waste in the developed countries and in some of the developing countries too. Even with implementation of waste reduction, recycling and transformation technologies, disposal of residual solid wastes in landfills still remains an important component of integrated solid waste

Table 8.1: Advantages and disadvantages of sanitary landfill [2]

Advantages	Disadvantages
Where land is available, a sanitary landfill is usually the most economical method of solid waste disposal.	In highly populated areas, suitable land may not be available within an economical hauling distance.
The initial investment is low compared to other disposal methods.	Proper sanitary landfill standards must be adhered to daily or the operation may result in an open dump.
A sanitary landfill is a complete or final disposal method as compared to incineration and composting which require additional treatment or disposal operations for residue, and unusable materials, etc.	Sanitary landfills located in residential area can provoke extreme public opposition.
A sanitary landfill can receive all types of solid wastes, eliminating the necessity of separate collections.	A completed landfill will settle and require periodic maintenance.
A sanitary landfill is flexible: increased quantities of solid wastes can be disposed off with little additional personnel and equipment requirement.	Special design and construction must be utilized for buildings constructed on completed landfill because of the settlement factor.
Sub marginal land may be reclaimed for use as parking lots, playgrounds, golf courses, airports, etc.	Methane, an explosive gas, and other gases produced from the decomposition of the wastes may become a hazard or nuisance and interfere with the use of the completed landfill.

management strategy. The advantages and disadvantages of sanitary landfills are given in Table 8.1.

8.2 Landfilling Methods

8.2.1 USA Methods of Landfilling

The principle methods used in USA for landfilling of MSW are: (1) Excavated cell/trench (2) Area; and (3) Canyon [3]. The main features of these types of landfills are illustrated in Fig. 8.3, 8.4, 8.5 and 8.6.

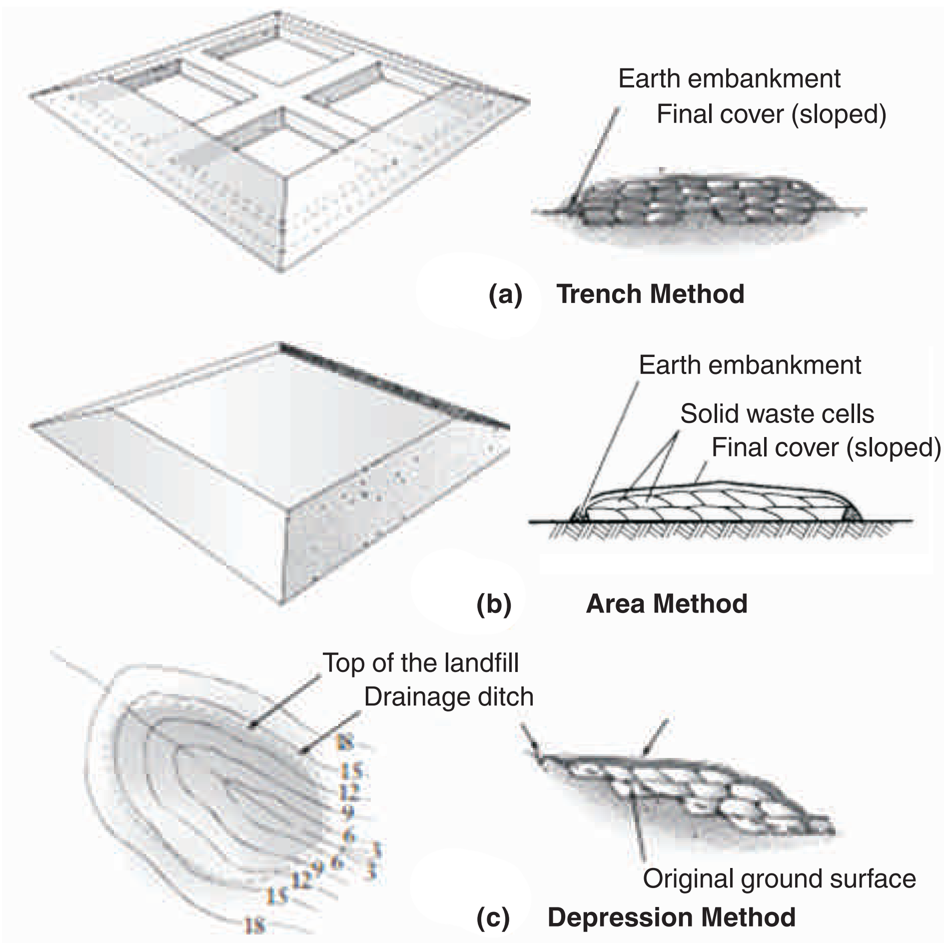


Figure. 8.3: Commonly used landfilling methods in USA [4]

8.2.1.1 Excavated Cell/Trench Method

This method is suitable to areas where an adequate depth of cover material is available at the site and where the water table is not near the surface. The soil excavated from the site is used for daily and final cover. Excavated cells are typically square, upto 300 meter in width and length with side slopes of 1.5: 1 to 2 : 1. Trenches vary from 60 to 300 meter in length, 1 to 3 meter depth, and 5 to 15 meter width.

8.2.1.2 Area Method

This method is used when the terrain is unsuitable for the excavation of cells or trenches in which to place the solid wastes. Also high-ground water levels necessitate the use of area type landfills. The wastes are unloaded and spread in long narrow strips on the surface of land in a series of layers that vary in depth from 40 to 75 cm. Each layer is compacted as the filling progresses until the thickness of the compacted

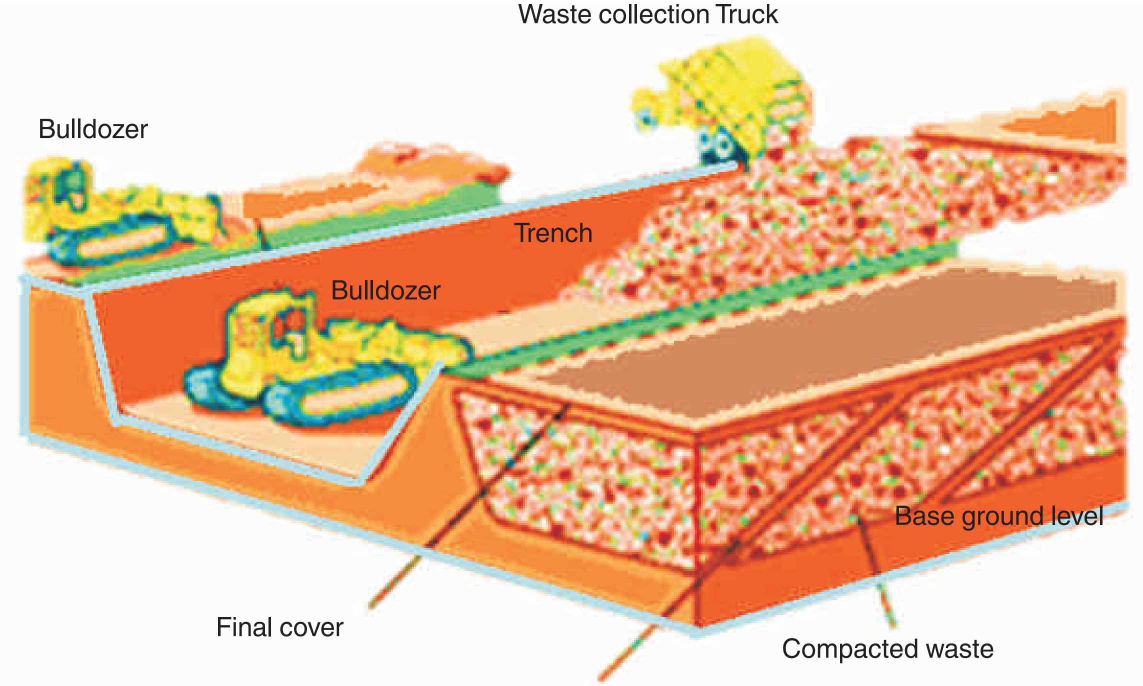


Figure 8.4: Cell method of landfilling [5]

wastes reaches the designed height varying from 2 to 3 meter at the end of the day's work. A soil cover of 15 to 30 cm thickness is then placed over the completed fill.

8.2.1.3 Canyon/Depression Method

Canyon, ravines, dry borrow pits and quarries have been used for landfills. The techniques to place and compact solid wastes vary with the geometry of the site, the characteristics of the

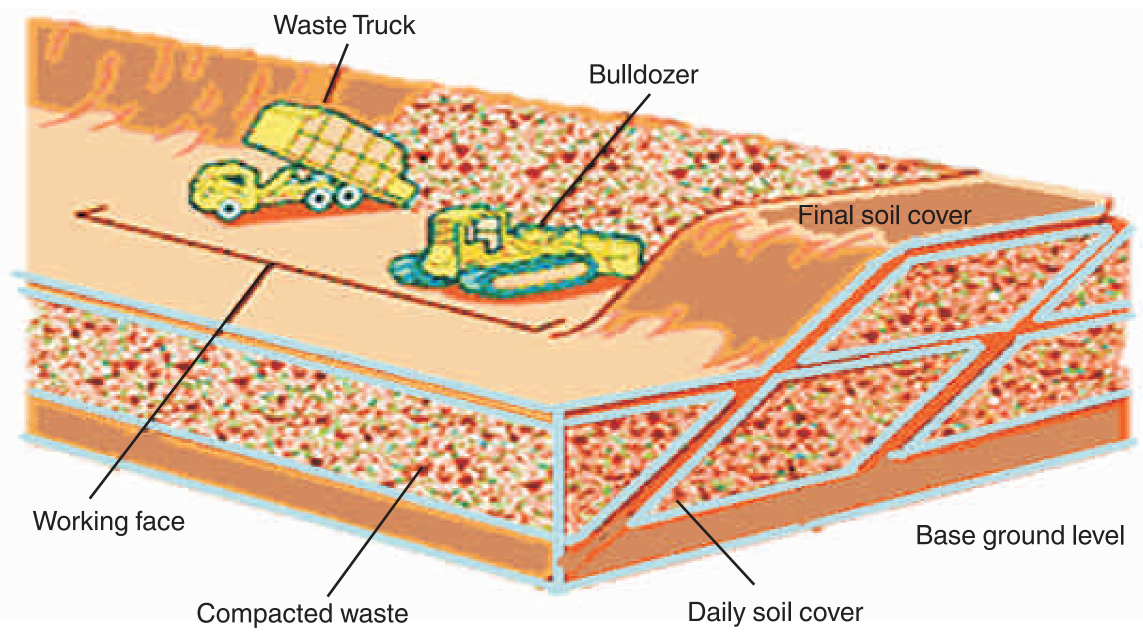


Figure 8.5: Area method of landfilling [5]

cover material, the hydrology and geology of the site and access to the site.

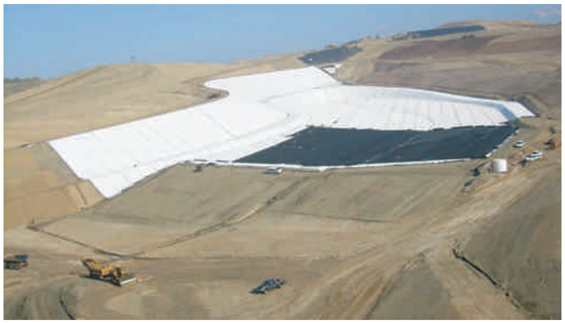


Figure 8.6: A typical canyon landfill site [6]

8.2.2 Japanese Methods of Landfilling

There is an acute shortage of land in Japan for the construction of sanitary landfills. Therefore, the space used for sanitary landfill is reused after some time. The waste inside is either converted to compost or reduced to such volumes that it can be removed, evacuating the landfill site, for the purpose of reuse. Due to the above reasons, Japanese have made certain innovation in the construction of landfills. Based on varying metabolic function of microorganism within landfills, following categories are used in Japan [7].

8.2.2.1 Anaerobic Landfill

Wastes are filled in dug area of plane field or valley. Wastes are filled with water and decomposition occurs in anaerobic condition.

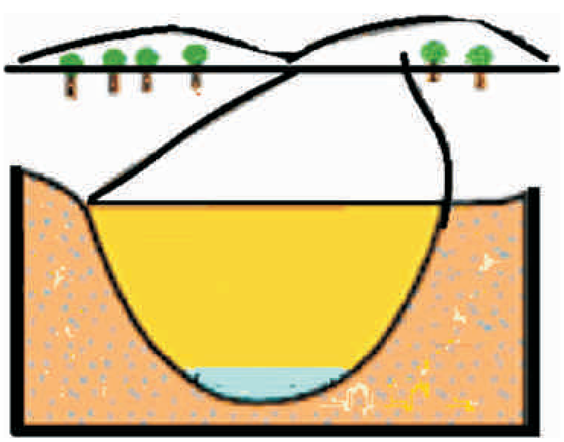


Figure 8.7: Anaerobic landfill

8.2.2.2 Anaerobic Sanitary Landfill

Anaerobic landfill with cover-like sandwich shape is used. Condition inside the landfill is same as anaerobic landfill.

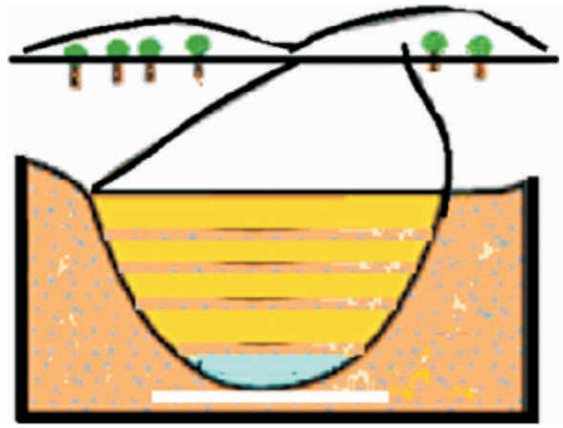


Figure 8.8: Anaerobic sanitary landfill

8.2.2.3 Improved Anaerobic Sanitary Landfill

This has leachate collection system in the bottom of the landfill site. Other conditions are same as in anaerobic sanitary landfill. The conditions are still anaerobic but moisture content is much less than in anaerobic sanitary landfill.

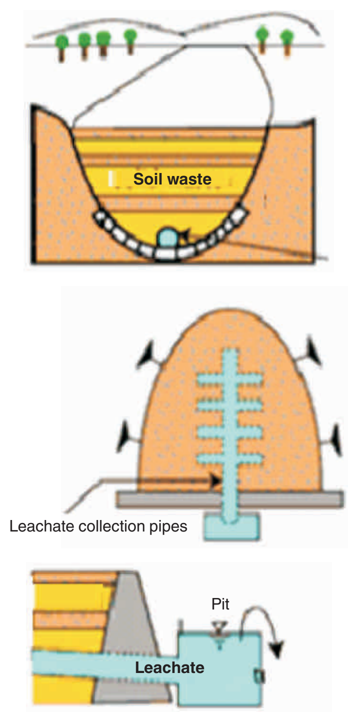


Figure 8.9: Improved anaerobic sanitary landfill

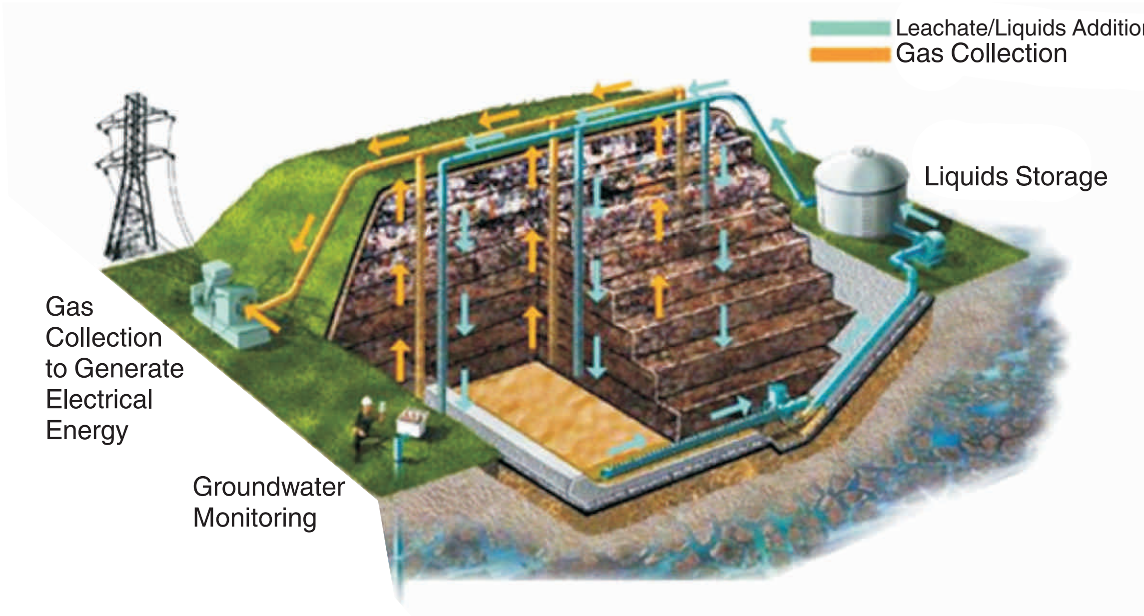


Figure 8.10: Improved bioreactor sanitary landfill [8]

8.2.2.4 Semi-Aerobic Landfill

Semi-aerobic landfill is defined as a sanitary landfill with perforated leachate collection pipes, which not only drains out the leachate but also supplies the waste with air through natural convection. Fig. 8.12 explains the difference between anaerobic landfill and a semi – aerobic landfill site. Perforated pipes are enclosed in packed gravels and covered with a layer of waste, which in turn, is covered with porous soil cover. These pipes are led to open air so that the inflow of air is induced naturally. Since oxygen is supplied to microorganisms by air, the waste can be stabilized biochemically through aerobic fermentation. Some of the advantages in semi-aerobic landfill are:

- Leachate is less problematic than the one from anaerobic landfill
- Volume of hazardous gases can be reduced.
- Waste is more quickly stabilized than in anaerobic landfill.
- Groundwater pollution of leachate can be reduced.
- Operations can be maintained at a low cost.

Due to the above reasons, this design or type is recommended for the landfill site accepting organic waste, in Japan.

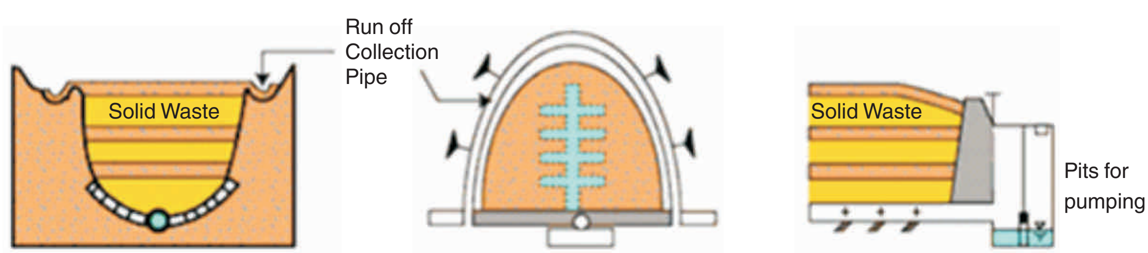


Figure 8.11: Semi-aerobic landfill

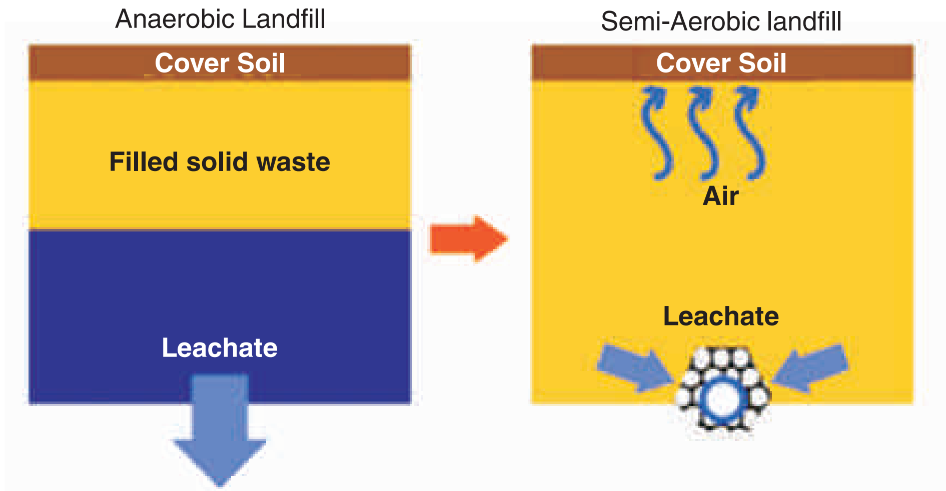


Figure 8.12: Difference between anaerobic and semi-aerobic landfill

8.2.2.5 Aerobic Landfill

In addition to the leachate collection pipe, air supply pipes are attached and air is forced into the aerobic landfill which results in quick decomposition of waste.

8.3.2 Haul Distance

It is one of the important variables in site selection. Site should be located at economical haul distance.

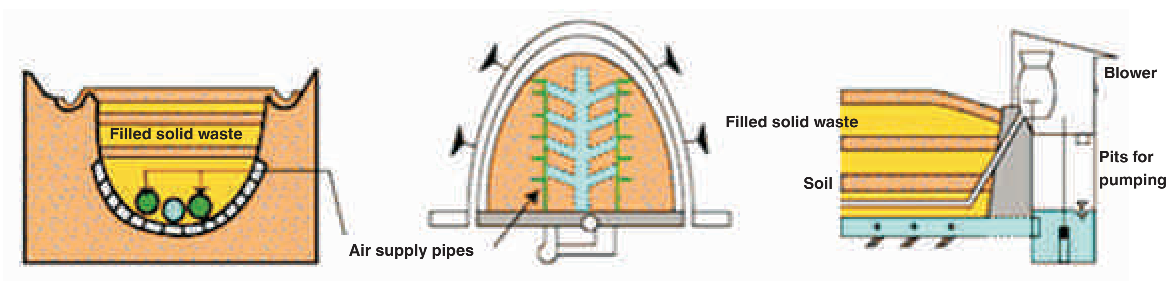


Figure 8.13: Aerobic landfill

8.3 Site Selection Criteria for Landfills

A brief account of the important points considered while selecting a landfill site is given below [2]:

8.3.1 Available Land area

Ensure that sufficient area is available to operate for at least 1 year. Preferably longer period i.e up to 5 years is recommended. Shorter periods make the operation expensive with respect to site preparation, provision of auxiliary facilities and completion of final cover.

8.3.3 Soil Conditions and Topography

Each day's cover and final cover require soil conditions to be investigated. Data can be obtained from geologic and hydro geologic investigations. Local topography is important to decide about the method of landfill, equipment requirement and extent of work necessary to make the site usable.

8.3.4 Climatic Condition

At many locations, access to the landfill site may be affected by weather conditions like snowfall etc. Where freezing is severe, landfill cover material should be available in stockpiles. Direction of wind will be known to establish wind breaks during filling operation.

8.3.5 Surface Water Hydrology

The local surface-water hydrology is important in establishing the existing natural drainage and runoff characteristics that must be considered.

8.3.6 Geologic and Hydro-Geologic Conditions

These are most important in establishing the environmental suitability of the landfill area. Data from these sources may be required to access the pollution potential of proposed site and the steps to be taken during construction to control leachate and gas movement problems which may contaminate local ground water aquifers.

8.3.7 Local Environmental Condition

Landfill site must be environmentally acceptable with respect to noise, odor, dust and vector control. Flying papers and plastic films must also be controlled by providing wind breaks.

8.4 Reactions Occurring in Completed Landfills

To plan and design sanitary landfill effectively, it is important to understand what takes place within a landfill after filling operation has been completed. Solid waste placed in a sanitary landfill undergoes a number of simultaneous processes as follows:

i) Biological degradation
ii) Chemical reactions
iii) Settlement
iv) Generation of gases and their horizontal and vertical movement (e.g., CH_4, Co_2).
v) Infiltration of rainwater, surface water and leaching of organic and inorganic components.
vi) Formation of leachate (obnoxious liquid generated, due to infiltration of rain and surface water and biological and chemical reactions) and its movement in horizontal and vertical direction.

Generation and movement of gases and leachate are discussed in detail in the following sections.

Solved Example 8.1

Calculate the area requirement for a sanitary landfill for a city with population of 1,000,000 having a solid waste generation rate of 0.5 kg/cap./day. Assume density in landfill to be 1.2 ton/m^3.

Solution:

Generation per year = 10, 00,000 x 0.5 x 365
= 1825 x 10^5 kg
= 1.825 x 10^5 tons (1000kg=1 ton)

Volume required per year= 1.825 10^5 / 1.2 = 1.52 10^5 m^3

Let depth of landfill = 3 m.

Area/year = 1.52 x 10^5/3 = 50666.6 m^2
= 5.06 hectare (10,000 m^2 = 1 hectare)
= 12.5 Acre (1 hectare = 2.47 acres)

Extra area for services = 20%
(Roads, garages etc.)

Total Area = 12.5 x 1.2 = 15.0 Acres

8.5 Generation of Landfill Gases

The principal gases, generated in a landfill are methane and carbon dioxide. The other trace gases are nitrogen, hydrogen, carbon monoxide, sulphides and ammonia. The generation of the principal landfill gases occurs in five sequential phases, as illustrated in Fig. 8.14. A brief description of these phases is as following.

Phase-I: In this phase decomposition occurs in aerobic conditions, because a certain amount of air is trapped within the landfill.

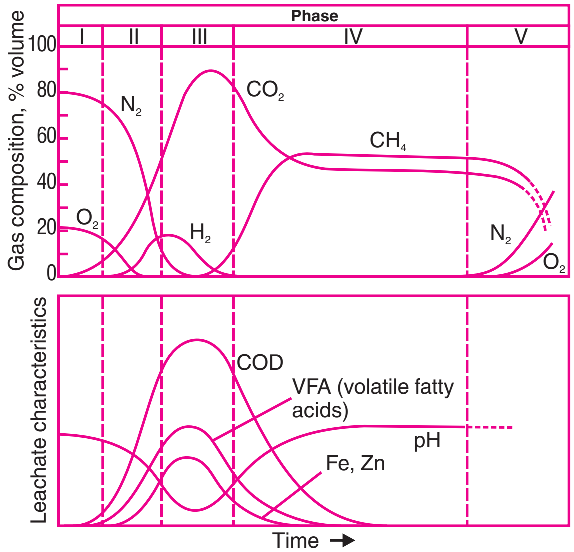


Fig. 8.14 : Generalized phases in the generation of landfill gases (I) = initial adjustment, (II) = transition phase, (III) = acid phase, (IV) = methane fermentation, and (V) = maturation phase.[2]

Phase-II: In this phase, oxygen is depleted and anaerobic conditions start developing.

Phase-III: This is the acid phase. The microbial activity initiated in phase II accelerates forming organic acids and hydrogen gas. CO is the principal gas generated during this phase. The micro-organisms taking part in this phase are known as acid formers.

Phase-IV: This is called the methane fermentation phase and the micro-organisms taking part are known as methane formers. They are strictly anaerobes. They convert the acetic acid and hydrogen gas to CH_4 and Co_2.

Phase-V: This is known as maturation phase. During this phase portion of biodegradable material that was previously unavailable will be converted due to continuation of migration of moisture content through the waste. The biodegradation process gets completed.

8.5.1 Gas Movement

Although most of the methane escapes to the atmosphere, both methane and carbon dioxide have been found at concentrations up to 40% at lateral distances of up to 120 meters from the edges of the unlined landfills. If methane is unvented in an uncontrolled manner, it can accumulate below buildings or in other enclosed spaces at, or close to, a sanitary landfill.

With proper venting, methane should not pose a problem. Carbon dioxide on the other hand, is troublesome because of its density. It tends to move towards the bottom of the landfill. As a result, the concentration of carbon dioxide in the lower portions of a landfill may be high for years. It is readily soluble in water and can react with it to form carbonic acid. The reaction lowers the pH, which in turn can increase the hardness and mineral content of the groundwater.

8.5.2 Passive Control of Landfill Gases

The movement of landfill gases is controlled to reduce atmospheric emissions, to minimize subsurface gas migration, and to recover energy from methane. Control systems may be passive or active. In passive controls the pressure of the gas generated serves as the driving force for its movement. In active controls, energy in the form of an induced vacuum is used to control the flow of gas.

Passive controls can be achieved during times when the principal gases are being produced at a high rate by providing paths of higher permeability to guide the gas flow in the desired direction. A gravel-packed trench, e.g., can serve to channelize the gas to a flared vent system (Figs. 8.15 and 8.16).

In modern landfills the movement of landfill gases through adjacent soil is controlled by constructing impermeable liner around the landfill [Fig. 8.15(c)]. The gases escape through gravel packed wells with perforated pipes, which terminate into solid pipes at the top. The gases thus collected are either flared or used as fuel.

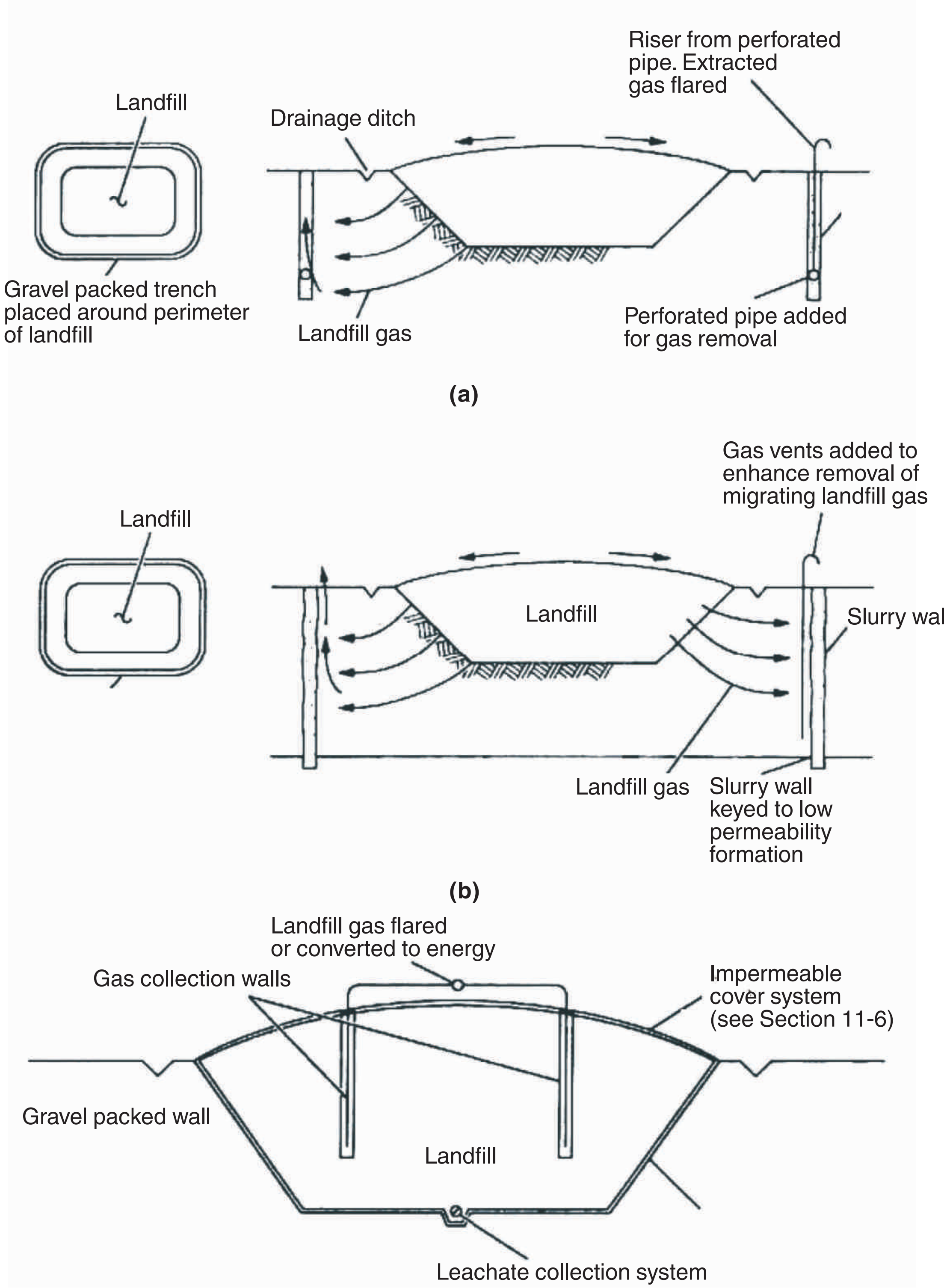


Figure 8.15: Passive facilities used for the control of landfill gases (a) interceptor trench filled with gravel and perforated pipe, (b) perimeter barrier trench, and (c) use of impermeable liner in landfill. [Note: interceptor and barrier trenches as mentioned in (a) and (b) above are used to control the off-site migration of landfill gas from existing unlined landfills.]

Figure 8.16: Typical candlestick type waste gas burner used to flare landfill gas from a well vent or several interconnected well vents

8.5.3 Active Control of Landfill Gases

The lateral movement of landfill gas can be controlled by using gas extraction wells and by creating a partial vacuum, which induces a pressure gradient toward the extraction well (Fig. 8.17 [9]. The extracted gas is either flared or used for the production of energy.

8.6 Movement and Control of Leachate in Landfills

Leachate may be defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials from it. In most landfills the leachate is composed of the liquid produced from the decomposition of the wastes and liquid that has entered the landfill from external sources, such as surface drainage, rainfall, groundwater, and water from underground springs.

When leachate percolates through solid wastes that are undergoing decomposition, both

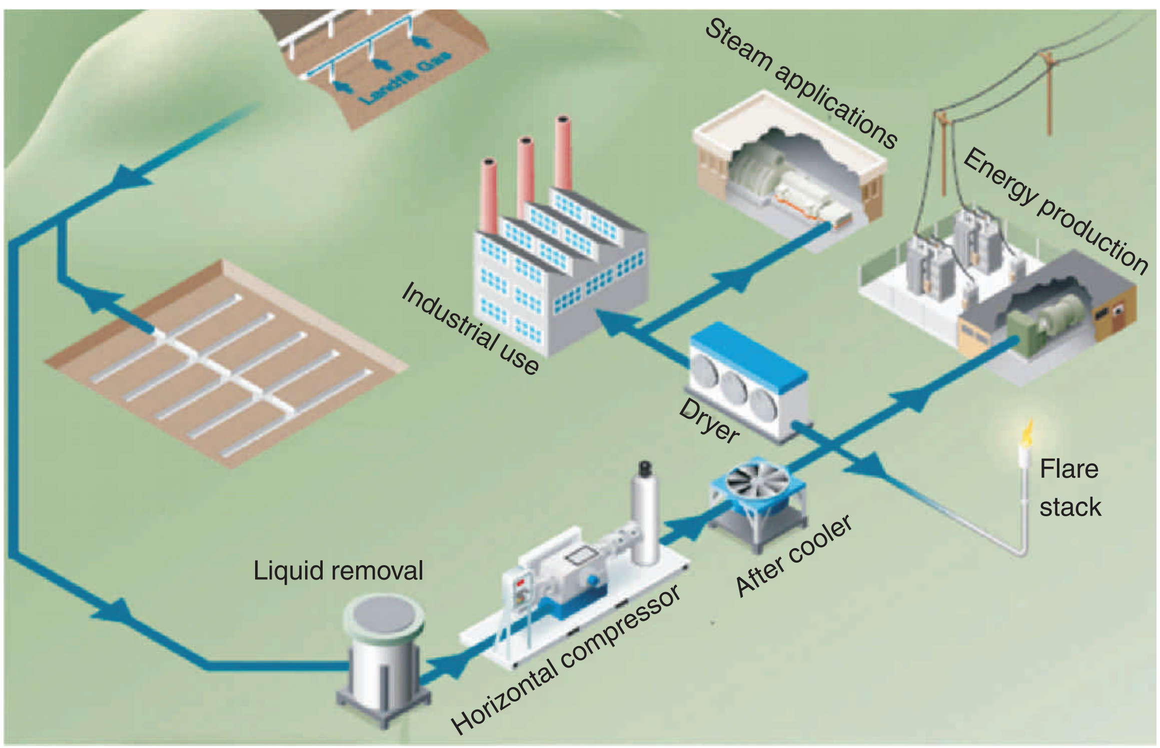


Figure 8.17: Landfill gas recovery system using vertical wells (Active control)

biological materials and chemical constituents are picked up. Representative data on the chemical characteristics of leachate, reported in Table 8.2, indicates that the range of concentration values for the various constituents is rather extreme. For this reason; no average value can be given for leachate. The typical values reported are intended to be used only as a guide.

methane produced, leachate control facilities must be provided.

8.6.1 Leachate Movement

Under normal conditions, leachate is found in the bottom of landfills. From there, its movement is through the underlying strata. Some lateral movement may also occur, depending on the characteristics of the surrounding material. Because of the importance of vertical seepage in the contamination of groundwater, this subject is considered further in the following discussion.

