Lecture 1

Introducing Municipal Solid Waste Management

STRUCTURE

OVERVIEW

Due to rapid increase in the production and consumption processes, societies generate as well as reject solid materials regularly from various sectors – agricultural, commercial, domestic, industrial and institutional. The considerable volume of wastes thus generated and rejected is called solid wastes. In other words, solid wastes are the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted. This inevitably places an enormous strain on natural resources and seriously undermines efficient and sustainable development. One of the ways to salvage the situation is through efficient management of solid wastes, and this is the focus of this

Course, Management of Municipal Solid Waste. In the 10 Units that constitute this Course, we will discuss the processes involved in the management of solid wastes – from waste generation to final disposal.

In Unit 1, we will describe solid wastes and introduce you to the classification of solid wastes and the functional elements, such as waste generation, storage, collection, transport, processing, recovery and disposal, in the management of solid wastes. In Units 2 to 7, we will explain with the support of case studies each of these functional elements. In Unit 8, we will explain the treatment of solid wastes by incineration and energy recovery from the incineration process. Subsequently, in Unit 9, we will deal with the treatment and management of hazardous (biomedical) wastes. Finally, in Unit 10, we will discuss the concept of integrated waste management.

Unit 1 begins with a description and classification of solid wastes. It then touches upon some basics of solid waste management and the need for environmentally sound management practices. It closes with a discussion of the current solid waste management (SWM) scenario in India by presenting the effect of temporal conditions on the quantity of waste generated, analysing the quantity and composition of urban wastes in nine major cities and describing the current disposal methods and their influence on public health and environment.

Before you read any further, note that for the purpose of this Course, we use the terms *solid wastes* and *solid waste* interchangeably.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- classify solid wastes;
- explain the functional elements of SWM;
- assess the current situation of SWM in India.

1.1 CLASSIFICATION OF SOLID WASTES

Solid wastes are the organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries, etc., produced in a society, which do not generally carry any value to the first user(s). Solid wastes, thus, encompass both a heterogeneous mass of wastes from the urban community as well as a more homogeneous accumulation of agricultural, industrial and mineral wastes. While wastes have little or no value in one setting or to the one who wants to dispose them, the discharged wastes may gain significant value in another setting. Knowledge of the sources and types of solid wastes as well as the information on composition and the rate at which wastes are generated/ disposed is, therefore, essential for the design and operation of the functional elements associated with the management of solid wastes.

Solid wastes are classified on the basis of source of generation and type. We will explain these in Subsections 1.1.1 and 1.1.2, respectively.

1.1.1 Source-based classification

Historically, the sources of solid wastes have been consistent, dependent on sectors and activities (Tchobanoglous, et al., 1977), and these include the following:

(i) **Residential:** This refers to wastes from dwellings, apartments, etc., and consists of leftover food, vegetable peels, plastic, clothes, ashes, etc.

(ii) **Commercial:** This refers to wastes consisting of leftover food, glasses, metals, ashes, etc., generated from stores, restaurants, markets, hotels, motels, auto-repair shops, medical facilities, etc.

(iii) **Institutional:** This mainly consists of paper, plastic, glasses, etc., generated from educational, administrative and public buildings such as schools, colleges, offices, prisons, etc.

(iv) **Municipal:** This includes dust, leafy matter, building debris, treatment plant residual sludge, etc., generated from various municipal activities like construction and demolition, street cleaning, landscaping, etc. (Note, however, in India *municipal* can typically subsume items at (i) to (iii) above).

(v) **Industrial:** This mainly consists of process wastes, ashes, demolition and construction wastes, hazardous wastes, etc., due to industrial activities.

(vi) **Agricultural:** This mainly consists of spoiled food grains and vegetables, agricultural remains, litter, etc., generated from fields, orchards, vineyards, farms, etc.

(vii) Open areas: this includes wastes from areas such as Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.

It is important to define the various types of solid wastes that are generated from various sources (see Subsection 1.1.1), which we will do, next.

1.1.2 Type-based classification

Classification of wastes based on types, i.e., physical, chemical, and biological characteristics of wastes, is as follows (Phelps, et al., 1995):

(i) **Garbage:** This refers to animal and vegetable wastes resulting from the handling, sale, storage, preparation, cooking and serving of food. Garbage comprising these wastes contains putrescible (rotting) organic matter, which produces an obnoxious odour and attracts rats and other vermin. It, therefore, requires special attention in storage, handling and disposal.

(ii) **Ashes and residues:** These are substances remaining from the burning of wood, coal, charcoal, coke and other combustible materials for cooking and heating in houses, institutions and small industrial establishments. When produced in large quantities, as in power-generation plants and factories, these are classified as industrial wastes. Ashes consist of fine powdery residue, cinders and clinker often mixed with small pieces of metal and glass. Since ashes and residues are almost entirely inorganic, they are valuable in landfills. (We will discuss landfills in Unit 4.)

(iii) **Combustible and non-combustible wastes:** These consist of wastes generated from households, institutions, commercial activities, etc., excluding food wastes and other highly putrescible material. Typically, while *combustible material* consists of paper, cardboard, textile, rubber, garden trimmings, etc., *non-combustible material* consists of such items as glass, crockery, tin and aluminium cans, ferrous and non-ferrous material and dirt.

(iv) **Bulky wastes:** These include large household appliances such as refrigerators, washing machines, furniture, crates, vehicle parts, tyres, wood, trees and branches. Since these household wastes cannot be accommodated in normal storage containers, they require a special collection mechanism.

(v) **Street wastes:** These refer to wastes that are collected from streets, walkways, alleys, parks and vacant plots, and include paper, cardboard, plastics, dirt, leaves and other vegetable matter. Littering in public places is indeed a widespread and acute problem in many countries including India, and a solid waste management system must address this menace appropriately.

(vi) **Biodegradable and non-biodegradable wastes:** *Biodegradable wastes* mainly refer to substances consisting of organic matter such as leftover food, vegetable and fruit peels, paper, textile, wood, etc., generated from various household and industrial activities. Because of the action of micro-organisms, these wastes are degraded from complex to simpler compounds. *Non-biodegradable* wastes consist of inorganic and recyclable materials such as plastic, glass, cans, metals, etc. Table 1.1 below shows a comparison of biodegradable and non-biodegradable wastes with their degeneration time, i.e., the time required to break from a complex to a simple biological form:

Table 1.1

Biodegradable and Non-Biodegradable Wastes: Degeneration Time

Category	Type of waste	Approximate time taken to degenerate
Biodegradable	Organic waste such as vegetable and fruit peels, leftover foodstuff, etc.	A week or two.
	Paper	10–30 days
	Cotton cloth	2–5 months
	Woollen items	1 year
	Wood	10–15 years
Non-biodegradable	Tin, aluminium, and other metal items such as cans	100–500 years
	Plastic bags	One million years
	Glass bottles	Undetermined

From Table 1.1, we can easily deduce the environmental consequences associated with non-biodegradable wastes such as plastics, glass, etc., which we will discuss later in Unit 6.

(vii) **Dead animals:** With regard to municipal wastes, dead animals are those that die naturally or are accidentally killed on the road. Note that this category does not include carcasses and animal parts from slaughter-houses, which are regarded as industrial wastes. Dead animals are divided into two groups – large and small. Among the large animals are horses, cows, goats, sheep, pigs, etc., and among the small ones are dogs, cats, rabbits, rats, etc. The reason for this differentiation is that large animals require special equipment for lifting and handling when they are removed. If not collected promptly, dead animals pose a threat to public health since they attract flies and other vermin as they decay. Their presence in public places is particularly offensive from the aesthetic point of view as well.

(viii) **Abandoned vehicles:** This category includes automobiles, trucks and trailers that are abandoned on streets and other public places. However, abandoned vehicles have significant scrap value for their metal, and their value to collectors is highly variable.

(ix) **Construction and demolition wastes:** These are wastes generated as a result of construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. They consist mainly of earth, stones, concrete, bricks, lumber, roofing and plumbing materials, heating systems and electrical wires and parts of the general municipal waste stream.

(x) **Farm wastes:** These wastes result from diverse agricultural activities such as planting, harvesting, production of milk, rearing of animals for slaughter and the operation of feedlots. In many areas, the disposal of animal waste has become a critical problem, especially from feedlots, poultry farms and dairies.

(xi) **Hazardous wastes:** *Hazardous wastes* are those defined as wastes of industrial, institutional or consumer origin that are potentially dangerous either immediately or over a period of time to human beings and the environment. This is due to their physical, chemical and biological or radioactive characteristics like ignitability, corrosivity, reactivity and toxicity. Note that in some cases, the active agents may be liquid or gaseous hazardous wastes. These are, nevertheless, classified as solid wastes as they are confined in solid containers. Typical examples of hazardous wastes are empty containers of solvents, paints and pesticides, which are frequently mixed with municipal wastes and become part of the urban waste stream. Certain hazardous wastes may cause explosions in incinerators and fires at landfill sites. Others such as pathological wastes from hospitals and radioactive wastes also require special handling. Effective management practices should ensure that hazardous wastes are stored, collected, transported and disposed of separately, preferably after suitable treatment to render them harmless. We will discuss hazardous wastes in detail in Unit 9.

(xii) **Sewage wastes:** The solid by-products of sewage treatment are classified as sewage wastes. They are mostly organic and derived from the treatment of organic sludge separated from both raw and treated sewages. The inorganic fraction of raw sewage such as grit and eggshells is separated at the preliminary stage of treatment, as it may entrain putrescible organic matter with pathogens and must be buried without delay. The bulk of treated, dewatered sludge is useful as a soil conditioner but is invariably uneconomical. Solid sludge, therefore, enters the stream of municipal wastes, unless special arrangements are made for its disposal.

Table 1.2 below summarises our discussion of waste classification based on sources of generation and their types:

Table 1.2
Classification of Solid Wastes

	Type	Description	Sources
Solid Wastes	Garbage	Food waste: wastes from the preparation, cooking and serving of food. Market refuse, waste from the handling, storage, and sale of produce and meat.	Households, institutions and commercial concerns such as hotels, stores, restaurants, markets, etc.
	Combustible and non–combustible	Combustible (primary organic) paper, cardboard, cartons, wood, boxes, plastic, rags, cloth, bedding, leather, rubber, grass, leaves, yard trimmings, etc.	
		Non-combustible (primary inorganic) metals, tin, cans, glass bottles, crockery, stones, etc.	
	Ashes	Residue from fires used for cooking and for heating building cinders	
	Bulky wastes	Large auto parts, tyres, stoves, refrigerators other large appliances, furniture, large crates, trees, branches, stumps, etc.	Streets, sidewalks, alleys, vacant lots, etc.
	Street wastes	Street sweepings, dirt, leaves, etc.	
	Dead animals	Dogs, cats, rats, donkeys, etc.	
	Abandoned vehicles	Automobiles and spare parts	
	Construction and demolition wastes	Roofing, and sheathing scraps, rubble, broken concrete, plaster, conduit pipe, wire, insulation, etc.	Construction and demolition sites.
	Industrial wastes	Solid wastes resulting from industry processes and manufacturing operations, such as, food processing wastes, boiler house cinders, wood, plastic and metal scraps, shavings, etc	Factories, power plants, etc.
	Hazardous wastes	Pathological wastes, explosives, radioactive materials, etc.	Households, hospitals, institutions, stores, industry, etc.
	Animal and agricultural wastes	Manure, crop residues, etc.	Livestock, farms, feedlots and agriculture
	Sewage treatment residue	Coarse screening grit, septic tank sludge, dewatered sludge.	Sewage treatment plants and septic tanks.

Having described solid wastes and their classification, we will now discuss some of the management aspects of solid wastes in Section 1.2. But, before we do so, let us complete Learning Activity 1.1.

LEARNING ACTIVITY 1.1

Based on the source and type, classify the waste generated in your locality.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

1.2 SOLID WASTE MANAGEMENT (SWM)

Solid waste management (SWM) is associated with the control of waste generation, its storage, collection, transfer and transport, processing and disposal in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, public attitude and other environmental considerations.

Put differently, the SWM processes differ depending on factors such as economic status (e.g., the ratio of wealth created by the production of primary products to that derived from manufactured goods, per capita income, etc.), degree of industrialisation, social development (e.g., education, literacy, healthcare, etc.) and quality of life of a location. In addition, regional, seasonal and economic differences influence the SWM processes. This, therefore, warrants management strategies that are economically viable, technically feasible and socially acceptable to carry out such of the functions as are listed below (http://ces.iisc.ernet.in/energy/SWMTR/TR85.html):

- Protection of environmental health.
- Promotion of environmental quality.
- Supporting the efficiency and productivity of the economy.
- Generation of employment and income.

SWM has socio-economic and environmental dimensions. In the socio-economic dimension, for example, it includes various phases such as waste storage, collection, transport and disposal, and the management of these phases has to be integrated. In other words, wastes have to be properly stored, collected and disposed of by co-operative management. In addition, poor management of wastes on the user side such as disposing of wastes in the streets, storm water drains, rivers and lakes has to be avoided to preserve the environment, control vector-born diseases and ensure water quality/resource.

Against this background, we will study in Subsection 1.2.1 SWM system.

1.2.1 SWM system

A SWM system refers to a combination of various functional elements associated with the management of solid wastes. The system, when put in place, facilitates the collection and disposal of solid wastes in the community at minimal costs, while preserving public health and ensuring little or minimal adverse impact on the environment. The functional elements that constitute the system are:

(i) **Waste generation:** Wastes are generated at the start of any process, and thereafter, at every stage as raw materials are converted into goods for consumption. The source of waste generation, as we touched upon earlier in Section 1.1, determines quantity, composition and waste characteristics (see Unit 2 for details). For example, wastes are generated from households, commercial areas, industries, institutions, street cleaning and other municipal services. The most important aspect of this part of the SWM system is the identification of waste.

(ii) **Waste storage:** Storage is a key functional element because collection of wastes never takes place at the source or at the time of their generation. The heterogeneous wastes generated in residential areas must be removed within 8 days due to shortage of storage space and presence of biodegradable material. Onsite storage is of primary importance due to aesthetic consideration, public health and economics involved. Some of the options for storage are plastic containers, conventional dustbins (of households), used oil drums, large storage bins (for institutions and commercial areas or servicing depots), etc. Obviously, these vary greatly in size, form and material. We shall discuss waste storage in detail in Unit 3.

(iii) **Waste collection:** This includes gathering of wastes and hauling them to the location, where the collection vehicle is emptied, which may be a transfer station (i.e., intermediate station where wastes from smaller vehicles are transferred to larger ones and also segregated), a processing plant or a disposal site. Collection depends on the number of containers, frequency of collection, types of collection services and routes. Typically, collection is provided under various management arrangements, ranging from municipal services to franchised services, and under various forms of contracts.

Note that the solution to the problem of hauling is complicated. For instance, vehicles used for long distance hauling may not be suitable or particularly economic for house-to-house collection. Every SWM system, therefore, requires an individual solution to its waste collection problem, and we will explain this in Unit 3.

(iv) **Transfer and transport:** This functional element involves:

- the transfer of wastes from smaller collection vehicles, where necessary to overcome the problem of narrow access lanes, to larger ones at transfer stations;
- the subsequent transport of the wastes, usually over long distances, to disposal sites.

The factors that contribute to the designing of a transfer station include the type of transfer operation, capacity, equipment, accessories and environmental requirements. We will discuss these in Unit 3.

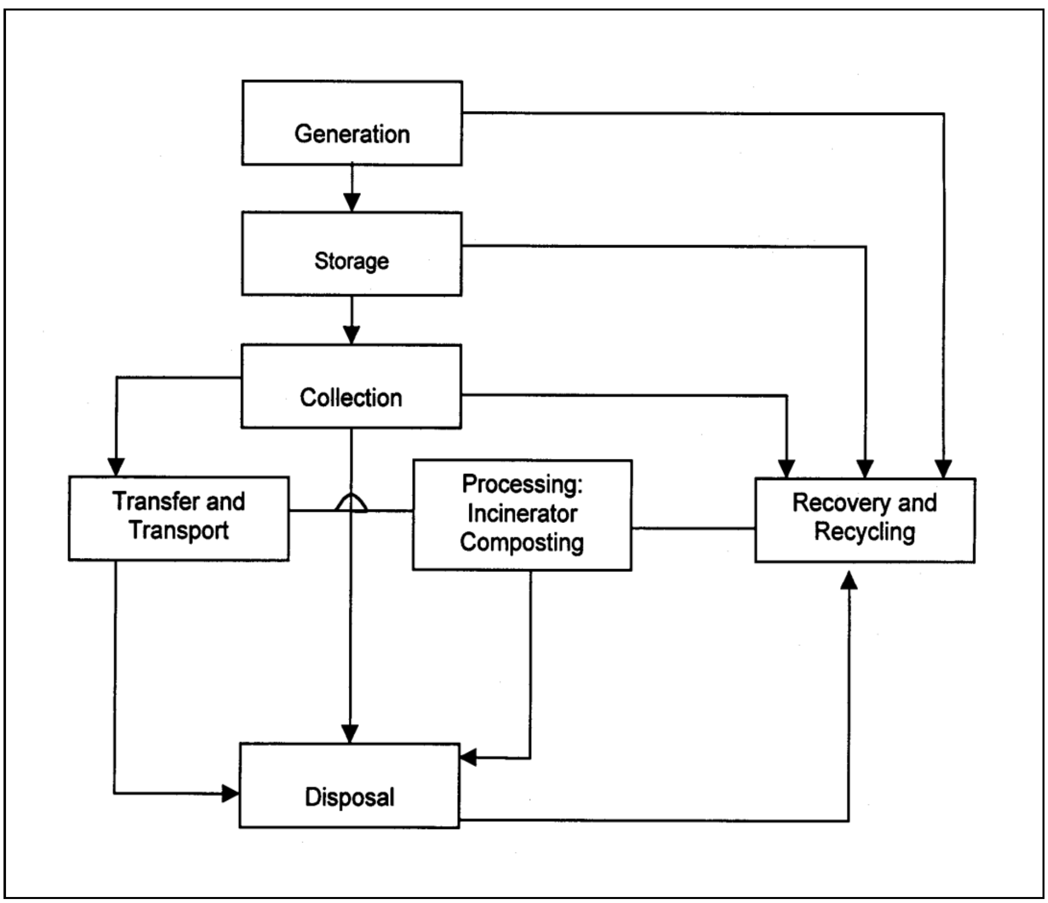
(v) **Processing:** Processing is required to alter the physical and chemical characteristics of wastes for energy and resource recovery and recycling. The important processing techniques include compaction, thermal volume reduction, manual separation of waste components, incineration and composting. We will discuss the various functions involved in waste processing in detail in Unit 5.

(vi) **Recovery and recycling:** This includes various techniques, equipment and facilities used to improve both the efficiency of disposal system and recovery of usable material and energy. Recovery involves the separation of valuable resources from the mixed solid wastes, delivered at transfer stations or processing plants. It also involves size reduction and density separation by air classifier, magnetic device for iron and screens for glass. The selection of any recovery process is a function of economics, i.e., costs of separation versus the recovered-material products. Certain recovered materials like glass, plastics, paper, etc., can be recycled as they have economic value. We will discuss the various aspects of recovery and recycling, respectively, in Units 6 and 7.

(vii) **Waste disposal:** Disposal is the ultimate fate of all solid wastes, be they residential wastes, semi-solid wastes from municipal and industrial treatment plants, incinerator residues, composts or other substances that have no further use to the society. Thus, land use planning becomes a primary determinant in the selection, design and operation of landfill operations. A modern sanitary landfill is a method of disposing solid waste without creating a nuisance and hazard to public health. Generally, engineering principles are followed to confine the wastes to the smallest possible area, reduce them to the lowest particle volume by compaction at the site and cover them after each day's operation to reduce exposure to vermin. One of the most important functional elements of SWM, therefore, relates to the final use of the reclaimed land.

In Figure 1.1 below, we show you a typical SWM system with its functional elements and linkages:

Figure 1.1
Typical SWM System: Functional Elements



You must, however, note that all the elements and linkages shown in Figure 1.1 need not necessarily be always present in a SWM system. Being generic in its form, this system is applicable to all regions, irrespective of their relative state of development (Tchobanoglous, et al., 1977).

✍ **LEARNING ACTIVITY 1.2**

Which functional elements do you think are needed for SWM in your locality?

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

1.2.2 ESSWM and EST

We must recognise that each functional element discussed in Subsection 1.2.1 is closely interconnected to minimise adverse impact of wastes on the environment and to maximise the ecosystem carrying capacity. To derive optimal benefits from this, we must apply environmentally sound solid waste management (ESSWM). This is an integrated approach for controlling and preserving the resources, both in quantity and quality. To improve environmental quality and achieve sustainable development, it is necessary we use EST – environmentally sound technologies (Matsumoto, et al., 2000). We will describe ESSWM and EST, next.

Environmentally sound solid waste management (ESSWM)

In any waste or resource management system, we must pay attention to the interaction between human activities and the ecosystem. We have to recognise that human activities including consumption of goods/services, production of wastes, etc., have a serious impact on the carrying capacity of the ecosystem. This in turn affects human health, as the environment deteriorates. The fundamental principles of ESSWM, which take into account economic and social issues along with environmental impact consideration, include the following:

- To ensure sustainable development of the ecosystem and human environment.
- To minimise the impact of human activities on the environment.
- To minimise the impact on the environment and maximise the ecosystem's carrying capacity.
- To ensure the implementation of ESSWM through environmentally sound technologies.

Environmentally sound technologies (EST)

EST refers to cost effective and energy efficient technologies, which generally perform better on the environment, as they do not pollute the ecosystem's vital components such as air, land or water and consider the reuse, recycling or recovery of wastes. EST can be categorised broadly as follows:

- **Hard EST**: This includes equipment, machines and other infrastructure with their material accessories to handle waste products and monitor/measure the quality of air, water and soil.
- **Soft EST**: This supports and complements hard technologies and include *nature-based technologies and management tools*. Nature-based technologies include processes and mechanisms nature uses within a specific ecosystem (such as vermin composting) and its carrying capacity, while management tools include system and procedures, policy and regulatory frameworks, and environmental performance standards and guidelines.

Note that, as implied above, hard and soft technologies complement one another to achieve the goal.

EST is selected based on the following generic criteria, the indicators of which may vary depending on the regions in which they are implemented:

- **Affordability:** This means low investment, reasonableness, maintenance-free and durability.
- **Validity:** This refers to effectiveness, easy operation and maintenance.

Sustainability: This means low impact, energy saving and cultural acceptability.

Examples of EST for collection and transfer of Waste

Set-out container is one of the major factors that most collection system depends on. This is usually a paper or plastic bag, or a metal or plastic garbage or kraft paper bags in a metal or wooden frame. Set-out containers of rural areas include bags, pots, plastic or paper bags, cane or reed baskets, concrete or brick vats, urns, boxes, clay jars, or any kind of container available.

Non-compactor trucks are more efficient and cost-effective than compactor trucks in small cities and in areas where wastes tend to be very dense and have little potential for compaction. The use of lighter, more energy- efficient box-trucks, vans, and dump trucks can be appropriate for sparsely populated areas, where the main constraint on collection efficiency is distance.

Transfer trailers or compacting vehicles can carry larger volumes of MSW than regular collection trucks, which allow them to travel longer distances carrying more waste. This lowers fuel costs, increases labour productivity, and saves on vehicle wear.

1.2.3 Factors affecting SWM system

Many factors influence the decision-making process in the implementation of a SWM system (Phelps, et al., 1995). Some of the factors that need to be considered in developing a SWM system are listed below:

(i) **Quantities and characteristics of wastes:** The quantities of wastes generated generally depend on the income level of a family, as higher income category tends to generate larger quantity of wastes, compared to low-income category. The quantity ranges from about 0.25 to about 2.3 kg per person per day, indicating a strong correlation between waste production and per capita income. One of the measures of waste composition (and characteristics) is density, which ranges from 150 kg/m^3 to 600 kg/m^3. Proportion of paper and packaging materials in the waste largely account for the differences. When this proportion is high, the density is low and vice versa. The wastes of high density reflect a relatively high proportion of organic matter and moisture and lower levels of recycling.

(ii) **Climate and seasonal variations:** There are regions in extreme north (> 70° N Latitude) and south (> 60° S Latitude), where temperatures are very low for much of the year. In cold climates, drifting snow and frozen ground interfere with landfill operations, and therefore, trenches must be dug in summer and cover material stockpiled for winter use. Tropical climates, on the other hand, are subject to sharp seasonal variations from wet to dry season, which cause significant changes in the moisture content of solid waste, varying from less than

50% in dry season to greater than 65% in wet months. Collection and disposal of wastes in the wet months are often problematic.

High temperatures and humidity cause solid wastes to decompose far more rapidly than they do in colder climates. The frequency of waste collection in high temperature and humid climates should, therefore, be higher than that in cold climates. In sub-tropical or desert climate, there is no significant variation in moisture content of wastes (due to low rainfall) and low production of leachate from sanitary landfill. High winds and wind blown sand and dust, however, cause special problems at landfill sites. While temperature inversions can cause airborne pollutants to be trapped near ground level, landfill sites can affect groundwater by altering the thermal properties of the soil.

(iii) **Physical characteristics of an urban area:** In urban areas (i.e., towns and cities), where the layout of streets and houses is such that access by vehicles is possible and door-to-door collection of solid wastes is the accepted norm either by large compaction vehicle or smaller vehicle. The picture is, however, quite different in the inner and older city areas where narrow lanes make service by vehicles difficult and often impossible. Added to this is the problem of urban sprawl in the outskirts (of the cities) where population is growing at an alarming rate. Access ways are narrow, unpaved and tortuous, and therefore, not accessible to collection vehicles. Problems of solid waste storage and collection are most acute in such areas.

(iv) **Financial and foreign exchange constraints:** Solid waste management accounts for sizeable proportions of the budgets of municipal corporations. This is allocated for capital resources, which go towards the purchase of equipments, vehicles, and fuel and labour costs. Typically, 10% to 40% of the revenues of municipalities are allocated to solid waste management. In regions where wage rates are low, the aim is to optimise vehicle productivity. The unfavourable financial situation of some countries hinders purchase of equipment and vehicles, and this situation is further worsened by the acute shortage of foreign exchange. This means that the balance between the degree of mechanisation and the size of the labour force becomes a critical issue in arriving at the most cost-effective solution.

(v) **Cultural constraints:** In some regions, long-standing traditions preclude the intrusion of waste collection on the precincts of households, and therefore, influence the collection system. In others, where the tradition of caste persists, recruits to the labour force for street cleaning and handling of waste must be drawn from certain sections of the population, while others will not consent to placing storage bins in their immediate vicinity. Social norms of a community more often than not over-ride what many may consider rational solutions. Waste management should, therefore, be sensitive to such local patterns of living and consider these factors in planning, design and operation.

(vi) **Management and technical resources:** Solid waste management, to be successful, requires a wide spectrum of workforce in keeping with the demands of the system. The best system for a region is one which makes full use of indigenous crafts and professional skills and/or ensures that training programmes are in place to provide a self-sustaining supply of trained workforce.

LEARNING ACTIVITY 1.3

Explain the role of environmental sound management and technologies in the context of the SWM system.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

1.3 SWM: THE INDIAN SCENARIO

The problem of municipal solid waste management has acquired alarming dimensions in India especially over the last decade, before which waste management was hardly considered an issue of concern as the waste could be easily disposed of in an environmentally safe manner. However, with time, due to changing lifestyles of people coupled with unplanned developmental activities, urbanisation and industrialisation, the waste quantity and characteristics have changed, and as a result, managing solid wastes has become torturous (Ogawa, 1989, Attarwalla, 1993, Vagale, 1997 and Development, 1999).

The physical and chemical characteristics of Indian city refuse, nonetheless, show that about 80% of it is compostable and ideal for *biogas* generation due to adequate nutrients (NPK), moisture content of 50-55% and a carbon-to-nitrogen ratio of 25-40:1. Therefore, the development of appropriate technologies for utilisation of wastes is essential to minimise adverse health and environmental consequences.

Against this backdrop, let us discuss below the quantum of wastes generated in India, their composition, disposal methods, recycling aspects, and health and environment impacts:

(i) **Waste quantum:** The per capita waste generation rate is about 500 g/day. This along with increased population has contributed to higher total waste generation quantum, as shown in Table 1.3, adding to the problems of municipalities:

Table 1.3
Waste Generation Statistics

Year	**Per capita waste generated (g/day)**	**Total urban municipal waste generated (Mt/year)**
1971	375	14.9
1981	430	25.1
1991	460	43.5
2000	500	48.8
2010	600	~70.2

During the last decade, garbage was generated in India at nearly twice the rate of the population growth. Estimates of the solid wastes generated in Indian towns and cities (299 Class I cities with >100,000 in population and 345 Class II towns) range from 52,000 tonnes to 85,000 tonnes of city garbage every day (while Delhi alone produces 4500-5000 tonnes of municipal solid waste per day). Out of this, only 2,832 tonnes get various types of treatment. In addition, studies in 9 major metropolitan centres in India indicate that the quantum of wastes generated ranges from 1000 tonnes per day in Patna to 5800 tonnes per day in Mumbai, out of which 80-85% is collected, and the rest is left unattended.

Table 1.4 presents the details about the garbage generated and cleared, and the annual municipal budget in nine major Indian cities:

Table 1.4
Urban Waste Situation in Nine Major Indian Cities

Major Cities	Garbage Generated (Tonnes per Day)	Garbage Cleared (Tonnes per Day)	Annual Municipal Budget (Rs. in crores)*
Delhi	3880	2420	1016.28
Kolkata	3500	3150	250.00
Mumbai	5800	5000	2436.00
Bangalore	2130	1800	237.00
Chennai	2675	2140	145.00
Lucknow	1500	1000	48.00
Patna	1000	300	15.00
Ahmedabad	1500	1200	270.00
Surat	1250	1000	170.00

Source: Integrated Modeling of Solid Waste in India (March, 1999) CREED Working Paper Series no 26
** 1 crore = 10 million*

(ii) **Waste composition:** Studies reveal that the percentage of the organic matter has remained almost static at 41% in the past 3 decades, but the recyclables have increased from 9.56% to 17.18% as shown in Table 1.5 below:

Table 1.5
Physico-chemical Characteristics of Municipal Solid Waste

Component	Percentage on wet weight basis	
	1971-73 (40 cities)	1995 (23 cities)
Paper	4.14	5.78
Plastics	0.69	3.90
Metals	0.50	1.90
Glass	0.40	2.10
Rags	3.83	3.50
Ash and fine earth	49.20	40.30
Total compostable matter	41.24	41.80

Source: Integrated Modeling of Solid Waste in India (March, 1999) CREED Working Paper Series no 26 and CPCB, 1999. Status of Solid Waste Generation, Collection and Disposal in Metropolis (cups/46,1999-2000)

Garbage in Indian cities is estimated to contain about 45-75% biodegradable waste (as against 25% of US city-garbage) with 50-55% moisture; 35-45% being fruits, vegetable and food biomass; and 8-15% non-organic materials like plastic, metal, glass, stones, etc.

Among various recyclables, plastics have had a quantum jump from 0.69% to 3.9%, i.e., more than a five-fold increase within last twenty years. Plastics due to their unique properties of flexibility, high impact strength, resistance to corrosion and rigidity have replaced valuable natural resources like wood and metals, resulting in a ten-fold increase during the last decade. Of the current consumption of 1.9 million tonnes of plastics, 15% are from the packaging sector, as packaging materials reach the waste bin as a post-consumer waste. Much of this does not have a recycling value, and hence its disposal without any treatment.

Refuse from Indian cities also contains high organic and low combustible matter, if the studies carried out in six cities are of any indication. Presenting the findings of these studies, Table 1.6 below shows that the highest organic content is found in Bangalore waste (75%) and the lowest in Kolkata (46%)

Table 1.6
Composition of Urban Solid Waste in Indian Cities (Percentage by weight)

City	Paper	Metals	Glass	Textiles	Plastic*	Ash and Dust	Organics	Others**
Chennai	5.90	0.70	-	7.07	-	16.35	56.24	13.74
Delhi	5.88	0.59	0.31	3.56	1.46	22.95	57.71	7.52
Kolkata	0.14	0.66	0.24	0.28	1.54	33.58	46.58	16.98
Bangalore	1.50	0.10	0.20	3.10	0.90	12.00	75.00	7.20
Ahmedabad	5.15	0.80	0.93	4.08	0.69	29.01	48.95	10.39
Mumbai	3.20	0.13	0.52	3.26	-	15.45	59.37	18.07

Source: Integrated Modeling of Solid Waste in India (March, 1999) CREED *Working Paper Series No 26. * Includes rubber and leather. ** Includes bones, stones and wooden matter*

(iii) **Waste disposal methods:** Waste disposal is the final stage of the waste management cycle. About 90% of the municipal waste collected by the civic authorities in India is dumped in low-lying areas outside the city/town limits, which have no provision of *leachate collection* and treatment, and landfill gas collection and use, as Table 1.7 below indicates:

Table 1.7
Waste Disposal Trends in India

Waste disposal method	1971- (40 cities)	1991 (23 cities) and 1999
Land dumping	Almost all	89.8%
Composting	-	8.6%
Others (Pelletisation, Vermi-composting)	-	1.6%

Source: CPCB, 1999. Status of Solid Waste Generation, Collection and Disposal in Metropolis (cups/46,1999-2000)

As a result, leachate containing heavy metals finds its way to the underground water, rendering it unfit for drinking. The landfill gas escapes into the atmosphere, adding to the greenhouse emissions, which otherwise could be used as thermal fuel. Solid waste management can be an income generating activity with cost benefits (the non-use of materials that would otherwise be required for the two activities, e.g., in the case of power generation, the use of wastes instead of conventional fuels). However, since the Indian city refuse has a low calorific value with high moisture content and quantity of non-combustibles, it is not suitable for incineration, and currently none of the municipal corporations in India runs a full-scale incineration plant. The potential for power generation from urban municipal wastes is tremendous, estimated to generate up to 1000 MW of electricity.

(iv) **Recycling:** This involves collection of recyclables from various sources, which ultimately reach recycling units. It is estimated that about 40-80% of plastic waste gets recycled in India, as compared to 10-15% in the developed nations of the world. However, due to lack of suitable government policies, incentives, subsidies, regulations, standards, etc., related to recycling, this industry is still far behind its western counterparts in terms of technology and quality of manufactured goods. Nevertheless, recycling in India is a highly organised and profit-making venture, though informal in nature.

(v) **Health impacts:** Due to the absence of standards and norms for handling municipal wastes, municipal workers suffer occupational health hazards of waste handling. At the dumpsites in the city of Mumbai, for example, 95 workers were examined and it was found that about 80% of them had eye problems, 73% respiratory ailments, 51% gastrointestinal ailments and 27% skin lesions. Also, municipal workers and rag pickers who operate informally for long hours rummaging through waste also suffer from similar occupational health diseases ranging from respiratory illnesses (from ingesting particulates and bio-aerosols), infections (direct contact with contaminated material), puncture wounds (leading to tetanus, hepatitis and HIV infection) to headaches and nausea, etc. Studies among the 180 rag pickers at open dumps of Kolkata city reveal that average quarterly incidence of diarrhoea was 85%, fever 72% and cough and cold 63%.