Table 8.2: Typical data on the composition of leachate from new and mature landfills [2]

Constituent	Value, mg/L[a]		
	New landfill (less than 2 years)		Mature landfill greater than 10 years
	Range[b]	Typical[c]	
BOD_5 (5-day biochemical oxygen demand)	2000-30000	10000	100-200
TOC (total organic carbon)	1500-20000	6000	80-160
COD (chemical oxygen demand)	3000-60000	18000	100-500
Total suspended solids	200-2000	500	100-400
Organic nitrogen	10-800	200	80-120
Ammonia nitrogen	10-800	200	20-40
Nitrate	5-40	25	5-10
Total phosphorus	5-100	30	5-10
Ortho phosphorus	4-800	20	4-8
Alkalinity as $CaCO_3$	1000-10000	3000	200-1000
pH	4.5-7.5	6	6.6-7.5
Total hardness as $CaCO_3$	300-10000	3500	200-500
Calcium	200-3000	1000	100-400
Magnesium	50-1500	250	50-200
Potassium	200-1000	300	50-400
Sodium	200-2500	500	100-200
Chloride	200-3000	500	100-400
Sulfate	50-1000	30	20-50
Total Iron	50-1200	60	20-200

a = Except pH, which has no units.

b = Representative range of values. Higher maximum values have been reported in the literature for some of the constituents.

c = Typical values for new landfills will vary with the metabolic state of the landfill.

In general, it has been found that the quantity of leachate is a direct function of the amount of external water-entering the landfill. In fact, if a landfill is constructed properly, the production of measurable quantities of leachate can be eliminated. When sewage sludge is to be added to the solid wastes to increase the amount of

8.6.2 Darcy's Law

The rate of seepage of leachate from the bottom of a landfill can be estimated by Darcy's law, which can be expressed as:

$$Q = -KA\frac{dh}{dL}$$

where;

Q = leachate discharge per unit time

K = coefficient of permeability

A = cross-sectional area through which the leachate flows

dh/dL = the hydraulic gradient.

The minus sign in Darcy's equation arises from the fact that the head loss dh is always negative. The coefficient of permeability is also known as the hydraulic conductivity, the effective permeability, or the seepage potential.

With regard to the movement of leachate, two problems are of interest. The first is the rate at which leachate seeps from the bottom of the landfill into the groundwater in the surface aquifer. The second is the rate at which groundwater from the surface aquifer moves into the bedrock aquifer. These two problems will be discussed here, but the question of how the mixing of the leachate and groundwater occurs in the surface aquifer will not be considered.

In the first problem, the leachate flow rate from the landfill to the upper groundwater is computed by assuming that the material below the landfill to the top of the water table is saturated and that a small layer of leachate exists at the bottom of the fill. Under these conditions the application of Darcy's equation is as follows:

Table 8.3: Typical permeability coefficients for various soils [10, 11]

Material	Coefficient of permeability, K	
	m/d ($m^3/m^2 . d$)	ft/day ($ft^3/ft^2.day$)
Uniform coarse sand	405	1333
Uniform medium sand	101	333
Clean, well-graded sand and gravel	101	333
Uniform fine sand	4.05	13.3
Well-graded silty sand and gravel	0.4	1.3
Silty sand	0.1	0.3
Uniform silt	0.05	0.16
Sandy clay	0.005	0.016
Silty clay	0.001	0.003
Clay (30 to 50 percent clay sizes)	0.0001	0.0003
Colloidal clay	0.00001	0.000003

The coefficient of permeability K for various soil strata has been presented in Table 8.3.

8.6.3 Estimation of Vertical Seepage

Before Darcy's law is applied to the estimation of seepage rates from a landfill, it is helpful to review the physical conditions of the problem by referring to Fig. 8.18. As shown, a landfill cell has been placed in a surface aquifer, composed of material of moderate permeability, which overlies a bedrock aquifer. In this situation, it is possible to have two different piezometric water surfaces if wells are placed in the surface and bedrock aquifers.

$$Q(m^3/day) = K(m^3/day/m^2)\frac{h_1\,(m)}{L_1\,(m)}A\,(m^2)$$

But because $h_1 = L_1$,

$$Q(m^3/day) = K(m^3/day/m^2)A(m^2)$$

If it is assumed that flow occurs through 1 m^2, then;

$$Q(m^3/day) = K(m^3/day/m^2)(m^2)$$

Thus, the leachate discharge rate per unit area is equal to the value of K multiplied by square meter.

For example, if the upper strata of material in Fig. 8.14 were sandy clay, the corresponding seepage rate would be equal to 0.005 m^3/day/unit area (see Table 8.3). The computed value represents the maximum amount of seepage that would be expected, and this value should be used for design purposes. Under normal conditions, the actual rate would be less than this value because the soil column below the landfill would not be saturated.

In the second problem, the rate of movement of water from the upper aquifer to the lower aquifer would be given by:

$$Q(m^3/day) = K(m^3/day/m^2)\,A(m^2)\,\frac{h_2\,(m)}{L_2\,(m)}$$

In this case, the thickness of the confining layer is used to determine the hydraulic gradient.

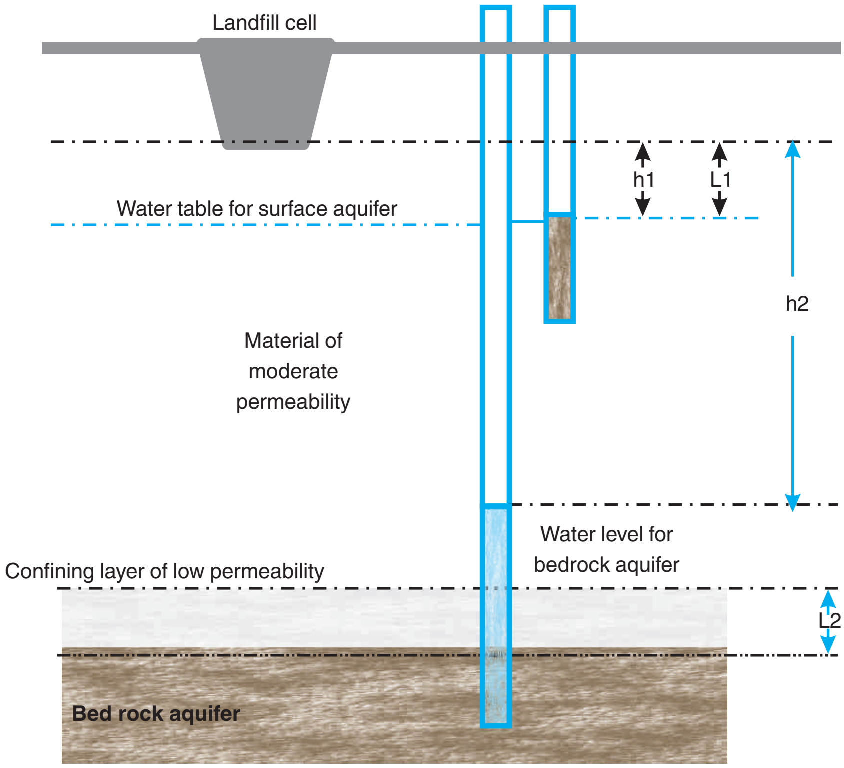


Fig.8.18: Definition sketch for determination of seepage from landfills and from surface to subsurface aquifers [2]

Solved Example 8.2

Determination of the thickness of a clay layer necessary to limit seepage of leachate

Determine the thickness of a clay layer that must be placed in the bottom of a landfill if the seepage flow rate is to be limited to about 0.002 m^3/day. Assume that the water table is located at the bottom of the landfill and that the leachate level in the landfill above the clay layer is to be maintained at 0.6 meter by pumping. Take coefficient of permeability K = 0.0008 m^3/m^2.day for the clay [2].

Solution:

k = $0.0008\ m^3/m^2.day$

Q = $0.002\ m^3/m^2.day$

A = $1\ m^2$ (say)

dL = Thickness of clay layers 't' m.

dh = 0.06 + t

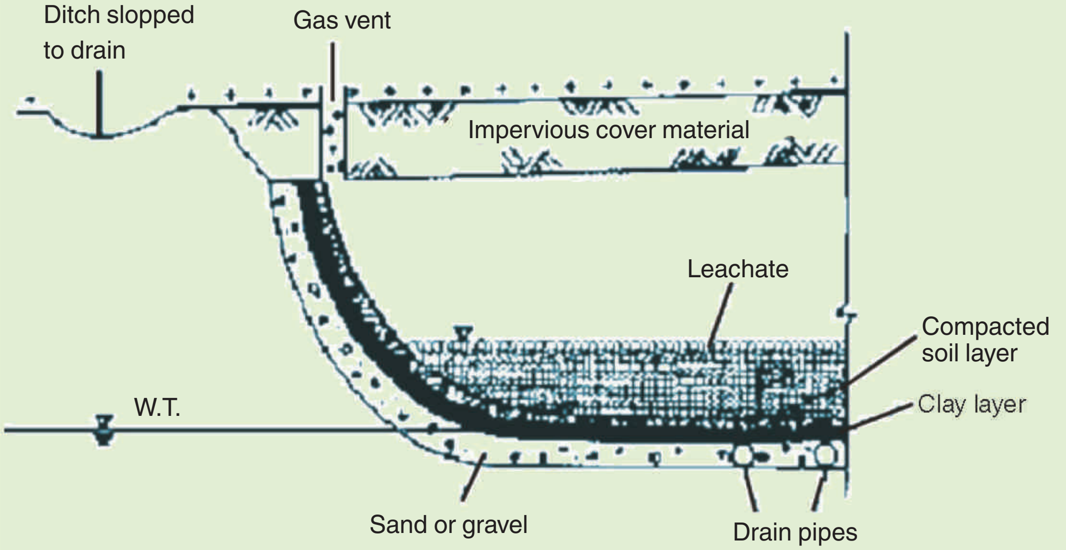
$$\frac{dh}{dL} = \frac{0.06 + t}{t}$$

$$Q = kA\frac{dh}{dL}$$

$$0.05 = 0.0008\ 1\ \frac{(06 + t)}{t}$$

t = 0.4 m.

A clay layer of 0.4 m should be provided at the bottom of landfill to limit the seepage of leachate to a rate of 0.002 m^3/day/unit area.



8.6.4 Control of Leachate Movement

As leachate percolates through the underlying strata, many of the chemical and biological constituents originally contained in it will be removed by the filtering and adsorptive action of the material composing the strata.

In general, the extent of this action depends on the characteristics of the soil, especially the clay content. Because of the potential risk involved in allowing leachate to percolate to the groundwater, best practice calls for its elimination or containment.

When gas is to be recovered, it is especially important to contain the leachate because the initial moisture content must be significantly higher than normal (50 to 60 percent versus 20 to 25 percent) to achieve the highest production of gas. In some gas recovery systems, this leachate is collected and recycled to the top of the landfill and re-injected through perforated lines located in drainage trenches, as shown in Fig. 8.10. Typically, the rate of gas production is greater in leachate recirculation systems. Ultimately, regardless of the system used, it may be necessary to collect and treat the leachate.

Landfill liners are now commonly used to limit or eliminate the movement of leachate and landfill gases from the landfill site. Use of clay, in this respect, is the most favored method. However the use of the combination of geo-membrane and clay liners has gained popularity. Some of the landfill sealants available are identified in Table 8.4.

Table 8.4: Landfill sealants for the control of gas and leachate movement [2]

Sealant		Remarks
Classification	Representative Type	
Compacted soil	-	Should contain some clay or fine silt
Compacted clay	Bentonites, illites, kaolinites	Most commonly used sealant for landfills; layer thickness varies from 15 to 120 cm; layer must be continuous and not allowed to dry out and crack
Inorganic chemicals	Sodium carbonate, silicate, or pyrophosphate	Use depends on local soil characteristics
Synthetic chemicals	Polymers, rubber latex	Experimental, use in the field is not well established.
Synthetic membrane liners	Polyvinyl chloride, butyl rubber, hypalon, polyethylene, nylon-reinforced liners	Commonly used for leachate control; increased usage for control of landfill gas. They are expensive.
Asphalt	Modified asphalt, rubber-impregnated asphalt, asphalt-covered polypropylene fabric, asphalt concrete.	Layer must be thick enough to maintain continuity under differential settling conditions.
Others	Gunite concrete, soil cement, plastic soil cement.	Not commonly used for control of leachate and gas movement because of shrinkage cracks after construction.

Equally important in controlling the movement of leachate is the elimination of surface water infiltration, which is the major contributor to the total volume of leachate. With the use of an impermeable clay layer, an appropriate surface slope (1 to 2 percent), and adequate drainage,

Table 8.5: Generalized ratings of various types of soils for use as landfill cover material [12]

Function	General soil types[1]					
	Clean Gravel	Clayey silty gravel	Clean Sand	Clayey-silty sand	Silt	Clay
Prevents rodents from burrowing or tunneling	G	F-G	G	P	P	P
Keeps flies from emerging	P	F	P	G	G	E[2]
Minimizes moisture entering fill	P	F-G	P	G-E	G-E	E
Minimizes landfill gas venting through cover	P	F-G	P	G-E	G-E	E
Provides pleasing appearance and controls blowing paper	E	E	E	E	E	E
Supports vegetation	P	G	P-E	E	G-E	F-G
Vents decomposition gas (be permeable)[3]	E	P	G	P	P	P

1. E, Excellent; G, good; F, fair, P, poor.
2. Except when cracks extend through the entire cover.
3. Only if well drained.

surface infiltration can be controlled effectively. With proper surface control, it may not be necessary to provide an impermeable barrier. Generalized ratings for the suitability of various types of soil for use as a landfill cover are reported in Table 8.5. It is evident from a scrutiny of the table that clay can act as the best sealant.

8.7 Design of Landfills

Once a limited number of potential sites have been selected on the basis of a review of the available preliminary information, it will usually be necessary to prepare an engineering design report for each site to assess the costs associated with preparation of the site for filling, placement of solid wastes, and completing the site once filling operations have ceased. The engineering design report in this context is preliminary in nature, as distinguished from a complete evaluation required for the final selection of a site, which includes environmental considerations.

Following are the important points that must be considered in an engineering design report, though not necessarily in the order given: (1) land requirements, (2) types of wastes that must be handled, (3) evaluation of seepage potential. (4) design of drainage and seepage control facilities, (5) development of a general operation plan, (6) design of solid waste filling plan, and (7) determination of equipment requirements. More important individual factors that must be considered are reported in Table 8.6.

Table 8.6: Important factors that must be considered in the design and operation of sanitary landfills [2]

Design Factor	Remarks
Access	Paved all-weather access roads to landfill site; temporary roads to unloading area.
Cell design and construction	Will vary depending on whether gas is to be recovered; each day's wastes should form one cell; maximum depth of 3 meters; cover at end of day with 15 cm of earth: gravel gas vent should be installed every 20 to 60 meters.
Cover material	Maximize use of onsite earth materials; approximately 1 m^3 of cover material will be required for every 4 to 6 m^3 of solid waste; mix with sealants to control surface infiltration.
Drainage	Install drainage ditches to divert surface water runoff; maintain 1 to 2 percent grade on finished fill to prevent ponding.
Equipment requirements	Vary with size of landfill (see Table 8.7 Page 142).
Fire prevention	Water onsite; if non-potable, outlets must be marked clearly; proper cell separation prevents continuous burn-through if combustion occurs.
Groundwater protection	Divert any underground springs; if required, install sealants for leachate control: install wells for gas and groundwater monitoring.
Land area	Area should be large enough to hold all community wastes for a minimum of 1 year but preferably 5 to 10 years period.
Landfilling method	Selection of method will vary with terrain and available cover.
Litter control	Use movable fences at unloading areas; crews should pick up litter at least once per month or as required.

Design Factor	Remarks
Operation plan	With or without the disposal of treatment plant sludge and the recovery of gas.
Spread and compaction	Spread and compact waste in layers less than 60 cm thick.
Unloading area	Keep small, generally less than 30 meters on a side: operate separate unloading areas for automobiles and commercial trucks.
Operation	
Communications	Telephone for emergencies.
Days and hours of operation	Usual practice is 5 to 6 days/week and 8 to 10 hours/day.
Employee facilities	Restrooms and drinking water should be provided.
Equipment maintenance	A covered shed should be provided for field maintenance of equipment.
Operational records	Tonnage, transactions, and billing if a disposal fee is charged.
Salvage	No scavenging: salvage should occur away from the unloading area: no salvage storage onsite.
Weigh Scale	Essential for record keeping if collection trucks deliver waste: capacity upto 50,000 kg.

Throughout the development of the engineering design report, careful consideration must be given to the final use or uses to be made of the completed site. Land reserved for administrative offices, buildings, and parking lots should be filled with dirt only and should be sealed against the entry of gases. A brief discussion on the important points mentioned above is given in the following sections.

8.7.1 Land Requirements

With the basic philosophy and the fact that in

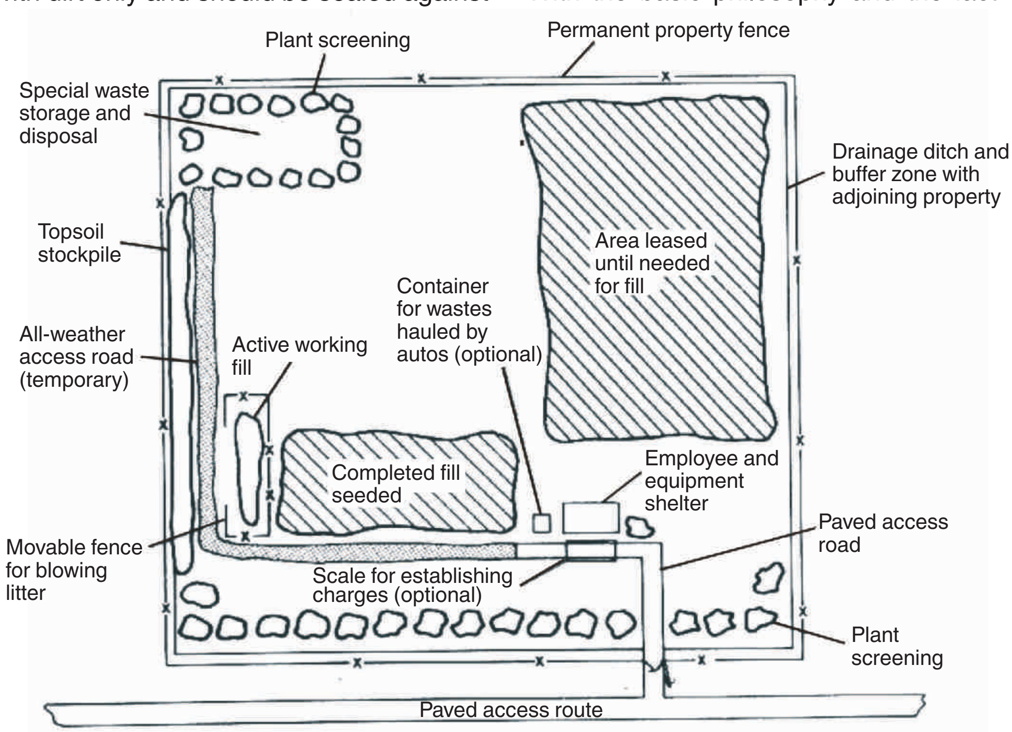


Figure 8.19: Typical landfill disposal site layout (Stanely consultants Inc.) (Example-1) [2]

Pakistan all the wastes could neither be collected and nor taken to the landfill sites, it is estimated that on an average 80% of the total wastes generated will be collected by the collection vehicles. This will comprise about 100% collection from the core of the urban areas while 60 – 70% from the peripheral areas. Out of the wastes so collected a portion will be recovered by the staff, while another portion will be dumped on private lands using it for raising their plinth level. Compactability at the landfill site will be another important factor affecting the land requirements.

8.7.2 Site Layout

During the planning of layout of a site the location of the followings must be determined (a) Access roads (b) Offices, garages and scales (c) Storage of stack piles (d) special wastes (e) Common wastes landfill areas (f) Drainage facilities and gas and leachate treatment facilities (if used). A typical layout is shown in Fig. 8.19.

Another example of site layout plan is given in Fig. 8.20. This shows the filling plan in equal width strips, area allocated for rainy season, brick paved access road, provision of weighing scale and shelter for the guard and tractor with front-end loader, site for stockpiled soil for covering the landfill.

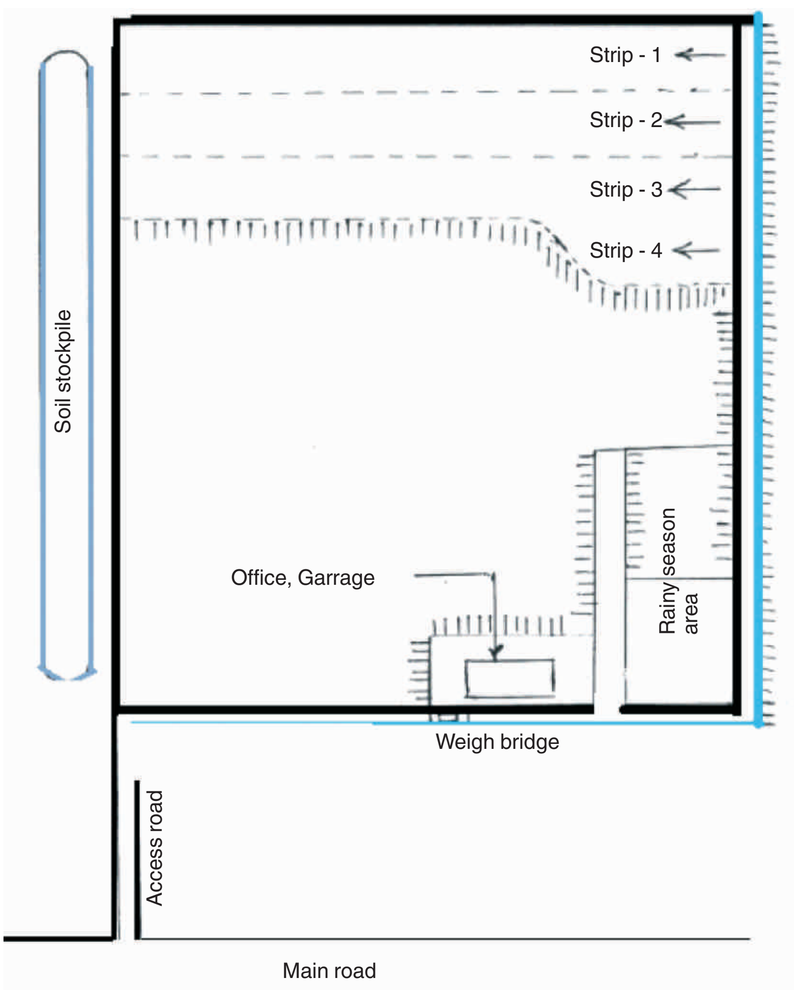


Figure 8.20: Landfill site layout. (Example-2)

a) Access

Paved all-weather access road will be constructed from the main road to a point, so that the site remains approachable even in the rainy season.

b) Landfill Method

In Pakistan manmade depressions due to excavation of soil for bricks may be used for sanitary landfills. In the case of manmade depressions the method of landfilling is called depression method.

As shown in Fig. 8.21, initially the site will be prepared by excavating the irregular shape soil deposits and to use the excavated soil as cover material. It then gives the landfill a regular shape as shown in the same figure.

c) Width of the Strip / Working Face

To ensure the orderly progress of filling and covering, each layer should be constructed from a number of side-by-side strips. The width of the strips depends upon the number of trucks unloading simultaneously at the working face. This width is calculated as following. The calculations are made for an assumed value of 200 tons of solid waste coming at the landfill site in one day. Truck trips are also assumed. Students may perform the following calculations with actual data.

For 200 tons/day, total number of trips of trucks = 50
Working hours per day = 8 hours
So Trips per hour = 50/8 = 6
Or available time per trip = 60/6 = 10 minutes

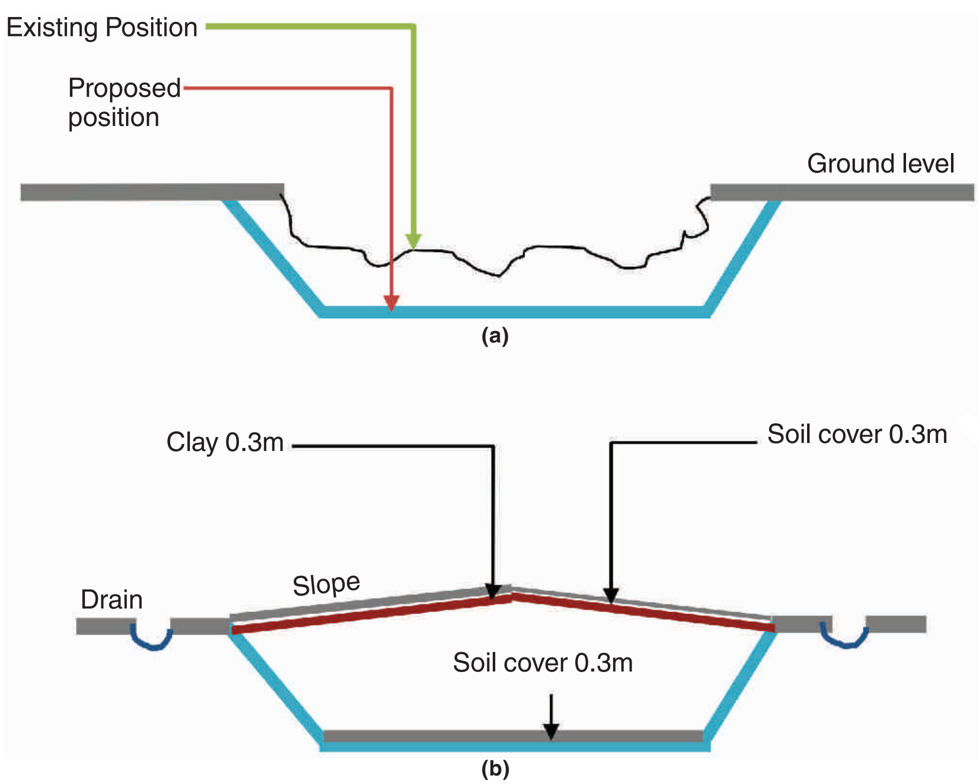


Figure 8.21: (a) Existing position of depression and new position after excavation of irregular soil deposits (b) Section of the proposed landfill site with clay and soil layers in Multan

Actual unloading time per trip = 10 minutes

So on an average one truck will be unloading at one time.

To take care of the peak hours, it is assumed that two trucks will unload simultaneously. So this requires width of the working face:
(Width of the strip) = 2 x 5 = 10 meters.

d) Cell Dimensions

The filling of wastes in the landfill will be started by fixing the dimensions of the cell based on the following data:

Total wastes received per day = 200 tons
Density of wastes in landfill = 1.2 tons/m^3
Volume of wastes received/day = 200/1.2 = 167m^3
Height of wastes in the landfill = 2.7 meters
Area filled per day = 167/2.7 = 62 m^2
Width of strip = 10 m
Width of the cell = 62/10 = 6.2 m

The collection vehicles will be unloaded at the top of the landfill as shown in Fig. 8.22.

Figure 8.22: Unloading of collection vehicles

e) Landfill Cover

It is usual practice to provide soil cover after filling the waste up to a depth of 3 meters. As the depth of the landfill is not expected to exceed that depth, only final cover will be provided. It will consist of two layers one of clay with a thickness of 30 cm and the other of soil, also 30 cm thick as shown in Fig. 8.21. When provided with a mild slope of 2-3%, it will help to avoid seepage of any surface runoff into the landfill and will support vegetation.

f) Drainage

Drains are provided on the four sides of the sanitary landfill to take care of the surface runoff during the rainy season.

g) Leachate Control / Collection

Leachate produced in a landfill must be collected, treated and disposed in an environmentally sound manner. Leachate is collected by providing a network of pipes at the bottom of landfill. Proper slope is given to these pipes to maintain gravity flow towards a single collection point that may be a well. A picture of landfill site Multan is shown in fig. 8.23. After collection, leachate is normally treated and disposed in the sewerage system. Sometimes, this leachate may also be used to sprinkle on the dumped solid waste, in the landfill, before compaction. This sprinkling increases moisture content of solid waste and improves compaction.

h) Gas Management

Production of biogas is also an outcome of biological decomposition of organic matter under anaerobic conditions prevailing in the sanitary landfills. But this also requires moisture content. Passive and active control measures are given in section 8.4.

i) Rainy Season Arrangements

During the rains the collection vehicles cannot reach the normal landfilling area. There needs to be allocated some area near the paved access road. Such area to the tune of 4000 m^2 needs to be allocated near the access road as shown in layout plan given in Fig. 8.20.

j) Ultimate Use

After completion landfill site may be mostly used as grazing land, or for cultivation of crops. It may also be used as a park or playground.

Figure 8.23: A picture of sanitary landfill site, Multan

A: Access road for trucks to enter into different cells

B: Permeable gas vents; uPVC pipes protected by steel drums with holes in them. Steel drums are filled with rounded pebbles for free air entry. uPVC pipes are guarded by steel drums to avoid pipe blockage by solid waste hindering free ventilation of gases.

C: Leachate collection pipes covered with gravel for protection and damage by moving vehicles and compactors

8.7.3 Operating Schedule

Factors to be considered here are (a) Arrival sequence of vehicles (b) Traffic patterns at site (c) Filling operation sequence and (d) Effects of winds and other climatic conditions etc.

8.7.4 Filling Plan

After establishing the layout plan, individual solid waste cells are designed. Care should also be given to the amount of cover material, the topography and local hydrology and geological

Table 8.7: Average equipment requirements for a sanitary landfill [13]

Population	Daily wastes (tons)	Equipment			Accessory
		No.	Type	Size, kg	
0 – 15,000	0–40	1	Tractor, crawler or rubber-tired	5,000 to 15,000	Dozer blade front-end loader (1 to 2 m) Trash blade
15,000 - 50,000	40–130	1	Tractor, crawler or rubber-tired	15000 to 30,000	Dozer blade front-end loader (2 to 4 m), Trash blade
		1	Scraper, dragline, water truck		
50,000 – 100,000	130–260	1 – 2	Tractor, crawler or rubber-tired	30,000 +	Dozer blade Front-End loader (2 to 5 m) Trash blade
		1	Scraper, dragline, water truck		
100,000 +	260+	2+	Tractor, crawler or rubber-tired	40,000+	Dozer blade, Front end loader, Bullclam Trash blade
		1	Scraper, dragline, steel wheel compactor, road grader, water truck		

conditions. A typical example is shown in Fig. 8.24.

8.7.5 Equipment Requirements

The type, size and amount of equipment required will depend upon the size of the landfill, and the method of operation. Local availability and operator preference are also important factors. Average equipment requirement is shown in Table 8.7.

EXERCISES

1. Delineate the site selection criteria for a sanitary landfill.
2. Draw a typical layout plan of a sanitary landfill and discuss the importance of its main features.
3. What adverse effects are caused by mixing of sanitary landfill gases with the groundwater?
4. Write a short note on gas and leachate movement in a completed landfill.

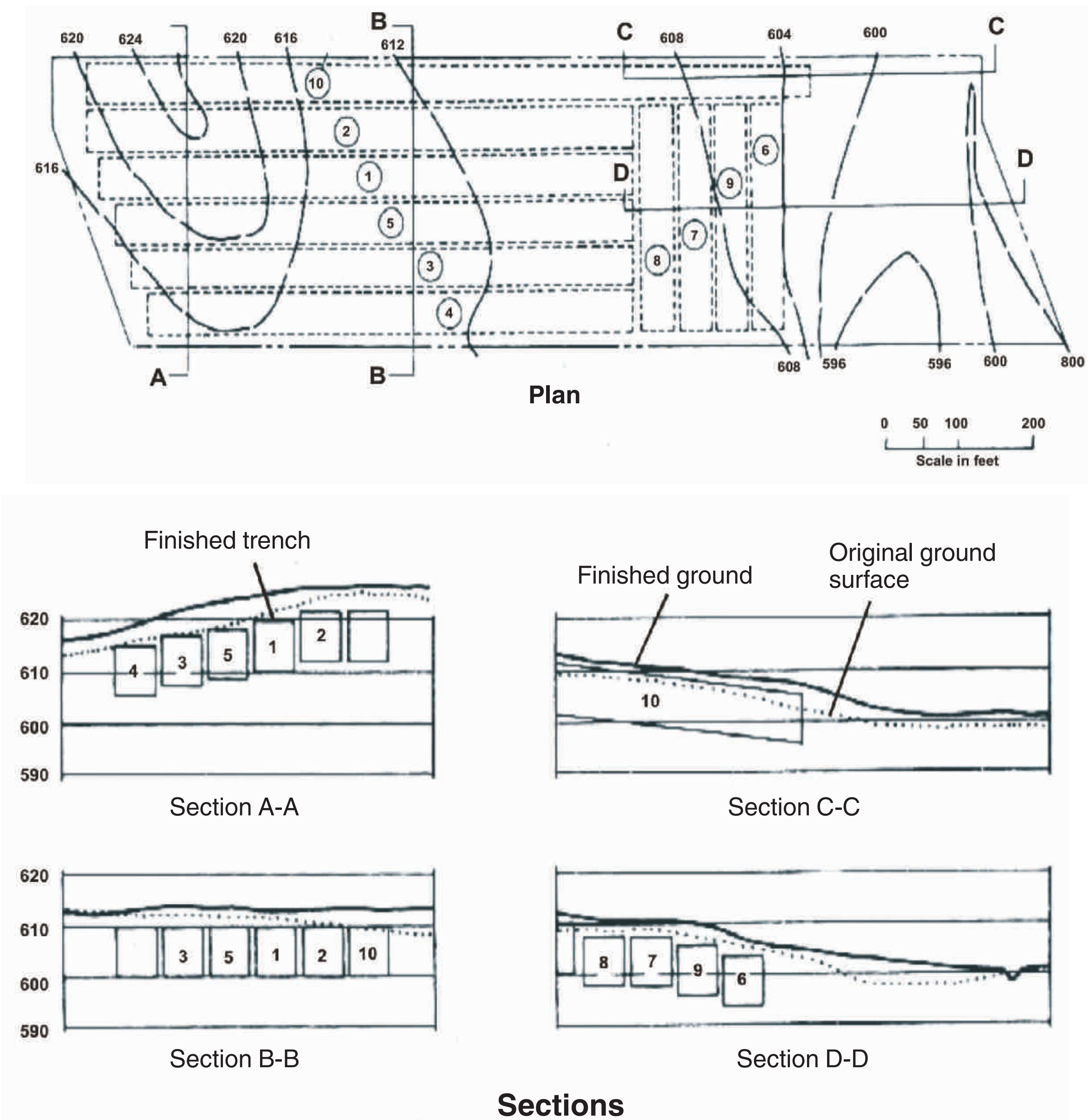


Figure 8.24: A typical layout plan with trench method [1]

5. Determine the concentration of carbon dioxide in the upper layers of groundwater in contact with landfill gases at 760 mm Hg and at 10°C. Assume that the composition of the gas is 50% carbon dioxide and 50% methane and the gas is saturated with water vapor. Absorption coefficients for carbon dioxide and methane are 1194, 41.8 ml/l respectively at 10°C, 760 mm Hg. Vapor pressure of water is 9.21 mL/L.
6. What advantages sanitary landfilling has over other methods of disposal?
7. Name different modes of sanitary landfilling. Illustrate each with sketches. Which method is applicable for your city and why?
8. What reactions occur in a completed landfill? What problems can arise if proper care is not taken at appropriate time? Write a detailed note on gas and Leachate movement and their control.
9. Write a note on gas movement control by permeable and impermeable methods. Illustrate your answers with rough sketches. What is the following equation known as? $Q = -KA\ dh/dL$. What is represented by different symbols?
10. How will you proceed to calculate the vertical seepage from landfill into surface aquifer and bedrock aquifer from a sanitary landfill?
11. What factors are involved in the design of a sanitary landfill?
12. Sketch a rough layout plan for a proposed landfill site near Lahore. What equipment is needed at site to perform different functions?

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9. WASTE TO ENERGY

9.1 Introduction

This chapter addresses the fundamental concepts of Waste to Energy (WtE), its significance in the overall context of SWM, different processes and technologies to convert the solid waste into energy and waste characteristics required for effective conversion. Technological options and their applicability in Pakistan are also discussed. Besides this, case studies from the developed and developing countries are also included in this chapter.

9.2 WtE as a Waste Management Option

Energy production from the non-recyclable waste materials means recovering energy content in the form of heat, fuel and gas through thermal and non-thermal technologies. It is one of the most interesting developments in the field of SWM as it reduces the land requirements for landfilling [1].

With the increasing population and growing solid waste generation rates, developed nations are considering innovative and state of the art ways for dealing with solid waste problem. The methods, technologies and practices for treatment of solid waste range from reduction of waste generation, recycling and reusing of usable materials, composting & bio-methanization of organic wastes, energy recovery and landfilling. It is estimated that presently, at global level, more than 80% of the total urban municipal solid waste (MSW) is landfilled (about 1 billion tons per year), and the rest is disposed by other methods. Majority of developed nations have fixed the target of reducing the landfilling of solid waste by adopting waste prevention, recycling and energy recovery as feasible options for waste management [2].

Sanitary landfilling has been the major option adopted in developing countries for final disposal of solid waste. However, due to stringent regulations regarding landfill liners, leachate treatment, landfill gas management and long term closure requirements, the sanitary landfilling option has become costly. In addition to this, the lands available near the urban areas are costly and sometimes not available, forcing authorities to locate landfill sites far away from the communities. It makes the transportation of solid waste not only difficult but also costly.