(vi) **Environmental impacts:** In addition to occupational health, injury issues and environmental health also need to be mentioned in the context of waste management. Contaminated leachate and surface run-off from land disposal facilities affects ground and surface water quality. Volatile organic compounds and dioxins in air-emissions are attributed to increasing cancer incidence and psychological stress for those living near incinerators or land disposal facilities. Drain clogging due to uncollected wastes leading to stagnant waters and subsequent mosquito vector breeding are a few of the environmental health issues, which affect the waste workers as well as the public. The pneumonic plague that broke out in November 1994 in India (Surat, Gujarat) is a typical example of solid waste mismanagement.

1.3.1 Progress of MSW management in India

Over the years, the problems faced due to MSW were highlighted by civic and environmental activists. This resulted in framing rules for MSW in the year 2000(MSWM, 2000; GOI, see Annexure 1) which are directed by the Supreme Court and MoEF. In October 2004, specific directions to the larger cities to meet the requirements of these rules were issued by Supreme Court. In 2005 Ministry of Urban Development giving priority to MSWM has allocated grants to the tunes of Rs 25000 million covering 423 classes I towns as part of 12th finance committee.

Let us now discuss about preparation of Detailed Project Report for managing solid waste at local levels.

1.3.1.1 Guidelines for preparation of detailed project reports for MSWM using 12th finance commission grants[1].

Detailed Project Report (DPR) needs to be prepared as per the guidelines laid down in the Manual on SWM, which include:

a) Existing status of SWM in the towns including mechanism and infrastructure for collection, transportation, treatment and disposal. The details include existing equipment/machinery and the infrastructure available with ULB with the condition and its age. The mechanism & O/M of the equipment available, present establishment expenditure, technical and non-technical manpower available.

b) Field study be carried out in commercial / institutional and residential areas to assess the quantity of garbage generated in the city before planning the system and report of the field study be included in the DPR.

c) Complete physical characterization of waste, including moisture content, density, etc. as well as weight and volume of quantity of bio-degradable, non bio-degradable and recyclables available in the waste produced in the town everyday and test report for quality of garbage from a standard test laboratory .

d) Existing system of collection, storage, transportation, processing, treatment and disposal of waste and proposed system of collection, transportation and process of treatment and disposal, fully justifying the process adopted including in-house facility of maintenance and repair if available in ULB.

e) Justification for equipment & machinery required, if any, for collection and transportation based on the time and motion study in order to ensure optimum utilization of the same.

f) Detailed designs and drawing of proposed Solid Waste Management System including sanitary landfill / waste processing plants should be included in the DPR. Details of the survey and geo-hydrological investigation carried out for development of sanitary land fill.

g) Mechanism of operation and maintenance of equipment and machinery and its upkeep, preventive maintenance on regular basis for existing and proposed equipment and machinery.

h) Mechanism of operation and maintenance of sanitary land fill / waste processing plant on self sustaining basis including details of engagement of private sector, if any.

i) A routing plan for storage and collection of garbage, marked out on the city's layout plan, to facilitate easy operations in SWM services.

j) Proposed institutional and financial reform after completion of scheme.

k) An action plan for effective O/M through imposition of user charges.

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[1] Twelfth Finance Commission Grant – Grant to Village Panchayats for Operation and Maintenance costs of Water Supply, Street Lighting and Sanitation – Release of first instalment of Rs.87.00 crores to Rural Local Bodies for the year 2009-2010

l) Details of suitable land for setting up of integrated waste management facility in possession including land for sanitary landfill

While preparing the detailed project report for any city / town, the guidelines laid down in the Manual on Municipal Solid Waste Management published by this Ministry in May, 2000 should be considered and each component of the project prepared as per the norms laid down therein.

Source:

http://www.urbanindia.nic.in/quickaccess/guidelineofschemes/GUIDELINES.pdf

LEARNING ACTIVITY 1.4

What is the composition of waste in your locality and have you seen any significant change during the last few years?

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

SUMMARY

In this Unit, we described solid waste and its flow pattern and classified wastes on the basis of source and type, and in that context, discussed residential, commercial, municipal, institutional, industrial and agricultural sectors as major sources of waste generation. Based on the type, we classified wastes as garbage, ashes, street wastes, etc., that indicate the physical, chemical and biological characteristics of wastes. We said that knowledge of these characteristics is important in evaluating alternative equipment needs, systems, and management programmes and plans, especially with respect to the implementation of disposal, and resource and energy recovery options.

We pointed out that the objective of SWM is to minimise the negative environmental effects and identified the functional elements of SWM as waste generation, storage, transfer and transport, processing, reuse and recycling and final disposal. We have also briefly mentioned Guidelines for preparation of detailed project reports for MSWM using 12th finance commission grants. These reports are useful in towns, urban areas for sound management of solid waste. We also said that SWM has economic, social and environmental dimensions. In the context of the socio-economic dimension, we discussed such phases as waste storage, collection, transport and disposal, which are to be integrated. For effective implementation of integrated approaches to management, we said that we require environmentally sound management and technologies for controlling and preserving the resources, both in quantity and quality.

After explaining the functional elements, we discussed the various factors such as quantity and characteristics of waste, climatic and seasonal variations, physical characteristics of urban areas, financial constraints, cultural constraints and management and technical resources, which affect decision-making in solid waste management system. Finally, we illustrated solid waste and its management issues, using the Indian scenario as a case.

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Annexure 1

[Rules 6(1) and (3), 7(1)]

Municipal Solid Wastes Management, 2000 (MSWM, 2000), Government of India

S.no	Parameters	Compliance criteria
1.	Collection of municipal solid wastes	1. Littering of municipal solid waste shall be prohibited in cities, towns and in urban areas notified by the State Governments. To prohibit littering and facilitate compliance, the following steps shall be taken by the municipal authority, namely :- i. Organising house-to-house collection of municipal solid wastes through any of the methods, like community bin collection (central bin), house-to-house collection, collection on regular pre-informed timings and scheduling by using bell ringing of musical vehicle (without exceeding permissible noise levels); ii. Devising collection of waste from slums and squatter areas or localities including hotels, restaurants, office complexes and commercial areas; iii. Wastes from slaughter houses, meat and fish markets, fruits and vegetable markets, which are biodegradable in nature, shall be managed to make use of such wastes; iv. Bio-medical wastes and industrial wastes shall not be mixed with municipal solid wastes and such wastes shall follow the rules separately specified for the purpose; v. Collected waste from residential and other areas shall be transferred to community bin by hand-driven containerised carts or other small vehicles; vi. Horticlutural and construction or demolition wastes or debris shall be separately collected and disposed off

		following proper norms. Similarly, wastes generated at dairies shall be regulated in accordance with the State laws; vii. Waste (garbage, dry leaves) shall not be burnt; viii. Stray animals shall not be allowed to move around waste storage facilities or at any other place in the city or town and shall be managed in accordance with the State laws. 2. The municipal authority shall notify waste collection schedule and the likely method to be adopted for public benefit in a city or town. 3. It shall be the responsibility of generator of wastes to avoid littering and ensure delivery of wastes in accordance with the collection and segregation system to be notified by the municipal authority as per para 1(2) of this Schedule.
2.	Segregation of municipal solid wastes	In order to encourage the citizens, municipal authority shall organise awareness programmes for segregation of wastes and shall promote recycling or reuse of segregated materials. The municipal authority shall undertake phased programme to ensure community participation in waste segregation. For this purpose, regular meetings at quarterly intervals shall be arranged by the municipal authorities with representatives of local resident welfare associations and non-governmental organizations.
3.	Storage of municipal solid wastes	Municipal authorities shall establish and maintain storage facilities in such a manner as they do not create unhygienic and insanitary conditions around it. Following criteria shall be taken into account while establishing and maintaining storage facilities, namely :- i. Storage facilities shall be created and established by taking into account quantities of waste generation in a given area and the population densities. A storage facility shall be so placed that it is accessible to users; ii. Storage facilities to be set up by municipal authorities or any other agency shall be so designed that wastes stored are not exposed to open atmosphere and shall be aesthetically acceptable and user-friendly; iii. Storage facilities or 'bins' shall have 'easy to operate' design for handling, transfer and transportation of waste. Bins for storage of bio-degradable wastes shall be painted green, those for storage of recyclable wastes shall be printed white and those for storage of other

		wastes shall be printed black; iv. Manual handling of waste shall be prohibited. If unavoidable due to constraints, manual handling shall be carried out under proper precaution with due care for safety of workers.
4.	Transportation of municipal solid wastes	Vehicles used for transportation of wastes shall be covered. Waste should not be visible to public, nor exposed to open environment preventing their scattering. The following criteria shall be met, namely:- i. The storage facilities set up by municipal authorities shall be daily attended for clearing of wastes. The bins or containers wherever placed shall be cleaned before they start overflowing; ii. Transportation vehicles shall be so designed that multiple handling of wastes, prior to final disposal, is avoided.
5.	Processing of municipal solid wastes	Municipal authorities shall adopt suitable technology or combination of such technologies to make use of wastes so as to minimize burden on landfill. Following criteria shall be adopted, namely:- (i) The biodegradable wastes shall be processed by composting, vermicomposting, anaerobic digestion or any other appropriate biological processing for stabilization of wastes. It shall be ensured that compost or any other end product shall comply with standards as specified in Schedule-IV; ii. Mixed waste containing recoverable resources shall follow the route of recycling. Incineration with or without energy recovery including pelletisation can also be used for processing wastes in specific cases. Municipal authority or the operator of a facility wishing to use other state-of-the-art technologies shall approach the Central Pollution Control Board to get the standards laid down before applying for grant of authorisation.
6.	Disposal of municipal solid wastes	Land filling shall be restricted to non-biodegradable, inert waste and other waste that are not suitable either for recycling or for biological processing. Land filling shall also be carried out for residues of waste processing facilities as well as pre-processing rejects from waste processing facilities. Land filling of mixed waste shall be avoided unless the same is found unsuitable for waste processing. Under unavoidable circumstances or till installation of alternate facilities, land-filling shall be done following proper norms. Landfill sites shall meet the specifications as given in Schedule -III.

Lecture 1

Model Answers to Learning Activities

LEARNING ACTIVITY 1.1

I reside in ward no. 89 of Bangalore (Karnataka, India), which is a residential area and has a population of 29,440. It has 2 colleges, 3 schools, 1 hospital and few commercial establishments. Based on source and type of wastes generated in my ward, they can be classified as follows:

(i) Based on source:

Residential: Consisting of single and multi-storied buildings (food leftovers, vegetable peels, plastics, clothes, etc.).
Commercial: Consisting of provision stores, hospital wastes and auto repair shops (food leftovers, glasses, metals, etc.).
Institutional: Consisting of schools and colleges (paper, plastics, glasses, etc.).
Municipal: Consisting of wastes from demolition and construction activities (dust, building debris, etc.).

(ii) Based on type:

- Garbage (food wastes, vegetable peels, etc.).
- Ashes and residue.
- Combustible and noncombustible wastes (plastics, textiles, glass, etc.).
- Bulky wastes (tires, trees, branches, crates, etc.).
- Street wastes (dirt, leaves, etc.).

- Dead animals (due to natural or accidental death, e.g., dogs, cats, cattle, etc.).
- Construction and demolition wastes (rubber, concrete, plaster, bricks, etc.).

LEARNING ACTIVITY 1.2

Currently, the functional elements in my locality are waste generation, storage, collection and disposal.

Improvements can be made on the existing functional elements by the addition of transport and processing. Since our locality is mostly residential, the quantity of biodegradable waste generated is high. It is, therefore, important that wastes are collected at least three times a week. In order to combat the problems of narrow access ways, a transfer station can be set up, which could be a small area along the street, where collectors transfer wastes from smaller trucks or pushcarts to bigger vehicles. Segregation of wastes can be done at the transfer station, and depending on the waste, they can be disposed of in landfills.

LEARNING ACTIVITY 1.3

Environmentally sound management is an integrated approach for controlling and preserving the resources, both in quantity and quality. Its role is to ensure sustainable development of the ecosystem and human environment by minimising the effects of human activities.

Environmental sound technologies (EST) are cost effective and energy efficient and they do not pollute the ecosystem's vital components such as air, land or water. EST can be categorised broadly as hard and soft. Hard ESTs include equipment, machines and other infrastructure with their material accessories, to handle waste products and monitor and measure environmental quality in the air, water and soil. Soft EST support and complement hard technologies and include nature-based technologies and management tools.

LEARNING ACTIVITY 1.4

Waste composition in our locality consists of wet waste and dry waste. Wet waste constitutes 60% of the solid waste generated, e.g., food wastes, vegetable peels, etc. Dry waste constitutes the remaining 40% of the solid wastes, i.e., paper 12%, plastics 14%, glass 4%, rubber 1%, battery and expired medicines 2%, iron 1%, dust 5% and cardboard boxes 1%.

There has been an increase in the number of residential dwellings in our locality. Due to the increase in population, the quantity of wet wastes (e.g., food leftovers, vegetable peels, etc.) and dry wastes (e.g., plastics, paper, etc.) have also increased, but the percentage of generation remains constant. The waste generated per person is 0.35 kg per capita per day.

Lecture 2

Waste Generation Aspects

STRUCTURE

OVERVIEW

In Unit 1, we introduced you to the functional elements that constitute a SWM system and suggested that each of these elements would be discussed in detail in Units 2 to 7. We will accordingly discuss waste generation, composition (i.e., components), and characteristics in Unit 2, and will explain the other elements in the subsequent Units. The present Unit thus begins with a discussion on the importance of analysis and field investigations to inform decisions about the planning and design of a SWM system. It then explains waste generation, composition and the physical and chemical characteristics as well as the various factors affecting them. It also outlines the impact of wastes on human health and the environment. It closes with a case study of SWM in Bangalore.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- carry out waste stream analysis;
- explain waste generation, composition and the factors affecting them;
- discuss the physical and chemical characteristics of solid wastes;
- determine the effects of poor waste management on public health and the environment.

2.1 WASTE STREAM ASSESSMENT (WSA)

Before we discuss waste generation *per se*, let us first explain the importance of collecting data on waste generation and composition, and the mechanisms that may be used for the purpose.

Waste stream assessment (WSA) is a means to determine the basic aspects of quantity (i.e., the amount of waste generated in the community, both in terms of weight and volume), composition (i.e., the different components of waste stream) and sources of wastes. The information relating to these basic aspects of wastes is vital for making decisions about the SWM system, finance and regulations. Put differently, an assessment of waste stream is essential in the analyses of short- and long-term problems within the local waste management system. It also helps in targeting waste management activities and setting goals for different elements of a waste management plan.

Waste stream assessment, however, is not a one-time activity. It is a continuous and dynamic process, because the characteristics of wastes differ depending on the regions, communities, seasons, etc. We will explain this further in Subsections 2.1.1 and 2.1.2.

2.1.1 Rationale for analysis

The reasons for the analysis of waste composition, characteristics and quantity include the following (Phelps, et al., 1995):

(i) It provides the basic data for the planning, designing and operation of the management systems.

(ii) An ongoing analysis of the data helps detect changes in composition, characteristics and quantities of wastes, and the rates at which these changes take place, which facilitates effective implementation of management systems.

(iii) It quantifies the amount and type of materials suitable for processing, recovery and recycling.

(iv) It provides information that helps in deciding appropriate technologies and equipment.

(v) The forecast trends assist designers and manufacturers in the production of collection vehicles and equipment suitable for future needs.

In the absence of a reliable basic data, carrying out field investigations becomes necessary (Phelps et al., 1995).

2.1.2 Field investigation

Field investigations may take any one or a combination of the following forms:

(i) **Waste sorting**: Sorting of wastes into predetermined components takes place at disposal sites for weighing and sampling in order to determine the percentage of each component and the physical and chemical characteristics of wastes. It is carried out manually, and the sample size for analysis is between 100 and 150 kg. The implements required for the purpose include sorting table, measuring box, bins or boxes to contain sorted materials and platform weighing machine.

(ii) **Vehicle weighing**: Vehicles are weighed when they enter the disposal sites loaded, and exit the sites empty. The vehicle's front wheels are weighed first, followed by the rear wheels and the sum of the two gives the total weight. Weighing is carried out each day of the weighing period in order to determine the average weight. The weighing of loaded and unloaded vehicles is accomplished with a weighing scale or weighbridge. Ideally, the weighing scale should be operated during the entire period of operation of the disposal site, round the clock, if necessary. An electronic or a mechanical portable axle scale, with a capacity of 20 tonnes is suitable for the purpose. An electronic scale comprises two load-cell platforms and an electronic control and a display unit. The quantity of waste measured at disposal sites reflects a disposal factor rather than a generation factor, since the measurements do not include wastes that are:

- salvaged at the generation and disposal sites;
- disposed of in unauthorised places such as vacant plots, alleys, ditches, etc.;
- salvaged by collectors;
- lost during transport.

(iii) **Field visits:** This means visiting institutional and industrial sites to identify wastes being generated and disposal methods. Field visits involve visiting the facility, i.e., industry, institutions, etc., viewing the waste handling system and completing a questionnaire with the assistance of the plant manager or senior technical personnel who usually investigate wastes from industries and institutions. Collection of samples in sealed polythene bags follows for laboratory analysis to identify physical and chemical characteristics. Each sample may be in the range of 1.5 to 5 kg.

An assessment of waste stream, in essence, helps us identify components that require improvement for effective implementation of waste management programmes (EPA, 1989 and 1995).