Era of establishment of landfill sites is on decline in the western world and there is more emphasis on recycling, reuse and WtE technologies. The purpose is to minimize the burden on landfill sites. Landfilling is now considered as a non-sustainable method. World population is increasing. It requires more land for providing housing facilities. In addition land is also required to fulfill the food requirements of this increasing population. Landfills acquire large pieces of land. Alternate methods are therefore needed to be considered for the disposal of waste with the option to recover energy. It does not require extensive land and also provides energy as a byproduct, which is also in great demand.

Presently in Pakistan, the common practice of disposal of MSW is open dumping. There is no engineered and scientific sanitary landfill site in Pakistan. Only one small sanitary landfill site was developed at Multan on a five hectare piece of land with the financial assistance of Asian Development Bank (ADB). Lahore Waste Management Company (LWMC) has planned and designed to establish a sanitary landfill site at Lakhodair village to handle about 2000 tons of MSW on daily basis. The sanitary landfill is being constructed by a Turkish firm and will be in operation very soon[3].

9.3 WtE as a Pollution Prevention Option

WtE plants help to reduce greenhouse gas emissions in the following three ways [4]:

a) Through producing electricity from municipal solid waste, dependence on fossil fuels such as oil, coal and gas is avoided resulting in avoidance of the GHG emissions.
b) WtE plants recover a portion of the metallic waste combusted in thermal operations including ferrous and non-ferrous metals. This helps in saving energy required for mining fresh metals and indirectly avoid the GHG emissions.
c) Methane (a GHG) emissions from the landfill site are avoided as in WtE plants methane is collected and is utilized for production of electricity.

To make decision, comparison should be drawn in order to assess the energy production and environmental degradation due to WtE plant's operations.

9.4 WtE as Renewable Energy Source

WtE technologies have revolutionized the idea of waste management. They have added a new industry that can produce cheap and clean energy for the society and reduce the need for landfills, if the waste characteristics are favorable.

Energy production from the waste is being practiced in most northern European countries, Japan, USA and China. India has also started a number of WtE interventions for SWM, in the recent past, but facing problems due to waste characteristics. Countries which are lagging behind in utilizing WtE option for dealing with solid waste issue have set their goals to deploy WtE option in upcoming years. For example, China will employ WtE technologies for handling 30% of its total waste produced.

In 2011, there were around 1,300 WtE facilities operating globally taking almost 600,000 metric tons of waste per day. Majority of the WtE facilities are based on thermal treatment of the solid waste [5]. In 2012, around 800 thermal WtE plants were operational globally treating 11% of the global solid waste [6]. Majority of the WtE Plants are located in Europe because of stringent EU directive of reducing 65% of organic waste going into the landfills [2]. The number of WtE plants is expected to grow in coming years. The family of WtE processes will be treating 261 million tons of waste annually by 2022 producing 283 tera watt hour (TWh) of electricity and heat [6].

The Global WtE market is steadily increasing. In 2012, the global WtE market was valued at 24 billion US$ and is expected to grow at the same compound growth rate of 5% to 29 billion US$ by 2015[7].

9.5 Objectives of Managing Waste through WtE Option

The overall objectives of sustainable waste management are fulfilled with the use of biological and thermal treatment before the remaining waste is finally disposed in the landfill. Some of the key objectives are explained as under [8-9].

a) Reduction in volume of waste; hence facilitating transportation and space reduction for landfilling
b) Stabilization of MSW
c) Killing of pathogens in hospital waste, which is sterilized and become ready for recycling
d) Recovery of heat energy and electricity

9.6 Determinants of Selecting WtE as Waste Treatment Option

The treatment or processing of solid waste is induced by one or all of the following factors;

9.6.1 Legislation

A law or rule can compel a municipality or any other relevant organization to process or treat a particular kind of waste, or a waste stream, with a specific technology. According to European legal regulations, alternative elimination methods are required besides existing methods [10]. These regulations fix a reduction of 35%, 50% and 75% by the target years 2015, 2018 and 2025, respectively. This binding will force the municipalities to look for alternate methods such as composting of the organic waste, material and energy recovery.

9.6.2 Cost and Sustainability

In the countries like Pakistan, cost is a major factor which determines the methodology to be adopted for WtE against other options. Sustainability refer to the technical know-how to run the WtE system, availability of spare parts and capability to carry out repairs. Any technology, without these pre-requisites cannot be run successfully on long term basis. Thus, while selecting a technology; all these factors should be kept in mind.

9.6.3 Public Awareness

Public awareness and opinion building can place tremendous emphasis on solid waste management and recycling options. The local governments and industry are under pressure from the general public to evaluate their solid waste management practices and adopt reduction of waste at source, induct recycling/resource recovery programs and lay out programs for waste management to improve the cleanliness and aesthetic value of cities and towns.

9.7 Assessment of WtE Potential

There are two basic parameters which can help to determine the energy potential from the solid waste.

a) Solid waste quantity
b) Physical and chemical composition

In biological decomposition of the solid waste, only degradable waste account for the energy production. A rough estimate of the bio-gas yield and ultimate power generation potential can be estimated by adopting the following procedure [11].

Total waste quantity = W (tons)
Total organic / volatile solids (VS) = 50% (supposed figure)
Organic bio-degradable fraction = 0.33 x W (approx. 66% of VS)
Typical digestion efficiency = 60 %
Typical biogas yield [B (m^3)] = 0.80 m^3 / kg of VS destroyed

$$= 0.80 \times 0.60 \times 0.33 \times W \times 1000$$
$$= 158.4 \times W \quad ....(9.1)$$

Calorific value of bio-gas = 5000 kcal/m^3(typical)
Energy recovery potential (kWh) = B x 5000/860
= 921 x W
Power generation potential (kW) = 921 x W/24
= 38.4 x W
Typical conversion efficiency = 30%
Net power generation potential (kW)=11.5xW ....(9.2)

Whereas in case of thermal treatment of the solid waste, energy potential can be estimated as per following procedure [11]:

Total waste quantity = W (tons)
Net calorific value = NCV k-cal/kg.
Energy recovery potential (kWh)=NCVxWx1000/860
= 1.16 x NCV x W ....(9.3)

Power generation potential (kW)=1.16xNCVxW/ 24
= 0.048 x NCV x W
Conversion efficiency = 25%
Net power generation potential (kW)=0.012x NCVxW ....(9.4)
If NCV is supposed as 1200 kcal/kg. then,
Net power generation potential (kW)
= 14.4 x W ....(9.5)

9.8 Waste to Energy Recovery Technologies

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

Organic contents, present in the municipal solid waste, in the form of bio-degradable and non-bio degradable form can be converted into energy through physical, biological and thermal methods [4, 12].

Thermal and physical methods are used for the conversion of solid waste rich in non-biodegradable materials and have low moisture content. On the other hand, biological processes are used for the waste containing higher fractions of organic waste. Most WtE processes produce electricity and/or heat directly through combustion, or produce a combustible fuel commodity, such as methane, methanol, ethanol or synthetic fuels [13]. Various technologies used for WtE conversion are depicted in the Fig. 9.1.

RDF systems refer to solid waste that has been mechanically processed to produce a storable, transportable, and more homogeneous fuel for combustion. Basically, this process consists of screening and shredding of the MSW, sorting out recyclable materials, and then drying of final product before it is palletized or baled as shown in the Fig. 9.2 [14-16].

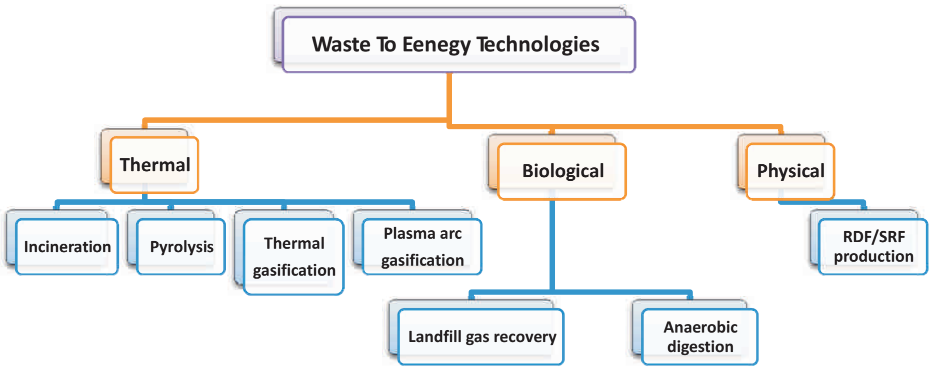


Figure 9.1: Classification of WtE technologies

9.9 Physical Methods

These are methods involve mechanical operations coupled with heating or steaming to convert the organic solid waste into the form which can be used an alternative to the fuel such as Refused Derived Fuel (RDF) or Solid Recovered Fuel (SRF).

The municipal solid waste on arrival to RDF facility is first processed for the separation of non-combustible materials such as glass, metal, stones, bones and horns etc. Metallic and other recyclable materials are separated through magnetic and manual separation techniques. Beside this, material with high calorific value

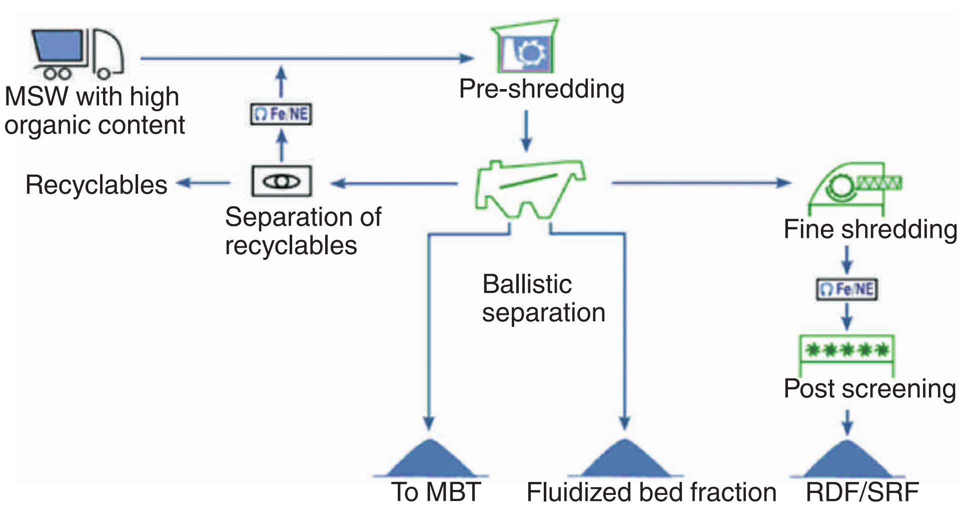


Figure 9.2: RDF production process

such as packaging materials and tires are separated to produce Processed Engineered Fuel (PEF). High calorific fraction of the shredded solid waste is composed of paper, plastic and other materials and is used as input for the last processing step i.e. post shredding operation to produce final product with required particle size, calorific value and moisture content [1, 14,20].

High pressure stream is used to kill bacteria and other pathogens. It also helps plastic material to become soft and flat. Municipal solid waste is non-homogeneous mixture of various commodities. Pre-shredding is done in order to reduce the particle size and to make the lot homogeneous to prevent the problem in subsequent operations of RDF production. A typical RDF plant operational at the ISTAC waste processing facility is shown in Fig. 9.3.

Figure 9.3: Typical RDF plant in istanbul [18]

After pre-shredding, the material is divided into different streams through ballistic separation screens having different size holes. The output material from the screen with small aperture is stabilized in biological-mechanical treatment plant. The output from the coarse screens has calorific value of 12-18MJ/kg [14] and is used in fluidized bed incinerator. Depending upon the percentage of the organic content present in the solid waste used in RDF production, the calorific value of RDF pellets might be 16.7472 MJ/ kg and it is 4 times the calorific value of the solid waste [17].

In US, there are 12 RDF production facilities, ranging in capacity from 360 to 2,700 tons per day and in total process about six million metric tons of MSW annually (i.e., 20% of the US production). In Europe, the RDF is derived through Mechanical Biological Treatment (MBT) process, which treats mixed MSW and produces an RDF product that is co-combusted with coal in power and cement plants. The challenge of such co-burning is the installation of air pollution control system as in case of incinerators [2].

MBT of waste is practiced in many European countries. In MBT, the waste material undergoes a series of mechanical and biological operations that aim to reduce the volume of the waste as well as stabilize it to reduce emissions from final disposal. The mechanical operations separate the waste material into fractions that undergoes further treatment (composting, anaerobic digestion, combustion, recycling). These may include separation, shredding and crushing of the material or converting it into RDF. The biological operations include composting and anaerobic digestion.

RDF is used as fuel or as supplement to the fuel. It can be co-fired with fossil fuels in existing large industrial or utility boilers or used as the primary fuel in specially designed 'dedicated' boilers. The prior processing of solid waste increases its heat value and its efficiency to substitute a fossil fuel. Cement and lime industry are the major consumer of the RDF/SRF produced globally. Steel mills also use RDF as alternative to the carbon [16]. Beside this, RDF pellets are used in industrial boilers for heat/steam production as fuel [17].

Box A - Lahore RDF Plant

The first RDF plant, in Pakistan, has been established at Lahore when LWMC signed an agreement with M/s DG Khan Cement. As per this agreement, LWMC will provide 1000 tons of mixed MSW at the rate Rs. 50/ per ton. RDF plant, imported from Germany, is established near landfill site of LWMC at Lakhodair. The waste is delivered by LWMC vehicles, which pass through screening and shredding process. The glass, metal and inert material is separated. The shredded waste is then pressed and bales are formed. The RDF is used as additive fuel by DG Khan Cement along with coal. It is estimated that about 30 to 40% of MSW is converted into RDF on weight basis. The rest of the waste is landfilled at Lakhodair landfill site.

9.10 Biological Methods

9.10.1 Anaerobic Treatment of Solid waste

A schematic of the anaerobic digestion of solid waste, production of useful by products and energy generation is shown in Figs. 9.4 and 9.5. The term bio-methanization or bio-gasification is used for anaerobic digestion of organic matter. The anaerobic treatment of organic part of MSW is fundamentally a two-stage process, the large organic polymers are fermented into short-chain volatile fatty acids, and these acids are then converted into methane and carbon dioxide. Both the processes occur at the same time in a single phase system. The separation of stages of acid producing (acidogenic) bacteria from the methane producing (methanogenic) bacteria will form the two stage anaerobic system [8]. The waste is degraded through microbes in the absence of oxygen and produces Methane and sludge.

Depending upon type of waste, its physical and chemical traits, 50-150 m^3 of biogas can be generated from one ton of the solid waste [19]. Biogas generated through this process contains 60-75% methane (CH_4), 25-40% Carbon Dioxide (CO_2) and small traces of the smelly gases such as H_2S and NH_3. The calorific value of the biogas is generally 20.934 MJ/m^3 (5000 $Kcal/m^3$) [20].

Energy production from the biogas is growing and is being used in many developed and under developing countries.

Biogas can be used directly in households for cooking, heating and lighting as well as it can be used as a fuel in internal combustion engine for electricity production replacing conventional fuels. It can be compressed to natural gas quality and can be used as a fuel source in vehicles. Nutrients remain in the sludge which can be used as fertilizer [21].

9.10.1.1 Steps Involved in Anaerobic Digestion of MSW

Following steps are involved during biogas production from the MSW [22]:

a) Pre-Treatment

Inert and non-biodegradable materials are separated and homogeneous feedstock is prepared to efficiently and effectively manage the upstream process of solid waste digestion.

b) Anaerobic Digestion

Destabilization, disinfection and controlling during the digestion process of gas production to generate energy.

Post Treatment

Digested organic waste is stabilized to produce a refined product which can be used as a soil nutrient.

c) Effluent Treatment

The sludge or liquid from the digestion process is treated with state of the art technology to meet the National Standard for discharge. Overall scheme of anaerobic digestion of solid waste is shown in the Fig 9.5.

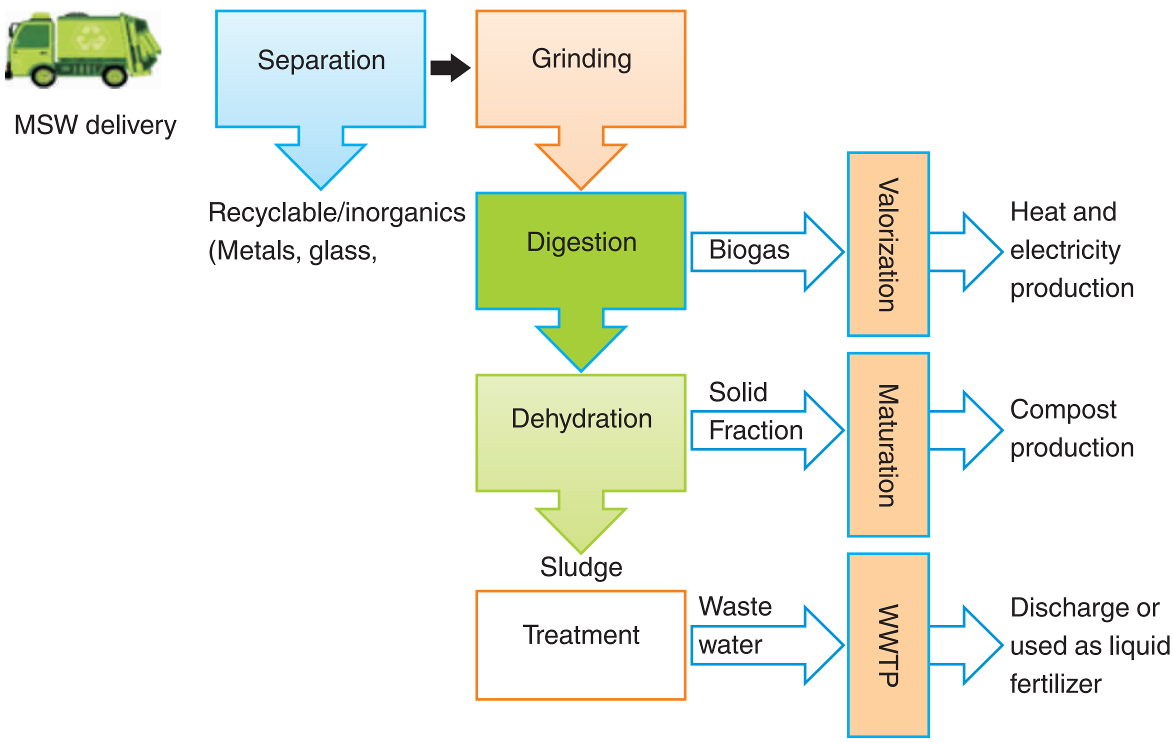


Figure 9.4: Schematic of the anaerobic digestion of solid waste

Anaerobic digestion takes place through a series of mutually co-related stages. Different stages of anaerobic digestion are defined as follows [23, 24].

Stage 1-Hydrolysis

The fats or lipids are found in most digester feed stocks, as these constituents are present in animal matter and in organic materials. The lipids in a digester feedstock are mainly compounds of glycerol and long-chain fatty acids while others contain more complex molecules. Irrespective of the number of chains, there is a breakdown of complex long chains organic molecules into simpler shorter molecules by the action of extra cellular enzymes. There are specific enzymes involved in the breakdown of these organic molecules. For instance, starch and glycogen, which are carbohydrates, are hydrolyzed to a disaccharide by the action of amylase – one of the enzymes. The enzyme trypsin is specific for bonds involving the amino acids

Stage 2 and 3 Acidogenises and Acetogenises:

The second and third stage involves the conversion of the fermented intermediate materials into acetic acid (CH_3COOH), Hydrogen (H_2) and Carbon Dioxide (CO_2) by bacteria, which react in acidic medium. The bacteria (acidogenic and acetogenic) use up all the oxygen present by creating an anaerobic environment for the methane-producing micro-organisms to react afterwards. They also reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen, sulphide and traces of methane.

Stage 4: Methane Production

The final stage of the process is the methane producing stage, which involves methane-producing bacteria called methanogenic bacteria. Methane forming bacteria are sensitive to pH and conditions should be mildly acidic (pH 6.6-7.0) and certainly not below pH 6.2. These bacteria convert the compounds formed during the second stage into a low molecular weight such as methane and carbon dioxide in the absence of oxygen. The reaction is shown by Organic matter (anaerobic process) = $CH_4 + CO_2 + H_2 + H_2S$

could be poisonous to those bacteria if not used up by other bacteria while the methanogenic bacteria could not also operate without such an environment.

9.10.1.2 Parameters Affecting the Anaerobic Digestion

There are many factors that affect biogas production and these factors may have either positive or negative impacts on the biogas production. The optimum level of each of the following factors will form the best environment for an efficient and reliable performance of the biogas plant.

A) Solid waste composition

Composition of the solid waste is the main factor in determining the yield of the methane production. If the objective is to produce biogas, only biodegradable organic waste should be used in the digester. Higher the biodegradability of the solid waste, higher will be the rate of methane production [19].

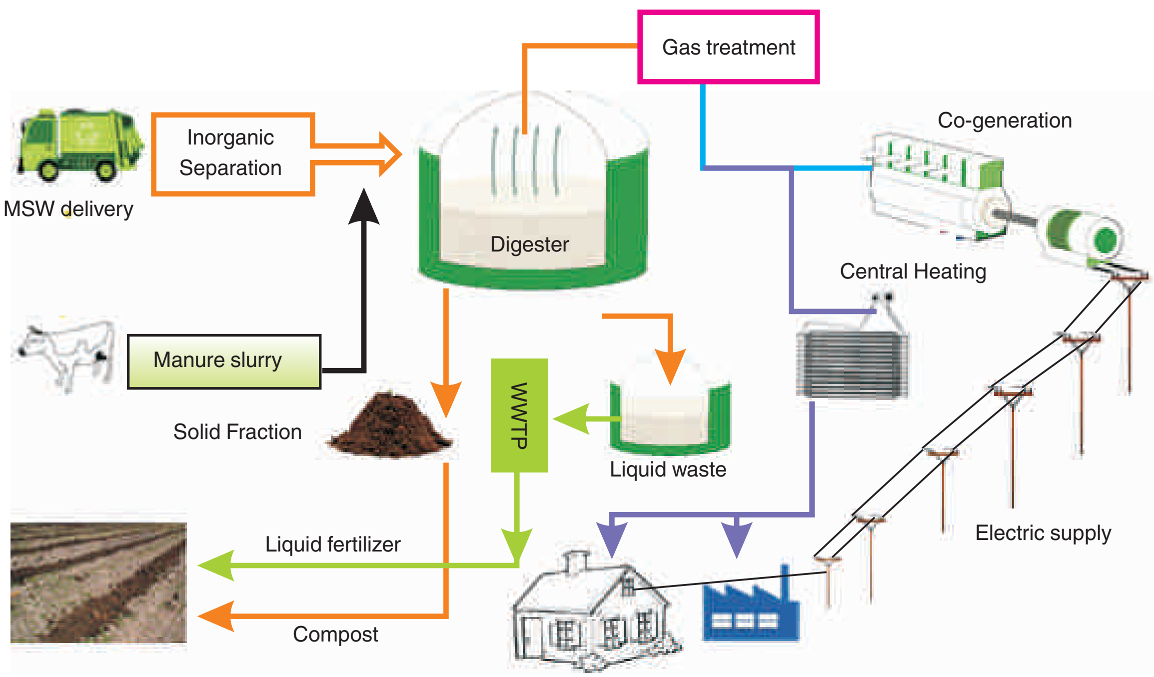


Figure 9.5: Anaerobic digestion flow diagram for generation of electricity

Both acidogenic & acetogenic bacteria and the methanogenic bacteria act in support of one another in that the anaerobic condition created

B) Moisture content

Moisture content is also an important parameter to be considered while planning for biogas generation in the organic fraction of the municipal solid waste. Higher moisture contents usually speed up the digestion process; however it is difficult to maintain the same moisture level throughout the proceeding of the digestion process. Higher methane production could be achieved at 60-80% humidity [24].

C) Temperature

Temperature is the key parameter that determines the activity and growth rate of the microbes, substrate utilization and biogas yield. On the other hand, higher temperature might give rise to the production of toxic ammonia gas [24].Therefore; a suitable temperature range is adopted to maintain the process. The optimum temperature is around 35^{0}C. However, there are three main temperature mediums for the production of biogas in the digester which are: (i) Psychrophilic (08-20°C),(ii)Mesophilic (25-40°C) and (iii)Thermophilic Temperatures (48-60°C).

D) Nutrients availability

The waste to be fed into the digester must contain a reasonable amount of nutrient (Nitrogen and Phosphorous) suitable for the growth of the organisms. C: N adjustment is crucial requirement for microbes to operate and grow and C: N determine the food content in the solid waste for the microbes. The optimal value of C: N for methogens is 20-30:1. Higher amounts of the nitrogen content will lead to ammonia inhibition of digestion [19].

E) Retention time

Time required in complete degradation of the organic fraction of the solid waste is called retention time. The retention time depends on the material and the temperature. For example, the retention period in mesophilic type digesters ranges between 15-30 days whereas in thermophilic digesters it ranges between 12-14 days [22]

F) Ammonium

Solid waste, rich in protein content releases higher amounts of NH_4 which is an important parameter for microbes in various biological activities. However, during Biogas production, release of NH_4 might inhibit the microbial growth because of its toxic nature. Therefore, it is highly recommended to use microbes that generate least NH_4. Digestion process at thermophilic stage is more susceptible to inhibition because of higher temperature as compared to mesophilic stage [19].

G) Level of contamination

The contamination level in the feed stock determines the efficiency of the digester. Contaminants such as plastic, textiles, hairs, metals, bones, stones and horns should be sorted out in pre-treatment stage in order to overcome any downstream process difficulties. After pre-treatment, the feed stock material is shredded and homogeneously mixed to increase the surface area for microbial attack and ultimately leading to the digestion efficiency [19].

H) pH level

An appropriate pH level is very important for an effective performance of the methanogenic bacteria. The optimum pH for the methanogenic bacteria is about 7.2. The ideal pH value for methane formation lies within 6.5-8. Generally, the animal dung and night soil have this ideal range of pH value. If the pH value falls below 6.5, the growth of the methogens starts retarding and the risk of washing out the biogas digester increases. Exact state of the Bio-Methanization process cannot be determined by just monitoring pH value of the process. In order to know the exact state of the process, pH should be compared with buffer capacity, bicarbonate alkalinity and total alkalinity [19].

9.10.1.3 Types of Digesters

There are several types of anaerobic waste digester depending upon mode of operation (continuous or batch), number of treatment stages (single stage, multi-stage) and the moisture content of solid waste. Beside this, digesters can also be arranged according to the digestion process temperature (mesophilic and thermophilic) and shape of the reactor (horizontal and vertical) [19, 25].

A) Batch or continuous reactors

Batch reactors are the simplest form of the anaerobic digesters. The solid waste with high organic content is loaded to the reactor, sealed and left for digestion. This kind of digesters are simple in design, require least equipment, cheaper and easy to use. Batch reactors are also known as "accelerated landfills" although they have much higher gas production rates than landfills.

In continuous type of the reactor, the organic solid waste is continually added and sludge, gas and by-products are continuously removed. This gives a regular production of the biogas. Initially these system were only designed for dealing with organic fraction of the solid waste, however, later these were adopted for industrial, market and agriculture wastes. Anaerobic digestion takes place at solid content of 16-40%. These systems are also known as "Dry Digestion" or anaerobic composting if the solid concentration is in the range of 25-40% and moisture and free water content is minimum. Continuous digesters are more suitable for household applications because operation fits for the daily activities. The biogas production remains constant and higher than batch digesters.

B) Based on Temperature

Anaerobic digestion process can be executed at different temperature ranges. Most commonly found operating temperatures for anaerobic digestion are psychophilic(below 25C^0), mesophilic(25-45C^0) and thermophilic(45-70 C^0). The latter two are commonly used temperature zones.

Mesophilic digestors are stable as compared to thermophilic digesters, however due to better growth rates, thermophilic digesters are preferred. Thermophilic temperature zone result in faster chemical reaction, higher solubility and low viscosity utilizing substrate in a better way as compared to mesophilic conditions. The temperature during the digestion process is kept constant. Any change in the temperature will affect the performance of the microbes and this will fluctuate the biogas production and thus overall economy of the plant.

C) Based on the solid content

Low solid content: The mixture of the liquid and feed stock with concentration of suspended solid less than 15 % is known as "Low Solid content" and

High solid content: The mixture of the liquid and a feed stock with concentration of the total suspended solid (TSS) greater than 20% is known as "High Solid Content".

High solid digesters are used to process slurry that requires higher energy to move the feed stock material inside the digester. Thickness of the slurry may also lead to the abrasion and associated problems. Low solid digesters require more space because of high liquid-feed stock ratio. The low liquid offer more benefits than high solid digesters. A large number of the systems are currently available globally for treating solid wastes of low (<10%) or medium (10-16%) solid concentration.

D) Single stage and multi stage digesters

In single stage digesters, four digestion stages i.e. hydrolysis, acetogenesis, acidogenesis and production of methane take place simultaneously without any separation of time and space in a single vessel. These types of digesters are simple in configuration, easy to operate and require less capital and operational expenditures.

However, biogas production is lower. Retention time varies between 14-18 days depending upon the physical and chemical properties of the feed stock and operating temperature. A typical single stage digester is shown in the Fig. 9.6.

In multi-stage digester (Fig. 9.7) two or more vessels are optimized to get maximum control over microbes operating inside the digester. Hydrolysis, acetogenesis and acidogegsis typically occur within the first vessel. The organic material in the form of slurry is slightly heated before pumping into the mathanogenic reactor.

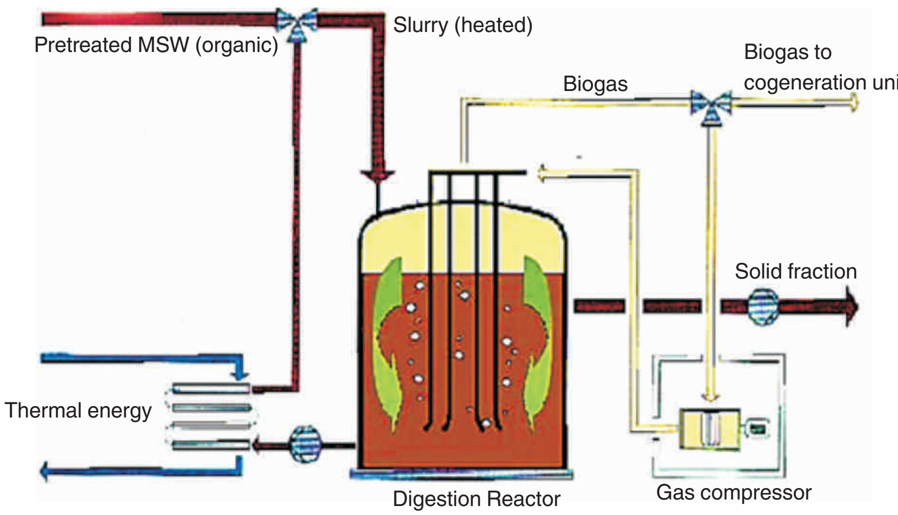


Figure 9.6: Single stage digester [26]

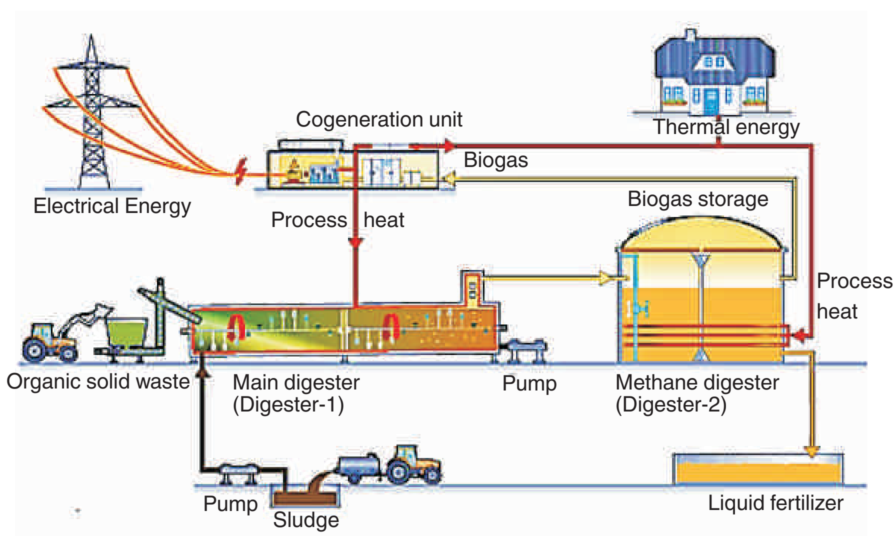


Figure 9.7: Typical two stage digester [27]

In two stage digester, the retention time varies between 15-40 days depending upon the composition of the organic waste. Multistage digesters have hydraulic and mechanical devices for mixing and transferring the material from one vessel to the next. These kinds of digesters are costly and require more technical know-how as compared to single stage digesters.

The lessons learned from Indian experience were presented by in a training program on "Biogas Production, Purification and Power Generation for Commercial Technology Packages" [29]. Box B shows the result of Indian experience. The salient points are abridged as under, which could be a learning experience for the success of such interventions in Pakistan:

- Problems in sampling and analysis of MSW
- Problem in sustaining supply of requisite quantity and quality of feedstock
- Lack of a guarantee for long term performance of the plant, which was key to the plant's economic feasibility
- Prediction of plant cost remained a major uncertainty
- Uncertainty in marketing of manure
- Periodic variation in the government policies relating to financial incentives,

Box B - Bio-methanization of MSW in India

The treatment and processing of MSW through bio-methanization was started in early 90s in India. The city of Lucknow produced around 1800 tons of MSW on daily basis. The city municipality set up a plant to handle 300 ton/day of municipal waste using the bio-methanation process for conversion of waste to energy with the help of a BIMA (Biogas-Induced-Mixing-Arrangement) digester, a technology that is being used in over 50 WtE plants worldwide. This project was designed as the first solid waste power project in India which the Ministry of Non-conventional Energy Sources (MNES), identified as a full-scale national demonstration plant. Although the project was initiated in 1998, the project got delayed because of finalization of land transfers, government guarantee, identification of financiers and other related formalities, which could be completed only by August 2001. The plant construction was completed in August 2003.The project was executed on a Build Operate and Transfer (BOT) basis. The Lucknow plant has been plagued by non-availability of "acceptable waste" despite the city's total waste generation of 1800 tons a day. The plant is currently non-operational due to the inability of the plant to receive quality waste. Most waste transported contained 50-70% inorganics, which rendered operations unviable. This is again because of inordinately high inerts in Indian waste, far higher than in comparable Asian countries. Hence, the "rejected" truckloads of untreated waste lie in growing hillocks around the entire plant. The failure of the plant has led to the evaluation of the waste to energy projects in the country by an Expert committee. The committee was of the opinion that the problem faced in the operation of the Lucknow plant may be attributed both to the ineffective segregation system and the quality of MSW available for the plant. The overall performance of the Biomethanation Plant is greatly influenced by the input feed specification and the plant requires segregated biodegradable MSW (e.g., hotel and restaurant waste, market waste) for optimal plant performance rather than un-segregated MSW.The homogeneity of the feed material is an important parameter from the efficiency point of view. [28]

tax rebates, cost of land lease deed, labor wages, etc.

- Delayed payment of electricity bills
- Lack of co-operation/support from local body
- Lack of public awareness for source segregating waste

9.10.2 Landfill Gas Recovery

The organic fraction present in municipal solid waste, deposited to the sanitary landfill site is decomposed by the microbes through a process very similar to the anaerobic digestion. As a result of this decomposition, landfill gas is produced which is different from the natural and methane gas because of its composition. Landfill gas contains 40-60% methane while rest of the proportion is CO_2 [30]. Methane possesses the combustible and explosive properties. It is 23 times more harmful for the environment than carbon dioxide. Landfill sites are major source of global warming because of the methane emissions. The Global Warming Potential (GWP) of Methane is 3.323 tons CO_2 per ton of the solid waste landfilled [31]. Especially;

Methane emissions in terms of CO_2 = 0.085 tons CH_4/ton of S W × 25 tons CO_2/ton of CH_4 = 2.13 tons CO_2 per ton of solid waste landfilled.

CO_2 emissions = 0.193 tons CO_2 per ton of the solid waste.

CO_2 total equivalent GWP = 2.323 tons CO_2 per ton of the solid waste.

Methane results in CO_2 emission which is less harmful as compared to methane itself [32]. Per year landfill gas production from a sanitary landfill site ranges between 0.005-0.040 m^3/kg of the solid waste [33].

9.10.2.1 Assessment of Energy Recovery Potential from Landfills

Current and future potential of the gas recovery from a landfill site depends upon the size of the landfill site, amount of the waste dumped, properties of the waste, meteorological condition, amount of water addition etc.[34].

Estimates of the quantities deposited at the landfill can be derived from the available information such as size of the landfill (area), waste density (tons/ m^3), waste records and contour plots. In the absence of such information a rough estimation method is adopted which uses information about the urban population, per capita waste generation, fraction of the solid waste landfilled and number of years of landfilling. A mathematical formula used for this estimation is as follows [35]:

Total waste land filled (W tons)
= Urban population x Waste generation rate (kg/person/year) x Fraction of waste in landfills x Years of landfilling x 0.001 ....(9.1)

After assessment of total waste landfilled from equation (6), energy recovery potential from the landfill gas recovery can be estimated.

9.10.2.2 Landfill Gas Collection System

The gas can be extracted or recovered through drilling a well into the landfill site. The depth of the well depends upon the thickness of the waste layers [39]. Active or passive systems for the extraction of the landfill gas can be used. Extraction well typically consists of slotted PVC pipe surrounded by concrete or other aggregate material. Above the surface of the waste mass (at top cover of the landfill), extraction wells have a well head for vacuum adjustments and collection of landfill gas. The extraction well can be vertical or horizontal. Most commonly used extraction wells as vertical. A typical vertical extraction well is shown in the Fig. 9.8.In case of vertical well borehole diameter varies 20-90 cm including 5-15 cm diameter pipe. Generally, a bore hole with 30cm diameter and 10 cm pipe diameter are recommended [36].

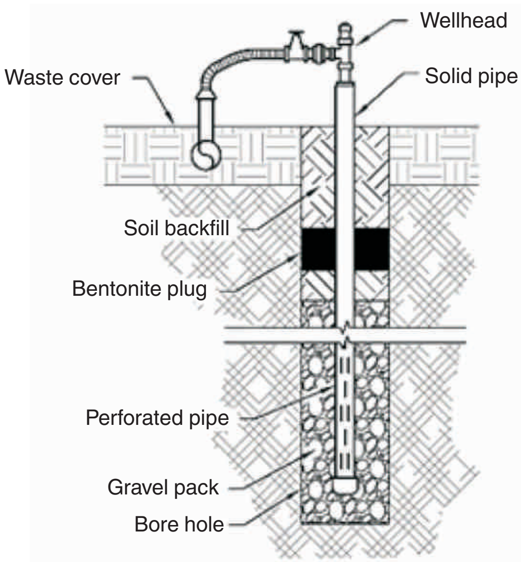


Figure 9.8: Vertical landfill gas (LFG) extraction well

Horizontal wells can be installed during the operation of the landfill site and can be used for the collection of the LFG before the final closure of the sanitary landfill site. A schematic of the horizontal well is shown in the Fig. 9.9.

The horizontal wells are installed in a trench parallel to the waste layers and the trench is back filled with aggregate material such as broken glass or tire chips. The slotted pipe with a diameter ranging 10-20 cm is placed in the center of the trench. A distance of 30-40 meter is recommended between the horizontal wells.

9.10.2.3 Advantages of Landfill Gas Collection

The collection and utilization of landfill gas offers various advantages according to current global policies. Through proper collection and utilization of the landfill gas, it is possible:

a) To reduce greenhouse gas emissions through capturing and utilizing two important GHGs i.e. Methane and Carbon Dioxide.
b) To prevent dangerous explosions at landfill site due to sudden expansion of the methane gas and to increase the safety of the surrounding areas.
c) To reduce the air pollution and odor problem at the landfill site.
d) To reduce the dependence on the fossil fuels through using captured methane as an energy source.
e) To generate revenue and to improve the social and economic stature of the society.

9.11 Thermal Systems

9.11.1 Incineration

Throughout the era of waste to energy, the experts refer to 'mass burn' incineration as the

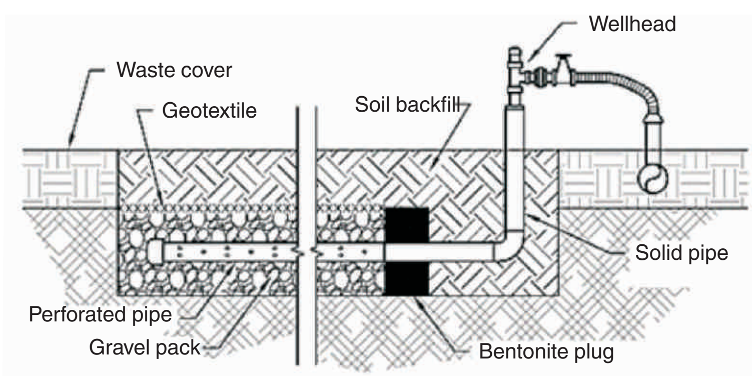


Figure 9.9: Horizontal LFG extraction well

thermal technology used for the conversion of solid waste into energy (power and heat). But this terminology refers to technology of the past when the combustion unit received all types of wastes into the unit and combusted it with the primary goal to maximize the reduction in volume of the waste. As a result of improved understanding of the combustion process (i.e.: health impacts) and the need to find alternatives to fossil fuels to mitigate climate change, Waste to Energy technologies emerged.

Theoretically, the main stages of incineration process are illustrated in the light of explanation narrated in the European Commission Report Reference Document on the Best Available Techniques for Waste Incineration [10].

Drying and Degassing: During this stage, volatile content is produced (e.g. hydrocarbons and water) at temperatures generally between 100 and 300 °C. The drying and degassing process do not require any oxidizing agent and are only dependent on the heat supplied.

Pyrolysis and gasification: Pyrolysis involves additional decomposition of organic substances in the absence of an oxidizing agent at approx. 250 – 700 °C. Gasification of the carbonaceous residues is the reaction of the residues with water vapor and CO_2 at temperatures, typically between 500 and 1000 °C, but can occur at temperatures up to 1600 °C. Resultantly, the solid organic matter is transformed into the gaseous phase. In addition to the temperature, water, steam and oxygen support this reaction.

Oxidation: The combustible gases created in the earlier stages are oxidized, depending on the selected incineration method, at flue-gas temperatures generally between 800 and 1450 °C.

These stages generally occur simultaneously; therefore spatial and temporal division of these stages during waste incineration may only be possible to some extent only. Actually, the processes partly occur in parallel and influence each other. However, these processes can be influenced through technological measures to reduce emissions. These measures may include incinerator design, air distribution and control engineering.

9.11.1.1 Determinants of Waste for Incineration

It is hard to suitably answer the question of whether a specific kind of waste should be recycled or incinerated to recover energy, because this can only be determined on a case-by-case basis. The particular waste composition and available treatment technologies should be considered with special attention on mass and energy balances, resource conservation, and environmental impacts. Following determinants may be evaluated for taking a decision whether waste should be incinerated?

a) Calorific Value

Waste calorific value increases with the increase with an increase in the packaged and burnable products. The average calorific value determined by LWMC on Lahore MSW is 7.084 MJ/kg. When calorific value increases over 12.56 MJ/kg, thermal technologies can be taken into consideration. Therefore it is considered that current level of mixed municipal waste, in Lahore, is not fit for thermal treatment because of its low calorific value [37].

b) Moisture Contents

The moisture content in MSW is a key determinant for energy recovery, because moisture content of MSW absorbs heat during combustion, and therefore decreases its heating value. The average moisture content of Lahore

MSW was determined to be 46%. However in monsoon rains, moisture content reaches 70% and above [37].

c) Composition of Waste

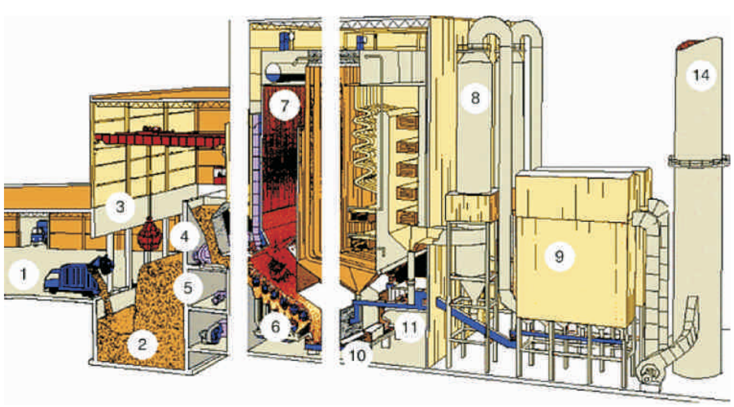
The quality of the waste, used as fuel, must be suitable for the industrial furnace (calorific value, chemical composition, storage stability, etc.). The incineration requirements must be met (control technology, minimum temperature and minimum residence time, minimum oxygen content, etc.), and the required atmospheric emission and residue treatment must be ensured, including monitoring by measurement. Certain wastes can be converted into quality-assured waste fuels through appropriate sorting, separating and processing steps.

Due to the constantly changing composition with unknown and sometimes strongly fluctuating contents of harmful substances, waste incineration plants need to fulfill more strict requirements than power plants and industrial furnaces in which specific fuels are fired. Co-incineration of certain waste fuels in suitable industrial production plants can be an economically and ecologically expedient way to complement dedicated waste incineration plants. The pulp, paper and timber industry uses large-scale furnace systems for cogeneration of electricity and heat, in which internal by-products and specific waste products from the production process are also used as fuel. Sawdust, paper pulp sludge and sludge from wastewater treatment in paper and cardboard industry as well as milled Styrofoam, can be used as pore-forming agents in brick production [38].

9.11.1.2 Types of Incinerators

A) Grate incinerator

In grate incinerator, the MSW bags and other wastes are discharged from the collection vehicles into the waste bunker in a fully enclosed building (Fig. 9.10). Typically, the waste bunker is large enough to hold over a week's feedstock. An overhead claw crane loads the solids into the feed hopper of the WtE furnace and a ram feeder at the bottom of the hopper pushes the wastes onto the moving grate. The grate can be inclined or horizontal and either air-cooled or water-cooled. The mechanical motion of the grate, and also the gravity force in the case of an inclined grate, slowly moves the bed of solids through the combustion chamber. The high temperature oxidation in the combustion chamber reduces objects as large as a big suitcase to ash that is discharged at the lower end of the grate.



1. Waste vehicle	2. Waste bunker	3. Crane	4. Hopper
5. Ram feeder	6. Grate	7. Combustion chamber	8. Acidic gas removal
9. Particulate removal	10. Bottom ash	11. Control room	14. Stack

Figure 9.10: Components of a WtE moving grate incineration plant [39]

The typical incineration plant for municipal solid waste is a moving grate incinerator. The moving grate enables the movement of waste through the combustion chamber to be optimized to allow a more efficient and complete combustion. A single moving grate boiler can handle up to 39 tons of waste per hour, and can operate 8,000 hours per year with only one scheduled shut-down for inspection and maintenance, which may take about one month's duration. Moving grate incinerators are sometimes referred to as Municipal Solid Waste Incinerators (MSWIs).

Moving grate furnace technologies are considered as the workhorse of waste thermal treatment with more than 1,000 operational plants worldwide.

Box C - Timarpur Incinerator Experience – New Dehli India

In 1987, the Ministry of Non-Conventional Energy Sources (MNES) commissioned the Timarpur Refuse Incineration-cum- Power Generation Station at a capital cost of Rs. 20 crores (US$ 4.4 million). Built by Volund Miljotecknik Ltd. of Denmark, the plant was designed to incinerate 300 tons of municipal solid waste (MSW) per day to generate 3.75 MW of electricity.

The plant ran for 21 days of trial operations before shutting down due to the poor quality of incoming waste. It required waste with a net calorific value of at least 6.123 MJ/kg, but the calorific value of the supplied waste was in the range of 2.510-2.930 MJ/kg. Plant operators tried to supplement the combustion with diesel fuel, but were unsuccessful.

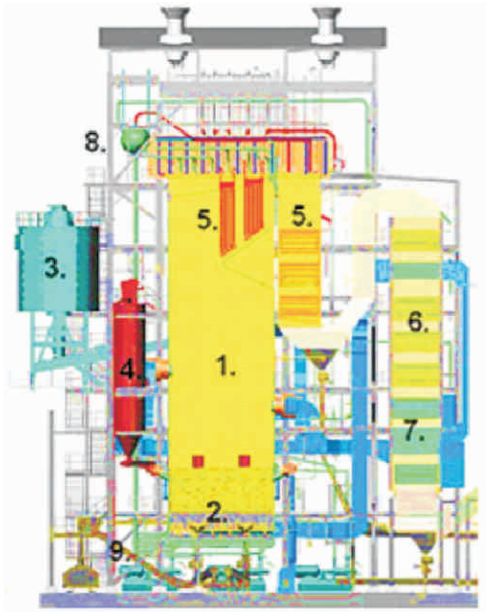
Delhi High Court ordered an enquiry on this failure. The findings of enquiry stated "The Refuse Incinerator-cum-Power Generation Plant remained inoperative since its installation in March 1987. The Ministry incurred an expenditure of Rs 1.25 crore (US$ 278,000) on maintenance and insurance of the plant." The project was officially scrapped in July 1990.

The Union Ministry of Environment and Forests (MoEF) stated that, "The experience of the incineration plant at Timarpur, Delhi and the briquette plant at Bombay support the fact that thermal treatment of municipal solid waste is not feasible, in situations where the waste has a low calorific value. This postulate was supported by many experts [40].

B) Circulating Fluidized Bed Incineration

Intense gas turbulence keep the suspended, small-piece fuel in hot sand and incineration gas in a "fluidized", dynamic state of movement. A strong airflow is forced through a sand bed. The air seeps through the sand until a point is reached where the sand particles separate to let the air through; mixing and churning occurs, thus a fluidized bed is created and fuel and waste can now be introduced. The sand with the pre-treated waste and/or fuel is kept suspended on pumped air currents and takes on a fluid-like character. The bed is thereby violently mixed and agitated keeping small inert particles and air in a fluid-like state. This allows all of the mass of waste, fuel and sand to be fully circulated through the furnace.

The pre-feasibility study conducted by LWMC reveals that on the basis of low Net Calorific Value (NCF), the Lahore MSW seems suitable for highly efficient recovery of energy from waste in fluidized bed combustion (FBC) plant. This technology has been tested and proven for various wastes throughout many years in Europe at the thermal fuel power levels of about 90 MW for Bubbling Fluidized Bed (BFB) and about 160 MW for Circulating Fluidized Bed (CFB) systems [42.43]. Because of the economies of scale, it is more cost-effective to have only one larger unit rather than two or three smaller units. For the



Main components and Systems:

1. Bubbling fluidized bed furnace
2. Fluidizing grid
3. Solid fuel feeding system
4. Bed material dosing system
5. Superheaters
6. Economizers
7. Flue gas air preheaters
8. Drum
9. Bottom ash system

Figure 9.11: Bubbling fluidized bed (BFB) incinerator

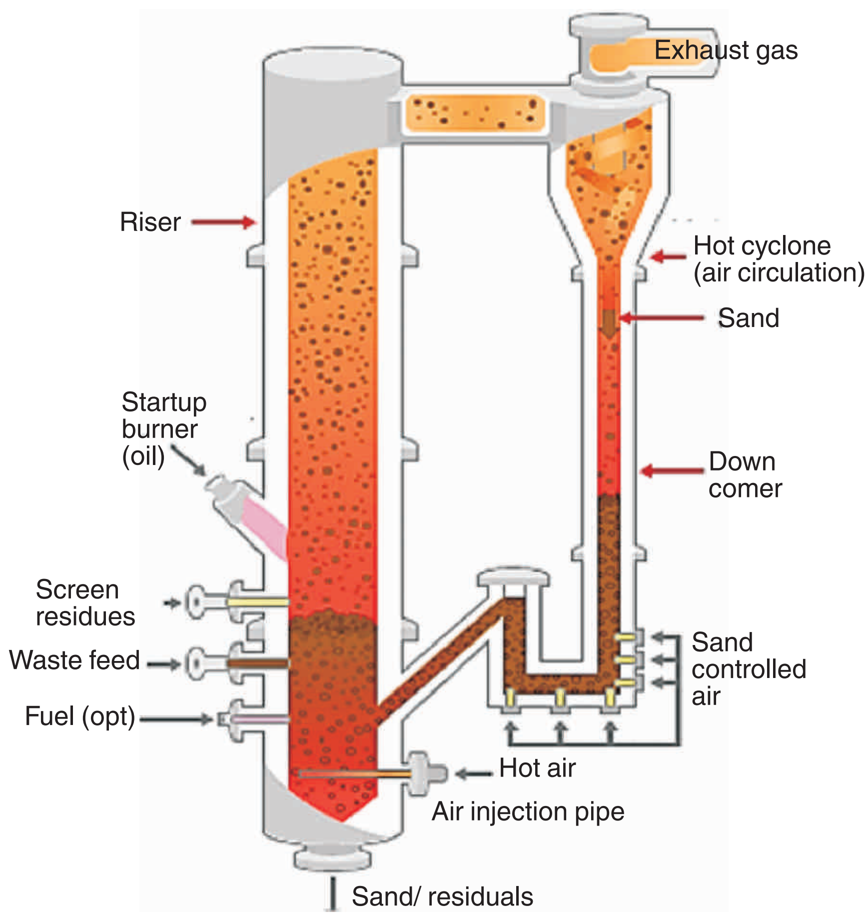


Figure 9.12: Circulating fluidized bed (CFB) incinerator

MSW in Lahore with an average NCV of 5.3 MJ/kg, a 160 MW CFB unit corresponds to a capacity of 109 tons per hour or 2,608 tons per 24-hour day. On the basis of a realistic availability of the plant at full operating capacity and a small amount of co-combustion of coal (e.g. suitable local low-grade coal with high sulfur content) the nominal capacity of the first Lahore CFB unit will be for treatment of about 2190 tons of MSW per day [41]. Main features of BFB, CFB are shown in Figs 9.11 and 9.12.

C) Gasification

Gasification is a partial combustion of organic substances to produce gases that can be used as feedstock (through some reforming processes), or as a fuel [44]. Fig. 9.13 shows a gasification plant.

D) Pyrolysis

Pyrolysis is the degassing of wastes in the absence of oxygen, during which, Pyrolysis gas and solid coke are formed. The heat values of Pyrolysis gas typically lies between 5 and 15 MJ/m^3 based on municipal waste and between 15 and 30 MJ/m^3 based on RDF. In a broader sense, "Pyrolysis" is a generic term including a number of different technology combinations.

A Pyrolysis plant for municipal waste treatment is operational in Germany and another in France. Pyrolysis projects also exist in Europe and elsewhere (notably in Japan) receiving certain specific types or fractions of waste, often after pretreatment. Pyrolysis plants for waste

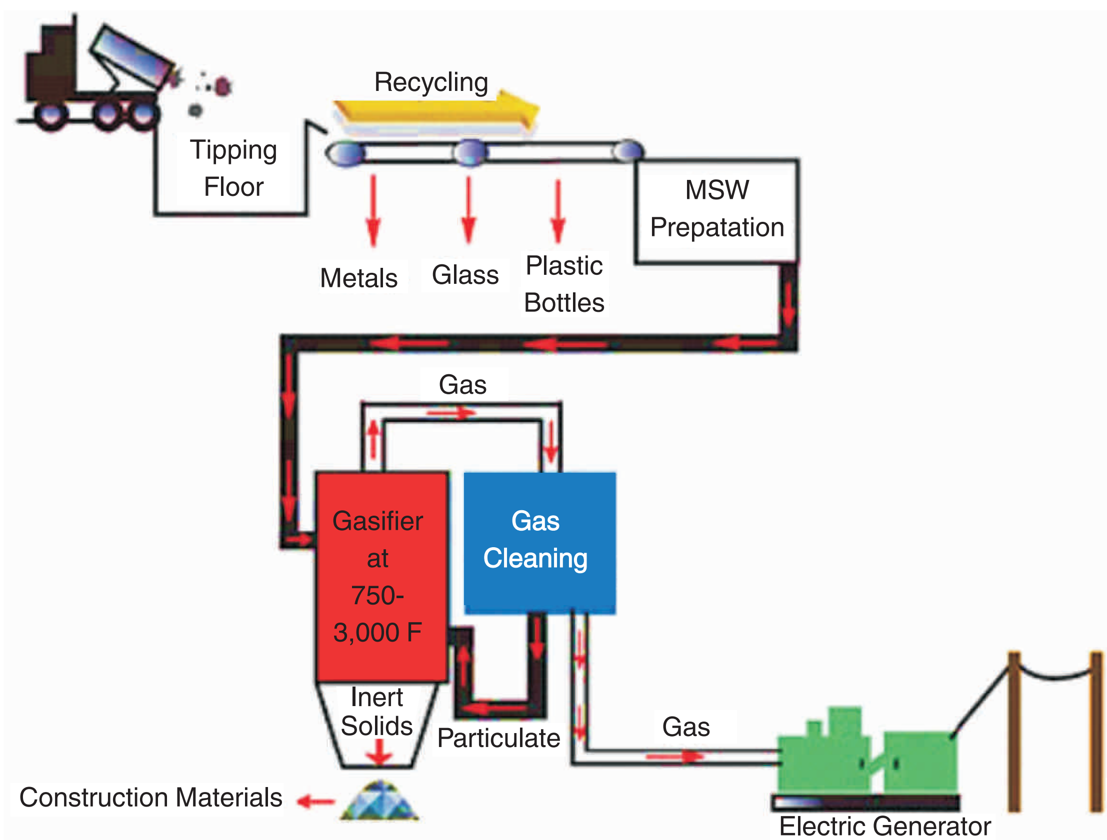


Figure 9.13: Fluidized bed gasifier with high temperature slagging furnace

treatment usually include the following basic process stages:

Preparation and grinding: The grinder improves and standardizes the quality of the waste presented for processing, and so promotes heat transfer.

Drying: A separated drying step improves the low heating value (LHV) of the raw process gases and increases efficiency of gas-solid reactions within the rotary kiln.

E) Plasma Technology

The plasma technology has been in use since long in industry; however its application to waste disposal is limited. During the past twenty years, the use of plasma technology for waste disposal has undergone extensive research. It has been tested and evaluated on many types of wastes, including automobile shredder residue, sludges, asbestos fibers, medical waste, and MSW. This R&D effort is continuing and some small-scale commercial plasma facilities for disposing of waste have been operating for more than a decade.

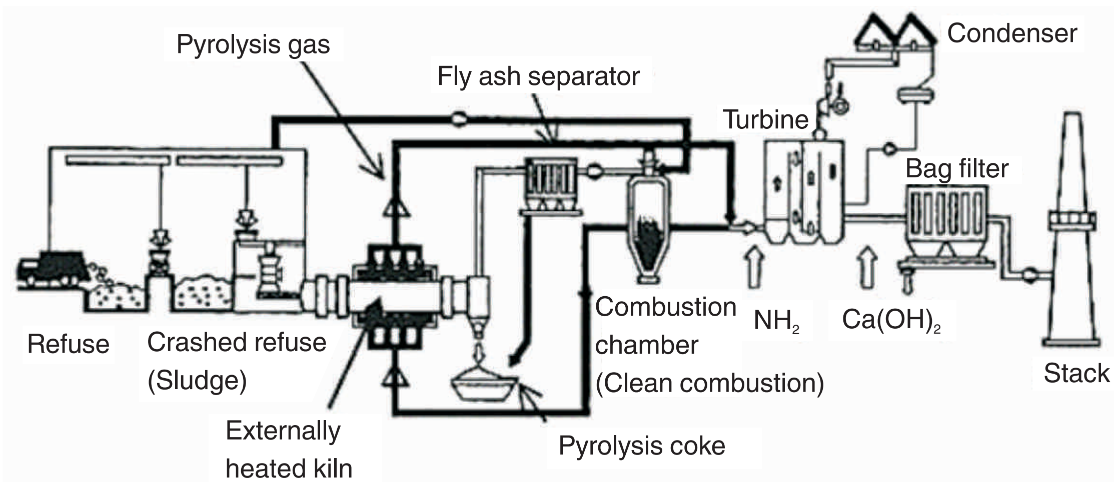


Figure 9.14: Structure of a pyrolysis plant for municipal waste treatment [45.]

Pyrolysis of wastes: Where in addition to the pyrolysis gas a solid carbon-containing residue accumulates which contains mineral and metallic portions also. A comparison of different thermal technologies is presented in Table 9.1.

Plasma is a hot ionized gas resulting from an electrical discharge. Plasma technology uses an electrical discharge (the “arc”) to heat a gas, typically oxygen or nitrogen, to very high temperatures, potentially in excess of 3000

Table 9.1: Comparison of Thermal methodology [46.]

Parameters\Technologies	Incineration	Pyrolysis	Gasification
Reaction temperature(°C)	800 – 1450	250 – 700	500 – 1600
Combustion chamber pressure(bar)	1	1	1–45
Environment	Air	Nitrogen	O_2,H_2O
Gas emitted	CO_2, H_2O, O_2, N_2	H_2, CO, H_2O, N_2	H_2, CO, CO_2, Ch_4, H_2O, N_2
Solid phase products	Ash, Coal clinker	Ash, Coal clinker	Coal clinker, Ash
Liquid phase products	-	Pyrolysis oil,Water	-

degrees Celsius (“C”). The heated gas can then be used as a controlled heat source for a particular application. These applications can include welding, cutting, or the disposal of waste materials. In the applications of plasma arc gasification on waste materials, the amount of oxygen in a plasma reactor, as in any gasification system, is carefully controlled to eliminate combustion and promote gasification. The extreme heat generated in a plasma reactor actually pulls apart the organic molecular structure of the material to produce a simpler gaseous structure, primarily CO, H_2, and CO_2 [47].

9.12 Key Questions for Evaluating a WtE Technology

Risks and other constraints attached while choosing a WtE technology are listed below which must be thoroughly examined before arriving at a final choice.

- Ensure the availability of suitable feedstock (municipal solid waste) for the entire duration of a WtE plant's life.
- Confirm that the technology choice is matched with the feedstock.
- The potential of WtE technology to meet the contractual targets and requirements of the proponent or municipality.
- Check the authenticity of the technology and that it is a demonstrated and proven technology.
- The technology if flexible enough to adapt to the change in composition of the waste, moisture contents and calorific value.

EXERCISES

1. What do you mean by energy recovery from MSW?
2. Why energy recovery from the MSW is crucial its management?
3. What are the main determinants to select WtE as a waste management option?
4. How MSW is converted to refuse derived fuel (RDF)?
5. What are the major markets for the RDF?
6. What are the main stages of anaerobic digestion?
7. How different factors can affect the anaerobic digestion process?
8. How landfill gas recovery could be beneficial for greenhouse gases emissions?
9. How landfill gas is different from natural gas?
10. Describe the construction of horizontal and vertical gas wells with sketches.
11. What are the main requirements for incineration of MSW?
12. Describe the difference between pyrolysis and gasification.
13. Write down the working principle of circulation fluidized bed (CFB) incinerator with sketch.
14. What kind of environmental problems are associated with MSW incineration?
15. How much energy can be produced form 100 tons of municipal solid waste with a net calorific value (NCV) of 1000 kcal/kg?

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10. SPECIAL WASTE MANAGEMENT

In addition to residential and commercial areas, solid waste is also generated from other sources like healthcare facilities, industries, electronic shops, packaging services and slaughterhouses. These are termed as special wastes. Handling, collection and disposal of these wastes is sometimes quite different from municipal solid waste. Hence these are discussed separately. The following sections deal with each type of these wastes.

10.1 Healthcare Waste and its Source

The waste generated from the healthcare facilities is called "healthcare waste" or "medical waste". Healthcare waste in generated as a result of the following activities:

a) Diagnosis and treatment of diseases at healthcare facilities
b) Research activities in biomedical research centers
c) Production and testing of the pharmaceuticals

Broadly, the main sources of healthcare waste are: hospitals, clinics, laboratories, dispensaries, pharmacies, nursing homes, maternity centers, blood banks, research institutes and veterinary hospitals. Such a waste is also generated when healthcare is being provided to the patient at home and is usually mixed with municipal waste.

10.1.1 Healthcare Waste Management

The healthcare waste management comprises of knowledge of quantity and quality of waste, its storage, handling, transportation and disposal in a manner that helps in (1) containment of infections; and (2) reduces public health risks both within and outside the healthcare facility.

Healthcare waste management is a sensitive issue when seen in the context of its risk to the public health. It is grossly neglected in Pakistan; both in public and private sectors with a few exceptions. The major reasons for this neglect are lack of awareness on its potential to affect public health and its inadequate coverage in the curriculum of the concerned professionals.

The focus in this chapter will be on the hospital waste management. It starts from the generation of waste in different sections of a hospital. Generation rates, for hospitals, are normally expressed as kg/bed of the hospital/day. After generation, waste is segregated, stored on site, transported within and outside the hospital, treated and finally disposed.

10.1.2 Classification and Categorization of Hospital Waste

Hospitals generate large quantities of solid waste which can be categorized into two distinct types i.e. (1) Hazardous waste and (2) Non- hazardous waste [1, 2]. If the hazardous waste is not handled and disposed carefully, it may pose a major threat to the public health (Fig. 10.1).

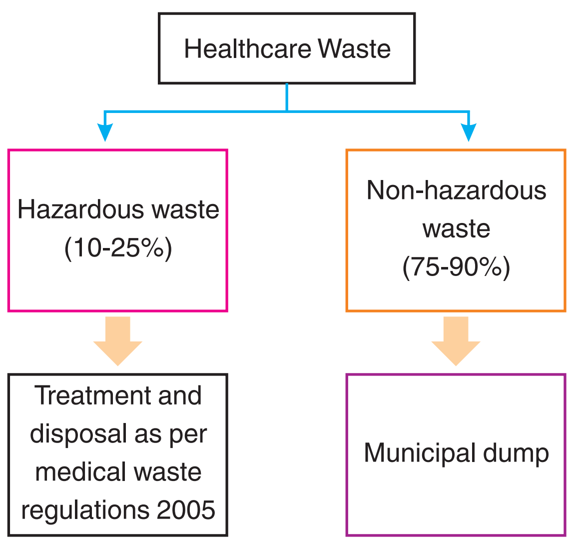


Figure 10.1: Classification of hospital waste (Healthcare) waste [3]

A) Non-Hazardous Healthcare Waste

This category covers the waste which is not infected and hence comparable to normal domestic solid waste. This waste does not entail more risk than the one generated from a normal home. Usually it constitutes 75 – 90% of the total quantity of waste generated in a hospital [3]. Such waste includes: paper and cardboard; packaging material, food waste and aerosol cans etc.

B) Hazardous Healthcare Waste

This category of waste consists of materials that are susceptible to contain pathogens (or other toxins) to cause diseases to a potential host. This waste may be contaminated by one or more types of bacteria, viruses, parasites or fungi. Usually, it is 10 – 25% of the total hospital waste [3]. The hazardous waste can be further classified into categories as shown in the Figure 10.2 [4].

a) Pathological Waste

The pathological waste consists of non-recognizable human body parts, whether infected or not. It includes human tissues, organs, fetuses and blood and bloody fluids. Anatomical waste (i.e. the recognizable human body parts) should be considered under infectious waste category, although it might contain health body parts (Fig.10.3).

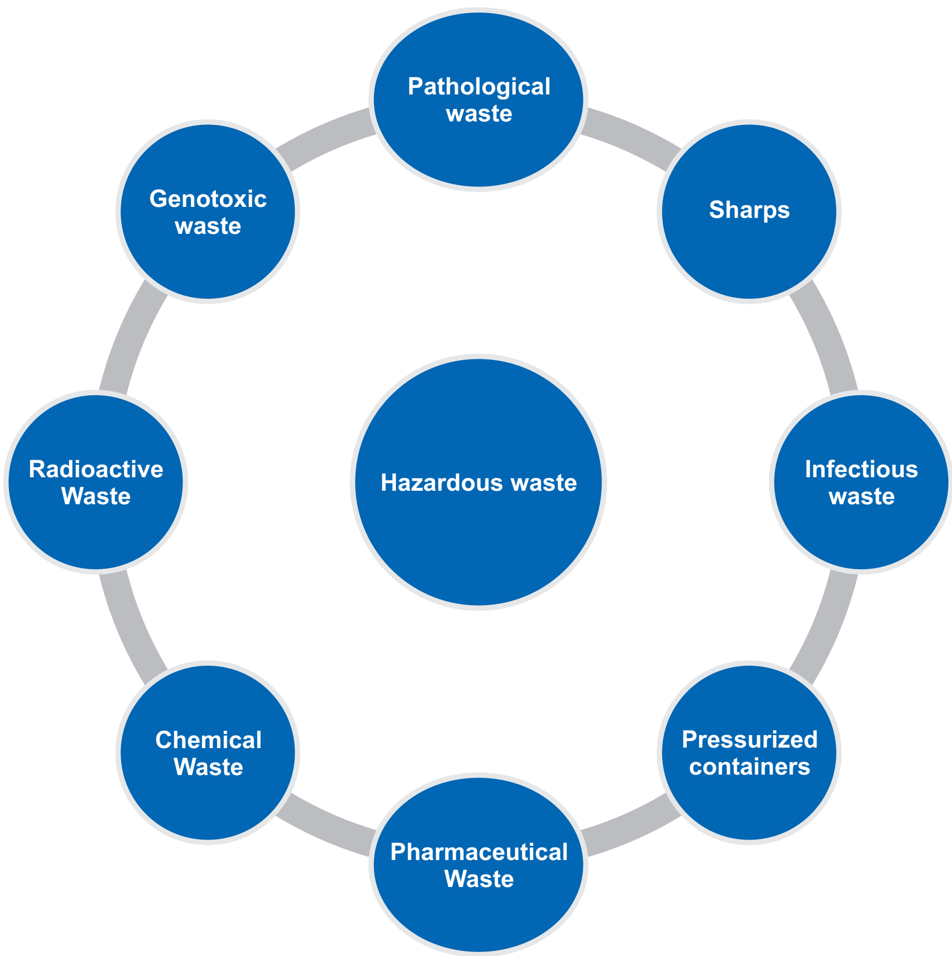


Figure 10.2: Categorization of hazardous hospital waste

(a) Body parts

(b) Human blood

Figure 10.3: Pathological waste

b) Sharpe Waste

Sharp waste included items that can cause cuts or puncture wounds like needles, syringes, scalpels, broken glass, knives, saws, infusion sets and blades or any other item that can cut or puncture wounds as shown in the Fig 10.4 . These kinds of waste are considered as highly dangerous whether infected or not.

(a) Used syringes

(b) Used glass bottles

Figure 10.4: Sharp waste

c) Pharmaceutical Waste

It includes expired, unused, spilt and contaminated pharmaceutical products, drugs and vaccines. It also includes discarded items used in handling of the pharmaceuticals such as bottles and boxed with residual medicines, gloves, masks, drug vials etc. (Fig. 10.5).

(a) Discarded drug handling materials

(b) Expired medicines

Figure 10.5: Pharmaceutical waste

d) Genotoxic Waste

This kind of waste derives from cytotoxic drugs generally used in oncology or radiotherapy units. The most commonly used genotoxic products used in healthcare include dangerous chemicals which are generally carcinogenic, probable carcinogenic and radioactive. These kind of waste are contained in a specially designed containers (bottles) before their safe disposal as shown in the Fig.10.6.

Figure 10.6: Safe disposal of genotoxic waste

e) Chemical Waste

It consists of discarded chemicals (solid, liquid or gaseous) that are usually generated during disinfecting procedures or cleaning processes (Fig.10.7). Chemicals used in healthcare facilities can be hazardous or non-hazardous. In the context of protecting human health, it should be classified as hazardous if is [5]:

- Toxic
- Corrosive(pH> 12 or pH< 2)
- Flammable
- Reactive(water reactive,
- Explosive or shock reagent)
- Genotoxic (e.g. cytotoxic drug)

Figure 10.7: Used chemicals

f) Infectious Waste

This waste consists of microbial cultures and stocks of highly infectious agents from medical analysis in (clinical) laboratories. This may also include body fluids of patients with highly infectious diseases.

(a) Infectious laboratory waste

(b) Infected drip

Figure 10.8: Infectious healthcare waste

g) Radioactive Waste

The radioactive waste producing in healthcare facilities consists of several types of liquid, solid and gaseous waste. It includes contaminated with radio nuclides generated during in vitro analysis of human body tissues and fluids by imaging and certain therapeutic procedures. It may be of high activity such as a technetium generator and sources used in radionuclide therapy, or low activity waste from biomedical procedures or research. The radioactive material may be mixed with different chemicals, in itself hazardous or flammable. Moreover some of the waste is mixed with biological substances such as blood and may be infectious subsequently special precautions must be taken for disposing of such items as needles used for injection.

h) Pressurized Containers

Gas cylinders containing compressed an-esthetic gas (used for sedation during surgery and painful procedures), ethylene oxide (used for sterilization of surgical equipment), Oxygen (for inhalation supply for patients) and air (used in laboratory for equipment cleaning and environmental controls) are used in healthcare facilities. Most of them are reused once they are empty, however aerosol cans cannot be reused. The discarded containers should be disposed of carefully (Fig. 10.9).

(a) oxygen cylinders

Figure 10.9: Pressurized cylinders in hospitals

(b) aerosol can

Figure 10.9: Pressurized cylinders in hospitals

10.1.3 Hazards from Healthcare Waste

All individuals exposed to risk HW are potentially at risk of being injured or infected. It is important to identify people at risk and the types of hazards they may face. Persons at risk include patients and medical staff, workers in support services linked to hospitals such as laundry and waste handling personnel and vehicles drivers.

If not properly handled, the persons who come in contact with risk waste can contract different diseases. Even the general public can be infected directly or indirectly through several routes of contamination. The unauthorized reuse and recycling practice, particularly of disposable syringes, is a very serious problem in our country, posing a potential danger to almost everyone. The dumping of HW alongside the Municipal Solid Waste can have a direct environmental effect through contamination of soil and underground water. Similarly, if air pollution control equipment are not used with incinerators, used inside hospitals, the surrounding air is polluted with potentially dangerous contamin-ants posing hazards to the nearby inhabitants.