LEARNING ACTIVITY 2.1

State the importance of waste stream assessment (WSA) and how WSA is carried out in your locality.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

Having explained the importance of waste stream assessment, we now discuss how wastes are generated and their composition.

2.2 WASTE GENERATION AND COMPOSITION

Information on waste quantity and composition is important in evaluating alternatives in terms of equipment, systems, plans and management programmes. For example, if wastes generated at a commercial facility consist of only paper products, the appropriate equipment are shredders and balers. Similarly, on the basis of quantity generated, we can plan appropriate means for separation, collection and recycling programmes. That is to say, the success of SWM depends on the appropriate assessment of quantity of wastes generated. We will elaborate on the aspects of waste generation and composition, respectively, in Subsections 2.2.1 and 2.2.2.

2.2.1 Waste generation

Waste generation encompasses those activities in which waste, be it solid or semi-solid material, no longer has sufficient economic value for its possessor to retain it.

The processing of raw materials is the first stage when wastes are generated, and waste generation continues thereafter at every step in the process as raw materials are converted into final products for consumption. Figure 2.1 below shows a simplified material-flow diagram indicating the path of generation of solid wastes (Tchobanoglous, et al., 1977):

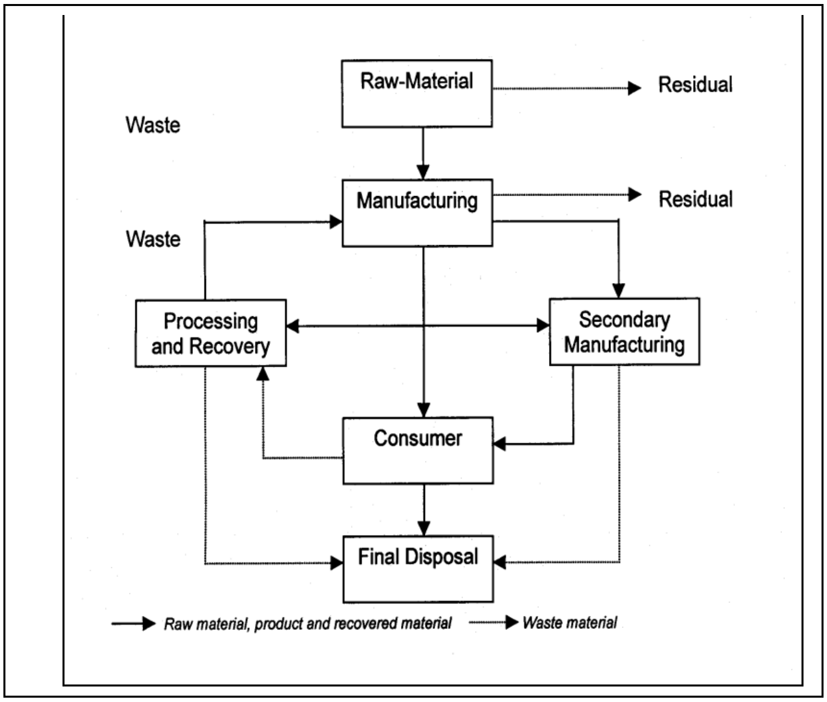
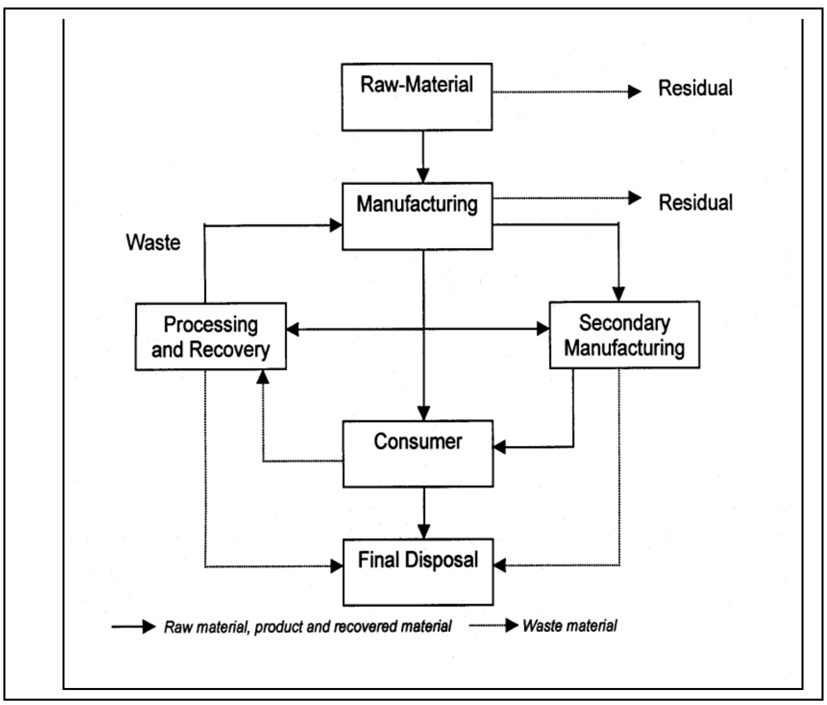


Figure 2.1 Material Flow and Waste



Generation

Figure 2.1 suggests that we can reduce the amount of solid waste by limiting the consumption of raw materials and increasing the rate of recovery and reuse.

There needs to be, therefore, a societal change in the perception of wastes. This sounds simple. But, implementing changes in the society is difficult, unless appropriate management solutions are provided. That said, we also must note that the changes in waste generation contribute to changes in waste composition, and this we will discuss next.

2.2.2 Waste composition

Some of the general observations associated with the composition of wastes include the following:

- The major constituents are paper and decomposable organic materials.
- More often than not, metal, glass, ceramics, textile, dirt and wood form part of the composition, and their relative proportion depends on local factors.
- Average proportions of the constituents reaching the disposal sites are consistent and urban wastes are fairly constant although subject to long-term changes such as seasonal variations.

Waste composition varies with the socio-economic status within a particular community, since income, for example, determines life style, composition pattern and cultural behaviour (http://ces.iisc.ernet.in/energy/SWMTR/TR85.html). Table 2.1 illustrates this phenomenon in India:

Table 2.1
Typical Waste Composition: Low/High Income Population

Characteristics	**Low income**	**High income**	**Comments**
Paper	1 – 4%	20 – 50%	Low paper content indicates low calorific value.
Plastics	1 – 6%	5 – 10%	Plastic is low as compared to high-income areas though the use of plastic has increased in recent years.
Ash and Fines	17 – 62%	3 – 10%	Ash and fines do not contribute to combustion

Characteristics	**Low income**	**High income**	**Comments**
			process.
Moisture Content	30 – 40%	15 – 30%	Moisture content depends largely on the nature of the waste, climate and collection frequency. Waste can dry out while awaiting collection.
Bulk Density	300 – 400 kg/ m^3	150 kg/m^3	Heavier waste may cost more to handle and difficult to burn.

Waste composition also depends on the moisture content, density and relative distribution of municipal wastes, as shown in Table 2.2 below, and is important for the characterisation of solid waste for most applications (Ali, et al., 1999):

Table 2.2
Solid Wastes: Typical Composition, Moisture and Density

Components	**Mass %**		**Moisture content %**		**Density in kg/m**	
	Range	**Typical**	**Range**	**Typical**	**Range**	**Typical**
Food wastes	6-26	14	50-80	70	120-480	290
Paper	15-45	34	4-10	6	30-130	85
Cardboard	3-15	7	4-8	5	30-80	50
Plastics	2-8	5	1-4	2	30-130	65
Textiles	0-4	2	6-15	10	30-100	65
Rubber	0-1	0.5	1-4	2	90-200	130
Leather	0-2	0.5	8-12	10	90-260	160
Garden Trimming	0-20	12	30-80	60	60-225	105
Wood	1-4	2	15-40	20	120-320	240
Misc. Organic substances	0-5	2	10-60	25	90-360	240
Glass	4-16	8	1-4	2	160-480	195
Tin cans	2-8	6	2-4	3	45-160	90
Non-ferrous metals	0-1	1	2-4	2	60-240	160

Components	Mass %		Moisture content %		Density in kg/m	
	Range	Typical	Range	Typical	Range	Typical
Ferrous metals	1-4	2	2-6	3	120-1200	320
Dirt, ash, bricks, etc.	0-10	4	6-12	8	320-960	480

Note that the density of waste changes as it moves from the source of generation to the point of ultimate disposal, and such factors as storage methods, salvaging activities, exposure to weather, handling methods and decomposition influence the density. In short, predicting changes of waste composition is as difficult as forecasting waste quantities.

2.2.3 Factors causing variation

As we know, wastes cause pollution. While the nature of wastes determines the type and intensity of pollution, it also helps us decide on the appropriate application, engineering design and technology for management. For example, the nature of wastes has implications for collection, transport and recycling. For effective SWM, therefore, we not only need information about the present but also the expected future quantity and composition of wastes.

There are several factors, which affect the present as well as the future waste quantity and composition (Tchobanoglous, et al., 1977), and some of which are listed below:

- **Geographic location:** The influence of geographic location is related primarily to different climates that can influence both the amount of certain types of solid wastes generated and the collection operation. For instance, substantial variations in the amount of yard and garden wastes generated in various parts of India are related to the climate. To illustrate, in the warmer southern areas, where the growing season is considerably longer compared to the northern areas, yard wastes are collected in considerably larger quantities and over a longer period of time.

- **Seasons:** Seasons of the year have implications for the quantities and composition of certain types of solid wastes. For example, the growing season of vegetables and fruits affect the quantities of food wastes.

- **Collection frequency:** A general observation is that in localities, where there are ultimate collection services, more wastes are *collected*. Note that this does not mean that more wastes are *generated*. For example, if a homeowner has access to only one or two containers per week, due to limited container capacity, he or she will store newspapers or other materials in some specified storage area. However, the same homeowner will tend to throw them away, if there is access to unlimited container services. In this latter situation, the quantity of waste generated may actually be the same but the quantity collected, as it relates to the frequency of collection, is considerably different.

- **Population diversity:** The characteristics of the population influence the quantity and composition of waste generated. The amount of waste generated is more in low-income areas compared to that in high-income areas. Similarly, the composition differs in terms of paper and other recyclables, which are typically more in high-income areas as against low-income areas (see Table 2.1).

- **Extent of salvaging and recycling:** The existence of salvaging and recycling operation within a community definitely affects the quantity of wastes collected.

- **Public attitude:** Significant reduction in the quantity of solid waste is possible, if and when people are willing to change – on their own volition – their habits and lifestyles to conserve the natural resources and to reduce the economic burden associated with the management of solid wastes.

- **Legislation:** This refers to the existence of local and state regulations concerning the use and disposal of specific materials and is an important factor that influences the composition and generation of certain types of wastes. The Indian legislation dealing with packing and beverage container materials is an example.

In short elements that relate to waste generation include land use characteristics, population in age distribution, legislation, socio economic conditions, household and approximate number.

LEARNING ACTIVITY 2.2

Discuss the factors that contribute to the variations in composition of solid wastes.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

Having discussed waste generation and its composition in Sections 2.1 and 2.2, respectively, we will introduce in Section 2.3 the physical and chemical characteristics of wastes that generally inform decisions regarding waste management including disposal methods.

2.3 WASTE CHARACTERISTICS

In order to identify the exact characteristics of municipal wastes, it is necessary that we analyse them using physical and chemical parameters (Phelps, et al., 1995), which we will discuss in Subsections 2.3.1 and 2.3.2, respectively.

2.3.1 Physical characteristics

Information and data on the physical characteristics of solid wastes are important for the selection and operation of equipment and for the analysis and design of disposal facilities. The required information and data include the following:

(i) **Density:** Density of waste, i.e., its mass per unit volume (kg/m^3), is a critical factor in the design of a SWM system, e.g., the design of sanitary landfills, storage, types of collection and transport vehicles, etc. To explain, an efficient operation of a landfill demands compaction of wastes to optimum density. Any normal compaction equipment can achieve reduction in volume of wastes by 75%, which increases an initial density of 100 kg/m^3 to 400 kg/m^3. In other words, a waste collection vehicle can haul four times the weight of waste in its compacted state than when it is uncompacted. A high initial density of waste precludes the achievement of a high compaction ratio and the compaction ratio achieved is no greater than 1.5:1. Significant changes in density occur spontaneously as the waste moves from source to disposal, due to scavenging, handling, wetting and drying by the weather, vibration in the collection vehicle and decomposition. Note that:

- the effect of increasing the moisture content of the waste is detrimental in the sense that dry density decreases at higher moisture levels;
- soil-cover plays an important role in containing the waste;
- there is an upper limit to the density, and the conservative estimate of in-place density for waste in a sanitary landfill is about 600 kg/$m^{3.}$

(ii) **Moisture content:** Moisture content is defined as the ratio of the weight of water (wet weight - dry weight) to the total weight of the wet waste. Moisture increases the weight of solid wastes, and thereby, the cost of collection and transport. In addition, moisture content is a critical determinant in the economic feasibility of waste treatment by incineration, because wet waste consumes energy for evaporation of water and in raising the temperature of water vapour. In the main, wastes should be insulated from rainfall or other extraneous water. We can calculate the moisture percentage, using the formula given below:

$$\text{Moisture content (\%)} = \frac{\text{Wet weight - Dry weight}}{\text{Wet weight}} \times 100$$

A typical range of moisture content is 20 to 40%, representing the extremes of wastes in an arid climate and in the wet season of a region of high precipitation. However, values greater than 40% are not uncommon.

(iii) **Size:** Measurement of size distribution of particles in waste stream is important because of its significance in the design of mechanical separators and shredders. Generally, the results of size distribution analysis are expressed in the manner used for soil particle analysis. That is to say, they are expressed as a plot of particle size (mm) against percentage, less than a given value.

The physical properties that are essential to analyse wastes disposed at landfills are:

I. Field capacity: The field capacity of MSW is the total amount of moisture which can be retained in a waste sample subject to gravitational pull. It is a critical measure because water in excess of field capacity will form leachate, and leachate can be a major problem in landfills. Field capacity varies with the degree of applied pressure and the state of decomposition of the wastes.

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

Porosity: It represents the amount of voids per unit overall volume of material. The porosity of MSW varies typically from 0.40 to 0.67 depending on the compaction and composition of the waste.

Porosity of solid waste $n = e/(1+e)$

Where e is void ratio of solid waste

III. Compressibility of MSW: Degree of physical changes of the suspended solids or filter cake when subjected to pressure.

$\Delta H_T = \Delta H_i + \Delta H_c + \Delta H_\alpha$ [ΔH_T= total settlement; ΔH_i=immediate settlement; ΔH_c = consolidation settlement; ΔH_α = secondary compression or creep.]

$C'_\alpha = \Delta H / [H_0 \times (\text{Log}\,(t_2/t_1))] = C_\alpha / (1+e_0)$

[*C*α, *C'α* = Secondary compression index and Modified secondary Compression index; and t1, t2= Starting and ending time of secondary settlement respectively.]

LEARNING ACTIVITY 2.3

Determine the moisture content of the sample from the following data:

Waste Composition	% by Weight	Moisture Content
Food wastes	15	70
Paper	45	6
Cardboard	10	5
Plastic	10	2
Garden trimmings	10	60
Wood	5	20
Tin, cans	3	3

Based on 100 kg's

Hint: Compute dry weight (i.e., individual constituent wet weight – moisture). Moisture content of the sample (wet weight – dry weight)* 100/wet weight.

Note:

a) Write your answer in the space given below.

b) Check your answer with the one given at the end of this Unit.

2.3.2 Chemical characteristics

Knowledge of the classification of chemical compounds and their characteristics is essential for the proper understanding of the behaviour of waste, as it moves through the waste management system. The products of decomposition and heating values are two examples of chemical characteristics. If solid wastes are to be used as fuel, or are used for any other purpose, we must know their chemical characteristics, including the following:

(i) **Lipids:** This class of compounds includes fats, oils and grease, and the principal sources of lipids are garbage, cooking oils and fats. Lipids have high heating values, about 38,000 kJ/kg (kilojoules per kilogram), which makes waste with high lipid content suitable for energy recovery. Since lipids become liquid at temperatures slightly above ambient, they add to the liquid content during waste decomposition. Though they are biodegradable, the rate of biodegradation is relatively slow because lipids have a low solubility in water.

(ii) **Carbohydrates:** These are found primarily in food and yard wastes, which encompass sugar and polymer of sugars (e.g., starch, cellulose, etc.) with general formula $(CH_2O)_x$. Carbohydrates are readily biodegraded to products such as carbon dioxide, water and methane. Decomposing carbohydrates attract flies and rats, and therefore, should not be left exposed for long duration.

(iii) **Proteins:** These are compounds containing carbon, hydrogen, oxygen and nitrogen, and consist of an organic acid with a substituted amine group (NH_2). They are mainly found in food and garden wastes. The partial decomposition of these compounds can result in the production of amines that have unpleasant odours.

(iv) **Natural fibres:** These are found in paper products, food and yard wastes and include the natural compounds, cellulose and lignin, that are resistant to biodegradation. (Note that paper is almost 100% cellulose, cotton over 95% and wood products over 40%.) Because they are a highly combustible solid waste, having a high proportion of paper and wood products, they are suitable for incineration. Calorific values of oven-dried paper products are in the range of 12,000 -18,000 kJ/kg and of wood about 20,000 kJ/kg, i.e., about half that for fuel oil, which is 44,200 kJ/kg.

(v) **Synthetic organic material (Plastics):** Accounting for 1 – 10%, plastics have become a significant component of solid waste in recent years. They are highly resistant to biodegradation and, therefore, are objectionable and of special concern in SWM. Hence the increasing attention being paid to the recycling of plastics to reduce the proportion of this waste component at disposal sites. Plastics have a high heating value, about 32,000 kJ/kg, which makes them very suitable for incineration. But, you must note that polyvinyl chloride (PVC), when burnt, produces dioxin and acid gas. The latter increases corrosion in the combustion system and is responsible for acid rain.

(vi) **Non-combustibles:** This class includes glass, ceramics, metals, dust and ashes, and accounts for 12 – 25% of dry solids.

(vii) **Heating value:** An evaluation of the potential of waste material for use as fuel for incineration requires a determination of its heating value, expressed as kilojoules per kilogram (kJ/kg). The heating value is determined experimentally using the *Bomb calorimeter test*, in which the heat generated, at a constant temperature of 25°C from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water (100°C), the combustion water remains in the liquid state. However, during combustion, the temperature of the combustion gases reaches above 100°C, and the resultant water is in the vapour form. Table 2.3 shows the typical inert residue and heating values for the components of municipal solid waste (Tchobanoglous, et al., 1977):

Table 2.3
Typical Heating and Inert Residue Values

Component	Inert Residue %		Heating Value (kJ/kg)	
	Range	Typical	Range	Typical
Food wastes	2-8	5	3500-7000	4500
Paper	4-8	6	11500-18500	16500
Cardboard	3-6	5	14000-17500	16000
Plastics	2-20	10	28000-37000	32500
Textiles	2-4	2.5	15000-20000	17500

Component	Inert Residue %		Heating Value (kJ/kg)	
	Range	Typical	Range	Typical
Rubber	8-20	10	21000-28000	18500
Leather	8-20	10	15000-20000	17500
Garden trimmings	2-6	4.5	2300-18500	6500
Wood	0.6-2	1.5	17500-20000	18500
Glass	96-99	98	120-240	140
Tin cans	96-99	96	-	-
Nonferrous metals	90-99	96	240-1200	700
Ferrous metals	94-99	98	240-1200	700
Dirt, ash, bricks, etc.	60-80	70	2300-11500	7000
Municipal solid waste			9500-13000	10500

Note that while evaluating incineration as a means of disposal or energy recovery, we need to consider the heating values of respective constituents (see Table 2.3). For example:

- Organic material yields energy only when dry.
- The moisture content in the waste reduces the dry organic material per kilogram of waste and requires a significant amount of energy for drying.
- The ash content of the waste reduces the proportion of dry organic material per kilogram of waste and retains some heat when removed from the furnace.

(viii) **Ultimate analysis:** This refers to an analysis of waste to determine the proportion of carbon, hydrogen, oxygen, nitrogen and sulphur, and the analysis is done to make mass balance calculation for a chemical or thermal process. Besides, it is necessary to determine ash fraction because of its potentially harmful environmental effects, brought about by the presence of toxic metals such as cadmium, chromium, mercury, nickel, lead, tin and zinc. Note that other metals (e.g., iron, magnesium, etc.) may also be present but they are non-toxic. Table 2.4 shows the result of ultimate analysis of a typical municipal solid waste:

Table 2.4
Municipal Solid Waste: A Typical Ultimate Analysis

Element	Range (%dry weight)
Carbon	25-30
Hydrogen	2.5-6.0
Oxygen	15-30
Nitrogen	0.25-1.2
Sulphur	0.02-0.12
Ash	12-30

(ix) **Proximate analysis:** This is important in evaluating the combustion properties of wastes or a waste or refuse derived fuel. The fractions of interest are:

- moisture content, which adds weight to the waste without increasing its heating value, and the evaporation of water reduces the heat released from the fuel;
- ash, which adds weight without generating any heat during combustion;
- volatile matter, i.e., that portion of the waste that is converted to gases before and during combustion;
- fixed carbon, which represents the carbon remaining on the surface grates as charcoal. A waste or fuel with a high proportion of fixed carbon requires a longer retention time on the furnace grates to achieve complete combustion than a waste or fuel with a low proportion of fixed carbon.

Table 2.5 illustrates a proximate analysis for the combustible components of municipal solid waste:

Table 2.5
Municipal Solid Waste: A Typical Proximate Analysis

Components	**Value, percent**	
	Range	**Typical**
Moisture	15-40	20
Volatile matter	40-60	53
Fixed carbon	5-12	7
Glass, metal, ash	15-30	20

What Subsection 2.3.2 implies is that to evaluate alternative processing and recovery options (e.g., incineration process), we need information on the chemical characteristics of wastes, and wastes can typically be a combination of combustible and non-combustible materials.

LEARNING ACTIVITY 2.4

Identify and list the chemical characteristics of two types of municipal wastes commonly present in your locality.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

Waste mismanagement, e.g., the practice of throwing wastes into streets, storm water drains, vacant land, etc., leads to breeding of disease vectors such as rats, with their attendant fleas carrying germs, etc., which results in an epidemic such as plague, malaria, etc. This has an adverse impact on public health and environment. We will look into the consequences of waste mismanagement on public health and the environment in Section 2.4.

2.4 HEALTH AND ENVIRONMENTAL EFFECTS

An effective solid waste management system is necessary to avoid public health disasters, spread of disease by insects and vectors and adverse effect on water and air (Phelps, et al., 1995). Solid waste workers are the most exposed to the risks of parasitic infections and accidents, and therefore, a SWM system must include proper mechanisms to avoid these incidences. To the direct and indirect risks through accidents, exposure and spread of disease, we must add the effect of visual pollution caused by litter and nuisance created by smoke and dust at disposal sites. Against this background, let us discuss the health and environmental effects of solid wastes in Subsections 2.4.1 and 2.4.2.

2.4.1 Public health effect

The volume of waste is increasing rapidly as a result of increasing population and improving economic conditions in various localities. This increased volume of wastes is posing serious problems due to insufficient workforce and other constraints in disposing of it properly. What are the consequences of improper management and handling of wastes? Consider the following:

(i) **Disease vectors and pathways:** Wastes dumped indiscriminately provide the food and environment for thriving populations of vermin, which are the agents of various diseases. The pathways of pathogen transmission from wastes to humans are mostly indirect through insects – flies, mosquitoes and roaches and animals – rodents and pigs. Diseases become a public health problem when they are present in the human and animal population of surrounding communities, or if a carrier transmits the etiological agent from host to receptor.

(ii) **Flies:** Most common in this category is the housefly, which transmits typhoid, salmonellosis, gastro-enteritis and dysentery. Flies have a flight range of about 10 km, and therefore, they are able to spread their influence over a relatively wide area. The four stages in their life-cycle are egg, larva, pupa and adult. Eggs are deposited in the warm, moist environment of decomposing food wastes. When they hatch, the larvae feed on the organic material, until certain maturity is reached, at which time they migrate from the waste to the soil of other dry loose material before being transformed into pupae. The pupae are inactive until the adult-fly emerges. The migration of larvae within 4 to 10 days provides the clue to an effective control measure, necessitating the removal of waste before migration of larvae. Consequently, in warm weather, municipal waste should be collected twice weekly for effective control. In addition, the quality of household and commercial storage containers is very significant. The guiding principle here is to restrict access to flies. Clearly, the use of suitable storage containers and general cleanliness at their location, as well as frequent collection of wastes, greatly reduces the population of flies. Control is also necessary at transfer stations, composting facilities and disposal sites to prevent them from becoming breeding grounds for flies. Covering solid wastes with a layer of earth at landfill sites at the end of every day arrests the problem of fly breeding at the final stage.

(iii) **Mosquitoes:** They transmit diseases such as malaria, filaria and dengue fever. Since they breed in stagnant water, control measures should centre on the elimination of breeding places such as tins, cans, tyres, etc. Proper sanitary practices and general cleanliness in the community help eliminate the mosquito problems caused by the mismanagement of solid waste.

(iv) **Roaches:** These cause infection by physical contact and can transmit typhoid, cholera and amoebiasis. The problems of roaches are associated with the poor storage of solid waste.

(v) **Rodents:** Rodents (rats) proliferate in uncontrolled deposits of solid wastes, which provide a source of food as well as shelter. They are responsible for the spread of diseases such as plague, murine typhus, leptospirosis, histoplasmosis, rat bite fever, dalmonelosis, trichinosis, etc. The fleas, which rats carry, also cause many diseases. This problem is associated not only with open dumping but also poor sanitation.

(vi) **Occupational hazards:** Workers handling wastes are at risk of accidents related to the nature of material and lack of safety precautions. The sharp edges of glass and metal and poorly constructed storage containers may inflict injuries to workers. It is, therefore, necessary for waste handlers to wear gloves, masks and be vaccinated. The infections associated with waste handling, include:

- skin and blood infections resulting from direct contact with waste and from infected wounds;
- eye and respiratory infections resulting from exposure to infected dust, especially during landfill operations;
- diseases that result from the bites of animals feeding on the waste;
- intestinal infections that are transmitted by flies feeding on the waste;
- chronic respiratory diseases, including cancers resulting from exposure to dust and hazardous compounds.

In addition, the accidents associated with waste handling include:

- bone and muscle disorders resulting from the handling of heavy containers and the loading heights of vehicles;

- infecting wounds resulting from contact with sharp objects;
- reduced visibility, due to dust along the access routes, creates greater risk of accidents;
- poisoning and chemical burns resulting from contact with small amounts of hazardous chemical wastes mixed with general wastes such as pesticides, cleaning solutions and solvents in households and commercial establishments;
- burns and other injuries resulting from occupational accidents at waste disposal sites or from methane gas explosion at landfill sites;
- serious health hazards, particularly for children, due to careless dumping of lead-acid, nickel-cadmium and mercuric oxide batteries.

(vii) **Animals:** Apart from rodents, some animals (e.g., dogs, cats, pigs, etc.) also act as carriers of disease. For example, pigs are involved in the spread of diseases like trichinosis, cysticerosis and toxoplasmosis, which are transmitted through infected pork, eaten either in raw state or improperly cooked. Solid wastes, when fed to pigs, should be properly treated (cooked at 100°C for at least 50 minutes with suitable equipment).

2.4.2 Environmental effect

Besides causing health disorders that we have touched upon in Subsection 2.4.1, inadequate and improper waste management causes adverse environmental effects such as the following:

(i) **Air pollution:** Burning of solid wastes in open dumps or in improperly designed incinerators emit pollutants (gaseous and particulate matters) to the atmosphere. Studies show that the environmental consequences of open burning are greater than incinerators, especially with respect to aldehydes and particulates. Emissions from an uncontrolled incinerator system include particulate matter, sulphur oxides, nitrogen oxides, hydrogen chloride, carbon monoxide, lead and mercury. Discharge of arsenic, cadmium and selenium is to be controlled, since they are toxic at relatively low exposure levels. Polychlorinated dibenzofurans (PCDFs), commonly called dioxins and furans, are of concern because of their toxicity, carcinogenicity and possible mutagenicity.

(ii) **Water and land pollution:** Water pollution results from dumping in open areas and storm water drains, and improper design, construction and/or operation of a sanitary landfill. Control of infiltration from rainfall and surface runoff is essential in order to minimise the production of leachate. Pollution of groundwater can occur as a result of:

- the flow of groundwater through deposits of solid waste at landfill sites;
- percolation of rainfall or irrigation waters from solid wastes to the water table;
- diffusion and collection of gases generated by the decomposition of solid wastes.

The interaction between leachate contaminants and the soil depends on the characteristics of the soil. Soil bacteria stabilise biochemical oxygen demand (BOD), i.e., the amount of oxygen required by micro-organisms to degrade organic matter, by anaerobic action, if toxic substances are in low concentration. The carbon dioxide produced keeps the pH level low, causing the water to dissolve minerals in the aquifers. Consequently, the change in groundwater quality may take place depending on the characteristics of the aquifer. Contamination can spread over considerable distances from the landfill, if the aquifers are of sand or gravel. In clayey soils, the rate of movement is greatly reduced. The capacity of clay to exchange ions restricts the movement of metal ions by capturing them in the soil matrix. Changes in its chemical characteristics are due to hardness, iron and manganese compounds.

(iii) **Visual pollution:** The aesthetic sensibility is offended by the unsightliness of piles of wastes on the roadside. The situation is made worse by the presence of scavengers rummaging in the waste. Waste carelessly and irresponsibly discarded in public thoroughfares, along roads and highways and around communal bins (i.e., makeshift containers, without lids, used for the storage of residential, commercial and institutional wastes) gives easy access to animals scavenging for food. The solution to this social problem undoubtedly lies in the implementation of public education at all levels – primary, secondary, tertiary and adult, both short- and long-term, and in raising the status of public health workers and managers in solid waste management.

(iv) **Noise pollution:** Undesirable noise is a nuisance associated with operations at landfills, incinerators, transfer stations and sites used for recycling. This is due to the movement of vehicles, the operation of large machines and the diverse operations at an incinerator site. The impacts of noise pollution may be reduced by careful siting of SWM operations and by the use of noise barriers.

(v) **Odour pollution:** Obnoxious odours due to the presence of decaying organic matter are characteristic of open dumps. They arise from anaerobic decomposition processes and their major constituents are particularly offensive. Proper landfill covering eliminates this nuisance.

(vi) **Explosion hazards:** Landfill gas, which is released during anaerobic decomposition processes, contains a high proportion of methane (35 – 73%). It can migrate through the soil over a considerable distance, leaving the buildings in the vicinity of sanitary landfill sites at risk, even after the closure of landfills. Several methods are available for control of landfill gas, such as venting, flaring and the use of impermeable barriers.

Evalution methodology for generated solid waste involves analysis of landfill performance, the unit weight and compressibility, economic viability, MSW constituents, equations for evaluating MSW, data acquisition, source of evaluating that is study plan, demographic study, Questionnaire design to know who, what, where and why and statistics generation to analyse planning data.

Let us discuss the case study of Bangalore waste generation in the next section before that let us do a learning activity.

LEARNING ACTIVITY 2.5

List the adverse health and environment impacts due to improper handling of solid waste. Identify at least four such effects in your locality.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

2.5 CASE STUDY: STATUS OF WASTE GENERATION IN BANGALORE

SWM in urban areas has interface with all aspects of life and government administration (Areivala, 1971). And, through this case study, we intend to share with you some practical aspects of SWM, from the disposal of building debris to

organic, putrescible, and bio-medical wastes and their possible recycling potential. For details, see http://stratema.sigis.net/cupum/pdf/E1.pdf.
Bangalore, also known as the Garden City, is one of the fastest growing metropolitan cities in South India. It is the state capital of Karnataka and the sixth largest city in India. Topographically, Bangalore is located in the south deccan and physically, has grown on watershed running through the middle of the Mysore Plateau from west to east which serves as the main water parting of the state at an average elevation of 900 meters above sea level. The city gets moderate rainfall of around 900 mm largely between June and October. On account of its elevation, Bangalore is bestowed with salubrious and equable climate comparable to those of temperate regions.

The city covers the local planning area of 500 sq. kms. Out of this, 226.16 sq. kms are developed at present. In 1991, its population was 4.16 million and has grown over 6 million, as per recent projected population estimates. Besides, the city has a floating population of over 0.5 million. It is a fast growing city beset with the usual problems of inadequate waste management, due to constraints such as lack of finance and other resources, deficiencies in equipment and workforce and paucity of space (for waste disposal).

The Bangalore Mahanagara Palike (BMP), the erstwhile Bangalore City Corporation (BCC), is concerned with the prime areas of public health, solid waste management including health care waste and sanitation, education, horticulture, etc. Working with non-governmental and voluntary organisations of all stakeholders in a participatory approach, BMP is striving to implement suggestions towards an improved SWM.

SWM is a vital function of the Health Department, supported by the Engineering Department of BMP and the health officer heads the SWM wing. In the present context, SWM in BMP essentially means the cleaning of streets, emptying dustbins, transportation of wastes to city outskirts and burning them in open areas for their disposal (Attarwalla, 1993, Gotoh, 1989, Development, 1998, Ogawa, 1989, and Vagale, 1997).

The waste generation and composition details of Bangalore are as follows:

(i) **Waste generation:** Bangalore produces over 2500 tonnes of solid waste per day and the Municipal Corporation has miserably inadequate infrastructure in managing the disposal of solid wastes generated. It is estimated that the per capita generation of solid waste works out to 0.59 kg/day. The sources of waste generation and the amount generated at each source are given in Table 2.6.

Table 2.6
Different Sources of Solid Waste Generation in Bangalore

Sl No.	Source	Quantity (in MT/day)
1	Households	1000
2	Shops, Establishments, Institutions, etc.	600
3	Markets	600
4	Others	300
5	TOTAL	2500

Source: Department of SWM, Bangalore Mahanagara Palike, Bangalore

(ii) **Waste composition:** The composition of wastes in Bangalore has wide variations in the proportion of contents. It varies from area to area, depending upon the socio-economic conditions and the population density. The composition of the total wastes generated in Bangalore city is given in Table 2.7.

Table 2.7
Composition of Solid Waste in Bangalore

Sl No.	Type of Waste	Composition (in percentage)
1	Putrescible waste	75.2
2	Dust and ash	12
3	Textiles	3.1
4	Paper	1.5
5	Plastic, leather and rubber	0.9
6	Glass	0.2
7	Metals	0.1
8	Earth and building debris and others	0.7

Source: Department of SWM, Bangalore Mahanagara Palike, Bangalore

In Bangalore, there are 401 slum pockets identified which come under the jurisdiction of three different authorities, viz., Bangalore City Corporation - 64 slums, Bangalore Development Authority – 64 slums, and Karnataka Slum Clearance Board – 273 slums. Fifteen percent of the city's population lives in these slums (Comprehensive Development Plan (Revised) Bangalore Report, 1995, p. 25). The slum locations are generally found to be least desirable from the point of view of habitation – being low lying areas, tank beds, quarry pits, near railway lines and cemeteries. The authorities have been unable to clear the garbage from most of the slums mainly due to the slum dwellers' practice of throwing their wastes into drains, and only part of the waste generated is available for collection. There are 12 large vegetable and fruit markets other than a number of small groups of pavement vegetable vendors. Approximately, these markets are producing more than 150 tonnes of wastes daily. In addition to this, large quantities of wastes get generated from slaughterhouses, food packing industries and cold storage facilities.