Types of diseases caused by improper handling of hospital wastes include AIDs, cholera, chickenpox, diarrhoea, dysentery, hepatitis C, B and many others.

10.1.4 Generation Rates and Physical Composition

Generation rates for hospitals are generally expressed as kg of solid waste/bed/day (kg/bed/day). Table 10.1 shows the range in which waste generation varies in Pakistan (Karachi) and abroad (Middle East, Europe and USA).

Kg/bed/day, which was in fact from the Agha Khan hospital. The minimum values for European and Middle Eastern hospitals are slightly higher than that of Karachi. Their maximum values are also comparable to that of Karachi. This leads to the conclusion that hospitals if managed by the highest standard, they will have a maximum waste generation lying in range of 4 to 5 kg/bed/day. Mostly the Government hospitals have a generation rate, which is on the lower side.

Table10.1: Hospital waste generation rate of various countries [6]

Hospital waste generation rates (Kg/bed/day)							
Pakistan		Middle East		Europe		USA	
Min	Max	Min	Max	Min	Max	Min	Max
1.63	5.13	2.1	4.9	2.5	4.4	4.10	5.24

It can be observed from Table 10.1 that while for USA the minimum (4.10 Kg/bed/day) is much higher than the minimum for Karachi (1.63 Kg/bed/day) and the max i.e 5.24 Kg/bed/day is almost the same as the max for Karachi i.e. 5.13

Table 10.2 show data collected from different hospitals in Peshawar. Number of beds, total waste (both risk and non-risk) per bed and percentage of risk and non-risk waste are shown.

Table10. 2: Composition of Peshawar hospital waste [7]

Sr.No	Name of Hospital	Beds	Generation rate (Kg/bed/day)	Govt/ Private	Waste Generated	
					Risk %	Non-Risk %
1	Lady Reading Hospital	1,400	1.8	Govt	20	80
2	Khyber Teaching Hospital	1,224	1.4	Govt	20	80
3	Hayatabad Medical complex	1,000	1.3	Govt	23	77
4	Nasr-Ullah Babar Hospital	200	1.2	Govt	15	85
5	I.D Children Hospital	105	1.5	Govt	17	83
6	Rehman Medical Complex	340	.08	Private	15	85
7	North West	200	2.5	Private	13	87
8	Paracha Hospital	15	1.3	Private	12	88
	Average		**1.48**		**19.5**	**80.5**

It can be seen in Table 10.2 that the risk waste in different hospitals in Peshawar varies from from 12 to 23%, while non-risk waste varies from 77 to 88 percent. The average values for risk and non-risk waste in Peshawar is 19.5 and 80.5%, respectively. The average value of total waste per bed per day is 1.48. This average figure is close to the minimum value of Karachi as shown in Table 10.1. For hospitals in Pakistan, an average value of 2 kg/bed/day may be adopted for the purpose of estimation of hospital waste, if the actual data is not available. However, if actual data is available then it should be adopted.

10.1.5 Colour Coding for Different Waste Types

Colour coding is usually used to differentiate between different waste types in hospitals [5]. Moreover, specific symbols are also used to identify the waste types. The colour coding, mostly used is shown in Fig. 10.9. It is important that same colour coding be used throughout the country.

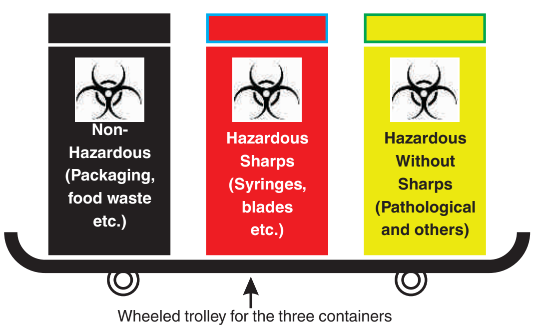


Figure 10.10: Wheeled trolley with three coloured containers for hospital waste

10.1.6 Onsite Storage and Segregation

All waste generated in a healthcare facility needs to be classified into defined categories for proper segregation, treatment and disposal [1]. A simple classification method is to use colour coding for different types of waste as explained in the previous section.

As shown in Fig. 10.10, a wheeled trolley is used inside the hospital for the on-site storage of waste. Each type of waste is put in its respective container with a specific colour. The container materials may be a good quality plastic bag, with a colour code. Plastic bags are normally used because they are easy to replace with new bags and the trolley remains at its place and does not have to be moved to the collection vehicle.

Figure 10.11: Medical waste segregation at Jinnah hospital, Lahore

At Jinnah Hospital Lahore, hospital waste is segregated at source using red, yellow and green buckets for infectious waste (including sharps), pathological (non-sharps) and general waste respectively as shown in Fig. 10.10 and 10.11.

The wheeled trolleys with bins are placed at different suitable locations including nursing stations in the hospital. A non-hazardous waste bin is placed near each patient's bed. A typical placement scheme is shown in Fig. 10.12.

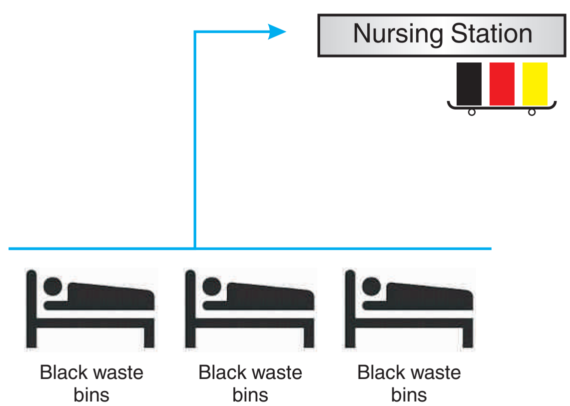


Figure 10.12: A typical placement of wheeled trolley with colour code waste bags/containers

In addition to colour coding, the use of symbols to show type of waste is also common. Sometimes both colour coding and symbols are used simultaneously. Symbols of infectious, radioactive and toxic waste are shown in Fig. 10.13.

Figure 10.13: Symbols used for infectious/bio-hazard, radioactive and toxic wastes [9, 10]

A uniform color coding system is to be followed in all the healthcare facilities throughout the country. Following guidelines may be followed for on-site storage and segregation.

a) Rigorous training and education of the entire staff is a must.
b) Every room, ward, laboratory, operation theatre etc. must have suitable bags, boxes and containers for the waste generated there.
c) The waste segregation and identification instructions should be placed at each waste collection point to ensure that proper procedures are followed.
d) Plastic bags for storing the waste may be suspended inside a frame or placed inside a sturdy container. A lid to cover the open bag is preferable.
e) Sharps must be collected in puncture-proof containers to avoid injuries and infection.
f) Empty collection bags or containers should be readily available at every location of waste generation and replenished daily.

10.1.7 Waste collection

A routine for the collection of waste should be established in the Waste Management Plan of a hospital [1]. Sanitary staff must wear protective clothing at all times when handling waste.

All waste bags should be sealed when they are about three quarters full. Stapling should not be used as this will puncture the bag. Sanitary staff/sweepers should ensure that: waste is collected at least daily, but more often if necessary and that all bags must be labeled before removal from the point of production (for example, the ward, Operation Theater, laboratory etc.). Bags and/or containers are immediately replaced with new ones of the same type.

10.1.8 Waste transportation

a) Intra-unit Transportation

The sealed plastic bags should be carefully loaded into an intra-unit transportation container preferably closed to prevent the risk of falling off waste. (Fig. 10.14a). The container can also be placed on a wheeled trolley as shown in the Fig (Fig.10.14 b) Bags should not be handled roughly to minimize the risks of punctures or tears. Yellow – bagged risk waste and black – bagged non – risk waste must be the subject of separate collection rounds. The containers should not be used for any purpose other than the transportation of waste.

The collection route should be the most direct one in accordance with the Waste Management Plan. On no account should collected waste be temporarily, even for very short periods, left anywhere other than the designated storage point. The trolleys should be: easy to load and unload; free of sharp edges which could damage the bags; easy to clean, daily with disinfectants [1].

(a) Container

(b) Container with Trolley

Figure 10.14: Intra unit transportation containers

b) Off- Site (when no on-site treatment facility is available)

It is vital that the same standards of segregation, handling and transportation are used during off site transportation as are used by the hospital staff. If this is not carried out, confidence in the system will be lost leading inevitably to the complete collapse of the procedures, once again putting health and lives at risk. For this purpose, for off-site transportation, collect all yellow – bagged waste at least daily and ensure that staff handling such waste wears protective clothing. The staff should be properly trained in the handling, transportation and disposal of yellow – bagged waste. Ensure that yellow – bagged waste is transported completely separately from all other waste. As far as possible ensure that vehicles used for the carriage of yellow bagged waste (Fig. 10.15) are: (1) Not used for any other purpose and are (2) Easy to load and unload [1].

Figure 10.15: Medical waste transportation vehicles

10.1.9 Temporary Storage

In a healthcare facility/hospital, a separate storage area for yellow bagged waste must be provided to ensure continued segregation of risk waste from non-risk waste. A temporary storage room in Jinnah hospital is shown in the Fig. 10.16. The designated risk waste storage area should have the following characteristics [1].

Figure 10.16: Jinnah hospital temporary storage room

a) It must be located within the hospital premises.

b) Located close to the incinerator or other treatment facility (if one is installed).

c) It should be large enough to contain all the risk waste produced by the hospital with additional capacity to cover collection / incinerator breakdowns.

d) The base should be impermeable hard-standing with good drainage.
e) It should be easy to clean/disinfect and equipped with a water supply.
f) It must be secure from unauthorized access and locked except during loading and unloading.
g) It should be easily accessible by authorized staff and collection vehicles.
h) It must be inaccessible to animals, insects and birds.
i) The site must not be close to any food storage or food preparation areas.
j) A supply for cleaning equipment, protective clothing and waste bags should be located nearby.
k) No waste should be stored for longer than 24 hours.

10.1.10 Treatment Processes

The risk-waste component of healthcare waste is potentially hazardous and needs some form of treatment to make it safe for final disposal.

Currently a number of pre-disposal treatment (PDT) technologies are available worldwide including incineration, autoclaving, irradiation and pyrolysis. These technologies employ different processes for disinfection of the risk waste. Major processes are: thermal process; chemical process; irradiative process; biological process; and mechanical process [11,12].

a) Thermal Process

Incineration, pyrolysis, autoclaving and microwave treatment are the technologies that use thermal process. Incineration and pyrolysis are high heat thermal processes operating at temperature range of 1000 to 1500°F. Autoclaving and microwave treatments are low heat thermal processes.

b) Chemical Process

Chemical processes employ disinfectants such as dissolved chlorine dioxide, bleach (sodium hypochlorite), per acetic acid, or some dry inorganic chemicals. Besides chemical disinfectants, there are also encapsulating compounds that can solidify sharps, blood or other body fluids within a solid mortar, prior to disposal. This eliminates the chances of unauthorized scavenging and reduces the risk of environmental pollution.

c) Irradiative Processes

Irradiation based technologies involve electron beams, Cobalt 60 or ultra-violet irradiation. These technologies, however, require shielding to prevent occupational exposures during operation. Irradiation, like many other processes does not alter the waste physically and would require a grinder or shredder to render the waste unrecognizable before disposal at a landfill site.

d) Biological Processes

Biological processes employ enzymes to destroy organic matter. However, only a few technologies have been based on biological processes.

e) Mechanical Processes

Mechanical processes such as shredding, grinding, hammer mill processing, mixing, agitation, liquid-solid separation etc., supplement anyone of the pre-disposal treatments (PDTs) mentioned earlier. Mechanical destruction renders the waste unrecognizable and is used to destroy needles and syringes.

f) Treatment technologies

Based upon the treatment processes enumerated above, a number of technologies and devices have been developed for the institutional treatment of hospital waste. Incinerators and autoclaves are the two most commonly used technologies in the world and are being described in detail [12, 13].

Incinerators: Incineration is the most commonly used and most versatile technology that treats all types of risk waste. An incinerator is basically a high temperature burning chamber; where the waste is burnt to kill all pathogens. Most of currently used incinerators have two chambers called "dual chamber systems" [14,15].

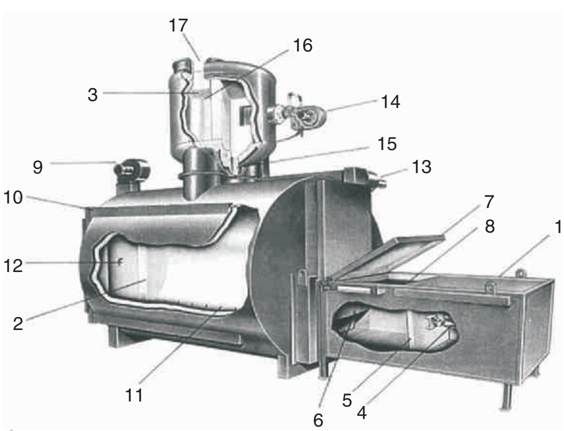
The gases produced during burning of waste in the first chamber are toxic. The modern incinerators detoxify these gases before release into the atmosphere. Under ideal conditions, there should be no smoke but only a colourless exhaust should go into the atmosphere. However, we do find smoke in many cases due to a number of reasons, making the conditions far from ideal. Emissions produced from incinerators have adverse consequences for workers, public health and the environment. A list of these pollutants that may escape from incinerators is given in Table 10.3.

Hospital authorities purchase incinerators from vendors specialized in the design and manufacturing of these equipment. The amount, nature of waste, the air emission standards to be complied with, is generally intimated to the vendor for the purpose of design and quoting the cost of incinerator.

With the passage of time, the use of incinerators have reduced. The major reason is the high capital cost, release of harmful emissions (furans, heavy metals, dioxins etc) even when strict air pollution control is exercised and high operational cost. In addition, recyclable material like plastic, iron etc is also burned. Due to these reasons Autoclave is gaining attention. A dual chamber incinerator, normally used in hospitals, is shown in Fig 10.17.

Table 10.3: Pollutants from medical waste incinerators [12]

Pollutants	Examples / Notes
Organic	Benzene, carbon tetrachloride, chlorophenols, trichloroethylene, toluene, xylems, trichlorotrifluoroethane, polycyclic aromatic hydrocarbons, vinyl chloride.
Dioxin and furans	2, 3, 7, 8-tetrachlorodibenzo-pdiozin (TCDD).
Heavy Metals	Arsenic, cadmium, chromium, copper, mercury, manganese, nickel, lead.
Acid gases	Hydrogen chloride, hydrogen fluoride, sulphur dioxides, nitrogen oxides.
Carbon monoxide	(A common product of incomplete combustion).
Particular matter	Fly ash



1. Ram Loader
2. Incinerator primary chamber
3. Incinerator secondary chamber
4. Loader hydraulic cylinders
5. Loader ram
6. Guillotine door
7. Waste hopper door
8. Waste hopper
9. Primary air fan
10. Primary air ducting
11. Under fire air parts
12. Ash/access door
13. Secondary air fan
14. Secondary burner
15. Transfer port
16. Secondary chamber baffle
17. Stack connection

Figure 10.17: Dual chamber incinerator [12]

Autoclaves: An autoclave consists of a metal chamber sealed by a charging door and usually surrounded by a steam jacket. Steam is introduced into both the outside jacket and the inside chamber which is designed to stand elevated pressures. Heating the outside jacket reduces condensation in the inside chamber wall and allows the use of steam at lower temperature.

Because air is an efficient insulator, the removal of air from the chamber is essential to ensure penetration of heat into the waste. Removal of air is done either through "gravity displacement" or through "pre-vacuuming". Pre-vacuum type autoclaves require less time for disinfection due to the greater efficiency in taking out air.

The types of waste suited for treatment in an autoclave include, cultures and stocks, sharps, surgery waste, laboratory and soft waste like gauze, bandages, drapes, gowns, beddings and linen from patients care, materials contaminated with blood and limited amounts of fluid.

Anatomical waste, chemical waste, volatile and semi-volatile organic compounds, mercury and radiological waste should not be autoclaved. Similarly, huge and bulky bedding materials, large animal carcasses, sealed heat resistant containers and other waste loads that impede the transfer of heat should be avoided.

Autoclave requires a minimum exposure time and temperature to achieve proper disinfection. A common exposure temperature-time criteria is 121°C (250°F) for 30 minutes. Plastic bottles, syringes and some other material can be recycled after autoclaving as compared to incinerator in which all such waste is burned.[16,17].

The first step is the waste collection in special containers. A cart or bin is lined with special plastic or large autoclavable bags to prevent waste from sticking to the container. Yellow bags are then placed in the lined container. Pre-heating of the chamber is the next step, for which steam is introduced into the outside jacket. Once heated, the waste containers are loaded into the autoclaving chamber. Next, air is removed through gravity displacement or pre-vacuuming, depending upon the type of equipment.

Steam is introduced into the chamber until the required temperature is reached. Additional steam is automatically fed into the chamber to maintain the temperature for a set period of time. After the steam has been retained for the requisite time, it is vented from the chamber, resulting in lower pressure and temperature. Before unloading however, additional time is

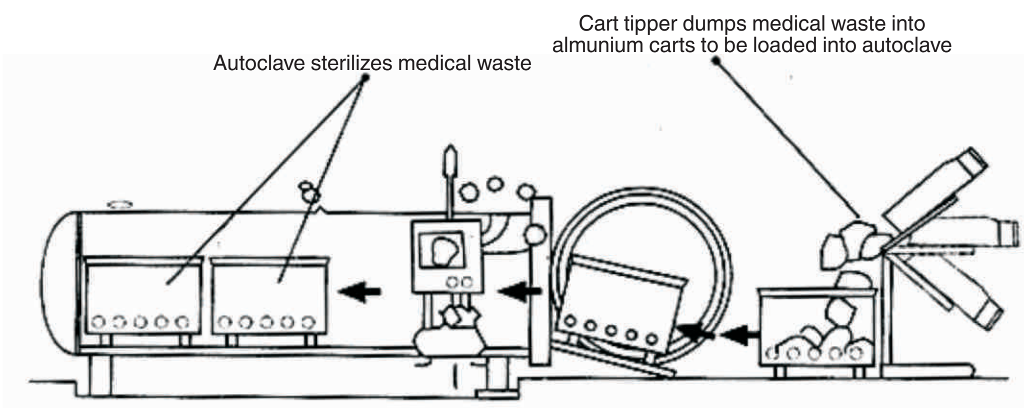


Figure 10.18: The working of a simple autoclave [8]

provided to allow the waste to further cool down. Finally, the treated waste is unloaded and the indicator strips if any are removed and evaluated. The waste is then fed into the shredder before landfilling (Fig. 10.18).

10.1.11 Disposal

After treatment hospital/healthcare waste would still need disposal in an environment friendly manner. Different disposal methods used for the purpose include sanitary landfilling, controlled dump site, small burial pit and encapsulation [9,12].

a) Sanitary landfill

This is of course the best option. A sanitary landfill is an isolated area of land where waste is dumped in excavated trenches and provided daily with a soil cover. The healthcare waste needs more precautions than required for the municipal waste. Such landfill is called a “Secure landfill site”.

b) Controlled dump site

Since engineered landfill sites are hardly available in Pakistan, an acceptable alternate is controlled dump site. In this method, essential burial of waste in earth is done on daily basis in an isolated and demarcated site away from the populated area. The site needs to be prepared for retaining the waste more effectively and burial of the waste daily so that chances of contact with humans and animals are minimized.

c) Small burial pit

A small burial pit up to 2 m depth may be used for hospital waste. It is filled with waste up to 1.5 meter. After every waste load a soil cover of 10 – 15 cm thickness is provided. If soil cover is not available lime may be deposited over the waste. Access to such pits should be restricted.

d) Encapsulation

Usually the sharps, chemicals and pharmaceuticals are disposed in this manner. Encapsulation means filling up the containers with waste, adding immobilizing material and sealing the containers. HD (high density) polyethylene boxes or metallic drums can be used for this purpose.

10.1.12 Legislation on Healthcare Waste in Pakistan

In Pakistan, Hospital waste management rules, 2005 were approved by Ministry of Environment, Government of Pakistan in August, 2005. As per these rules, following steps are mandatory for a healthcare facility

- Form a waste management team
- Designate responsibility to each team member
- Form a waste management plan for the healthcare facility
- Segregate risk and non-risk waste at the point of generation
- Store risk waste in color coded containers/bags at the healthcare facility premises and keep record of weightage of risk waste.
- Review waste management plans at regular intervals

10.2 Electronic Waste (E-Waste)

E-waste is term used for electronic products nearing the end of their useful life. It includes old, outlived or discarded electrical and electronic equipment and appliances such as computers, televisions, VCRs, stereos, copiers, fax machines, electric lamps, cell phones, audio equipment, refrigerators, and batteries which have been discarded by their original users. Broadly, e-waste is loosely discarded, surplus, obsolete, broken, electrical or electronic devices as shown in the Fig 10.19 [18].

The processing of electronic waste in developing countries causes serious health and pollution problems due to the fact that electronic equipment contains toxic contaminants such as lead, cadmium, beryllium and brominates flame retardants. Even in developed countries recycling and disposal of e-waste involves significant risk.

(a)

(b)

Figure 10.19: E-waste [19]

10.2.1 E- Waste Generation

Globally, around 40 million metric tons of e-waste is produced each year. About 13 percent of that waste is recycled, mostly in developing countries. European Union (EU) discard about 9 million tons of e-waste including televisions, computers, cellphones, and other electronics [20].

Currently, e-waste from developed countries is sent in bulk to the developing countries, where it is either sold and recycled. Currently, an estimated 70 percent of e-waste handled in India is from developed countries such as USA, UK. EU and China. UNEP estimates that between 2007 and 2020, domestic television e-waste will double, computer e-waste will increase five times, and cell phones 18 times. Unfortunately, no data is available about the e-waste generation in Pakistan. The growth rate of e-waste is three times that of other municipal waste. Although e-waste makes a small fraction of municipal waste (only 1-4% percent), it may be responsible for as much as 70 percent of the heavy metals in landfills, including 40 percent of all lead [21].

The Basel Convention on the “Control of Transboundary Movements of Hazardous Wastes and their Disposal” bans the exchange of hazardous waste, including e-waste, between developed and developing countries. The United States is the largest generator of e-waste world wide and the only industrialized nation not yet ratifying the Basel Convention.

10.2.2 Composition of E-waste

The composition of e-waste is diverse and falls under 'hazardous' and 'non-hazardous' categories. Broadly, it consists of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete, ceramics, rubber and other items. Iron and steel constitute about 50% of the waste, followed by plastics (21%), non-Ferrous Metals (13%) and other constituents. Non-Ferrous metals consist of metals like Copper, Aluminum and precious metals like Silver, Gold, Platinum, Palladium and so on [22]. The presence of elements like Lead, Mercury, Arsenic, Cadmium, Selenium, Hexavalent Chromium, and flame retardants beyond threshold quantities make e-waste hazardous in nature. It contains over 1000 different substances, many of which are toxic, and creates serious pollution upon disposal [23]. Obsolete computers pose the most significant environmental and health hazard among the e-waste.

10.2.3 Impacts of E-waste

Electronic waste can cause widespread environmental damage due to the use of toxic materials in the manufacture of electronic goods [24]. Heavy metals such as Lead, Mercury and Hexavalent Chromium in one form or the other are present in such wastes primarily consisting of Cathode Ray Tubes (CRTs), printed board assemblies, capacitors, Mercury switches and relays, batteries, Liquid Crystal Displays (LCDs), cartridges from photocopying machines, Selenium drums (photocopier) and electrolytes. The above mentioned E-waste contains Lead and Cadmium in circuit boards; Lead Oxide and Cadmium in monitor CRTs; Mercury in switches and flat screen monitors; Cadmium in computer batteries; Polychlorinated Biphenyls (PCBs) in older capacitors and transformers; and brominated flame retardants on printed circuit boards, plastic casings and cables. Polyvinyl Chloride (PVC) cable insulation releases highly toxic dioxins and furans when burned to retrieve Copper from the wires [25].

Landfilling of e-wastes can lead to the leaching of lead into the ground water. If the CRT is crushed and burned, it emits toxic fumes into the air [26]. These products contain several rechargeable battery types, all of which contain toxic substances that can contaminate the environment when burned in incinerators or disposed in landfills. The Cadmium from one mobile phone battery is enough to pollute 600 m^3 of water [27]. Cadmium in landfill sites may cause long-term effects if leaks into the surrounding soil [28].

Informal recycling of e-waste takes place in China, India, Pakistan, Vietnam, and Philippines. Often shredding, burning, and dismantling the e-waste takes place in the "backyards." Emissions from these recycling practices damage human health and the environment [29]. However, some people think that this recycling open up job opportunity for a large number of people and provide raw material to many local industries. Thus there is a need to regulate this recycling maximizing benefits and reducing the harmful effects [30].

10.2.4 E-waste Management

The best option for dealing with e-wastes is to reduce the volume. Designers should ensure that the product is built for re-use, repair and/or upgradeability. Stress should be laid on use of less toxic, easily recoverable and recyclable materials which can be taken back for refurbishment, remanufacturing, disassembly and reuse. Recycling and reuse of material are the next level of potential options to reduce e-waste [30]. Recovery of metals, plastic, glass and other materials reduces the magnitude of e-waste. These options have a potential to conserve the energy and keep the environment free of toxic material that would otherwise have been released.

Therefore, for effective e-waste management, there is a need to quantify and characterize this waste stream, identify major waste generators, and assess the risks involved. A scientific, safe and environmentally sound management system, including policies and technologies, needs to be developed and implemented. There are three major components of e-waste management system:

- E-waste collection, sorting and transportation system.
- E-waste treatment system.
- E-waste disposal system.

10.2.5 E-waste Collection, Sorting and Transportation System

E-waste collection system consists of producer / retailer take back system, municipal collection system and recycler's / dismantler's collection system. Since e-waste is hazardous in nature, it is collected, sorted, stored and transported under controlled conditions. The collection means will vary, following distances, rural or urban patterns, and the size of collected appliances. Some categories will require specific collection routes like flatbed collection (for fridges and other reusable household appliances).

A) Collection Channel

The three major e-waste collection channels, which are being successfully used, are municipal collection sites, retailer take-back, and producer take-back. The collection mechanism used by each collection channel is given below:

- In municipal collection mechanism, consumers and/or businesses can leave e-waste at municipal sites. A number of sorting containers and/or pallets are provided at their collection site according to the product scope and logistical arrangements with recyclers and transporters. This collection mechanism is usually free for household e-waste, although charges sometimes apply for commercial companies.
- In retailer take-back collection mechanism, consumers can take back e-waste to retail stores that distribute similar products. They may give back the product at the retail store depending upon purchase of a new product, or without any purchase required, and is sometimes done at the point of home delivery and installation of a new item by the retailer/distributor. Where available, this service is usually free to private households.
- Under producer take-back mechanism, e-waste is taken back directly by producers either directly at their facilities or collection centers and then fed into the e-waste system. This usually applies to larger commercial equipment and operates on the principle of “new equipment replacing the old ones”.

Collection infrastructure requires establishment of e-waste collection points and storage area in a city/ geographical region.

B) Sorting and Transportation System

The second step involves separation or sorting. According to available literature, e-waste in general is being sorted/ separated into five groups as given below depending on different material composition and treatment categories. This facilitates efficient collection, recycling and data monitoring for compliance:

- Refrigeration equipment —Due to ozone depleting substance usage, this has to be separated from other e-waste
- Equipment containing CRTs —the CRTs need to remain intact because of health and safety reasons. Therefore, TVs and computer monitors will have to be collected separately from other waste and handled carefully
- Lighting (linear and compact fluorescent tubes) — this needs to be deposited in a special container (due to Mercury) to ensure it does not contaminate other waste and that it can be recycled
- All other e-waste— These wastes can be collected in the same container because there are no recycling or health and safety reasons

An efficient e-waste collection and transportation system will ensure reuse, recycle and adequate e-waste management including avoiding damage or breaking components that contain hazardous substances. The major factors, which determine the efficiency of collection system, are given below:

- Accessible and efficient collection facilities
- Ensure minimal movements of products
- Minimize manual handling
- Aim to remove hazardous substances
- Separate collection of reusable appliances
- Adequate and consistent information to the users

10.2.6 E-Waste Treatment and Disposal System

The major environmental impacts are due to uncontrolled treatment of e-waste in unorganized/informal sector. The simplified flow diagram for e-waste treatment is given in Fig. 10.20. It starts from product collection followed by product testing in order to sort reusable and non-reusable e-waste separately. Non-reusable e-waste is disassembled and e-waste fractions are sorted into reusable and non-reusable parts. Non-reusable e-waste parts undergo size reduction, separation and recovery of different materials, while the remaining e-waste fractions are disposed.

A) E-Waste Reuse and Recycling

It constitutes direct second hand use or use after slight modifications to the original functioning equipment. It is commonly used for electronic equipment like computers, cell phones etc. Inkjet cartridge is also used after refilling. This method also reduces the volume of e-waste generation. It is one of the most widely used methods for disposal of e-waste. Recycling involves dismantling i.e. removal of different parts of e-waste containing dangerous substances like PCB, Hg, separation of plastic, removal of CRT, segregation of ferrous and non-ferrous metals and printed circuit boards. Recyclers use strong acids to remove precious metals such as copper, lead, gold. The value of recycling could be much higher if an appropriate technology is used.

Reusing and recycling are the good ways of dealing with e-waste. They have been preferable

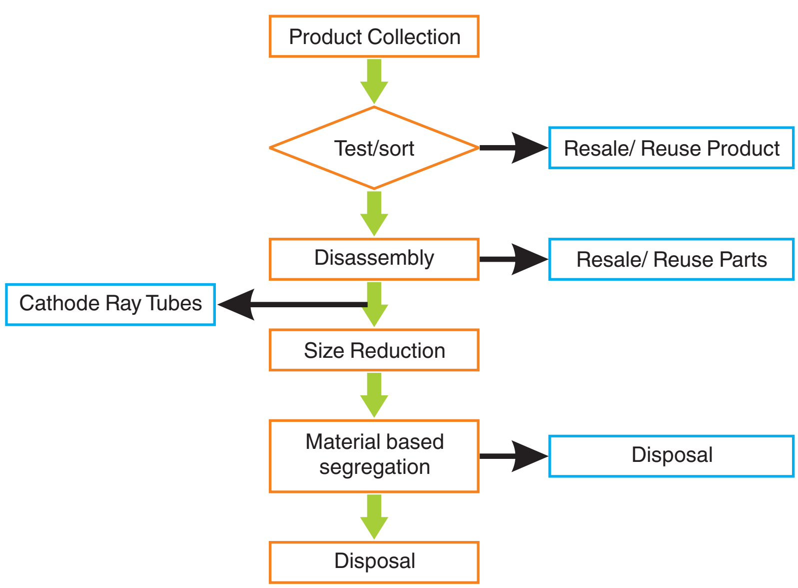


Figure 10.20: Treatment technology flow diagram [30]

because they increase the lifespan of the products and therefore imply less waste over time. Re-use constitutes direct second hand use, or use after slight modifications are made to the original functioning equipment like memory upgrades, etc. However, they end up as waste eventually as they have limited life span. The reuse of second-hand electronic goods in the developing world including Pakistan falls in this category, where the waste ends up locally and where there is no adequate facility and competence to deal with them appropriately.

B) E-Waste Incineration

Advantage of incineration of e-waste is the reduction of waste volume and the utilization of the energy content of combustible materials. Some plants remove Iron from the slag for recycling. By incineration some environmentally hazardous organic substances are converted into less hazardous compounds. Disadvantage of incineration is the emission to air of substances, escaping flue gas cleaning equipment, which may be a source of air pollution. E-waste incineration plants contribute significantly to the annual emissions of cadmium and mercury. In addition, heavy metals not emitted into the atmosphere are transferred to slag and exhaust gas residues and can re-enter the environment on disposal. Therefore, e-waste incineration will increase these emissions, if specialized control equipment are not used.

C) E-Waste Disposal

The environmental risks from landfilling of e-waste cannot be neglected. It is mainly due to leaching of heavy metals like Lead, Cadmium and Mercury. These metals may also emit via the landfill gas combustion plant. Landfills are also prone to uncontrolled fires, which can release toxic fumes. Therefore, landfilling does not appear to be an environmentally sound treatment method for substances, which are volatile and not biologically degradable (Cd, Hg,), persistent (Poly Chlorinated Biphenyls) or with unknown behavior in a landfill site (brominated flame retardants).

10.2.7 E-Waste Management Challenges in Pakistan

Following are the key challenges pertaining to the e-waste management in Pakistan:

a) Lack of Awareness regarding E-waste management.
b) Inadequate regulatory measures, inadequate strategies and poor implementation of law.
c) Lack of technical expertise in this area.
d) Non availability of technology for recycling of E-waste.
e) Lack of coordination among different stakeholders and ministries / departments.
f) Lack of system to regulate the import of refurbished e-waste.
g) Low attention from government on e-waste.
h) Inadequate funding available for the implementation of various provisions of Basel Convention.
i) Non availability of proper inventories of hazardous waste, particularly in E-waste.
j) No research and development work in this area so far.
k) Non availability of guidelines for recycling and disposal of E-waste.
l) Inadequate public awareness about the toxicity of chemicals in E-waste and their health impacts.
m) Unskilled workers/technicians for handling of E-waste.
n) Lack of proper system for inventory of imported and local E-waste.
o) No mechanism for developing centralized E-waste recycling facility.

10.3 Packaging Waste

Packaging is defined as: “all products made of any materials of any nature to be used for the containment, protection, handling, delivery and preservation of goods from the producer to the user or consumer".

Packaging wastes are produced by people who, in the course of business, sell or otherwise supply packaging material, packaging or packed products (e.g. shops, supermarkets, retailers, manufacturers, importers, fast food outlets etc.). Packaging waste is highly visible to consumers – it's what's left over when a product has been used and provokes strong reactions. In a developed country like UK, it makes up around 20% of domestic waste and around 6% of total waste by weight [31].

10.3.1 Packaging Materials

Most packaging is made from paper, board, plastic, glass, steel, aluminum or a combination of these materials. Wood packaging and packaging made from other materials (for example hessian, jute, cork, and ceramics) are also included. New bio-plastics are beginning to be used but are currently a very small proportion of the total.

During the selection of packaging material, the packaging designers consider many factors including flexibility or rigidity, transparency, barrier properties, delivery, recyclability and cost. The choice depends on the product, how it will be stored, how it will be dispensed, whether it will be heated or cooled, how it will be transported, displayed in shops, used by consumers and disposed.

10.3.2 Packaging Types

- 'Primary' or 'Sales' packaging is packaging which forms a sales unit for the user or final consumer, for example, a box containing soap powder
- 'Secondary' or 'Grouped' packaging is that which contains a number of sales units, for example, a cardboard outer containing a number of boxes of soap powder.
- 'Tertiary' or 'Transport' packaging is packaging that is used to group secondary packaging together to aid handling and transportation and prevent damage to the products, for example, the pallet and shrink wrap used to transport a number of cardboard outers containing boxes of soap powder.

10.3.3 Consideration while designing Packaging

Packaging waste may be effectively handled, if following considerations are kept in mind while making packaging for a product:

- Keep volume and weight of packaging to a minimum that is required for the safety of the product.
- Avoid using noxious and hazardous material.
- Recyclable material may be used as far as possible for packaging.
- Currently, most of the plastic bags are made of non-biodegradable material. They persist in nature once disposed. A new biodegradable material has been introduced but few manufacturers are aware of and are using it. These bags once disposed slowly biodegrade.
- Effort should be made to use such packaging material that can be used several times. Once it has been reused, it must meet the requirements for recycling, energy recovery or composting.

10.4 Slaughterhouse Waste

A slaughter house is a facility where animals are processed into meat foods. It acts as the starting point of the meat industry, where stock comes from farms/market to enter the food chain [32]. Billions of animals are slaughtered every year. In Pakistan there is no proper mechanized system for the slaughtering or its waste management [33].

10.4.1 Source and Types of Waste

Sources of solid wastes generated at slaughterhouse facility include:

- Animal holding areas;
- Slaughterhouse and processing areas;
- Waste treatment plant; and
- Unwanted hide or skins, feathers and pieces, and unwanted carcasses and carcass parts.

Manure is generated in animal holding areas. Materials not suitable for rendering, such as unwanted carcasses, come from the processing areas, along with paper, cardboard and plastics. The types of waste produced by the separate operations are shown as under:

Source	Waste
Stockyard	Manure
Killing floor	Blood
Dehairing	Hair and dirt
Insides removal paunch	Manure and liquor
Rendering stick	Liquor or press liquor
Carcass dressing	Flesh, grease, blood, manure
By-products	Grease, offal

Table 9.1: Classification of slaughterhouse over scale

Scale	Classification Details
Large Scale	More than 200 large animals i.e. Bovines per day or more than 1000 goat and sheep per day
Medium Scale	More than 50 and upto 200 large animals or more than 300 upto 1000 goat and sheep/day.
Small Scale	Less than 50 Bovines and 300 goat and sheep per day

At present there are no official norms for classification of slaughter houses. However, depending upon the type of animals slaughtered, the slaughter houses are classified into:

- Large animal (i.e. cattle, buffalo etc.) slaughter house
- Goat and sheep slaughter house
- Poultry slaughter house

In order to assess the variations in pollution load with respect to number of animals slaughtered. Bovines and Goat & Sheep slaughter houses are further classified into following categories:

Large scale slaughter houses are located mainly in big cities, medium slaughter houses in district/towns while the small scale slaughter houses are scattered all over the country.