SUMMARY

This Unit began with a discussion on the significance of collecting information and data on wastes, and in that context discussed some aspects of waste stream assessment that would help in the planning and design of waste management activities. Following this discussion, we explained waste generation and composition and pointed out that solid wastes generated vary in composition and characteristics depending on the source of generation (domestic, industries, agriculture, institution or commercial sectors) and factors such as geographic location, seasonal variation, collection frequency, public attitude, etc. Then, we discussed how the information on the physical and chemical characteristics of wastes would help decide the various elements of waste management and disposal options. Subsequently, we discussed the consequences of improper disposal of solid waste on public health and the environment (e.g., air, water, visual, noise and odour pollution, explosion hazards, etc). We then touched upon some of these aspects through a case study of Bangalore.

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Lecture 2

Model Answers to Learning Activities

LEARNING ACTIVITY 2.1

The cornerstone of successful planning for a waste management programme is reliable information about the quantity, composition and sources of wastes. Waste stream assessment (WSA) helps in analysing the short- and long-term problems within the local waste management system. WSA is required to identify components that require improvement for implementing waste management programs. Field investigations for WSA are carried out in the absence of reliable basic data in three ways: (i) sorting of wastes, (ii) vehicle weighing at disposal sites and (iii) visiting institutional and industrial sites to identify wastes being generated and disposal methods.

Waste stream assessment at present is not practised in our locality, and the waste is usually dumped in storage containers and taken to landfill sites.

LEARNING ACTIVITY 2.2

Some of the important factors involved in the variation of composition of wastes are geographic location, seasons, collection frequency, population diversity, extent of salvaging and recycling, public attitude and legislation.

Geographic location is related primarily to the different climates that can influence both the amount of a particular type of solid waste generated and the collection operation. A majority of the developing countries are in the tropical region and thus their composition of wastes differs from that of developed countries. The frequency of waste collection depends on the quantity of waste generated. It is seen that the amount of wastes generated is more in low-income area compared to high-income area. Similarly, the composition differs in terms of paper and other recyclables, which are more in high-income area compared to low-income area. However, public attitude towards wastes will bring about a significant reduction in the quantities of solid wastes, if and when people are willing to change, on their own volition, their habits and lifestyles to conserve the natural resources. The last but not the least is the existence of local and state regulations concerning the use and disposal of specific materials.

LEARNING ACTIVITY 2.3

Component	**Percent by mass**	**Moisture content (%)**	**Dry mass, kg**
Food waste	15	70	4.5
Paper	45	6	42.3
Cardboard	10	5	9.5
Plastics	10	2	9.8
Garden trimmings	10	60	4.0
Wood	5	20	4.0
Tin cans	5	3	4.9
Total	100		79.0

Using the formula:

$$\text{Moisture content} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} \times 100$$

$$\text{Therefore, moisture content} = \frac{(100 - 79)}{100} \times 100 = 21\%$$

LEARNING ACTIVITY 2.4

The information on the chemical characteristics is important in evaluating alternative processing and recovery options. If solid waste is to be used as fuel or used for any other purpose, we must know its chemical characteristics including lipids, carbohydrates, proteins, natural fibres, synthetic organic materials (plastics) and noncombustible materials.

The 2 types of wastes commonly present in our locality are combustible wastes and garbage. Combustible waste such as plastics consists of natural fibres, and garbage such as food wastes have carbohydrates, lipids and proteins.

LEARNING ACTIVITY 2.5

Some of the adverse health and environmental effects, due to the improper handling of wastes are:

(i) **Health effects**: Wastes dumped indiscriminately provide the food and environment for breeding of various vectors, e.g., flies (salmonellosis, dysentry, etc.), mosquitoes and roaches (malaria, dengue fever, typhoid, cholera, amoebiasis, etc.) and animals, e.g., rodents and pigs (trichinosis, cysticerosis, etc.).

(ii) **Environmental effects**: Inadequate and improper waste management has serious environmental effects. These include air, water, land, visual, noise and odour pollution, and explosion hazards.

I reside in ward no. 89 of Bangalore, Karnataka, India where sufficient precaution is not practised, while handling municipal solid wastes. Based on a general observation, the four effects are the following:

- Due to open dumping, mosquitoes thrive in our locality, which may cause diseases like malaria or dengue fever.
- Rodents, notably rats proliferate in uncontrolled deposits of solid waste, which provide them with a convenient source of food and shelter.
- There is a risk of injury during handling of wastes, as workers are not provided with safety materials, e.g., gloves.
- The aesthetic sensibility (i.e., visual pollution) of concerned residents is offended by the unsightliness of piles of wastes.

Lecture 6

Source Reduction, Product Recovery and Recycling

STRUCTURE

OVERVIEW

As you recall, the focus of our discussion in Unit 5 was on some of the processing techniques in use in SWM systems to improve the efficiency of operations and recover resources (that could be reused) and energy. Now, in Unit 6, we analyse the recovery and recycling processes. We will, accordingly, begin the Unit by discussing the various aspects of source reduction including the design and implementation of specific source reduction programmes that inform decision-making. We will then examine how product recovery and recycling play a critical role in waste management plans. In this context, we will discuss the factors (e.g., material markets, building local expertise and fostering public participation) that are needed for planning an effective recycling programme and the elements of the recycling programme such as source separation, collection, material recovery facilities and processing. We will also look into the processing of some of the common materials that are recycled. We will close the Unit by presenting a case study on source reduction, resource recovery and recycling carried out in Bangalore.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- explain waste reduction;
- discuss the significance of waste recycling;
- plan a recycling programme;
- discuss recycling programme elements;
- identify commonly recycled materials, their use and economic values;
- assess technical options and processes involved in recycling of wastes;
- explain the constraints involved in the implementation of reducing and recycling programmes.

6.1 SOURCE REDUCTION: BASICS

Source reduction, also known as waste prevention, is an approach that precedes waste management and addresses how products are manufactured and, purchased. Put differently, this refers to the activities that reduce the amount of waste generated at source as well as activities that involve any change in the design, manufacture, purchase or usage of materials/products to reduce their volume and/or toxicity, before they become part of the solid waste stream (EPA, 1989 and 1995). Reducing waste before it is generated is a logical way to save costs and natural resources, and preserve the local environment. For instance, waste reduction cuts the municipal and commercial costs involved in waste collection and disposal, and improves the productivity by targeting wasteful processes and products.

However, a successful implementation of source reduction programme requires the co-operation of all stakeholders, (e.g., businesses, industries, consumers and state and local governments), as the goals and actions of the local waste management system are specific to local conditions. In fact, source reduction programme should be part of a community waste management plan. Source reduction activities vary widely and many factors have to be considered while evaluating them. In Subsections 6.1.1 to 6.1.4, we will examine some of the basics of source reduction processes (EPA, 1989 and 1995).

6.1.1 Purpose

Source reduction can serve several purposes, including the following:

(i) **Product reuse:** Using reusable products, instead of their disposal equivalents, reduce the amount of materials that are to be managed as wastes. An example of product reuse is the reusable shopping bag.

(ii) **Material volume reduction:** Reducing the volume of material used changes the amount of waste entering the waste stream. This helps in controlling the waste generated and its disposal. For example, buying in bulk or using large food containers reduces the amount of packaging waste generated.

(iii) **Toxicity reduction:** Source reduction reduces the amount of toxic constituents in products entering the waste stream and reduces the adverse environmental impacts of recycling or other waste management activities. For example, substitution of lead and cadmium in inks (solvent-based to water-based) and paints is a source reduction activity.

(iv) **Increased product lifetime:** Source reduction facilitates the use of products with longer lifetime over short-lived alternatives that are designed to be discarded at the end of their useful lives. Put differently, it encourages a product design that allows for repair and continued use rather than disposal. Manufacturing long-life tyres is a good example of increasing product lifetime.

(v) **Decreased consumption:** This refers to the reduced consumption of materials that are not reusable (e.g., using a reusable shopping bag instead of picking up plastic bags from the store). Consumer education about the materials that are difficult to dispose of or are harmful to the environment is essential. Buying practices can thus be altered (e.g., buying in bulk) to reflect environmental consciousness.

In brief four main advantages of source reduction are *

- Reduction in extent of environmental impacts
- Reduction in resource consumption and generation of pollution
- It includes producer, consumer, prudent and efficient activities.

6.1.2 Implementation

There are several specific actions that can take place at the local level to encourage source reduction, some of which are given below:

(i) **Education and research:** Consumers, businesses, industries, schools, etc., can implement education and research activities to address the need for source reduction, its consequences, available choices, benefits and costs. Essentially, the aim of such education and research activities is to provide and develop information about source reduction goals, needs and methods and to elicit voluntary efforts from the public and private sectors to help bring about some specific changes. Some of the activities that reflect education and research to encourage source reduction include:

- forming stakeholder councils (industry, government agencies, etc.) to develop a source reduction message to the public and to carry out educational and research activities;
- exploring and developing funding sources, such as government grants, financial support for industries, private funding grant, direct tax and solid waste surcharge;
- developing media campaign for public outreach, including posters, conferences and forums concerning source reduction;
- developing curricula for schools and universities as well as organising a group of professionals with knowledge of source reduction and solid waste management.

(ii) **Financial incentives and disincentives:** Linking an economic benefit to the implementation of source reduction activities encourages source reduction. For example, financial disincentives represent additional costs to the waste producing activities that could be avoided through source reduction activities. The various measures that can be targeted at consumers and industries include the following:

- Tax credit or exemption may be given to companies and institutions that follow specific source reduction procedures for manufacturing and consuming.
- As variable waste disposal charges for garbage collection are generally taken for post-consumer solid waste, the fees or payment can be based on the number of garbage cans used, number of bags collected or the frequency of collection.

- Graduated fee structure for garbage collection can be based on quantity and frequency.

- Product disposal charges can be assessed either on the producers at the time of manufacture or on the consumers at the time of purchase. However, we need to note that though these charges can encourage source reduction on economic grounds and the funds generated from the charges can be used to correct and reduce the impacts of product disposal, it is difficult to assess such charges effectively and efficiently.

(iii) **Regulation:** Although most regulation occurs at the national and state level, local authorities can participate in legislative activities in developing regulations that affect municipal SWM. It is possible, for example, to establish a programme to inform the consumers about environmental impacts, durability, reusability and recyclability of products as well as to declare source reduction as a top priority in SWM. Regulatory option of source reduction can include the following:

- Quantity control regulation, which encourages substitution of products that have the same function but pose less threat to human health and environment, through restrictions and bans.

- Product design regulation, which includes products that do not meet certain design criteria and could be subjected to quality control by sales tax and restrictions.

6.1.3 Monitoring

Monitoring facilitates the evaluation (i.e., efficacy and efficiency) of source reduction, the identification of possible source reduction measures and programme revisions and the obtaining of funds and resources for source reduction initiatives/programmes. Monitoring should, therefore, be an integral part of a source reduction programme. We must, however, note that source reduction is more difficult to measure on a broad scale than other methods of SWM. When several waste reduction techniques are used simultaneously, for example, it is not easy to determine which portion of the diversion was due to source reduction.

Source reduction often results in substantial and measurable cost savings from activities such as waste collection, transportation and disposal, and direct savings. In addition, source reduction is cost-effective in decreasing pollution, purchase, use, and regulatory compliance costs. It also reduces product and material use and disposal costs in the manufacturing process, making business operations more efficient. There is, however, some concern that source reduction might reduce economic growth by decreasing consumption. Nonetheless, it offers opportunities for economic gain by resource recovery and employment generation in source reduction programmes. Costs associated with source reduction must, therefore, form part of the monitoring process to ensure accountability.

Life cycle analysis

An environmental economic analysis will help us understand the trade-offs between source reduction, durability, recyclability, use of recycled material and other environmental benefits. Obviously, we choose the process that yields the greatest overall environmental benefits. Ideally, to assess and quantify these trade-offs, a life cycle analysis (LCA) – variously known as life cycle assessment, 'cradle to grave analysis' or 'econ-balance' – is required, which involves the evaluation of some aspects, particularly most often the environmental aspect, of a product through all stages of its life cycle.

LCA, in essence, takes a detailed look at all resources used and the products and by-products generated throughout the entire life of a product or process. The analysis begins with raw materials and energy acquisition, examines manufacturing and product fabrication, filling, packaging and distribution, and consumer use and reuse, and finally ends with an analysis of waste management.

Note that LCA represents a rapidly emerging family of tools and techniques designed to help in environmental management and long-term sustainable development (European Environment Agency, 1998) and the LCA procedures are being developed to assess the overall environmental impact of products and their packages. We will discuss LCA in detail later in Unit 10.

6.1.4 Evaluation

Before adopting source reduction policies, it is important that we develop a framework for evaluating various options. Some of the criteria to be considered in this regard are:

- Social and economic equity.
- Economic and administrative feasibility, efficiency and cost.
- Volume requirement and scarcity of materials and natural resources in product manufacture.
- Volume of product and its by-products that must be eventually disposed.
- Useful life, reusability and/or recyclability of a product.
- Priority of source reduction of more hazardous products to less hazardous ones.

LEARNING ACTIVITY 6.1

(i) Explain the need for source reduction in waste management.

(ii) List the criteria to be considered in the evaluation of various options before adopting a source reduction policy.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

Having studied the various aspects of source reduction, we will next deal with handling (i.e., reusing, recycling or disposing of) that portion of waste stream which cannot be reduced at the source. We will also explain how wastes can be recycled and utilised to derive from them optimum economic value.

6.2 SIGNIFICANCE OF RECYCLING

Recycling is perhaps the most widely recognised form of source reduction involving the process of separating, collecting, processing, marketing and ultimately using a material that would have otherwise been discarded. This form of source reduction, i.e., recycling, is similar to other forms, in that it:

- lessens reliance on landfills and incinerators;
- protects human health and the environment by removing harmful substances from the waste stream;
- conserves natural resources by reducing the demand for raw materials.

Recycling is one of the fundamental parts of the waste management plan. Although it alone cannot solve a community's municipal SWM problem, it can divert a significant portion of waste stream from disposal in landfill and combustion facilities. Recycling has a lot of direct and indirect significance for the society, and this can be grouped under the following three broad areas (UNCHS, 1994):

(i) **Economic significance:** Economic assessment of waste recycling is a difficult task as many of the beneficial environmental and social impacts of recycling are long-term and are intangible, and, therefore, are difficult to quantify. Some of the short- and long-term economic benefits are:

- **Cost reduction:** Resource recovery through recycling of solid waste could be of interest to waste management authorities as a means of reducing the waste disposal cost. Any saving in waste management cost could be a significant incentive to the authorities to increase the coverage of service areas and improve the service level. They can save cost from fuel for transportation, operation and maintenance, and generate revenue by sale of recyclables, etc.
- **Employment:** Recycling of waste is a labour intensive activity, and its potential to ease the unemployment problem is high. Enhanced recycling activities, for example, can create an additional job market for skilled and unskilled workforce, and they can adapt to any of the occupations such as a labourer in recycling business or industry or a dealership.

- **Energy saving:** Use of recyclables in some industrial processes is known to consume less energy than the use of any other raw material. The reduction in energy consumption in one industry could mean its availability for some other industry in need.

- **Reduced health care costs:** Improved health and sanitary conditions in urban areas resulting from indirect benefits of waste recycling can reduce the investment in public health programme.

- **Saving costs for other public utilities:** Enhanced solid waste recycling practices can reduce the frequency of sewer clogging, blocking of natural watercourses and pollution of water bodies. This will benefit the concerned public utilities through reduced cost in cleaning sewers and improved public safety due to blocked sewers and narrowing of natural watercourses.

(ii) **Environmental and health significance:** The volume of waste is increasing rapidly because of population growth and economic development. The composition of waste is also changing, leading to waste production with more recyclables. At the same time, polluted waste fractions are increasing because of increasing complex processes being used in industries, and these contribute increasingly to environmental degradation. This notwithstanding, recycling helps, among others, in the following ways, to facilitate effective waste management:

- **Improved environment:** The environmental pollution may be due to inadequate SWM as well as due to its effect on other urban infrastructure. Recycling reduces the volume of waste that has to be finally dumped, and thereby causing reduction in pollution at the waste disposal sites. When there is reduction in volume of waste because of its increased reuse, different types of pollution (e.g., water, air and land) will get abated.

- **Natural resource conservation:** Industries with natural products as their raw material for production are depleting natural resources. Use of more and more recyclable solid wastes in industrial production will relieve the tremendous pressure on these precious resources. For example, recycling of waste paper means a lower demand for wood, which means less cutting of trees and an enhanced possibility for sustainable use of the forest. Using recyclable items in the production process would reduce the demand for energy as well.

(iii) **Social significance:** People engaged in waste collection activities are normally of low social and economic standing. This is especially true with scavengers, which is evident from persisting poor quality of their living and working conditions. Different groups of people engaged in waste recycling have a hierarchical social and economic status, in which, processors are at the top of the hierarchy followed by waste dealers and wholesalers, waste buyers and waste collectors in that very order, while scavengers are at the bottom. Although there is this social and economic hierarchy within the waste recycling business, the overall social esteem of waste recycling operators is low.