10.4.2 Current Practices in Pakistan

In Pakistan slaughtering of animals is done by halal method. In this methods of slaughtering, blood collection is not done immediately on slaughtering and most of the blood goes down into municipal drains. Due to inadequate facilities at the slaughter houses and scattered illegal slaughtering of animals, a very few slaughter house collect blood. Due to lack of means and tools, de-hiding of the carcasses is done on the floor itself, which causes contamination of the meat. The hides and skins are spread on the floor of the slaughtering area. Similarly legs, bones, hooves etc. are not removed immediately from the slaughtering area. This particular process during slaughtering generates maximum amount of waste. Mostly slaughter houses throw visceral material at the community bins and wash the small intestines at their shops itself and thus create pollution problem.

10.4.3 Slaughterhouse Waste Management

Slaughterhouse waste is generally categorized into both liquid and solid nature. The liquid waste should be washed away by safe potable and constant supply of fresh water at adequate pressure throughout the premises of slaughtering. The wastewater from slaughter house is heavy in pollution and, therefore, it should not be allowed to mix with the municipal drain system without pre-treatment. The wastewater treatment system should essentially comprise of:

- Self-cleaning type screening or two stage screening (Bar type);
- Anaerobic treatment;
- Aerobic treatment; and
- Filter press for dewatering of the sludge.

A) Collection of Blood

The blood available from the slaughter houses should be collected and made use of in pharmaceutical industry. Bleeding areas should be clearly identified in the slaughter houses and blood drained should be collected immediately so that its full potential could be utilized.

B) Improved Method of Dressing

At each slaughter house adequate tools should be provided for de-hiding of the animals, hides and skins should be immediately transported out of the slaughtering area in a closed wheel-barrow or similar other devices. In no case the hides and skins should be spread on the floor of the slaughtering area for inspection. Legs, bones, hooves etc. should also be removed immediately from the slaughtering area through a spring load floor chute or closed wheel-barrow.

C) Evisceration

At slaughter houses adequate compartments for immediate separation and disposal of condemned material must be provided. The authority must take care that intestines are not punctured during evisceration to avoid contamination of carcasses.

D) Safe Disposal of Waste Products

Slaughtering of animals generates wastes consisting of non-edible offal (like lungs, large intestines, various glands, animal tissues, organs, various body parts, etc.) stomach / intestinal contents, dung, bones, etc. All these types of wastes are required to be disposed by adopting methods like rendering, controlled incineration, burial, composting, anaerobic digestion etc.

E) Odors Control

The tropical climate of our country enhances the process of degeneration of any tissue material remaining as a waste in the premises of the slaughter houses. Therefore, the slaughter house premises always give a particular stink. In order to avoid this stinking odour proper ventilation of slaughtering halls, washing of the floors with non-poisonous disinfectants; and if needed aerobic deodorants must be provided at each slaughter house.

F) Modernization of Slaughter House

The slaughter houses are normally controlled by local bodies, which should follow the standards prescribed, but due to non-existence of modernized slaughter houses, environmental pollution arising out of the slaughtering activities cannot be controlled. The local bodies must, therefore, take up modernization of slaughter houses and achieve the pollution control norms.

G) Curbing Activities of Illegal Slaughtering of Animals

The places where illegal slaughtering is taking place should be carefully identified and the illegal activity should be curbed by the local body with the help of local police to ensure that slaughtering takes place at the slaughter house only under hygienic conditions and meat eating population gets fresh and disease free meat. This will also prevent clogging of drains due to illegal dumping of animal waste into the drains. Till the activity of illegal slaughtering is not brought under control, the waste generated needs to be managed by the urban local bodies by putting community bins for collection of this waste so that the waste does not get mixed up with the domestic waste and can be disposed separately.

H) Provision of Dry Rendering Plants

In most of the cities the animals dying of natural death are carried away to outskirts of the city limits by the people who perform the job of de-hiding of the carcasses. After de-hiding these carcasses are left in open. Vultures and other animals feed on meat of these carcasses.

This entire activity is a nuisance to the aviation industry and a hazard for public health. The carcass utilization plants which are run by adopting dry rendering process should be provided at all the major towns to process the dead animal carcasses in a scientific manner. These plants should process the solid waste generated from the slaughterhouses as well as the places of illegal slaughter. The products of the rendering plants are widely used as meat meal/bone meal, etc. The slaughter house waste can also be subjected to bio-methanation as resources recovery.

10.5 Industrial Waste

It includes solid waste generated by industrial processes and manufacturing. Industrial growth has led to an increase in this type of waste. Many industrial solid wastes hold hazardous characteristics, therefore, require special attention. Industrial solid waste can be divided into different types, as discussed below.

10.5.1 Types of Industrial Solid Waste

Industrial solid waste is divided into (1) hazardous and (2) non-hazardous waste. The waste, with any one of the characteristics (i) explosive (ii) oxidizing (iii) inflammable (iv) irritant (v) harmful (vi) toxic (vii) carcinogenic (viii) corrosive (ix) infectious (x) mutagenic, is called hazardous and others as non-hazardous. Hazardous wastes pose hazard to humans or other living organisms because of their non-biodegradability and persistence in nature. On the other hand, the non-hazardous wastes are not harmful to human beings and other living organisms. Mostly, nonhazardous waste is disposed at municipal disposal facilities. In this case, the industries make arrangements for the transportation of the waste to the disposal facility and they may pay disposal charges. A few typical industrial solid wastes are discussed below.

A) Coal Ash

Coal ash is usually generated in power plants using coal for the production of electricity. In general, a 1,000 MW coal fired power plant would need 500 hectares of land for disposal of fly ash produced during 30 years' operation. It is, therefore, necessary that fly ash should be utilized wherever possible to minimize land requirements.

Figure 10.21: Fly ash from coal power plant

B) Integrated Iron & Steel Plant Slag

Slag is the waste produced in Blast Furnace (BF) and Steel Melting Shop (SMS). Currently slag is usually dumped in the surrounding areas of the steel plants making hillocks encroaching on the agricultural land. Although, the BF slag has potential for conversion into granulated slag, which is a useful raw material in cement manufacturing, however, it is yet to be practiced in Pakistan. Even the use of slag as road subgrade or land-filling is also very limited.

Figure 10.22: Slag waste from blast furnace

C) Phosphogypsum

Phosphogypsum is the waste generated from the phosphoric acid, ammonium phosphate and hydrofluoric acid plants. This is very useful as a building material. At present very little attention has been paid to its utilization in making cement, gypsum board, partition panel, ceiling tiles, artificial marble, fiber boards etc.

D) Red Mud

Red mud is generated in non-ferrous metal extraction industries like aluminum and copper. The red mud, at present, is disposed in tailing ponds for settling, which more often finds its way into the rivers, especially during monsoon. However, red mud has recently been used in the country for making corrugated sheets. Demand for such sheet should be encouraged for use. This may replace asbestos which is imported and also banned in developed countries for its hazardous effect. Attempts are also made to manufacture polymer and natural fibers composite panel doors from red mud.

E) Lime Mud

Lime mud, also known as lime sludge, is generated in pulp & paper mill. In large mills it is used for reclamation of calcium oxide. However, small mills discard it as waste. The lime mud is usually disposed into low-lying areas or into water courses. It creates serious pollution problem in water bodies.

F) Waste Sludge and Residues

Treatment of industrial effluents results in generation of waste sludge/residues. It may contain heavy metals and other toxic elements. If not properly disposed, it may cause ground and surface water pollution.

Figure 10.23: Sludge from wastewater treatment plants

10.5.2 Industrial Waste Management

Different kinds of industrial processes and product manufacturing units generated solid waste of different physical and chemical characteristics. Therefore, the collection, transportation and disposal of huge quantities of solid waste must be undertaken in the comprehensive waste management plan to deal with this diversified waste. For developing a well-planned waste management strategy, a complete and detailed knowledge of waste generation characteristics for that particular industrial area are mandatory. However, practically, it is very difficult to manage all kinds of generated waste by industry or waste management authorities and thus generally is limited to only the management of nonhazardous waste. Therefore, at first the understanding of different kinds or types of industrial solid waste is essential for developing integrated industrial waste management approaches.

As far as the hazardous waste is concerned, the management is critical for industrial unit under privatized solid waste management system. For segregation of hazardous and non-hazardous waste, there must be an alternate disposal or treatment methods for both these types of waste. In case of no other alternative disposal or treatment method available, it is likely the failure of whole segregation process that resulted in the special care for whole waste disposal facility and thus the contractor operating this facility needs to give special consideration. The health and safety procedures may also be affected because of the inherent dangers associated with hazardous waste forms.

The problems relating to disposal of non-hazardous industrial solid waste are generally associated with lack of infrastructure facilities and negligence of industries to take proper safeguards. The large and medium industries located in identified industrial areas still have some arrangements to dispose solid waste. However, the problem persists with small scale industries. In number of cities and towns, small scale industries find it easy to dispose waste here and there and it makes difficult for local bodies to collect such waste though it is not their responsibility. In some cities, industries are located in the residential and commercial areas. Thus industrial waste gets mixed with municipal waste. Therefore, it is necessary that the private and public (government) sector collaborate to work out requisite strategy for organizing proper collection and disposal of industrial solid waste.

The assessment of industrial solid waste management problem greatly varies depending on the nature of the industry, their location and mode of disposal of waste. Further, for arriving at an appropriate solution for better management of industrial solid waste, assessment of nature of waste generated is also essential.

Industries are required to collect and dispose their waste at specific disposal sites and as such collection, treatment and disposal is the responsibility of the public sector organization. The following problems are generally encountered in cities and towns while dealing with industrial solid waste:

- There are no specific disposal sites where industries can dispose their waste
- Industries are located in residential areas and as a result they cause water and air pollution problems besides disposal of solid waste, and
- Industrial estates located in city limits do not have adequate facilities for collection and disposal of their waste.

EXERCISES

1. Write a short note on types and sources of healthcare/hospital wastes
2. Delineate the steps involved in proper healthcare/hospital waste storage and collection practices.
3. Draw a comparison between incineration and autoclaving as the two healthcare/hospital waste treatment options.
4. What are the types of disposal options for healthcare/hospital waste?
5. Try to find out a place in your city where slaughtering of animals is taking place. Evaluate it in the light of guidelines given in this chapter
6. Make a survey of the E-waste in your city.

7. Visit an industry to see how it is handling its solid waste.

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containers and (3) suburban areas comprising of new residential developments and villages falling within sub urban limits. Different collection systems are required in these areas.

1.4 Proposed Solid Waste Management System for Model City

1.4.1 General

Storage, collection, transfer and transport, recycling and reuse, processing and disposal are the cardinal features of a solid waste management system. Community participation and private sector involvement are also to be given due importance. All these features are addressed in the following sections with reference to the proposed system for Model City.

The storage and collection of solid wastes in Model City is planned to be split in two stages i.e., primary and secondary. In the primary stage, collection will be from the individual premises and the wastes collected from there will be transferred to the communal storage containers on the streets.

In the secondary stage, communal storage containers will be served by motor vehicles and the wastes shifted to the transfer stations or directly to the disposal site. Arrangements for each stage are delineated in the following sections. These arrangements are also presented in the flow sheet in Table 1.8. As resource recovery is mostly being taken care at source and storage locations, direct discharge type transfer stations will be used instead of storage discharge type. Use of transfer stations reduces the cost of transportation.

Finally disposal will be done. Different options are considered, and most suitable one recommended for each step.

1.4.2 Storage and Collection

Storage and collection may be split into two stages. (i) primary storage and collection and (ii) secondary storage and collection. The details of each stage are as follows:

1.4.3 Primary Storage and Collection of Solid Wastes

House to house/shop to shop collection is proposed to be introduced in whole of the city except for the premises who will take the responsibility to shift the wastes on their own to the communal containers (secondary storage) on the road sides. Primary storage at the individual premises is proposed to remain in the makeshift type containers (canisters, baskets, plastic bags etc). Different options to be considered for primary collection include:

(i) Manual collection (ii) Use of hand Carts (iii) Use of Donkey Carts (iv) Use of Auto Triwheelers.

All these options will be employed simultaneously according to requirement.

a) Manual Collection (Option-I)

Manual collection will be effective in many situations, where the inhabitants will shift the wastes to the communal containers themselves or through their servants.

b) Use of Hand Carts (Option-ii)

A hand cart (normally called wheelie bin) with a minimum capacity of 200 litre (Fig. 1.3) will be used for door to door collection by each sanitary worker. The proposed handcart is also of pulling type and ergonomics of the human body make pulling action easier than pushing. The sanitary worker performing the job will ring a hand bell at fixed intervals at approximately fixed timings in each area. The occupants will put out/hand over their wastes/ bins to the collector. He will shift the

Table 1.8: Proposed solid waste management system for model city

Areas	Storage at the Premises	Primary Collection			Secondary Collection		Transfer and Transport		Disposal
		Collection from Premises	Storage on Street Sides	Collection from Streets	Communal Storage	Collection Vehicle	Transfer Container	Transfer Vehicle	
Narrow Street Area	Make shift containers	Manually			7 m3 Container	Arm roll/ Hoist Truck	20 m3 Container	Arm-roll Vehicle	Sanitary landfill/ composting plant -do-
		Hand carts / Auto triwheelers			7 m3 Container	-do-			
	Street weeping Nullah cleaning		Street side heaps	Donkey Carts Auto triwheelers	7m3 Container	-do-		-do-	-do-
Wide Street Area	Make Shift containers	Manual			7m3	-do-	-do-	-do-	-do-
		Hand Carts/ Auto triwheelers			-do-	-do-	-do-	-do-	-do-
	Street Sweeping	Manual	Street side heaps	carts/ auto triwheelers	-do-	-do-	-do-	-do-	-do-
		Mechanical			-do-	-do-	-do-	-do-	-do-

wastes to the communal container on the main road side. The sanitary worker will also be responsible for sweeping the streets and cleaning the open drains of the area exclusively assigned to him. Each sanitary worker is expected to serve on an average 100 houses or 150 shops. No one is to be allowed to throw the wastes open in the streets.

c) Use of Auto-Tri-Wheelers Suzuki Pickup (Option-iii)

In case of areas where the distance to reach the communal container increases beyond the capacity of hand cart, auto-rickshaw dumpers/ Suzuki pickups (Fig. 1.4 (a) and 1.4 [b]) are supposed to replace them in the long run, as the hand carts are slow moving . Such auto-rickshaw dumpers have been developed in Lahore and use of Suzuki dumpers are already in use in CDG Model City.

73 auto-rickshaw dumpers are included at the start of the project. These are with manual loading and mechanical unloading arrangements.

d) Use of Suzuki Mounted Dumper (Option-iv)

Some local manufacturer of SWM vehicles like Kissan Engineering (10-Km Multan Road, Phone: 37512165) and Colibrative Heavy Industries (Chowk Al-Saeed, Sagian Bypass Road, Kot Abdul Malik, Shahdra) have recently introduced 1 m^3 container mounted on Suzuki pick up. It can easily collect waste from narrow streets where bigger vehicle cannot be used (Fig. 1.4(b)). Waste is manually dumped into the dumper. After dumper is filled, it can be mechanically unloaded.

1.4.4 Secondary Storage and Collection

Three options are considered under this heading. Their details are as under:

a) Option – 1 (Storage in 5 m^3 Containers, Collection by Arm-Roll Vehicle

The communal containers will be provided with a size of 5 m^3 as in Lahore. These containers, when filled with waste, will be lifted by arm-roll vehicles as shown in Fig. 1.5; emptied at the transfer station or disposal site and the containers re-deposited at their original places.

Figure 1.4 (a): Locally manufactured Auto Tri-Wheeler with manual loading and mechanical unloading arrangements

Figure 1.3: Proposed hand cart (Wheelie Bin) and its unloading in communal container

Compactor truck, 6 m^3 capacity used by LWMC

Mechanical sweeper 4 m^3 capacity

Dumper for construction and demolition waste

Suzuki pick up mounted 1 m^3 dumper
(manual loading and mechanical unloading)

Figure 1.4(b): Some locally manufactured vehicles for Solid Waste proposed for model city

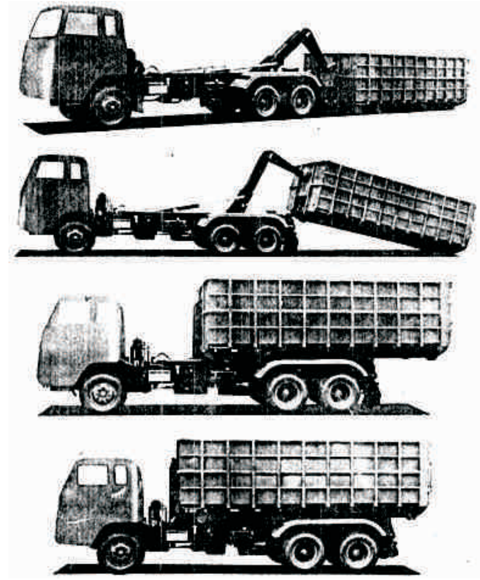


Figure 1.5: 5m^3 Container and arm-roll vehicle

b) Option – 2 (Storage in 5m^3 Containers, Collection by Tractor Container-Carrier)

The 5 m^3 containers as shown in Fig. 1.6, when loaded with waste will be taken up by tractor container carrier system to transfer station or disposal site, and emptied there. Empty containers are brought back to original position.

c) Option – 3 (Storage in 7 m^3 Containers, Collection by Hoist Truck)

The 7 m^3 containers (Fig. 1.7) may be used. When it is filled with waste Hoist Truck may be used to lift and take it to the point of final disposal and the container is emptied there.

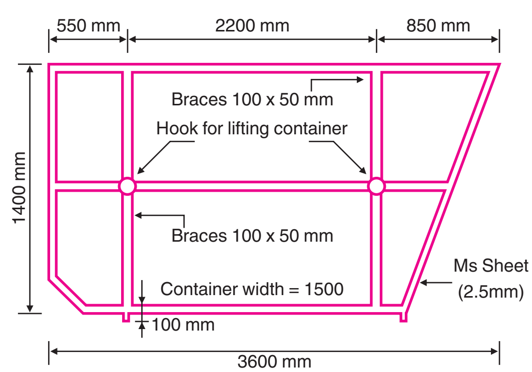


Figure 1.6: 7 m^3 Container

Figure 1.7: Hoist truck with 7 m^3 container loaded on it

1.4.5 Vehicles and Equipment Requirement for Different Options

As technological advances and social and cultural changes may require more appropriate technology in the later part of the planning horizon (2014 - 2028), the requirements of vehicles and equipment have been worked out only for a period of 5 years starting from 2009 up to year 2013. Future vehicle requirement, from 2013 onwards, can be worked out on similar grounds. Population distribution of Model City in different areas of the city, i.e. narrow street area, wide street area and sub urban area is given in Table 1.9. This distribution has been used to calculate the physical requirements in these areas.

Table 1.9: Population distribution of model city in different areas (for design year of 2013)

Area type	Population (2013)
Narrow street	618,403
Wide street	998,594
Sub urban	354,950
Total	1,971,947

Requirements for Primary Storage and Collection Options

For primary storage makeshift type containers will be used. The owners of the premises are responsible to provide and maintain them. For primary collection, all the options discussed above, will be simultaneously employed in different areas.

Table 1.10 gives a summary of the type of equipment needed for primary storage and collection. It can be seen in the table that hand carts, litter bins, water sprinklers, mechanical sweeper, motor cycles and auto rickshaw dumper are proposed for primary storage and collection. The total number of each equipment required to cater for the population of 2013 has also been shown. In addition capital cost and annualized cost is also exhibited in the table. (For detailed calculations please see Appendix-1.1).

Table 1.10 shows that 200 litter bins will be provided on street sides for use of pedestrians. Provision of only 200 litter bins is just introducing the concept on pilot scale. With adoption of the concept, thousands of such litter bins may be added through motivation of private sector, making them as an instrument for their advertisement. Four water sprinklers will be used to keep the dust down and 6 mechanical sweepers employed to clean city roads. The requirement of mechanical sweepers is worked out in Appendix 1.6. Please note that only summary tables are shown in the main chapter, while detailed calculations are attached at the end of chapter in the form of additional Appendices. The capital cost shown in Table 1.10 is that of year 2010. The capital cost is one time cost incurred at the time of purchase while the annualized cost is the sum of (1) depreciation cost per year; (2) establishment charges; (3) POL(petrol, oil, lubricants) cost and (4) maintenance and repair charges (see Appendix 1.5 for details). All prices are of 2010.

Requirements for Secondary Storage and Collection Options

Table 1.11 shows the summary of requirements of vehicles, their cost and annualized cost for secondary storage and collection according to the three options discussed in section 1.4.4.

Table 1.10: Summary of requirements and cost for primary storage and collection for different options for year 2013 (Year 2010 prices)

Vehicles/ Equipment	Number[1] Required	Capital Cost (Rs.)		Annualized Cost (Rs.)	
		Unit[2]	Total	Unit[2]	Total
Hand carts	1094	11,000	12,034,000	4,000	4,376,000
Litter Bins	200	700	140,000	300	60,000
Water Sprinklers	4	2,250,000	9,000,000	1,101,000	4,404,000
Mechanical Sweepers	6	2,800,000	16,800,000	1,069,000	6,414,000
Motor Cycles	12	60,000	720,000	3,100	372,000
Auto-rickshaw dumper	73	300,000	21,900,000	225,000	16,425,000
TOTAL:			60,594,000		3,250,000

[1]From Appendix-1.1 and 1.6; [2]From Appendix-1.5.

Detailed calculations are carried out in Appendix-1.2, 1.3 and 1.4. The cost for equipment as per 2010 rates has been adopted.

It can be seen in Table 1.11 that for Option-1, 69 arm-roll vehicles and 418 containers will be required. For Option-2, 70 tractors with container-carriers and 418 containers each of 5 m^3 capacity are needed. For Option-3, 270 containers of 7 m^3 capacity each, and 45 hoist trucks will be required.

Table 1.11: Secondary storage and collection for year 2013 (2010 prices)

Option	Vehicles and Containers	No. required	Capital Cost (Rs.)		Annualized Cost (Rs)	
			Unit	Total	Unit	Total
1	Arm-roll vehicles	69	2,900,000	200,100,000	1,108,000	76,452,000
	5 m^3 containers	418	160,000	66,880,000	25,000	10,450,000
	Total			**266,980,000**		**86,902,000**
2	Tractor-container carrier	70	10,500,000	73,500,000	874,000	61,180,000
	5 m^3 containers	418	160,000	66,880,000	25,000	10,450,000
	Total			**140,380,000**		**71,630,000**
3	Hoist trucks	45	2,875,000	129,375,000	1,107,000	49,815,000
	7 m^3 containers	270	170,000	45,900,000	39,000	10,530,000
	Total			**175,275,000**		**60,345,000**

1.4.6 Capital and Annual Costs for Storage and Collection Options

The capital and recurring costs are calculated for each vehicle and equipment required for different options in Appendix-1.5. According to the overall requirements upto year 2013, the total costs for (1) primary storage and collection and the (2) three options for secondary storage and collection are given in Table 1.10 and 1.11, respectively.

1.4.7 Selected Storage and Collection Options

For primary collection all the options will be employed simultaneously according to requirement. In case of secondary storage and collection as presented in Table 1.11, annualized costs of Option – 3 is lowest (Rs 60.3 million). Furthermore, it is successfully working in Model City and Peshawar and thus is easily adaptable and therefore proposed for adoption.

1.4.8 New Design of 7 m^3 Containers

The present design of 7 m^3 container does not allow its full utilization. Most of the volume remains empty due to its faulty design i.e. due to their opening on one side up to the bottom for unloading the handcarts directly in the containers. Fixed cover provided partially at the top of these containers is another reason for its low utilization. The new design as given in Fig. 1.6 is without cover and allows the waste to be loaded throughout the top. Cover will be provided by a net during transportation. Some of the tentative locations of the containers will be same as of the existing filth depots.

1.4.9 Door-to-Door Collection

With successful operation of door-to-door collection in selected areas of Model City it needs to be expanded in steps to whole of the city. This will not only decrease the littering habits, but will also be economical in the long-run and a great step towards "Clean City".

1.4.10 Street Waste Management

There is need to increase the efficiency of sweepers by providing them with suitable contrivances i.e., long handled brooms, lifting pans or synthetic sheets and hand carts. Wherever possible, mechanical sweepers should be replaced by manual sweeping. According to the local conditions, 4 mechanical sweepers are proposed which have already been provided.

Besides that, to decrease load on street sweepers, small litter bins will be provided for pedestrians' use. The owners of animal carts will be directed to provide suitable dung-containment bags at the animals' backs. Passenger vehicles owners will be directed to maintain suitable bags/containers for use by the passengers.

Four water sprinklers are also needed to keep the dust down especially on unpaved streets, which have also been provided.

The proposed street waste management system is shown in Table 1.12.

Table 1.12: Proposed street wastes management system

Source	Onsite Storage	Primary Collection	Communal Storage	Collection from Communal Storage	Disposal
Pedestrian's Walkway	Litter bins	Hand-cart	7m^3 containers	Hoist Trucks	Recycling and Composting/ Sanitary landfill
Animal Carts	Bags at the back	-	-do-	-do-	-do-
Motor Vehicles/ Vendor's Trolleys	Plastic bags/ containers	-	-do-	-do-	-do-
Manual Street Sweeping	Small heaps	Hand-cart	-do-	-do-	-do-
Mechanical Street Sweeping			7m^3 container	Hoist Truck	Composting/ Sanitary landfilling

1.4.11 Litter Bins

For pedestrians convenience 20 - 30 liters capacity litter bins shown in Fig. 1.8 should be provided at appropriate locations throughout the city. This will help in keeping the streets clean and litter free.

1.4.12 Requirements and Costs for Street Waste Management

As mentioned above, 200 litter bins need to be provided for pedestrians. Brooms and pans with hand carts will be provided to sanitary workers for manual sweeping with 6 water sprinklers, and 6 mechanical sweepers for sweeping carpeted roads as already mentioned in section 1.4.10.

1.4.13 Resource Recovery

The present practice of recovery of recyclable materials at source and through scavengers may be allowed to continue, as it decreases the loads and provides chances of reutilization of resources and creates self-employment. The resource recovery can be made more efficient by educating the public to adopt "3 Bin System" at the premises. One for putrescibles (wet waste), second for recyclable (dry waste) and third for polyethylene bags exclusively.

1.4.14 Transfer Stations

Transfer stations are needed, when the disposal sites are at long distances, and it becomes uneconomical for the individual collection vehicles to take waste up to the disposal site. There are two disposal sites in Model City. Two transfer stations are proposed in Model City, one for each disposal site. Keeping in view the road conditions, the size of the transfer container is kept as 20 m^3 and arm roll type vehicles will be used to carry the containers to disposal sites. Tentative design along with cost estimation is presented in (Appendix-1.7).

1.4.15 Vehicles and Equipment Requirements & Costs for Transfer Stations

The summary of equipment requirements and cost for the transfer stations is summarized in Table 1.13. While detailed calculations are presented in Appendix-1.7. Two transfer stations are required. In total 12 arm-roll vehicles and 12 containers each of $20m^3$ will be required for two transfer stations. The capital cost is estimated to be Rs. 127,520,000 and the annualized cost will be approx. Rs. 27,079,200 as per details in Appendix-1.5.

1.4.16 Location of Transfer Stations

Strategic locations may be selected in different parts of the city for building transfer stations.

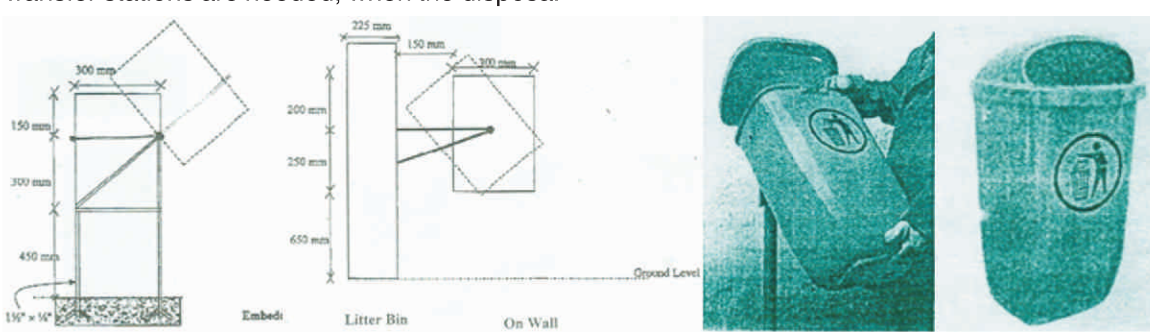


Figure 1.8: Road side litter bins

Note:

Left: Drawing of litter bin. It is installed on a pedestal and bin is attached to it with a hinged arrangement. This facilitate turning of bin in order to empty it.

Right: Actual bin, which is installed on a pole and a person is turning it for removing waste from it.

Table 1.13: Vehicles & equipment requirements & costs for two transfer stations (year 2010 prices)

Sr. No.	Vehicles/ Equipment	No.	Capital Cost Rs.		Annualized Cost Rs.	
			Per Unit	Total	Per Unit	Total
	Transport Vehicles (Arm-roll)	12	9,500,000	114,000,000	2,037,000	24,444,000
	Transfer Containers 20m^3	12	460,000	5,520,000	119,600	1,435,200
	Transfer Stations Structure	2	4,000,000	8,000,000	600,000	1,200,000
			TOTAL:	127,520,000		27,079,200

1.4.17 Mandatory Provision in New Colonies

It is to be made mandatory that proper arrangements should be made in newly developing residential colonies and commercial and industrial establishments with respect to provision of locations for storage containers and transfer stations.

1.4.18 Disposal

There are four alternatives to deal with the disposal of solid wastes in Model City.

1. Compositing
2. Incineration
3. Sanitary land filling.
4. Conversion of Waste to Energy

Sanitary land filling is the cheapest alternative if sufficient land is available at reasonable distance and cost as well. This is used almost in 80% of the cases throughout the modern world. A suitable site named A is available at appropriate distance along main road. The work has already been started on this site while the acquisition of land at site B has not been accomplished. Collectively, both the above sites will meet the demand up to year 2025. After year 2025, more land is to be acquired.

Composting is another viable alternative which provides recycling of the putrescible content. But costs of a modern plant are prohibitively high under local conditions. Windrow composting may be tried on pilot scale if non-putrescible waste can be segregated easily. It will be more useful when sewage can be added by placing the composting plant near sewage disposal stations no suitable land is available. Under the new plan the newly selected sanitary landfill sites will also be used for establishing semi-mechanized composting plants.

Incineration is an extremely expensive alternative. The calorific value of local solid wastes is very low to make the combustion process self-sustainable. This option is only feasible for medical waste disposal. An incinerator has been provided in National hospital for the purpose. But it has not been properly utilized. An expert's services are to be acquired to solve the problem.

Conversion of Waste to Energy is also feasible in those situations when the solid wastes can be burnt without addition of auxiliary fuel. Negotiations are in process with a Chinese firm by the Govt. of Punjab to start the project in Model City.

1.4.19 Selected Disposal Option and Physical Requirements

Sanitary land filling along with composting will be the most suitable method for Model City and is therefore recommended to be used.

On the basis of physical composition it is estimated that 60% of the waste including putrescibles (44%) and some non-putrescible fines (16%) as per Table 11.3 will be composted, 30% land filled and 10% recycled. Accordingly total amount of solid waste reaching the landfill sites have been estimated in Table 1.7 to be 1,667,884 m^3 for the year 2028.

Using an average density of 1.2 tons/ m^3, and average depth of 4.6 meters, 1,667,884 m^3 of waste will require an area of 97 acres for landfilling.

$$\text{Area} = \frac{1,667,884}{4.6 \times 10,000} \times 2.7 = 97 \text{ Acre}$$

[Note: 10,000 m^2=1 Hectare; 1 Hectare=2.7 acre**]**

1.4.20 Proposed Sites for Sanitary Landfills and Composting.

Landfill site, usually selected, should be away from main city at a reasonable distance.

1.4.21 Reduction of Land fill area Requirements.

As the solid wastes of the city contain almost 44% putrescible content, if regular composting process is not applied, sanitary land-filling operation may be performed semi-aerobically which will also produce compost by natural decomposition over a longer period, say two to three years. Farmers being conversant with the use of manure can use it as land conditioner. Alternately, it can be used as cover material for sanitary land fill operation. In this way the available sites for sanitary landfills will be used for longer period and there will be no need for additional land for the plan period.

1.4.22 Typical Design of a Sanitary Landfill

a) Access

Paved all-weather access road will be constructed from the main road to the sanitary landfill site, so that the site remains approachable even in the rainy season.

b) Landfill Method

In Model City manmade depressions due to excavation of soil for bricks will be used for sanitary landfills. In the case of manmade depressions, the method of landfilling is called excavated cell or trench method.

c) Layout Plan

A simple layout plan is given in fig. 8.20. This shows the filling plan in equal width strips, area allocated for rainy season; brick paved access road, provision of weighing scale and shelter for the guard and tractor with front-end loader, site for stockpiled soil for covering the landfill.

d) Width of the Strip and cell Dimension

To ensure the orderly progress of filling and covering, each layer should be constructed from a number of side-by-side strips. The width of the strips depends upon the number of trucks unloading simultaneously at the working face. This width and cell dimension will be calculated as per procedure given in section 8.7.2.

e) Landfill Cover

The depth of the landfill adopted is 4.4 m. It is expected that the solid waste coming to the landfill site in one day will be reaching about 4 m depth. Therefore, after each day's work, only the final cover over the landfill will be provided. The final cover provided will consist of two layers; one of clay having 30 cm thickness and on its top will be soil layer of 30 cm thickness. Thus the total depth will become 4.6 m (4+0.3+0.3=4.6m). When the cover is provided with a mild slope of 2-3%, it will help to avoid seepage of any surface runoff into the landfill and will support vegetation.

f) Drainage

Drains will be provided on the four sides of the sanitary landfill to take care of the surface runoff during the rainy season.

g) Leachate Control/Groundwater Protection

Water table depth in the landfill sites in Model City ranges between 6 – 15 meters. And the strata from the ground level to water table depth include clay, silt, sandy silt and silty sand etc., which are fairly impermeable. With a total depth of sanitary landfill up to 4.6 meters, there is no possibility of groundwater pollution.

Dry weather conditions prevailing over most parts of the year and good arrangement for drainage of surface runoff will further ensure this aspect.

h) Gas Management

Production of biogas is also an outcome of biological decomposition of organic matter under anaerobic conditions prevailing in the sanitary landfills. But this also requires moisture content. Due to dry weather prevailing over most parts of the year, moisture content in the landfill will not be sufficient to cause sufficient gas production which requires collection and disposal.

i) Rainy Season Arrangements

During the rains the collection vehicles cannot reach the normal landfilling area. There needs to be allocated some area near the paved access road. Such area to the tune of 4000 m^2 has been allocated near the access road as shown in layout plan (Fig. 8.20).

j) Ultimate Use

After completion landfill site will be mostly used as grazing land, or for cultivation of crops. It may also be used as a park or playground or area for windrow composting.

1.4.23 Vehicles, Equipment and Land Requirements for Landfill

Two chain bulldozer and two large size tractors with bucket loader are required to compact, level and cover the sanitary landfill, for operation at two different sites at a time. In total 82 acres of land (appendix-1.3) will be required up to year 2028.

1.4.24 Vehicles, equipment and infrastructure cost for landfill

The capital and annual costs for landfills has been calculated for each vehicle and equipment required up to year 2013 and infrastructure up to

Table 1.14 (a): Capital costs for sanitary land fill (year 2010 prices)

Sr. No.	Particulars	Unit Cost	Number	Cost Rs.
1	Chain Bulldozers	15,000,000	2	30,000,000
2	Tractor with front end loader	1,730,000	2	3,460,000
3	Infrastructure*	40,000,000	2	80,000,000
TOTAL:				113,460,000

* Details at Appendix-1.4, 1.5

Table 1.14 (b): Annual sanitary landfill costs* (year 2010 prices)

Sr. No.	Vehicle/ Equipment Staff	No.	O&M Cost*		Depreciation Cost		Total Annual Cost*
			Per Unit	Total	Per Unit	Total	
1	Chain Bulldozer	2	1,734,000	3,468,000	1,000,000	2,000,000	5,468,000
2	Tractors with front end loader	2	588,000	1,176,000	1166,000	232,000	1,408,000
3	Infrastructure	2	1,200,000	2,400,000	800,000	1,600,000	4,000,000
TOTAL:				7,044,000		3,832,000	10,876,000

year 2028. The capital and annual costs are given in Table 1.14 (a,b).

* Details calculation of O&M cost and Annual/annualized cost for Chain Bulldozer and Tractor with front end loader are shown in Appendix-1.5. While for Infrastructure O&M and depreciation see Appendix-1.8 .

1.4.25 Handling of Special Wastes

Wastes like human excreta, animal dung, hospital wastes, slaughter house wastes, dead animals, demolition and construction wastes, and polythene bags are to be treated as special wastes and need special attention from the solid wastes managers.

Human Excreta

Past experience shows that a very minor part of this waste is being mixed with other municipal wastes. Such waste can be taken care of easily, if collection is performed efficiently on daily basis. So no separate arrangements are proposed for this waste.