A formal recycling arrangement will help promote the social esteem of waste workers and facilitate their upward social mobility due to increased earning. In addition, the improved recycling activity will increase the economic value of the waste and will reduce waste scavenging activity providing opportunity for scavengers to switch to a more socially acceptable occupation. In short, institutionalised recycling programmes will help remove the stigma associated with waste scavenging and transform it to an economic enterprise.

LEARNING ACTIVITY 6.2

Explain how recycling takes place in your locality and list its advantages?

Note:

a) Write your answer in the space given below.

b) Check your answer with the one given at the end of this Unit.

Now that we learnt the importance of recycling, which is more than just the separation and collection of post-consumer materials, let us plan a recycling programme, which indeed is the focus of Section 6.3.

6.3 PLANNING OF A RECYCLING PROGRAMME

Numerous recycling options are available, and recycling programme development requires strategic planning. Planning for recycling involves understanding markets, assessing local expertise, setting goals and fostering public participation. An efficient recycling programme requires a systematic approach to all programme components, which are interrelated, and therefore, decisions about one must be made taking into consideration other components. As a successful recycling requires public participation, programmes must be designed keeping in view public convenience and support. The factors involved in the planning process include the following (EPA, 1989 and 1995):

(i) **Build local expertise:** Small projects help build local expertise in recycling and minimise the problems associated with poor planning. With small-scale projects, it is easy to compare and evaluate the programmes and techniques that are considered most successful within the community. When the time comes to develop a large-scale programme, there will be practical experience and an established decision-making framework, which will enhance the programme's success.

(ii) **Understand and develop a recycling market:** While planning for a recycling programme, it is important to find an outlet for the recyclable material. Market analysis is both a planning and ongoing activity, as even the most successful recycling programme can be severely affected by market fluctuations. Recycling programmes must, therefore, be designed with the flexibility to handle fluctuating markets and uncertain outlets for material.

(iii) **Foster public education and involvement:** Public participation is one of the most important factors deciding a programme's success. The public has a right and a responsibility to understand the full costs and liabilities of managing the waste they produce. A well-planned public education and involvement programme will foster public interest in recycling.

(iv) **Assess local waste stream:** Planning any recycling programme requires the knowledge of the local waste stream. Choosing the right material to recycle and designing the logistics of the programme are the important parts of the planning process.

(v) **Augment existing programme:** Recycling should augment the success that has been attained by other groups operating recycling programmes. This is very important for planning and success. Other programmes may be run by local volunteer organisations to raise funds or as a community service.

(vi) **Set goals and objectives:** Part of the planning process involves setting goals and objectives. The preliminary assessment of waste stream helps in deciding long-term goals for a community. Planning objectives may include determining the type of waste stream component that should be programmed, investigating the feasibility of the curbside (kerbside) programme, public outreach avenues, etc. The community will benefit from carefully developed achievable goals and objectives, and from an integrated approach to waste management (see Unit 10 for a detailed discussion of the integrated approach to waste management).

(vii) **Coordinate the programme:** Recycling programme is considered a public service. Therefore, local governments are required to ensure that all services are provided properly. Like any other public service, recycling programmes should be consistent, predictable, equitable and efficient.

(viii) **Evaluate the programme:** New programmes and technologies are evolving continuously, which make the planning for recycling an ongoing process. This requires experiment and evaluation. Even the best recycling programmes experiment with new techniques to improve on their current efforts.

If recycling programmes are properly planned and implemented, they would then add to the overall municipal waste management activity.

LEARNING ACTIVITY 6.3

List the factors that you will consider while planning a recycling programme.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

6.4 RECYCLING PROGRAMME ELEMENTS

Recycling programmes are designed according to the needs and priorities of the communities. Elements of a recycling programme include source separation, curbside (kerbside) collection, material resource facilities and full stream processing. Recycling, generally, has a positive impact on other municipal waste management programmes. This may include a mix of strategies, ranging from simple, single material drop-off centres to large scale, centralised processing facilities. We will discuss some of the major elements (EPA, 1989 and 1995) in Subsections 6.4.1 to 6.4.8.

6.4.1 Source separation

Source separation refers to the segregation of the recyclable and reusable materials at the point of generation. This requires that several designated materials be separated into their own specific containers, while other programmes use only two containers – one for the storage of mixed recyclables and the other for regular wastes. Source separation may be voluntary or mandated and is done in conjunction with several recycling programmes.

6.4.2 Drop-off/buy-back

A *drop-off* programme requires residents to separate the recyclable materials and bring them to a specified drop-off or collection centre. However, we must take into account local conditions when designing a collection programme. For a community that does not provide a curbside pickup, for example, educating and encouraging citizens to deliver materials to a drop-off site may be all that is needed. A recycling centre can be established at the same location where residents deliver waste. Mobile recycling drop-off trailers can also be used. Drop-off recycling, however, is less convenient than curbside pickup. If a thorough educational and promotional effort is not made, drop-off programme tends to have lower participation rates than curbside collection.

Buy-back refers to a drop-off programme that provides monetary incentives to participate. In this type of programme, the residents are paid back for their recyclable material directly or indirectly through the reduction in collection and disposal fees. Establishing a buy-back centre (i.e., a place where recyclables are purchased) may help induce citizens to recycle. Some buy-back centres purchase some materials and accept others, depending on current market conditions. Private or public mobile buy-back operations can serve some areas, purchasing recyclables from small communities or from neighbourhoods of large metropolitan areas on a regular schedule.

6.4.3 Curbside programme

In a curbside system, source separated recyclables are collected separately from regular refuse from the curbside, alley, or commercial facility. Curbside programmes vary greatly from community to community. Some programmes require residents to separate different materials that are stored in their own containers and collected separately. Other programmes use only one container to store recyclables or two containers, one for paper and the other for heavy recyclables (e.g., glass aluminium, etc.).

6.4.4 Storage and collection of recyclables

Collection of source-separated materials is a necessary component of recycling programme. Establishing a collection system for source-separated materials will require more careful planning than regular trash collection. Some principles of sound recyclables storage and collection should be understood, while developing a programme, and these include:

- **Resident convenience:** The easier it is for residents to separate materials, the higher the participation and recovery rates will be.
- **Collection crew convenience:** The system should be convenient for collection crews. For example, loading and sorting activities should be as simple as possible.

- **Cost effectiveness:** Equipment and procedures must be designed to maximise collection crew and vehicle productivity.
- **Integrity of materials:** The storage and collection system should keep recyclables in the best shape possible. It should be properly handled, dry and contaminant free.

How residents store recyclables in a household and curb has a direct impact on the success of a recycling programme. The storage container should provide a handy way to store materials until collected, and it must be easy for the collector to distinguish recyclables from garbage.

6.4.5 Collection vehicles for recycling

Collection vehicles that are designed specifically for collecting recyclables have several storage bins, which can be easily loaded and often equipped with automatic container-tipping devices. Although these modified vehicles may still be considered as options, a dedicated, closed-body collection vehicle for recycling with sufficient capacity offers such significant advantages as easy loading and unloading, flexible compartments and protection from weather. Of course, this warrants a substantial initial investment.

6.4.6 Processing equipment for recycling

Recycling involves a number of processing techniques and these processes require different equipments, many of which we discussed in Unit 5. However, some of the special equipments used in recycling are:

- **Balers:** Balers can be used to densify many types of materials including paper, cardboard, plastics and cans. Balers can improve space utilisation and reduce material transportation costs.
- **Can densifiers:** Can crushers are used to densify aluminium and steel cans prior to transport.

- **Glass crushers:** These are used to process glass fraction separated by colour and break it into small pieces. This crushed material is then called cullet, and can be reprocessed into new glass products.
- **Magnetic separators:** These are used to remove ferrous material from a mixture of materials.
- **Wood grinders:** These are chippers and are used to shred large pieces of wood into chips that can be used as mulch or as fuel.
- **Scales:** These are used to measure the quantity of materials recovered or sold.

6.4.7 Material recovery facilities (MRF)

MRF (pronounced 'murf') is a centralised facility that receives, separates, processes and markets recyclable material. It can be operated with both drop off and curbside programmes. The primary advantage of MRF is that it allows materials directly from the municipalities and processes them uniformly. It is generally designed to handle all type of recyclables. Implementation of MRF in a municipality depends upon a number of factors as follows:

- **Market demand:** When additional processing is required, MRF is more useful as buyers may have certain material specifications.
- **Separate collection:** In systems that require residents to separate their recyclables, intermediate separation and processing is required.
- **Number of different recyclables:** In general, a MRF will be more beneficial when a large number of different recyclables are collected.
- **Quantities of materials:** Because MRF involves substantial capital and operating costs (e.g., buildings, equipment and labour), it is expected to handle a significant amount of materials to justify its operation.

6.4.8 Full stream processing

This is a high technology separation technique, which processes all components of municipal waste. The materials recovered by this process tend to be of lower quality than those recovered or source separated in MRF because the former is a mix of various types of wastes. To achieve a better quality, the materials obtained through the full stream processing must be cleaned, which is a costly process. However, this technique remains attractive because it does not require source separation, and it is used in the following applications:

(i) **Refuse derived fuel (RDF) preparation:** In this application, it is used to extract the combustible portion of municipal waste.

(ii) **Municipal waste composting:** In this application, it is used to concentrate the compostable portion of municipal solid waste. Note that this is sometimes performed as part of RDF preparation.

(iii) **Material recovery:** In this application, it is used to recover and resell certain materials, and thereby making material recovery a recycling technology as well.

In full stream processing, depending on the facility design, the materials are separated either mechanically or by hand, and size and weight are the main characteristics used to separate the materials. For example:

- when the material is dumped, oversized materials such as furniture, etc., are removed;
- rotating screens are used to separate materials of different sizes (small and large);
- ferrous material is extracted using a magnet system;
- air classifier is used to separate the lighter material;
- light materials including plastic and paper are further processed into RDF;

- heavy fraction is mechanically or manually sorted to recover saleable materials such as cardboard, etc.

LEARNING ACTIVITY 6.4

Explain the recycling programme elements adopted in your locality.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

6.5 COMMONLY RECYCLED MATERIALS AND PROCESSES

In this Section, we will discuss some commonly recycled materials, the technologies used to recycle them and their specific environmental and economic impacts.

6.5.1 Paper and cardboard

Paper and cardboard form the second biggest component of domestic waste after organic waste, and contribute to about 13% of the total domestic solid waste (UNCHS, 1994). Paper recycling is one of the most profitable activities and is practised extensively. It reduces the demand for wood and energy and helps solve littering problem in the city and around dumping site. It has an acceptable working condition and health risks are limited. Recovered paper and paper products are bought and sold through a well-established network of local processors and vendors who typically bale these materials for sale. Of late, paper mills have started buying directly from the collectors.

The paper industry is making a significant investment in manufacturing capacity for making paper and paper products with recycled content. Recovered paper is classified as newsprint, corrugated cardboard, mixed paper (including magazines, junk mail and cardboard), high-grade paper (white office paper, photocopying paper), and pulp substitute paper (usually mill scrap). Paper mills, the most common end users of recovered paper, use the material as a feedstock to manufacture recycled paper and paper products, such as newsprint, chipboard, craft linerboard, corrugating medium, roofing felt and tissue products. Shredded paper is used to make animal bedding, hydro mulch, moulded pulp products and cellulose insulation.

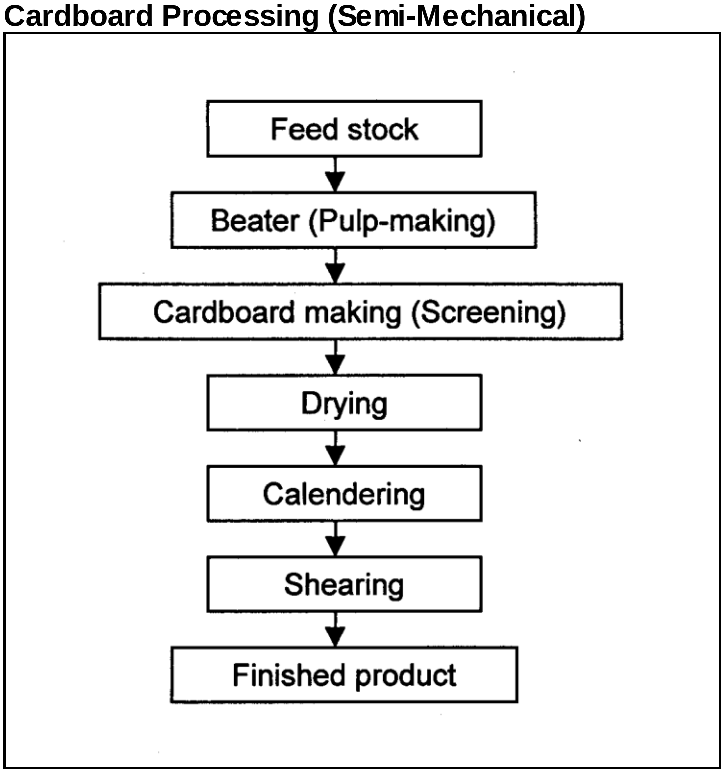
A typical input-output model of the paper processing technique consists of the following:

- **Material inputs:** Paper/cardboard scrap, magazines, newspapers, computer paper, wrapping paper, craft sacks, cartons, etc.
- **Product outputs:** Paper sheets, boxes, filter paper, mosquito mats (to absorb chemical repellent), merchandising packets, decorative items, etc.

And, the technology in the recycling of paper and cardboard involves the following processes:

(i) **Cardboard processing (semi-mechanical) plant:** In semi-mechanical plants, paper scrap is pulped in a beater machine. The paper pulp is spread on a rotating sieve and pressed mechanically. Cutting is done manually and after cutting and sun-drying, the cardboard is calendered and sheared into sheets, as illustrated in Figure 6.1 below, from which boxes for shoes, sweets, etc., are made:

Figure 6.1
Cardboard Processing (Semi-Mechanical)

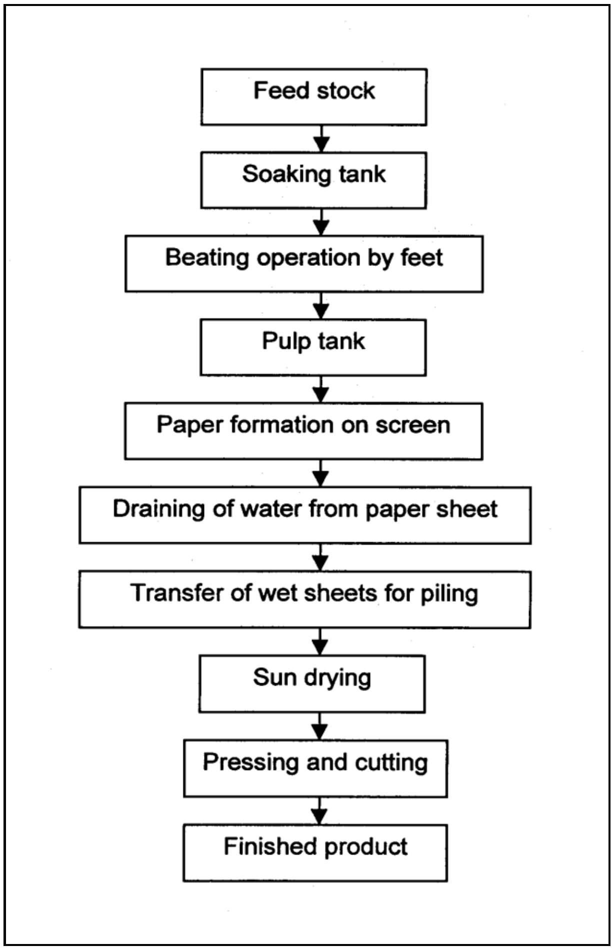


The various machineries used in the processes include:

- **Beater:** This consists of a masonry and concrete tank and a mild steel beater roll, driven by an electric motor.
- **Sieving screen:** This separates materials of different size.
- **Cardboard making unit:** This is a nylon conveyor screen driven by an electric motor.
- **Calendering machine:** This is used to finish the surface of paper and is electrically operated.

(ii) **Hand-made paper**: In hand-operated units, pulping and beating of paper is done manually in an open masonry or concrete tank. The material is sieved in a second tank and diluted with water to a specific consistency. A wooden framed screen is dipped in the tank in order to form an even layer of the wet pulp to a desired thickness (over the screen mat). The layer is skillfully removed and transferred from the mat and the sheets are sun dried on smooth walls or on other smooth surfaces. The dried sheets are then pressed and cut into required sizes. The calendering is performed in an electrically operated machine. Figure 6.2 illustrates the processing sequence in a hand-made paper unit:

Figure 6.2
Hand-Made Paper Processing



6.5.2 Glass

Glass is one of the most commonly recycled materials, and the market for post consumer glass has historically been steady. Glass generally accounts for 2.5% by weight of the total solid waste generated (UNCHS, 1994). Though it does not contribute to the environmental problem, glass does cause a serious problem of littering. The economic impacts are cost of waste collection and disposal, reduction in use of natural products and energy consumption.

Recycling of broken glass reduces the risk of diseases caused by cuts and wounds. Glass recycling is a labour intensive process and provides employment opportunity. Glass is typically broken for size reduction or crushed and ultimately sold to glass manufacturers as furnace-ready cullet after metal caps, rings, labels, etc., are removed.