Animal Dung

Animals walking on city roads foul them badly. Their existence in the cities should be phased out by shifting milch cattle to lots in the suburbs and replacing the animal driven carts by motor vehicles. Attaching of bags at the back of animals should be made compulsory till the complete phase out process.

Hospital Waste Management

Nishtar Hospital is the largest hospital in the city 1100 bed capacity. There are two other government hospitals and around 70 private clinics and small hospitals.

Proper hospital waste management practices require segregation of infectious and non-infectious components at source. Then infectious component needs to be transported to a central facility, which may be an incinerator or autoclave. After processing in an autoclave, residues can be disposed off along with municipal wastes in the sanitary landfill.

Slaughter House Wastes

Special arrangements are to be made to shift such wastes to the sanitary landfills efficiently.

Dead Animals

Sanitary way of disposal of dead animals is through incineration. Burial is the other alternative. Those can also be incinerated but the cost is very high. Burial is, therefore, recommended in a specific area of the sanitary landfills.

Demolition and Construction Wastes

Storage and collection of such waste should not be the responsibility of the CDG. Generators of these wastes should make their own arrangements for transportation to disposal sites or recycling facilities. To facilitate the process, private firms may be encouraged through advertisements in the media to maintain vehicles and skips for hiring by the people generating such type of wastes.

Industrial Wastes

A large number of power looms and a number of tanneries are located within the city. Besides that, linear industrial clusters along inter-city roads are another common phenomenon in Model City. Most of the wastes from these industries are recycled except a minor portion mixed with normal city wastes.

Model City Industrial Estate, located in south western direction of urban area, accommodates various medium and heavy industries. The Estate is responsible for its own waste management. The total quantity of wastes from this industrial estate is negligible when compared to the waste generated by the entire city.

Polyethylene Bags

For getting rid of littered polyethylene shopping bags from the roads and streets, the inhabitants may be educated to dispose them in the form of tight bundles and place them into containers for final disposal. At the moment, the CDG should depute some sweepers for the specific purpose of collecting these shopping bags, put them in tight bundles and place them in the communal containers for final disposal. Extensive use of these bags should be discouraged through legislation and its enforcement. Polyethylene bags may be replaced with degradable bags if found suitable.

1.4.26 Workshop

With induction of new vehicles and equipment it is necessary, that a good maintenance workshop should be established to take care of the system. The City Distt. Government Model City is already aware of the challenge and has taken up the task of establishing a new workshop in the area of Latifabad. Besides that a mobile workshop is also being purchased under Prime Minister's Package.

1.4.27 Staff Requirements and Costs (2010 Prices)

The staff requirements for Executive District Officer (EDO) and District Officer (DO) Offices, the primary and secondary collection, workshop, transfer station and sanitary landfills for the year 2013 have been worked out separately. Table 1.15 summarizes these requirements along with annual expenditure on salaries. Detailed working is shown in Appendix-1.9. The Appendix also lays down the pre requisites and job descriptions for the staff.

Table 1.15: Proposed staff and cost estimate (2010 prices) for year 2013

Sr. No.	Vacancy	Number	Grade	Monthly Pay (Rs)	Total Annual Cost (Rs.)
EDO Office					
1	Executive Distt. Officer SWM	1	19	70,000/-	840,000/-
2	P.A. to E.D.O	1	12	18,000/-	216,000/-
3	Distt. Officer SWM	1	18	35,000/-	420,000/-
4	P.A. to D.O.	1	5	11,000/-	132,000/-
5	D.D.O. (Planning & Enforcement)	1	17	30,000/-	360,000/-
6	D.D.Os (Sanitation)	2	17	30,000/-	720,000/-
7	D.D.O. (W/S, Transp)	1	17	30,000/-	360,000/-
8	D.D.O (Landfill, T.S's)	1	17	30,000/-	360,000/-
9	Office Superintendent	1	16	25,000/-	300,000/-
10	Senior Clerks	2	9	14,000/-	360,000/-
11	Junior Clerks	4	7	12,000/-	576,000/-
12	Drivers	6	8	13,000/-	936,000/-
13	Naib Qasids	6	2	10,000/-	720,000/-
Primary Collection /Sanitation Section					
14	Sanitation Officers	4	16	30,000/-	1,440,000/-
15	Asstt. Sanitation Officers	8	11	22,000/-	2,112,000/-
16	Sanitary Inspectors	16	10	13,000/-	2,496,000/-
17	Sanitary Supervisors	75	5	12,000/-	10,800,000/-
18	Sanitary Workers	1620	2	10,000/-	194,400,000/-
19	Telephone Attendant	1	5	10,000/-	120,000/-

Workshop Section					
20	Sub Engineer	1	11	22,000/-	264,000/-
21	Head Mechanic/ Foreman	1	11	22,000/-	264,000/-
22	Skilled Workers/ Mechanics	10	5	12,000/-	1,440,000/-
23	Helpers	14	2	10,000/-	1,680,000/-
24	Chowkidars	1	2	10,000/-	120,000/-
Secondary Collection/ Transport Section					
25	Transport Officers	1	17	35,000/-	420,000/-
26	Juniors clerks	2	7	12,000/-	288,000/-
27	Supervisors	2	5	12,000/-	288,000/-
28	Drivers	30	8	13,000/-	Included in Vehicles
29	Cleaners	30	2	10,000/-	annualized cost
30	Naib Qasids	1	2	10,000/-	120,000/-
31	Chowkidars	2	2	10,000/-	240,000/-
Transfer Station Staff					
32	Drivers	8	8	13,000/-	Included in Vehicles
33	Helpers	8	2	10,000/-	annualized cost
34	Sanitary Inspectors	2	10	14,000/-	336,000/-
35	Sanitary Workers	2	2	10,000/-	240,000/-
36	Chowkidars	2	2	10,000/-	240,000/-
Sanitary Landfill Staff					
37	Sanitary Inspectors	2	10	14,000/-	336,000/-
38	Bulldozer Drivers	2	8	14,000/-	Included in Vehicles
39	Tractor Drivers	2	8	13,000/-	annualized cost
40	Helpers	4	2	10,000/-	-do-
41	Labourers	4	2	10,000/-	480,000/-
	Total	**1861**			**224,472,000/-**

Table 1.16 shows a comparison of the proposed staff with the existing staff. From the comparison it is evident sufficient staff is already present in CDG and only 28 new staff members will have to be hired to implement the proposed system up to year 2013. No doubt, additional recruitment will be required after 2013 to run the system. Furthermore, the present staff also needs to be trained to meet the challenges of a mechanized system.

Table 1.16: Comparison of proposed and present SWM staff and additional staff required upto 2013

Sr. No.	Position	Required No.	Existing No.	Additional Requirement
EDO and DO Offices				
1	EDO	1	1	-
2	PA TO EDO	1	1	-
3	D.O. SWM	1	1	-
4	PA TO DO	1	1	-
5	DDO (Planning & Enforcement)	1	-	1
6	DDO (Sanitation)	2	-	2
7	DDO (W/S, Transap.)	1	-	1
8	DDO (Landfill, T.S.)	1	-	1
9	Office Superintendent	1	1	-

Sr. No.	Position	Required No.	Existing No.	Additional Requirement
EDO and DO Offices				
10	Senior Clerk	1	1	-
11	Junior Clerk	4	4	-
12	Drivers	6	3	1
13	Naib Qasids	6	2	-
Primary Collection				
14	Sanitation Officer	4	1	3
15	Asstt. Sanitation Officer	4	4	-
16	Sanitary Inspectors	18	16	2
17	Sanitary Supervisor	65	73	(-8)
18	Sanitary Workers	1620	1574	46
19	Telephone Attendant	1	1	-
20	Sanitation Suptd.	-	1	(-1)
21	Naib Qasid	-	8	(-8)
Workshop				
22	Sub-Engineer	4	1	3
23	Head Mechanic	1	1	-
24	Skilled Workers	10	10	-
25	Helpers	14	14	-
26	Chowkidar	1	1	-
27	Service Men	2	2	-
Secondary Collection				
28	Transport Officer	1	1	-
29	Junior Clerks	2	2	-
30	Supervisors	2	-	2
31	Drivers	30	43	(-13)
32	Cleaners	30	2	28
33	Naib Qasid	1	1	-
34	Chowkidars	2	2	-
35	Baildars	-	65	(-65)
Transfer Station				
36	Sanitary Inspector	2	-	2
37	Drivers	8	-	8
38	Helpers	8	-	8
39	Sanitary Workers	2	-	2
40	Chowkidars	2	-	2
Sanitary Landfill				
41	Sanitary Inspector	2	-	2
42	Bulldozer Drivers	2	-	2
43	Tractor Drivers	2	-	2
44	Helpers	4	-	4
45	Labourers	4	-	4
	Total:	**1866**	**1836**	**30**

1.4.28 Organization

A good organizational structure with clear job descriptions and professional training is the backbone of any successful system. For the system to be most efficient, all the services like solid waste storage, collection, street cleansing, transfer operation and disposal should be performed by one department and the above components should not be assigned to different agencies. The management should be able:

i) To provide services to all levels and sections of the city to an acceptable standard.

ii) To provide continued planning of the system and to ensure continued service with the changing of the urban set up.

iii) To ensure that adequate financial means are available, not only to provide, but also to maintain, renew and if necessary expand the facility.

This requires the creation of a planning cell within the organization. The officials in this cell will not be involved in the operational activities. Rather their job will be to plan and manage finances for the smooth operation of services, introduction of new technologies/equipments for the better efficiency of the SWM system. The organizational structure proposed in this regard is presented in Fig. 1.9 and satisfies the above criteria.

1.4.29 Staff Training

Regular, on the job training facilities need to be provided to keep the staff abreast with the new requirements.

1.4.30 Short Term and Long Term Plans

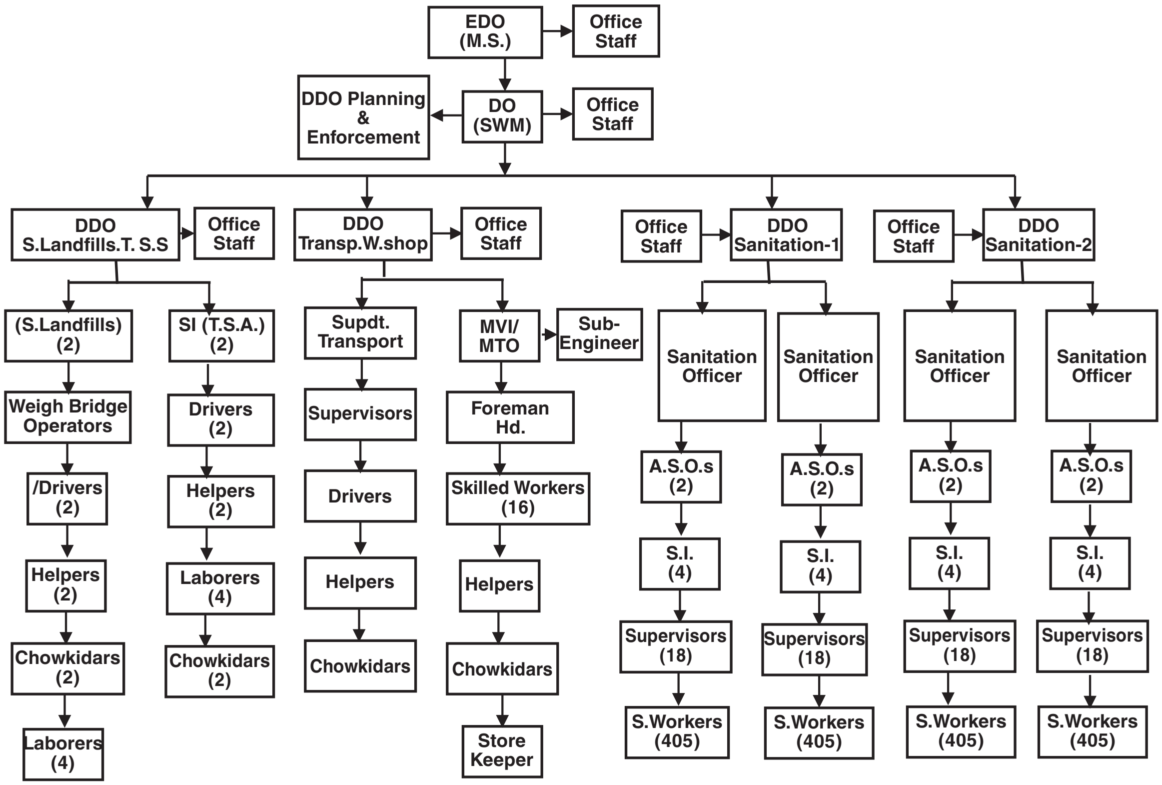
With 20 years as the planning period, physical requirement in terms of land, staff, vehicles, equipment, training and technical assistance need to be worked out giving due consideration to the future trends, and their costs are to be worked out. The whole project period also needs to be divided into short term and long term plans. The short term plan extends from 2008 to 2013 while long term plan extends from 2104-2028.

- **Short Term Plan and Cost Estimates**

As the technological advances and social and cultural changes may require different/new measures for storage and collection of solid wastes in later part of the project period (2014-2028) the requirements of vehicles and equipment have been only worked out for short term plan i.e for 2008-2013. The infrastructure requirements for transfer stations and sanitary landfills are included both in short term and long term plans. The overall requirements for short term plan (2008-2013) and their costs are summarized in Table 1.17.

It can be seen in Table 1.17 that total equipment requirements are calculated first, then in the next column the detail of existing equipment is shown. The next column shows the additional equipment requirement, which is obtained by subtracting the total equipment requirement from the existing equipment. The subsequent column shows the cost of additional equipment.

The capital cost for additional requirements, from Table 1.17, comes out to be Rs. 371,429,000/- and annualized cost for the whole system operational in year 2013 will be Rs. 377,121,000/- which include depreciation, operation maintenance and staff costs.



MS=Municipal Services;DDO=Deputy District Officer; SI=Sanitary Inspector; MVI=Motor vehicle Inspector; MTO=Motor transport officer; ASO=Assistant sanitary officer

Figure 1.9: Proposed organization chart of SWM department, CDG model city

Table 1.17: Vehicles equipment and land costs for year 2013 (2010 prices)

Sr. No.	Vehicle Equipment Land	Capacity	Total Requirement	Already present	Additional requirements	Capital Cost of Additional requirement		Annualized Cost (Rs)		
			Number/ Quantity	Number/ Quantity	Number/ Quantity	Unit (Rs)	Total (Rs)	Unit	Total of Additional	Total for Overall
Primary collection and street sweeping										
1	Hand Carts	300 litre	1094	800	294	11,000	3,234,000	4,000	1,176,000	4,376,000
2	Tri-wheelers (Rickshaw)	0.5 m^3	73	-	73	300,000	21,900,000	225,000	16,425,000	16,425,000
3	Mechanical Sweepers	-	6	3	3	2,800,000	8,400,000	1,069,000	3,207,000	6,414,000
4	Water Sprinklers	5m^3	5	2	3	2,250,000	6,750,000	1,101,000	3,303,000	5,505,000
5	Litter Bins		200	-	200	800	160,000	300	60,000	60,000
	Sub-Total						**40,444,000**			**17,997,000**
Secondary storage and collection										
1	Hoist Trucks	7 m^3	45	16	29	2,875,000	83,375,000	1,107,000	32,103,000	49,815,000
2	7m^3 containers	7 m^3	271	80	191	170,000	32,470,000	39,000	7,449,000	10,569,000
3	Dumpers	10 ton	5	4	1	4,500,000	4,500,000	1,404,000	1,404,000	1,404,000
4	Mech. Loaders	-	5	9	-	170,000	-	760,000	-	3,800,000
Sludge and grit removal										
5	Tractor Trolleys	3 ton	10	30	-	900,000	-	1,002,000	-	10,020,000
Complaint cell										
6	Suzuki Dumpers	1m^3	10	5	5	700,000	3,500,000	361,000	1,805,000	3,610,000
	Sub-Total						**123,845,000**			**79,218,000**
Transfer stations										
1	Transfer Station	400 Tons/day	12	-	2	4,000,000	8,000,000	600,000	1,200,000	1,200,000
2	Transfer Vehicle	20m^3	2	-	12	9,500,000	114,000,000	2,037,000	24,444,000	24,444,000
3	Transfer Container	20m^3	12	-	12	460,000	5,120,000	119,600	1,435,200	1,435,200
	Sub-Total						**127,120,000**			27,079,200

Disposal										
1	Chain Bulldozer	100 HP	2	-	2	15,000,000	30,000,000	2,734,000	5,468,000	5,468,000
2	Tractor with front end loader	60 HP	2	-	2	1,730,000	3,460,000	704,000	1,408,000	1,408,000
3	Infrastructures for Landfills	-	2	1	1	40,000,000	40,000,000	2,000,000	2,000,000	4,000,000
	Sub-Total						**73,460,000**			**10,876,000**
Workshops										
	Mobile Workshop	-	1	-	1	3,600,000	3,600,000	956,000	956,000	956,000
Administration										
	Jeep (Suzuki Carry)	650 cc	4	-	4	560,000	2,240,000	342,000	1,368,000	1,368,000
	Motor Bikes	70cc	12	-	12	60,000	720,000	31,000	372,000	372,000
	Sub-Total						6,560,000			2,696,000
	Total:						**371,429,000**			**152,649,200**

Annualized cost of vehicles and Equipment in year 2013 = Rs. 152,649,000

Staff Costs in year 2013 = Rs. 224,472,000

Total annualized cost in year 2013

= Rs. 377,121,000

- ## Long Term Plan and Physical Requirements

Vehicles and Equipment requirement is worked out only for short – term plan (2008-2013). Only land requirement is to be assessed for the complete period of Master Plan for 20 years i.e. 2028. The students may ask that why landfill area for the year 2028 has been used here. It is due to the reason that acquiring of land is a lengthy process. Sometimes land owner resist acquisition and start litigation by filing court cases and take stay from courts. This makes the process of land acquiring a complicated process. Hence it is advisable to acquire land for terminal year of design. However, it is easy to add vehicles, container etc and therefore their planning can be done for a shortage period as is done in this solved example i.e. year 2008 to 2013.

- ## Comparison of short term plan with the Present System

For comparison of proposed short term plan with the present system, unit costs need to be worked out for the short term plan/system. Please note that the unit costs for the existing system have already been calculated, as shown on page 242.

For calculating the unit cost for the proposed short term plan/system, the total requirement for vehicles, equipment and staff and their cost in the year 2013 are required. The calculation of unit cost for the proposed short term plan is given below.

Unit costs of proposed short-term plan.

Collection Efficiency = Waste Collected / day ÷ Waste generated/day

= 743 ÷ 923 = 80 % (waste quantities for year 2010.

Annualized cost for year 2013 = Rs. 377,121,000.

Waste collected / year = 293,690 tons (for the design year 2013)

Cost/ ton = 377,121,000/ 293,690 = Rs. 1284

Population in years 2013 = 1,972,128

Cost/capita/year = 377,121,000/1,972,128

= Rs. 191

Cost/ household/ month = 191 x 7.5/12 = Rs. 119

(7.5 is the household size adopted)

Staff / population ratio

= 1861 x 1000/1,972,128 $\simeq$ 0.94

(Staff=1861 from Table 1.15).

The comparison of proposed short term plan/system with the existing system is made in Table 1.18. It can be seen in Table 1.18 that the proposed system is better than the existing. For proposed system the cost per ton is Rs 1284/ton while for existing system it is Rs 1877/ton. So the cost for existing system is 31% higher than the proposed system. The per capita cost for proposed system is Rs 191/year and for existing system it is Rs 232 / year. Similarly cost per household for proposed system is Rs 119/month while for existing system it is Rs 145/month. Similarly staff /1000 person is also less for the proposed system.

brings the CDG a meager amount of Rs. One million per year as against the annual expenses of Rs. 431 Million in year 2009-10. Of course the people will not be ready to pay full expanses. It is

Table 1.18: Comparison of present and proposed systems

System	Cost/ton (Rs.)	Cost/ capita/year (Rs.)	Cost/household/ month (Rs.)	Staff / 1000 persons
Present (68% coverage)	1877	232	145	0.98
Proposed (80% coverage)	1284	191	119	0.94
Savings	31%	17%	18%	4%

1.4.31 Cost Recovery / Sanitation Fee

Services are never free. We have to pay for the services, we receive. This is also true for the solid waste management service. There must be some fee to recover the cost incurred in providing solid waste services in the city.

There was a time when the solid wastes being generated were overwhelmingly organic in nature and a major portion of these wastes was lifted away by suburban farmers for use as natural fertilizer. This saved the municipalities heavy cost of transportation. But with the use of polyethylene bags and other plastics, the suburban farmers have stopped the use of wastes as natural fertilizer. Expansion of cities and towns has increased the cost of transportation. The scientific measures to dispose of the wastes, in a sanitary manner, have further increased the solid waste management costs.

The situation necessitates the levying of sanitation fee. As calculated in section previous, average cost/household/month for the proposed system is Rs 119. CDG of the model city has started solid waste service to the commercial enterprises, and has levy charges for the service. The charging from commercial enterprises

therefore proposed that the process should be started with an introductory fee of Rs. 100/- per month for houses of size less than or equal to 5 marlas. For houses more than 5 marla and upto 2 kanals, Rs 200/- per month is proposed. The fee may be charged directly or if possible may be made a part of electricity bills.

APPENDIX-1.1
Vehicles and equipment-Primary storage and collection (2013)

1. GENERAL

Name of the City = Model City

Population (Year 2013 A.D.) = 1,972,128 (Table 11.1)

Generation Rate (Year 2013) = 0.51 kg/c/d

Production per day = 1005 tons

2. AREAS WITH NARROW STREETS

2A. General

Population (Year 2013) = 618,403 (Table 1.9.)

SW generation rate = 0.51 kg/c/d

Generation per day = 315 tons

2B. Primary Storage

Make shift type of containers will be allowed to be used for separate storage at the premises.

2C. Primary Collection

60% of collection will take place with the help of handcarts, 10% by auto triwheelers and 30% manually. The wastes thus collected will be transferred to communal containers in wide street areas.

Collection per day (80% of generation) = 315 0.8 = 252 tons

Collection by hand carts (60%) = 252 0.6 = 151 tons

Collection by auto triwheelers (10%) = 252 0.1 = 25.2 tons

Density in hand carts = 0.25 tons/m^3

Density in auto triwheelers = 0.3 tons/m^3

Volume of solid waste carried by handcarts = 151/0.25 = 604 m^3

Volume of solid waste carried by

= 25.2/0.3 = 84 m^3

Auto triwheelers

Size of the hand cart = 0.3 m^3

Size of the auto triwheelers = 0.5 m^3

Trips/day by hand carts = 604/0.3 = 2013

Trips/day by auto triwheelers = 84/0.5 = 168

Trips adopted per day per hand cart = 5

Adopted Trips/day per auto triwheelers = 6

Adopted Trips per day per donkey cart = 4

No. of hand carts required = 2013/5 = 403

No. of auto triwheelers = 168/6 = 28

3. WIDE STREET AREAS

3A. General`

Population (Year 2013) = 998,594 (Table 1.9)

SW generation rate = 0.51 kg/capita/ day

Generation = 509 tons

3B. Primary Storage

Make shift type of containers will be allowed to be used for separate storage at the premises.

3C. Primary Collection

Auto triwheelers will collect 10%, hand carts will collect 60% wastes from houses or street side heaps and will shift to large containers while 30% will be shifted there manually.

Total waste to be collected per day (80% of generation) = 407 tons

Waste collected by auto triwheelers (10%)

= 407 x 0.1 = 40.7 tons

Waste collected by hand carts (60%)

= 407 x 0.6 = 244 tons

Density in auto triwheelers = 0.3 tons/m^3

Density in hand carts = 0.25 tons/m^3

Volume to be handled per day by

= 40.7/0.3 = 136 m^3

Auto triwheelers

Volume to be handled per day by

= 244/0.25 = 976 m^3

hand carts

Size of hand cart = 0.3 m^3

Total trips per day by auto triwheelers

= 136/0.5 = 272

Total trips per day by hand carts

= 976/0.3 = 3253

Adopted Trips per day per auto triwheelers

= 6

Trips adopted per day per hand cart

= 5

No. of auto triwheelers required

= 272/6 = 45

No. of hand carts required

= 3253/5 = 651

4. SUB URBAN AREA

4A General

Population (year 2013) = 354,950 (Table 1.9)

Generation rate = 0.51 kg/ capita/ day

Generation per day = 181 tons

4B Primary Storage

Make shift type of containers will be allowed to be used for separate storage in the premises.

4C Primary Collection

10% collection will take place with the help of hand carts and 90% manually. Approximately only 10% collected by hand carts and 10% manually will be stored in large containers.

Total collection/ day by hand carts

(10% = 0.1 x 181 = 18 tons of generation)

Density in hand carts = 0.25 tons/ m^3

Volume carried/ day by hand carts

= 18/0.25 = 72 m^3

Volume/ hand carts

= 0.3 m^3

Number of trips per day

= 72/0.3 = 240

Trips adopted per handcart per day

= 6

Number of handcarts

= 240/6 = 40

Summary of Requirements for Primary Storage and Collection

Hand Carts = 403+651+40 = 1094

Auto triwheelers = 28+45 = 73

APPENDIX-1.2
Vehicles and equipment-Secondary storage and collection (option-1) (Storage in 5 m^3 Containers, collection by Arm-roll Vehicles)

1. GENERAL

Name of the City = Model City

Population (Year 2013 A.D.) = 1,972,128

Generation Rate = 0.51 kg/c/d

Production per day = 1005 tons

2. AREAS WITH NARROW STREETS

2A. General

Population (Year 2013) = 618.460

SW generation rate = 0.51 kg/c/d (Table 1.9)

Production per day = 315 tons

2B. Secondary Storage

5 m^3 steel containers to be served by arm-roll vehicles will be used. The required number of such containers is as under:

Total amount of waste stored in containers

= 315 0.8 = 252 tons (80%)

Volume per container = 5 m^3

Utilization factor = 0.8

Density = 0.5 tons/m^3

Waste/container = 5 0.8 0.5 = 2 tons

No. of containers = 252 / 2 = 126

Additional 20% = 25

Total containers = 126+25 =151

2C. Secondary Collection

Loaded 5 m^3 steel containers will be lifted and hauled to transfer station/ disposal site with the help of arm-roll vehicles. The calculations for the number of such vehicles are as under:

Total number of containers to be served

= 126

Trips per day = Number of Containers

= 126

Trips adopted per vehicle per day = 6

Number of vehicles required=126/6 = 21

Additional vehicles 20% = 4

Total vehicles required = 21 + 4 = 25

3. WIDE STREET AREAS

3A. General

Population (Year 2010) = 998,594 (Table 1.9)

SW generation rate = 0.51

Production per day = 509 tons

3B. Secondary Storage

5 m^3 steel containers will be used for communal storage on street sides.

Total weight of wastes stored/day

= 407 tons 80% = 509 x 0.8

Volume per container = 5 m3

Utilization factor = 0.8

Density in containers = 0.5 tons/m^3

Waste/ container = 5 x 0.8 x 0.5 = 2 tons

Containers required = 407/2= 204

Additional number of containers (20%) = 41

Total containers = 204 + 41 = 245

3C. Secondary Collection

Armroll vehicles will carry the 5 m^3 storage containers to the disposal site, empty them and bring them back to their original position.

Total trips/ day = total containers to be served

= 204

Trips adopted per vehicle per day. = 6

No. of vehicles required = 204/6 = 34

Additional vehicles required (20%) = 7

Total vehicles = 34 + 7 = 41

4. SUB URBAN AREA

4A. General

Population (year 2013)

= 354,950 (Table 1.9)

Generation rate = 0.51 kg/ capita/ day

Generation per day = 181 tons

4B. Secondary Storage

Steel containers of 5 m^3 size will be used for communal storage on street sides.

Total amount of waste stored in 5 m^3

= 181 x 0.2 = 36 tons containers (20% of generation)

Volume/ container = 5 m^3

Utilization factor = 0.8

Density in containers = 0.5 tons/ m^3

Waste stored/ container = 5 x 0.8 x 0.5

= 2 tons

Number of containers required

= 36/2 = 18

Additional 20% = 4

Total containers = 18 + 4 = 22

4C. Secondary Collection

5 m^3 containers will be served by arm-roll vehicles. The number of such vehicles required is as under:

Total number of containers to be served

= 18

Total trips/ day = number of containers

= 18

Trips adopted per Vehicle per day = 6

Number of vehicles required = 18/6 = 3

Summary of Requirements for Secondary Storage and Collection

5 m^3 containers	=	151+245+22	=	418
Arm-roll vehicles	=	25+41+3	=	69

APPENDIX-1.3
Vehicles and equipment-Secondary Storage and Collection (Option – 2) (Storage in 5 m^3 Containers, collection by Tractor – Container Carrier)

1. GENERAL

Name of the City = Model City

Population (Year 2013 A.D.)

= 1,972,128 (Table 1.1)

Generation Rate= 0.51 kg/c/d

Production per day = 1005 tons

Max. collection per day 80% = 804 tons

2. AREAS WITH NARROW STREETS IN THE CITY

2A. General

Population (Year 2013) = 618,460 (Table 1.9)

SW generation rate = 0.51 kg/c/d

Generation per day = 315 tons

2B. Secondary Storage

5 m^3 steel containers will be used for communal storage in street sides. The required number of such containers is as under:

Total amount of waste stored in containers

= 315 x 0.8 = 252 tons

Volume per container = 5 m^3

Utilization factor = 0.8

Density = 0.5 tons/m^3

Waste/container = 5 x 0.8 x 0.5 = 2 tons

No. of containers = 252 / 2 = 126

Additional 20% = 25

Total containers = 126+25 =151

2C. Secondary Collection

5 m^3 containers will be served by tractor-container carriers. The number of vehicles required is as under.

Total number of containers to be served = 126

Total trips per day = Number of containers = 126

Trips adopted per vehicle per day = 6

Number of vehicles required = 126/6 = 21

Additional vehicles 20 % = 4

Total vehicles required = 21 + 4 = 25

3. WIDE STREET AREAS IN THE CITY

3A. General

Population (Year 2013) = 998, 594 (Table 1.9)

SW generation rate = 0.51

Production per day = 509 tons

3B. Secondary Storage

Communal containers of 5 m^3 capacity will be used on street sides. Their number is calculated as below:

Total waste stored/day (80% of generation)

= 0.8 509 = 407 tons

Size of storage containers = 5 m^3

Utilization = 0.8

Density in containers = 0.5 tons/m^3

No. of containers required = 407/2 = 204

Additional 20% = 41

Total required = 204 + 41 = 245

3C. Secondary Collection

5 m^3 containers will be served by tractor-container carrier. The number of vehicles is as under:

Total Number of containers to be served/day

= 204

Total trips/day = Number of containers = 204

Trips adopted per vehicles per day = 6

No. of vehicles required = 204/6 = 34

Additional 20% = 7

Total vehicles required = 34 + 7 = 41

4. SUB URBAN AREA

4A General

Population (year 2013)

= 354,950 (Table 1.9)

Generation rate = 0.51 kg/ capita/ day

Generation per day = 181 tons

4B Secondary Storage

5 m^3 containers will be used for communal storage on street sides which will be served by tractors-container carrier.

Total amount of waste stored in 5 m^3 = 181x0.2=36 tons containers (20% of generation)

Volume/ container = 5 m^3

Utilization factor = 0.8

Density in containers = 0.5 tons/ m^3

Waste stored/ container

= 5 x 0.8 x 0.5 = 2 tons

Number of containers required

= 36/2 = 18

Additional 20% = 4

Total containers = 18 + 4 = 22

4C Secondary Collection

5 m^3 containers will be served by tractors with container-carriers. The number of such vehicles required is as under:

Total number of containers to be served = 18

Total trips/day = number of containers = 18

Trips adopted per vehicles per day = 5

No. of vehicles required = 18/5 = 4

5. SANITARY LANDFILLING / COMPOSTING

Chain Bulldozers = 2

Tractors with front end loaders = 2

6. LAND FOR SANITARY LANDFILL

Note:

The volume of waste for landfill adopted below is the waste that will be produce in year 2028 (Table 1.1) The students may ask that why landfill area for the year 2028 has been used here. It is done due to the reason that acquiring of land is a lengthy process. Sometimes land owner resist acquisition and start litigation by filing court cases and take stay from courts. This makes the process of land acquiring a complicated process. Hence it is advisable to acquire land for terminal year of design. However, it is easy to add vehicles, container etc and therefore their planning can be done for a shortage period as is done in this solved example i.e. year 2008 to 2013.

Total volume = 1,667,884 m^3

Average depth = 4.6 m

Required area = 82 acres

Summary of Requirements for Storage, Collection and Land Area

5 m^3 containers = 22 + 245+151 = 418

Tractor-Container carrier = 4 + 41+ 25 = 70

Land Area = 82 Acres

APPENDIX-1.4
Vehicles and equipment-Secondary storage & collection(Option – 3) (Storage in 7 m^3 Containers, collection by Hoist Truck)

1. GENERAL

Name of the City = Model City

Population(Year 2013 A.D.)=1,972,128(Table 1.1)

Generation Rate (Year 2013) = 0.51 kg/c/d

Production per day = 1005 tons

2. AREAS WITH NARROW STREETS

2A. General

Population (Year 2013) = 618,403 (Table 1.9)

SW generation rate = 0.51 kg/c/d

Generation per day = 315 tons

2B. Secondary Storage

7 m^3 steel containers will be used for communal storage in street sides.

Total amount of waste stored in containers

= 315 x 0.8 = 252 tons (80%)

Volume per container = 7m^3

Utilization factor = 0.8

Density = 0.55 tons/m^3

Waste/container = 7 x 0.8 x 0.55 = 3.08 tons

No. of containers = 252 / 3.08 = 82

Additional 20% = 16

Total containers = 82 + 16 = 98

2C. Secondary Collection

7 m^3 containers will be served by Hoist Truck. The number of such vehicles required is as under.

Total number of containers to be served = 82

Total trips per day = Number of containers = 82

Trips adopted per vehicle per day = 6

Number of vehicles required = 82/6 = 14

Additional vehicles 20 % = 3

Total vehicles required = 14 + 3 = 17

3. WIDE STREET AREAS

3A. General

Population (Year 2013) = 998,594 (Table 11.9)

SW generation rate = 0.51 kg/capita/ day

Generation = 509 tons

3B. Secondary Storage

Communal containers for secondary storage will be of 7 m^3 size put on the street sides. Their number is calculated as below:

Waste collected (80% of generation)

= 509 x 0.8=407 tons

Size of storage containers = 7 m^3

Utilization factor = 0.8

Density in containers = 0.55 tons/m^3

Waste/container = 7 x 0.8 x 0.55= 3.08 m^3

No. of containers required = 407/3.08 = 132

Additional 20% = 26

Total required = 132 + 26 = 158

3C. Secondary Collection

7 m^3 containers will be served by Hoist Trucks. The number of such vehicles is as under:

Total number of containers to be served/day

= 132

Total trips/day = Number of containers = 132

Trips adopted per vehicle per day = 6

No. of vehicles required = 132/6 = 22

Additional 20% = 4

Total vehicles required = 22 + 4 = 26

4. SUB URBAN AREA

4A General

Population (year 2013)

= 354,950 (Table 1.9)

Generation rate = 0.51 kg/ capita/ day

Generation per day = 181 tons

4B Secondary Storage

Steel containers of 7 m^3 size will be used for communal storage on street sides.

Total amount of waste stored in 7 m^3
= 181 x 0.2 = 36 tons containers (20% of generation) = 36 tons

Volume/ container = 7 m^3

Utilization factor = 0.8

Density in containers = 0.55 tons/ m^3

Waste stored/ container
= 0.8 x 7 x 0.55 = 3.08 tons

Number of containers required
= 36/ 3.08 = 12

Additional 20% = 2

Total containers = 12 + 2 = 14

4C Secondary Collection

7 m^3 containers will be served by hoist trucks. The number of such vehicles required is as under:

Total number of containers to be served
= 12

Total trips/ day = number of containers
= 12

Trips adopted per vehicle per day = 6

Number of vehicles required = 12/6 = 2

5. SANITARY LANDFILLING

Chain Bulldozers = 2

Tractors with front end loaders = 2

6. LAND FOR SANITARY LANDFILL

Total volume of waste (for 2028 population) = 166,7884 m^3

Average depth = 4.6 m

Required area = 82 acres

Summary of Requirements for Secondary Storage and Collection, Sanitary Landfilling

7 m^3 containers = 98+158+14 = 270

Hoist Trucks = 17 + 26 + 2 = 45

Chain Bulldozers = 2

Tractors with front end loaders = 2

Land Area of Landfill = 82 Acres

APPENDIX-1.5
Estimated capital annualized costs of vehicles and equipment (2010 prices)

Sr. No.	Type of Vehicle/ Equipment	Capital Cost (Rs)	Expected Life (Years)	Depreciation cost per year (Rs.) (1)	Establishment Charges per year (Rs.) (2)	POL Cost (Rs.) (3)	Main. & Repair charges (Rs.) (4)	Total Annualized Cost (Rs.) (1)+(2)+ (3)+(4)
1	Bulldozer	15,000,000	15	1,000,000	276,000	558,000	900,000	2,734,000
2	Tractor with front end loader	1,730,000	15	116,000	276,000	209,000	103,000	704,000
3	Transfer Vehicle	9,500,000	15	633,000	276,000	558,000	570,000	2,037000
4	Containers (20 m^3)	460,000	15	92,000	-	-	27,600	119,600
5	Transfer Station	5,000,000	20	250,000	276,000	-	100,000	626,000
6	Arm-roll Vehicle	2,900,000	15	193,000	276,000	465,000	174,000	1,108,000
7	Hoist Truck	2,875,000	15	192,000	276,000	465,000	170,000	1,107,000
8	Tractor with container carrier.	1,050,000	15	70,000	276,000	465,000	63,000	874,000
9	5 m^3 container for carrier	160,000	5	20,000	-	-	5,000	25,000
10	5 m^3 container for arm roll	160,000	5	20,000	-	-	5,000	25,000
11	7 m^3 container	170,000	5	34,000	-	-	5,000	39,000
12	Tractor Trolleys	900,000,	15	60,000	516,000	372,000	54,000	1,002,000
13	Dumpers	4,500,000	15	300,000	276,000	558,000	270,000	1,404,000
14	Donkey Carts	40,000	10	4,000	60,000	60,000	2,000	126,000
15	Hand Carts	11,000	4	3,000	-	-	1,000	4,000
16	Litter Bin	800	3	260	-	-	40	300
17	Mechanical Sweepers	2,800,000	10	280,000	156,000	465,000	168,000	1,069,000
18	Water Sprinkler	2,250,000	10	225,000	276,000	465,000	135,000	1,101,000
19	Motor Bike	60,000	15	4000	-	23,400	3,600	31,000
20	Arm rolls (10 m^3)	4,100,000	15	273,000	240,000	372,000	246,000	1,131,000
21	10 m^3 Containers	225,000	5	45,000	-	-	13,500	58,500
22	Auto rickshaw Loader	300,000	15	20,000	156,000	31,000	18,000	225,000
23	Automobile Workshop	3,600,000	20	552,000	552,000	116,000	108,000	956,000
24	Suzuki Carry	560,000	15	156,000	156,000	116,000	33,000	342,000

Note-1:

The oil prices used below are old. Students will used the latest oil prices for calculation of POL cost for vehicles. However, the amount of liter used by a specific vehicle may remain same. To be more price students may carry out a survey for the consumption of oil used by each type of vehicle.

Notes:

i) Bulldozer uses 24 liters/day x 310 days/year x Rs. 75/ litres

ii) Tractor with front-end loader 9 liters/ dayx 310 days/year x Rs. 75/ litre diesel.

iii) Hoist truck uses 20 Litres/day -do

iv) Transfer vehicles uses 24 litres / day x 310 days/ year x Rs. 75/Ltr

v) Compactor truck uses -do- -do-

vi) Water sprinkler uses -do- -do-

vii) Triwheeler uses 2 kg gas/day x - do - Rs. 50/kg

viii) Suzuki Carry uses 5 Litres day x -do- x Rs. 75/ Litres.

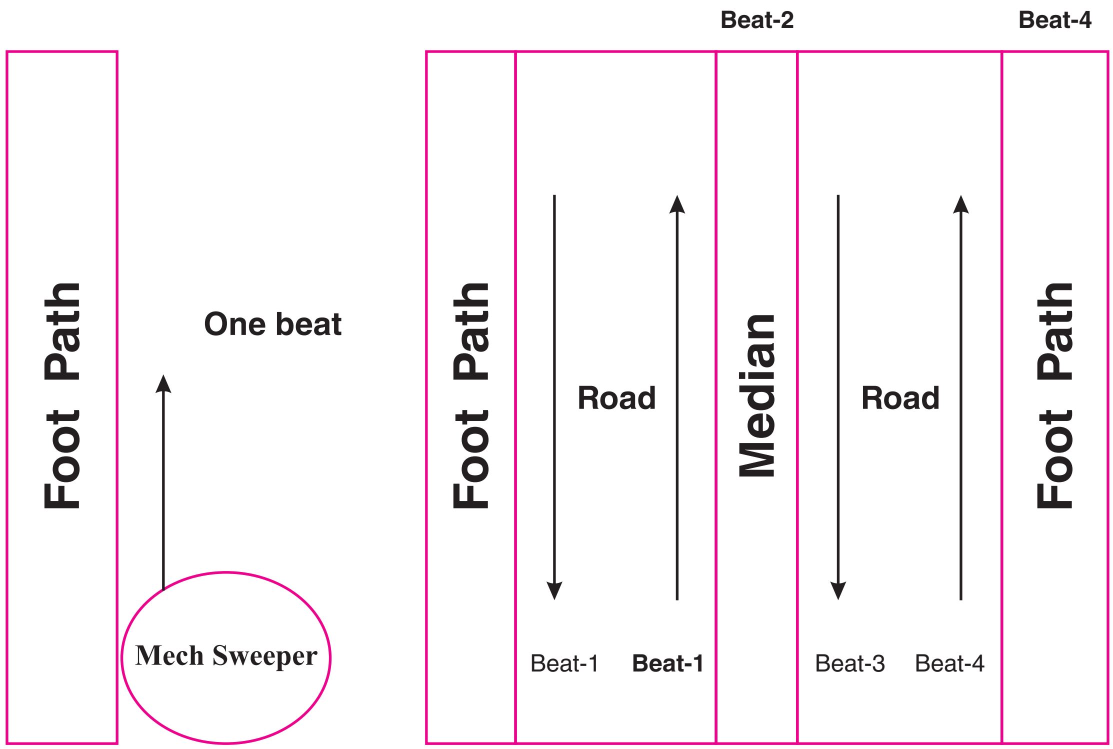
ix) Mechanical Sweeper uses 20 Litres/day x 310 days/year x Rs.75/ Litres.

x) Automobile W/S uses 5 Litres day

xi) Tractor Trolley uses 16 Litres/ day

APPENDIX-1.6
Calculations for determining number of mechanical sweepers

Total length of foot paths	=	41 Km
Total length of median	=	8.5 Km
Total one way sweeping beat	=	(41) +(4 x 8.5) (Road with median has 4 beats)
	=	58 Km



Single beat for footpath on one side **Double road with median have 4 beats**

One way sweeping beat covered/ sweeper/day (with low speed)	=	12 Km
Number of mechanical sweepers required	=	58/12 = 5
Additional number required (20%)	=	1
Total number required	=	5 + 1 = 6

APPENDIX-1.7
Vehicles, equipment and infrastructure requirements for transfer stations

Total population of 203	=	1,972,128 (Table 1.1)
Generation rate	=	0.5 kg/capita/day
Total generation	=	1005 tons
Total collection (80% of generationa)	=	1005x0.8=804 tons
No. of transfer Stations	=	2
Amount of Waste/ transfer station	=	402 tons
Size of transfer container	=	20 m^3
Waste density in transfer container	=	0.6 tons/ m^3
Amount of wastes transferred/ container	=	0.6 x 20 = 12 tons
No. of trips required/day	=	402/12 = 34
Trips adopted per vehicle per day	=	6
No. of vehicles required	=	34/6 = 6
No. of container locations	=	3
No. of containers on vehicles	=	3
No. of containers/ transfer station	=	3 + 3 = 6
Total number of vehicles	=	6 + 6 = 12
Total number of containers	=	6 + 6 = 12
Area required/ transfer station	=	50 x 40 meters (4 kanal)

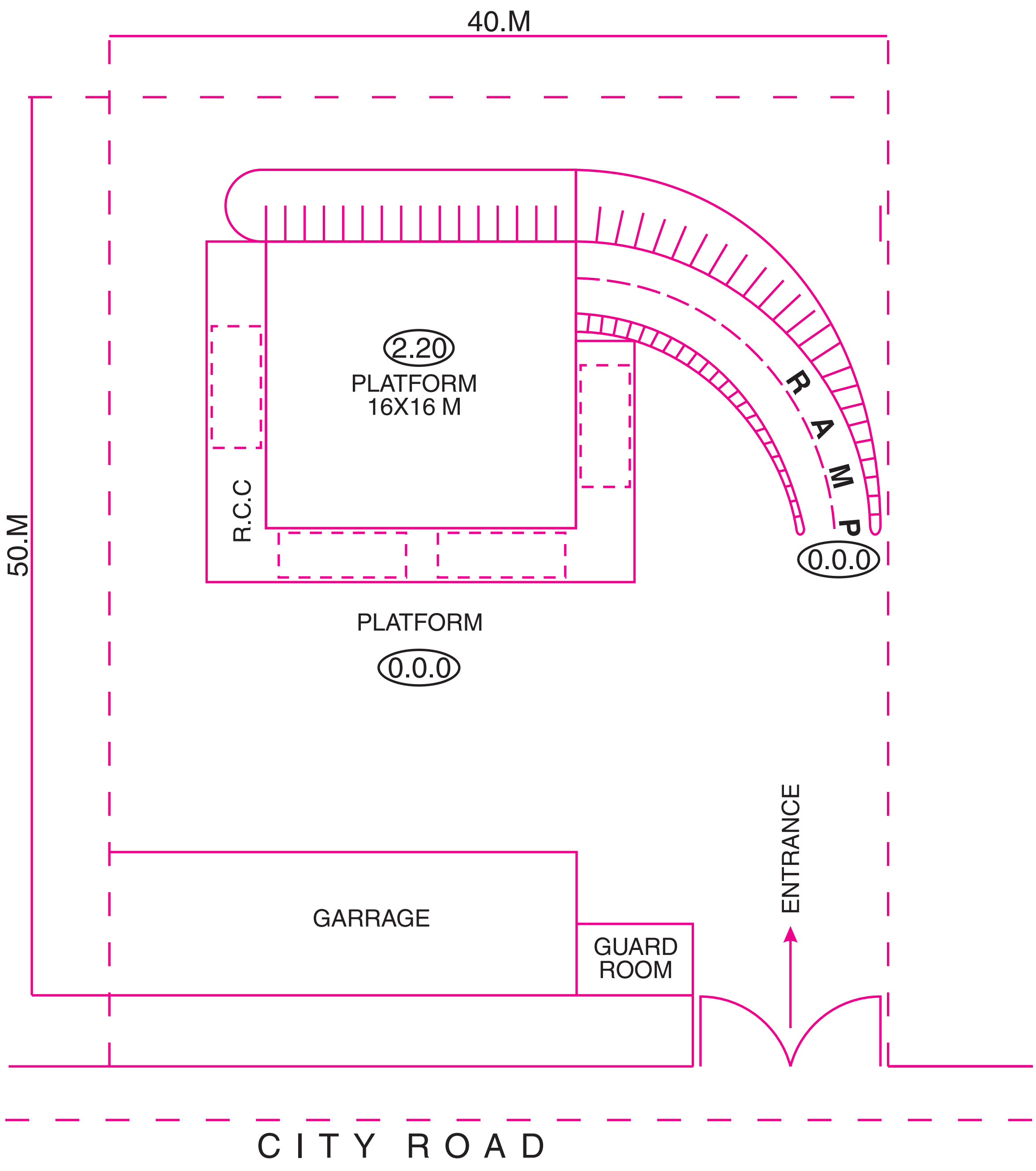
Area depends upon number of vehicles to parked in transfer station, , space for ramp and unloading platform, space for vehicles coming for unloading, weighing scale and may be small office, guard romm etc.

Size of raised platform	=	20 x 15 meters(per site conditions)
Height of raised platform	=	2 meters
Size of Garrage	=	9 x 25 meters(as per vehicles to be parked in the transfer station)

Summary of Requirements for Transfer Station

Civil Infrastructures	=	2
20 m^3 Containers	=	12
Arm-roll Vehicles	=	12
Land Area	=	2 No. (4 Kanal each)

Typical Layout of a Transfer Station



BOQ and Cost Estimate Transfer Station

Bill of quantities (BOQ) and cost estimates are the job of Quantity Surveyors. However, for the information of students, the BOQ and cost estimate of a typical transfer station shown in Fig. above has been worked out. The first column of Table below shows the sr. no. of item. The second column refers to the Market Rate System (MRS) chapter and item number. MRS is released by Government of Punjab biannually (from year 2012; previously MRS for each quarter was issued separately) and is available on the website of Government of Punjab in PDF files for downloading. All the Government departments in Punjab use this MRS for the cost estimation of their projects. Consulting firms also used this MRS as basis for their cost estimation. However, if an item is not given in MRS then non-MRS rates i.e. market rates are used. Rate analysis for all the market rates are to be attached with cost estimates. The rates used for different items have been taken from MRS of year 2008, 4th Quarter.. The students may use the rates given in the latest MRS.

SR. NO.	M.R.S 4th Quarter 2008	DESCRIPTION	QUANTITY	UNIT	UNIT RATE (Rs)	AMOUNT (Rs)
1	Chap-3,I-21 (b)/4	Excavation in foundation of building, bridgesand other structures, including dagbelling, dressing, refilling around structure with excavated earth, watering and ramming lead upto one chain (30m) and lift upto 5 ft (1.5m)				
		b) In ordinary soil	0.79	cu.m	94.55	75
2	Chap-6,I-5 (h)/2	Cement concrete including placing, compacting, finishing and curing complete (including screening and washing of stone aggregates ratio (1:4:8)	9.90	cu.m	4,188.80	41,469
1	Chap-6,I-6/ P-2	Providing and laying reinforced cement concrete (including prestressed concrete), using coarse sand and screened graded and washed aggregate, in required shape and design, including forms, moulds, shuttering, lifting, compacting, curing, rendering and finishing exposed surface, complete (but excluding the cost of steel reinforcement, its fabrication and placing in position, etc.):-				

SR. NO.	M.R.S 4th Quarter 2008	DESCRIPTION	QUANTITY	UNIT	UNIT RATE (Rs)	AMOUNT (Rs)
		(a) (i) Reinforced cement concrete in roof slab, beams, columns lintels, girders and other structural members laid in situ or precast laid in position, or prestressed members cast in situ, complete in all respects:- (3) Type C (nominal mix 1: 2: 4)	48.00	cu.m	7,180.55	344,666
		(a)(ii) Reinforced cement concrete in slab of rafts / strip foundation, base slab of column and retaining walls; etc and other structural members other than those mentioned in 5(a) (i) above not requiring form work (i.e. horizental shuttering) complete in all respects:- (3) Type C (nominal mix 1: 2: 4)	78.00	cu.m	5,670 65	44,311
13,844 2	Chap-6,I-9/ P-4	Fabrication of mild steel reinforcement for cement concrete, including cutting, bending, laying in position, making joints and fastenings, including cost of binding wire and labour charges for binding of steel reinforcement (also includes removal of rust from bars):-				
		(b) deformed bars	181.44	100kg	9,509 65	17,254
		Total Amount				**2,553,952**

RAMP FOR TRANSFER STATION = 16.00 METRE						
SR. NO.	M.R.S 4th Quarter 2008	DESCRIPTION	QUANTITY	UNIT	UNIT RATE (Rs)	AMOUNT (Rs)
1	Chap-7, I-7/54	Pacca brick work other than building upto 10ft. (3 m) height. i) cement, sand mortar:- Ratio 1:4	0.79	m	3807.35	3,008
2	Chap-3, I- 15/3	Filling, watering and ramming earth under floors:- ii) with new earth excavated from outside, lead upto one chain (30 m).	60.80	Cu.m	78.70	4,785
3	Chap-3,I-16/4	Extra for every 50 ft. (15 m) additional lead or part thereof (up to 3 km):-				
		i) for earhtwork soft, ordinary, hard and very hard.	60.80	Cu.m	227.70	13,844
4	Chap-3, I- 25/5	Compaction of earthwork with power roller, including ploughing, mixing, moistening earth to optimum moisture content in layer, etc.				
		i) 95% to 100% maximum modified AASHO dry density.	60.80	Cu.m	23.85	1,450
5	Chap-18 ,I-3/1	a) Providing and laying sub-base course of stone product of approved quality and grade, including placeing, mixing spreading and compaction of sub-base material to required depth, camber, grade to achieve 100% maximum modified AASHO dry density, including carriage of all material to site of work . (Lead up to 300 Km)				
		ii) Crushed stone aggregate.	18.24	Cu.m	1680.91	30,660

SR. NO.	M.R.S 4th Quarter 2008	DESCRIPTION	QUANTITY	UNIT	UNIT RATE (Rs)	AMOUNT (Rs)
6	Chap-18, I-4/1	a) Providing and laying base course of crushed stone aggregate of approved quality and grade, including placing, mixing spreading and compaction of sub-base material to required depth, camber, grade to achieve 100% maximum modified AASHO dry density, including carriage of all material to site of work except gravel and aggregate (Lead up to 300 Km)	12.16	Cu.m	2118.10	25,756
7	Chap-18 ,I-8 (a)/3	Providing surface treatment to roads, including supply of bitumen and bajri/crushed stone aggregate of approved quality, including cleaning of road surface, heating and spraying bitument, spreading bajri and rollingg with road roller(including its operation cost, fuel and hire charges etc) complete including carriage of all materials to site of work except bajjri/ crushed stone aggregate. (Lead up to 300 Km)				
		1) 1st coat:- i) 40 lbs. bitumen, and 5.5 Cft. bajri of nominal size 1" (25 mm) per 100 sq. feet or 1.96 Kg bitumen and 0.017 cu.metre bajri per square metre. 2) 2nd coat:- i) 25 lbs. bitumen, and 2.75 Cft. bajri of nominal size ½" (13 mm) per %sft or 1.23 Kg bitumen and 0.008 cu. metre bajri per sq.metre. 3) 3rd coat:- 14 lbs. bitumen, and 1.5 Cft. bajri of nominal size ¼" (6 mm) per %sft or 0.69 Kg bitumen and 0.005 cubic metre bajjri per sq.metre.	121.60	Sq.m	336.59	40,929
		Total Amount				**120,432**

APPENDIX-1.8
Construction of model landfill facility for disposal of municipal solid waste

INFRASTRUCTURE COST
(ABSTRACT OF COST)

ANNEXURE No.	DESCRIPTION	AMOUNT (Rs.)
101	TRENCH FOR LANDFILL FACILITY CIVIL WORKS	26,540,071
102	LIGHTING AT MAIN GATE	128,000
103	OFFICE BUILDING - CIVIL WORKS	432,516
104	OFFICE BUILDING - CIVIL WORKS - NON-MRS.	136,198
105	OFFICE BUILDING - ELECTRICAL WORKS	2,605
106	OFFICE BUILDING - ELECTRICAL WORKS - NON-MRS.	158,475
107	GARAGE FOR VEHICLES	584,632
108	TUFF TILES PAVEMENT IN GARAGE (IN & OUT SIDE)	233,555
109	GUARD ROOM	111,630
110	ROOM FOR WEIGH BRIDGE	164,495
111	SURFACE DRAIN	1,102,382
112	PUMPING STATION - CIVIL WORKS	1,299,902
113	PUMPING STATION - CIVIL AND MECHANICAL - NON-MRS	1,200,888
114	PUMPING STATION - ELECTRIC WORKS - NON-MRS	1,043,770
115	SEPTIC TANK FOR OFFICE BUILDING	88,252
116	FORCE MAIN - CIVIL WORKS	163,440
117	ACCESS AND INTERNAL ROADS	2,369,916
118	R.C.C PIPE LINE FOR LEACHATE COLLECTION	557,778
	TOTAL	**36,318,504**
	ADD 3% CONTINGENCIES	**1,089,555**
	GRAND TOTAL	**37,408,059**
	SAY Rs.	**40,000,000**
	ANNUAL OPERATION & MAINTENANCE COST (3% OF CAPITAL COST)	**1,200,000**
	DEPRECIATION COST (2% OF CAPITAL COST	**800,000**

APPENDIX-1.9
Staff requirements

A. Sanitary Workers (Street sweepers-cum-refuse collectors)

With the proposed system, the job of the street sweepers will reduce due to the decrease in littering. The street sweepers would be provided long-handled brooms to prevent bending, and protect themselves from breathing in the cloud of dust. They will also be provided with a long-handled pan or a piece of plastic sheet into which litter and debris can be swept for transferring to hand cart.

i) Narrow street areas

In such areas street sweepers will be required to do house to house collection along with street sweeping. In this way, on an average every sweeper is expected to serve 150 dwellings.

Number of sweepers-cum-collectors required

= Total Population in year 2013 / (Persons/ house x Properties Served/ sweeper)

$$= \frac{618,460}{7.5 \times 150} = 549$$

ii) Wide street areas with dense population and commercial areas

The street sweepers assigned to such areas are not required to perform house to house collection. The residents are expected to have their own arrangements to shift the wastes to the communal storage units. Therefore longer beats may be assigned to the street sweepers. The present ratio of one sweeper/1000 person can thus be safely maintained.

No. of sweepers required = Total Population of area in year 2013 Ratio for sweepers

= 998500 X 1/1000 = 998

iii) Sub urban areas

The street sweepers assigned to such areas are only required to collect wastes from main streets. The residents are expected to shift the wastes to the communal containers themselves. Only 20% of the population is provided the service.

Therefore number of sweepers required

= Total population x 0.2 x ratio of sweepers

$$= 354,983 \times 0.2 \times \frac{1}{1000}$$

= 71

iv) Total No. of Sanitary workers

= 549 + 998 + 71 = 1618 or Say = 1620

B. Collection Vehicles Staff

With 45 Hoist trucks

Transport Officer	=	1
Total Number of drivers	=	45
Total number of helpers	=	45
Supervisor	=	2

C. Transfer Stations Staff

With 12 transfer vehicles

Total Number of drivers	=	12
Total number of helpers	=	12
Supervisor	=	2
Sweepers	=	2
Chowkidars	=	2

D. Workshop Staff

A medium size workshop should be maintained to cater for basic needs of repairs and maintenance. The present staff is sufficient for the purpose, which include:

M.V.I/ Motor Transport Officer	=	1
Sub Engineer	=	1
Foreman/ head mechanic	=	1
Skilled workers/ mechanics	=	10
Helpers	=	14

E. Sanitary Landfill Staff

The minimum possible staff requirements for proper operation and maintenance of a sanitary landfill site are:

Bulldozer Drivers	=	2
Tractor Drivers	=	2
Helpers	=	4
Labourers	=	6
Supervisors	=	2

F. Supervisory Staff

As enlisted in design criteria, an efficient organization needs planning, operation and maintenance cells separately besides control over normal collection, transfer and disposal operations. The overall estimate of managerial staff is as given below:

EDO	=	1
PA to EDO	=	1
District Officer SWM	=	1
DDO (Planning S.Landfills, T.Section)	=	1(T=transport)
DDO Sanitation	=	2
DDO (Workshop, Transport)	=	1
Office Superintendent	=	1
Senior Clerk	=	1
Junior Clerks	=	4

Primary Collection

Sanitation Officer	=	4
Asstt. Sanitation Officers	=	8
Sanitary Inspectors	=	17

One supervisor can monitor and control about 25 sweepers.

Therefore, Supervisors = 1618/25 = 65
(25 sweepers/supervisor)

G. Other Office Support Staff

Office support services are also integral part of any organization. The staff required for the proposed system is as under:

Office Superintendent	=	1
Senior Clerk	=	2
Junior Clerk	=	6
Naib Qasids	=	2

H. Qualifications and Job Description for Posts of Officers

1. Distt. Officer (D.O) SWM

Qualifications

i) B.Sc Envir. Engg/ Civil Engg/ Mech. Engg.
ii) 5 Years Experience in the field of Solid Waste Management

Job Description

He is overall responsible for planning, management, of SWM and disposal services, maintaining the fleet of vehicles in working order or outsourcing of these services and coordinating with other deptts; for smooth functioning of SWM Deptt; and implementing the policies of the government with regards to SWM.

2. Deputy Distt. Officer (DDO) SWM

Qualifications

i) B.Sc Envir. Engg/ Civil Engg/ Mech. Engg.

or

B.A./ Diploma holder in Civil Engg/ Mech. Engg with 20 years experience in the field of SWM. Certificates of training in the field of SWM from local or foreign institutes in preferable.

Job Description

He is responsible for door-to-door collection of solid wastes, their storage in communal container and coordination with DDO transport for timely service of communal containers

3. Deputy Distt. Officer (DDO) Workshops, Transport

Qualifications

i) B.Sc Mech. Engg.
or
Diploma holder in Mech Engg with 20 years experience in the maintenance of workshops and solid waste collection fleet.

Job Description

He is responsible for transportation of wastes from secondary storage containers to transfer stations and designing of collection routes and controlling maintenance workshops.

4. Deputy Distt. Officer (DDO) Landfill, Transfer Station

Qualifications

i) B.Sc Envir. Engg/ Civil Engg/ Mech. Engg.
or
B.A./ Diploma holder in Envir.Engg/Civil Engg/ Mech. Engg with 20 years experience in the field of SWM certificates of training in the Landfill Technology and Operation of Transfer Stations from local or foreign institutes is preferable.

Job Description

He is responsible for proper operations at transfer stations and landfill sites under the guidance of DO SWM.

5. Deputy Distt. Officer (DDO) Planning & Enforcement

Qualifications

i) B.Sc Envir. Engg/ Civil Engg/ Mech. Engg.

Job Description

He is responsible for planning the SWM functions in such a manner that the service is performed efficiently and economically. He is responsible for devising the polices for inducting the private sector and obtaining the cooperation of the community through community participation techniques. He is also responsible for enforcement of the policies of the CDG in case of defiance of SWM by-laws.

APPENDIX-2
Physical composition of solid wastes in selected areas of Lahore as source of combustibles % by weight)-1991

Component	Selected Areas											
	Shad-man	New Muslim Town	GOR-1	Gulberg	Shah Jamal	New Garden Town	Model Town	GOR-11	Faisal Town	Town-ship	Mozang Commercial	Overall Average	Moisture
Vegetable and Fruit Wastes	49.00	7.90	7.40	25.30	29.90	24.80	1.10	35.40	18.40	29.30	17.70	22.30	15.60
Paper Card Board	4.60	9.80	1.10	0.30	2.20	0.50	0.70	3.80	1.70	2.50	8.90	2.80	0.17
Plastics & Rubber	6.40	3.30	2.50	1.50	3.70	5.10	1.70	4.10	2.60	9.10	6.50	4.20	0.08
Garden Trimmings, Leaves, Straws	18.00	84.00	72.10	69.50	37.80	69.10	68.40	52.10	72.60	10.30	23.70	51.50	30.90
Rags	6.80	0.90	2.10	2.00	5.80	3.70	1.10	2.90	1.20	4.30	1.60	4.10	0.40
Wool	0.50	0.30	1.00	0.50	0.90	0.20	14.40	0.20	0.20	2.20	0.60	1.90	0.40
Bones	0.70	0.20	0.30	0.10	0.40	0.10	0.10	-	-	0.90	2.70	0.50	0.30
Animal Dung	-	-	-	-	0.40	-	-	-	-	-	0.60	0.10	0.05
Total Combustibles	86.00	97.40	86.50	99.20	81.10	103.50	90.50	98.50	96.70	58.60	72.30	87.40	47.90
Glass	0.30	0.10	-	0.10	0.20	1.80	0.20	0.20	1.90	1.60	0.30	0.60	
Metals	0.70	-	0.20	0.20	0.20	0.10	0.10	0.30	-	0.30	1.40	0.30	
Dust, Stones, and other Animal dung	13.00	2.50	13.30	0.60	18.50	4.60	9.20	1.00	1.40	39.50	26.00	11.70	
Total Non Combustibles	14.00	2.60	13.50	0.90	18.90	6.50	9.50	1.50	3.30	41.40	27.70	12.60	0.00

(Source:Dr. Nawaz Tariq (1991), Disposal of Lahore Waste, Study by World Bank

APPENDIX-3
Three bin system

تین کوڑا دان نظام (Three Bin System)

شہر میں کوڑا کرکٹ کا انتظام بہتر کرنے کے لئے آپ کا تعاون درکار ہے۔ جیسا کہ آپ کو معلوم ہے شہروں میں کوڑا کرکٹ آج ایک بہت بڑا مسئلہ بن چکا ہے کوڑا کرکٹ ماحولیاتی آلودگی کو جنم دیتا ہے۔ کوڑا کرکٹ اگر مناسب طریقے سے نہ سنبھالا جائے تو یہ متعدی پیشہ وارانہ بیماریوں کا سبب بن سکتا ہے اس کے علاوہ کوڑا کرکٹ خصوصاً پلاسٹک کے لفافے سیوریج سسٹم اور گندے پانی کی کھلی نالیوں کو بند کر سکتے ہیں۔ کوڑا کرکٹ کو ایک بیکار چیز سمجھنے کے بجائے ایک کارآمد چیز سمجھنے سے مسئلے پر کافی حد تک قابو پایا جا سکتا ہے۔ مثلاً

1. کوڑا کرکٹ کے گلنے سڑنے والے اجزا یعنی پتے پھلوں اور سبزیوں کے چھلکوں وغیرہ سے عمدہ قسم کی کھاد بنائی جا سکتی ہے۔
2. کاغذ گتہ پلاسٹک شیشہ دھاتوں وغیرہ کو دوبارہ کام میں لایا جا سکتا ہے۔
3. ملبے کو گڑھوں میں بھر کر زمین کو دوبارہ کارآمد بنایا جا سکتا ہے۔

اور یہ اس وقت تک ممکن نہیں جب تک معاشرے کا ہر فرد خصوصاً گھر کی خواتین اس میں تعاون نہ کریں۔

لہٰذا اس کام کا مقصد کوڑا کرکٹ سے معقول آمدنی حاصل کرنے کے لئے آپ کی رہنمائی حاصل کرنا ہے۔ آپ سے گزارش ہے کہ کوڑے کو تین حصوں میں تقسیم کریں۔

ا۔ گلنے سڑنے والی اشیاء پھلوں، سبزیوں کے چھلکے۔ (Bin-1 میں ڈالیں)

ب۔ دھاتی اشیاء، لوہا، ایلومینیم وغیرہ، شیشہ، پلاسٹک کی اشیاء، اینٹ پتھر کاغذ وغیرہ۔ (Bin-2 میں ڈالیں)

ج۔ شاپنگ بیگ دیوار سے لگے بیگ میں ڈالیں۔

گلنے سڑنے والے حصے کو معمول کے مطابق کوڑے والے کو دیں جبکہ باقی دو حصوں کو ہفتہ وار آپ سے اکٹھا کیا جائے گا۔ امید ہے کہ آپ اپنے علاقے کی صفائی کو مدنظر رکھتے ہوئے تعاون فرمائیں گے۔

شکریہ

APPENDIX-4
Sample advertisement for land acquisition for landfill site

مالکان زمین متوجہ ہوں

ایسی زمین کے مالکان متوجہ ہوں جو کوڑا کرکٹ ڈالنے/ڈسپوزل کے لئے موزوں ہو۔زمین پر کوڑا کرکٹ ڈالنے کے بعد اس کو روزانہ بلڈوزر کے ذریعے دبایا جائے گا۔ ہفتہ وار کوڑا کرکٹ کے اوپر مٹی ڈالی جائے گی تاکہ اس سے علاقے میں بدبو اور بیماریاں نہ پھیلیں۔کام مکمل ہونے پر اوپر 6انچ مٹی کی تہہ ڈالی جائے گی۔

زمین کے لئے درج ذیل کوائف ضروری ہیں۔

1. زمین میں کوڑا کرکٹ ڈالنے کی کم از کم گنجائش 200,000 مکعب میٹر ہو۔اور کوڑا کرکٹ پر مٹی ڈالنے کے مواقع موجود ہوں۔
2. زمین تحریری معاہدہ کے تحت، جس میں تمام شرائط درج ہوں گی۔TMA کو کم از کم ایک سال کے لئے واگزار کرنا ہوگی۔
3. کام مکمل ہونے پر تمام اخراجات بحساب۔۔۔۔۔۔۔۔۔۔روپے فیصد مکعب یا زمین کی قیمت میں اضافہ کا نصف کارپوریشن کو ادا کرنا ہوں گے۔

جو مالکان زمین دینے کو خواہشمند ہوں وہ مورخہ۔۔۔۔۔۔۔۔۔۔۔۔۔تک زیردستخطی کے دفتر میں مجوزہ فارم جمع کروائیں۔تکنیکی طور پر زمین قابل قبول ہونے کی صورت میں معاملات معاہدہ ایک ماہ کے اندر گفت شنید کے ذریعہ طے کر لئے جائیں گے۔

ڈائریکٹر (برائے کوڑا کرکٹ)

مجوزہ فارم برائے حصول اراضی برائے کوڑا کرکٹ ڈسپوزل

نام مالکان بمعہ ولدیت۔۔۔۔۔۔۔۔۔۔۔۔کل رقبہ۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔موضع۔۔۔۔۔۔۔۔۔۔

نمبر ہائے خسرہ۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔زمین کی موجودہ صورتحال۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔

پیداواری فصلیں۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔شہر کی کسی مخصوص جگہ سے فاصلہ۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔

ڈالے گئے کوڑا کرکٹ کی مجوزہ موٹائی۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔۔پہنچنے کا راستہ (نقشہ کے ذریعے واضح کریں)

APPENDIX-5
Sample question paper

1. What are different types of storage containers being used in our cities? What improvements you suggest for making the system more efficient?

2. a) What type of transfer stations you propose to be used in Lahore? Illustrate the reasons for your choice, and make a hand-drawn sketch of the facility.

   b) Fill in the blanks.

i) Make shift-type of containers are used at ______________________

ii) Vertical chutes are used for ______________________ and should have a minimum diameter of ______________________

iii) Type of bacteria surviving at normal temperature is known as ______________________

iv) ______________________ is used for the most common impermeable layer to______________________

3. In the context of scientific approach to solid waste management technology discuss the needs of the present day solid wastes management systems of major urban centres of the country.

4. Fill in the blanks/Give appropriate answer to the following:

i) HCS system is more efficient for long distances as compared to SCS.Yes/No.

ii) Nitrosomonas and Nitrobactors are distinguished as ______________________

iii) Magnitic separation techniques include:

a)______________________ b)______________________

iv) Leachate movement can be controlled by:

a) ______________________ b)______________________

v) Cardinal features of solid waste management include:

a) ______________________ b)______________________

c) ______________________ d)______________________

5. What is the importance of solid waste management law in controlling the system? Briefly discuss in light of some important provisions for situation in Pakistan.

6. a) Write a short note on hazardous wastes disposal techniques.

   b) What authorities should be given to the solid waste management bodies under law.

c) Name the unloading techniques for collection vehicles.

7. Discuss the local situation with respect to solid waste management for any city keeping in view the technology and costs incurred. Suggest improvements in technology with their cost effectiveness.

8. a) What are the major problems encountered in the management of solid wastes in Pakistan. Delineate your recommendations with sound reasons to address the situation in brief.

b) Fill in the blanks/Give proper answers.

i) $Q = -KA\, dh/dL$ is known as ________________________________ and the terms indicate ____

ii) Four major products of anaerobic digestion of organic wastes are ____

iii) The diameter of vertical chutes range between _____________________ and they are used for ____

iv) Density of solid waste in a sanitary landfill can be determined by __________________ method_____________________ and ranges between _________________ in Pakistan.

SUBJECT INDEX

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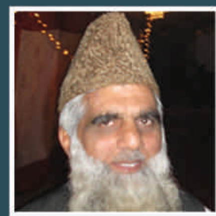
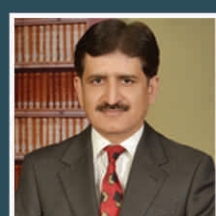
ABOUT THE AUTHORS



PROF. SHAUKAT HAYAT

Prof. Shaukat Hayat, at present, is working as a freelance consultant in the fields of solid waste management and air pollution control with local companies of National and International repute including NESPAK. He started his career in these fields as lecturer in 1976 at the University of Engineering and Technology, Lahore. He graduated in Mechanical Engineering from the same university securing a Gold Medal. Being awarded WHO fellowship he proceeded to University of Cincinnati USA where he completed his M.Sc. Environmental Engineering specializing in air pollution control and solid waste management in 1978. Since then Prof. Shaukat Hayat had been teaching these subjects at UET Lahore to both under-graduate and post-graduate classes, until he retired as Director, Institute of Environmental Engineering and Research in year 2005. During this period he also served as visiting professor at Punjab University and Institute of Public Health. He conducted a number of short courses in the fields of SWM and Healthcare waste management and acted as resource person at different seminars under sponsorship of WHO and Government of the Punjab.



PROF. DR. SAJJAD H. SHEIKH

Dr. Sajjad H. Sheikh is presently working as a Professor in the Institute of Environmental Engineering and Research, UET, Lahore. He graduated from UET and started his career as an environmental engineer in the Public Health Engineering Department, Punjab. After 10 years of practical experience in planning, design and construction of water supply and sewerage facilities, he joined UET. Afterwards he did his M.Sc. and Ph.D. in environmental engineering. Teaching water supply and sewerage design, water and wastewater treatment plant design at the undergraduate level. At the post-graduate level, he is teaching solid waste management and wastewater treatment. He has authored 3 books; one published in Pakistan and two abroad. He has more than 40 research publications in peer reviewed international and national journals. Research work is cited in more than 200 international journals and books. Supervised research work of 4 PhD and more than 30 M.Sc. students. Also engaged in peer review of research papers for 12 international journals. Provided advisory services on projects of World Bank, Asian Development Bank, USAID, UNICEF and KOICA. Guest speaker at the Punjab Engineering Academy, advisor to the Punjab Public Service Commission and adviser to Pakistan Standards and Quality Control Authority (PSQCA) on environmental management.

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