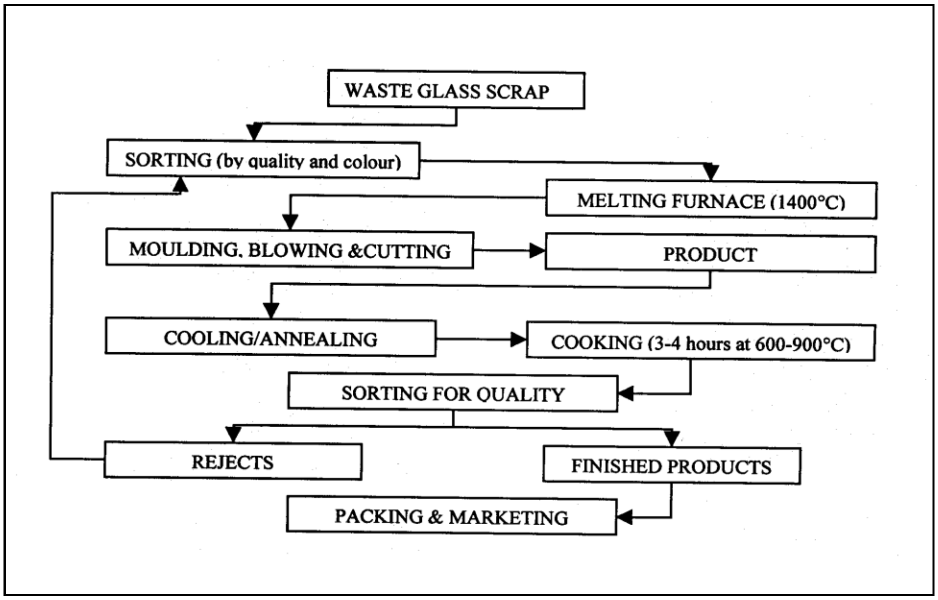
Glass manufacturers purchase glass for reprocessing into new, clear, green and brown glass jars and bottles. The market for recovered glass has been strong and stable for brown and clear containers. Green glass, however, is seldom used to package goods domestically, so fewer companies produce glass of this colour. Alternative markets for glass include art glass, sandblasting, and industrial windowpane glass and fibreglass insulation. Although the glass industry has made a commitment to increase the demand for recovered glass, there is an important and pervasive market concern about the quality of material being produced by collection programmes and processing facilities. Recycling programme planners must address this concern for high-quality recovered glass as well as for other commodities.

Typically, while glass scrap is the material input, glass products are the product outputs in the glass recycling technique which involves a semi-mechanical process. This, we will study next.

Semi-mechanical process

The waste glass cullet is sorted according to colour and melted in an oven at 1400°C. The oven used in a small production unit is locally made from fire clay and known as pot furnace. To improve the unbreakability of the glass product, chemicals such as soda ash, potassium carbonate, borax, lime, etc., are added to the cullet before melting. When the metal has completely melted, the temperature is raised to refine the glass. After refining, the temperature is lowered to carry out the moulding operation. After the glass takes the shape of the mould and hardens, unwanted portions are cut and removed, and sharp edges are smoothened in a machine. The product is then annealed by cooling and heating for three to four hours at 600 – 900°C to reduce the brittleness of the glass. After quality inspection, defective glass products are returned to the recycling process. The approved products are packed for marketing. Figure 6.3 depicts the processes described above:

Figure 6.3
Glass Processing (Semi-Mechanical)



The following machinery is used in the process:

- **Furnace:** It is used to melt the glass cullet. The glass cullet is melted at 1400°C (locally fabricated) and the product obtained is annealed at 600°C (locally fabricated).
- **Semi-mechanical die:** It is used to cast the die. It uses both mechanically and manually operated moulds.
- **Air compressor:** It is used for blowing molten glass into dies.
- **Printing machine:** It is used for printing trademark.

6.5.3 Metals

Ferrous metals like iron, steel, etc., and non-ferrous metals like aluminium, copper, zinc, lead, silver, etc., are some of the metals, which exist in the waste stream. On an average, metals account for 2% of total solid waste generated (UNCHS, 1994). Extraction of metals from natural ores depletes the mineral resources. Metals when dumped at landfill sites produce hazardous leachate with heavy metals in solution.

Using recycled metals substantially reduces operating costs of industries. Metal scrap is cheap and the energy consumption is lower when products are manufactured from scrap. The long-standing track record makes ferrous and non-ferrous metal market among the most stable of all recyclable materials. Ferrous and non-ferrous metals can be bought and sold through processors and vendors. Ferrous scrap includes household appliances, equipments, cans, and other iron and steel products. Non-ferrous scrap metals include aluminium, copper, lead, tin, etc. Both ferrous and non-ferrous metals can be prepared for sale through some combination of processing by flattening, baling, and shredding of the material. In some cases, processors melt the metal into ingots before selling it to end-use markets. Several foundries and steel mills have begun or expanded recycling efforts, and steel mini-mills also appear to be increasing their use of recovered steel in regions, which typically lack large mills.

The typical material inputs and product outputs in this industry are the following:

(i) **Material inputs:** Aluminium, brass, copper, zinc, tin, iron, steel, etc.

(ii) **Product outputs:** Sanitary and gas fittings, funnels, buckets and storage bins, reinforced steel bars, hand tools, etc.

Metal processing

Now, we will discuss the process involved in recovering metals. Most of the recovered metals are processed by big industries. Ferrous metals are processed by iron industries to produce iron bars, channels, angles, etc. Local artisans process part of the ferrous metal in many cities. In a small-scale cottage industry, a particular kind of metal (ferrous or non-ferrous) is melted in a crucible in the coal furnace and the molten metal is cast into the desired mould to make ingots of required shapes and size. New and melted recycled metals are mixed together in a 3:1 ratio for better quality products. Ingots are sold to manufacturers to obtain different products from the metal. Local artisans heat the iron ingots in a coal furnace and beat them into different shapes for various kinds of tools and implements. Annealing hardens the cutting edges of the tools. The tools used in the process include coal burner, furnace (coal fired), moulding gadgets, dies (pattern) and auxiliary tools.

6.5.4 Plastic

These days, plastic is posing serious littering problem in cities and around collection points and dumping sites. With an average 8% by weight of the total amount of domestic waste, plastic is one of the major constituents in waste stream (UNCHS, 1994). Un-recycled plastic, when burned, contributes to green-house gases. The direct benefits of recycling plastic waste are reduction in the cost of raw material and energy saving. Plastic recycling also helps in employment generation along with reduction of volume transport and space requirements for dumping.

Most plastics are densified locally by flattening, baling, or granulating, and sold either to converters, where the resins are turned into pellets, or directly to domestic or export end users for remanufacture into products such as bottles, carpet and carpet backing, flower pots, and insulation material.

Post consumer plastic-resin recycling technology has developed more rapidly than technologies for any other recovered material in the last half century. Only five to ten years ago post consumer high-density polyethylene (HDPE) and polyethylene terephthalate (PET) plastics were vaguely considered recyclable. These two resins, especially HDPE milk jugs and bottles and clear PET plastics, now hold a stronger place in the market. End uses for recycled HDPE include non-food bottles, drums, toys, pipes, sheets and plastic pallet, and for PET include plastic fibres, injection moulding, non-food grade containers and chemicals. The recyclability of other resins, such as polystyrene, polyvinyl chloride, low-density polyethylene (LDPE), polypropylene and mixed plastic resins is making strides but much remains to be done. The input materials, the output products involved in the recycling of plastics are given below:

(i) **Material input:** Plastic scrap (thermoplastic and thermosetting).

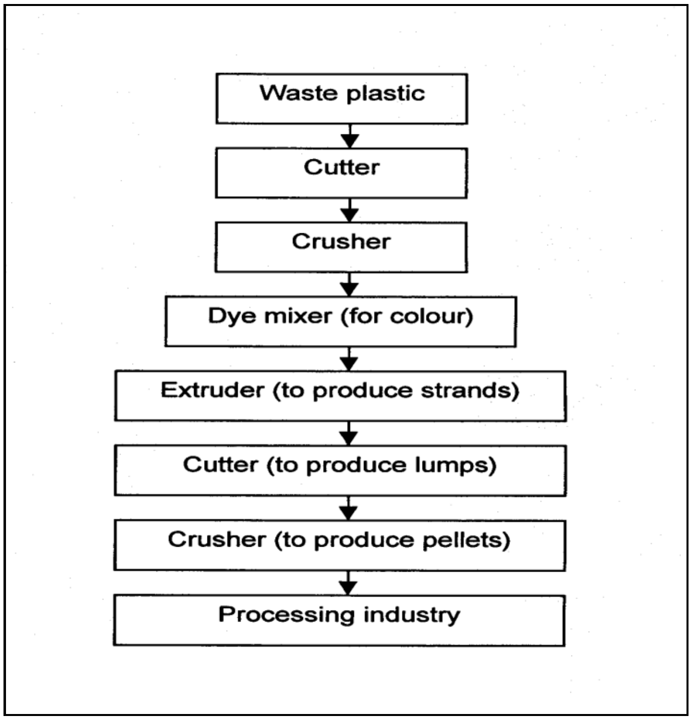
(ii) **Product output:** Toys, boxes, slippers, shoes, pellets, buckets, cans, etc.

We will now discuss the processes involved in plastic recycling.

Plastic processing

In plastic processing, the primary steps are sorting by colour and quality, and cutting and crushing the sorted material. The crushed product (granules) of plastic is melted, colour dyed and manually moulded into a cheaper product. The poly vinyl chloride plastic is blended with a specific colour dye in a mixing machine. The coloured material passes through an extruder machine to produce thick plastic strands. The strands are manually cut into lumps and these are used for manufacturing items either manually or mechanically, as shown in Figure 6.4:

Figure 6.4
Plastic Processing (Raw Material for Plastic Product)



Note that in the manual process, the lumps are further chopped into smaller pieces and melted. The melted material is moulded into products such as shoe soles, toys and boxes. Machineries used in this process are electrically operated crusher, extruder, mixer and manually operated moulding machine (in which material is electrically heated at 359°C).

6.5.5 Batteries and tyres

Battery recycling is not only a response to market condition (i.e., price of lead) but also is important due to concern over the toxic compound including lead, cadmium and mercury present in many batteries. Like other materials, battery recycling depends largely on market conditions and requires consistent collection and processing. Household batteries come in a variety of types including alkaline, carbon, zinc, silver, nickel, cadmium, etc. Only those containing mercury and silver are marketed to end users, who extract metals. Automobiles use lead acid battery, which contains lead and sulphuric acid, both hazardous materials. Battery reprocessing includes breaking open the batteries, neutralising the acid, chipping the container for recycling and smelting the lead to produce recyclable lead.

Tyres represent a special challenge to solid waste and recycling programme managers. The use of chipped or shredded tyres as a source for fuel is growing. Electricity-generating facilities, pulp and paper mills and cement kilns are the most common processes using scrap tyres (EPA, 1989 and 1995).

LEARNING ACTIVITY 6.5

State the end uses of recycled plastic.

Note:

a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

6.6 CASE STUDY: SOURCE REDUCTION AND RECYCLING IN BANGALORE

Source reduction, including reuse and recycling, can help reduce waste disposal and handling costs, because it avoids the costs of municipal composting, landfilling and combustion. Source reduction also conserves resources and reduces pollution, including greenhouse gases that contribute to global warming. Waste reduction, reuse and recycling, thus, play an important role in SWM. In what follows, we present the statistics on waste recovery and recycling done in Bangalore, India.

In Bangalore, 66% of the waste generated is collected for recovery, i.e., about 2,373 tonnes per day. While 722 tonnes per day is reused, the rest (i.e., 1,450 tonnes) goes for recycling. The agents involved in the collection and recovery of wastes in the city include waste pickers, IWB (i.e., itinerant waste buyer), middlemen (or intermediaries), the municipality and recycling units (both large and small). While the three agents in the informal sector and the municipality are directly involved in waste collection activities, the waste is processed by the recycling units, which receive recyclable waste from middlemen and municipality. Table 6.1 gives the statistics of waste recovered and collected by stakeholders in Bangalore:

Table 6.1
Waste Recovery and Collection by Stakeholders

Stakeholders	For reuse	For recycling		
		Waste pickers	**IWB**	**Intermediaries**
Households	101.7	74.5	60.4	57.7
Commercial establishments	350.8	227	0.0	24.3
• markets	112.7	200	0.0	8.8
• hotels	238.1	27	0.0	15.4
Institutes	0.0	9.6	0.0	61.3
• hospitals	0.0	1.0	0.0	0.0
• offices	0.0	8.4	0.0	0.0
• educational institutions	0.0	0.2	0.0	61.3
Industries	269.3	0.8	0.0	934.5
Total	**721.8**	**312**	**60.4**	**1077.8**

Of the 1450 tonnes collected for recycling, 1077.8 tonnes come from intermediaries, 60.4 come from IWB and 312 tonnes come from waste pickers. This amounts to 40% of the total waste (i.e., 3613 tonnes per day) generated.

SUMMARY

In this Unit, we discussed source reduction and recycling aspects, which precede the management of solid wastes. We began the Unit with an introduction to source reduction and its purpose, which is to reduce the amount of wastes generated at source and reduce their volume and/or toxicity before they become part of the solid waste stream. In this context, we explained how a source reduction programme could be successfully implemented and evaluated. We also said successful implementation requires education and research, financial incentives and disincentives and regulation and evaluation for various options using certain criteria.

Subsequently, we discussed recycling, which perhaps is the most widely recognised form of source reduction, and its significance. In addition, we explained the planning processes (i.e., understanding the market, identifying local expertise, setting goals and fostering public participation) and elements (i.e., source separation, curbside collection, material resource facilities and full stream processing) involved in a recycling programme. We then discussed commonly recycled materials such as paper, glass, metals, plastics and battery and tyres along with their processing techniques. Finally, we presented the source reduction and recycling programme carried out in Bangalore as a case.

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Lecture 6

Model Answers to Learning Activities

LEARNING ACTIVITY 6.1

(i) Source reduction tops the hierarchy of solid waste management because of its potential to reduce system costs, prevent pollution, conserve resources and increase efficiency. Source reduction programmes are designed to reduce both the toxic constituents in products and quantities of waste generated. Source reduction is a front-end waste avoidance approach that includes strategies such as designing and manufacturing products and packaging with minimum volume and toxic content and with longer useful life.

(ii) Criteria to be considered in this regard are:

- Social and economic equity.
- Economic and administrative feasibility, efficiency and cost.
- Volume requirement and scarcity of materials and natural resources in product manufacture.
- Volume of product and its by-product that must be eventually disposed.
- Useful life, reusability and/or recyclability of a product.
- Priority of source reduction of more hazardous to less hazardous products.

LEARNING ACTIVITY 6.2

Recycling as such is not practised in our locality. However, waste buyers show interest in buying used newspapers, which considerably reduces the paper content in the waste generated. The waste buyers, in turn, sell the papers to retail waste dealers or wholesale dealers. Apart from this activity, the awareness and the advantages of recycling have not been given due importance, and the authorities concerned have not shown any interest in properly addressing recycling of waste in our locality.

LEARNING ACTIVITY 6.3

The factors that are involved in planning are:

- Building local expertise.
- Understanding and developing a recycling market.
- Fostering public education and involvement.
- Assessing local waste stream.
- Augmenting existing programme.
- Setting goals and objectives.
- Municipal coordination.
- Programme evaluation.

LEARNING ACTIVITY 6.4

Our locality does not have an organised recycling programme. However, informal sectors do contribute to recycling of wastes – paper, glass bottles, polyethylene envelops, etc.

LEARNING ACTIVITY 6.5

The end uses for high-density polyethylene (HDPE) are non-food bottles, drums, toys, pipes, sheets and plastic pellets. The end uses of polyethylene terephthalate (PET) include plastic fibres, injection moulding, non-food grade containers and chemicals.

Lecture 3

Waste Collection, Storage and Transport

STRUCTURE

OVERVIEW

For the final disposal of the wastes generated (see Unit 2), it is imperative that we put in place an effective waste collection system, which we described in Unit 1 (see (iii) of Subsection 1.2.1). In Unit 3, we will build on this description and discuss in detail the various aspects of collection system. Accordingly, we will first explain the components of waste collection such as storage, collection crew, route, transfer station, etc. We will then discuss each of these components. We will also discuss the design, operation and implementation of waste collection systems. We will close the Unit with a case study highlighting waste storage, collection and transport.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- discuss the various components of a waste collection system;
- explain the characteristics of waste containers relative to their use;
- state the purpose of a transfer station;
- evaluate how a collection system is planned and implemented;
- collect and maintain the required data for record keeping and inventory control;
- design and implement a collection system.

3.1 COLLECTION COMPONENTS

As described in Subsection 1.2.1, Unit 1, waste collection does not mean merely the gathering of wastes, and the process includes, as well, the transporting of wastes to transfer stations and/or disposal sites. To elaborate, the factors that influence the waste collection system include the following (EPA, 1989 and Ali, et al., 1999):

(i) **Collection points:** These affect such collection system components as crew size and storage, which ultimately control the cost of collection. Note that the collection points depend on locality and may be residential, commercial or industrial.

(ii) **Collection frequency:** Climatic conditions and requirements of a locality as well as containers and costs determine the collection frequency. In hot and humid climates, for example, solid wastes must be collected at least twice a week, as the decomposing solid wastes produce bad odour and leachate.

And, as residential wastes usually contain food wastes and other putrescible (rotting) material, frequent collection is desirable for health and aesthetic reasons. Besides climates, the quality of solid waste containers on site also determines the collection frequency. For instance, while sealed or closed containers allow collection frequency up to three days, open and unsealed containers may require daily collection. Collection efficiency largely depends on the demography of the area (such as income groups, community, etc.), where collection takes place. While deciding collection frequency, therefore, you must consider the following:

- cost, e.g., optimal collection frequency reduces the cost as it involves fewer trucks, employees and reduction in total route distance;
- storage space, e.g., less frequent collection may require more storage space in the locality;
- sanitation, e.g., frequent collection reduces concerns about health, safety and nuisance associated with stored refuse.

(iii) **Storage containers** (see also Subsection 3.2.1)**:** Proper container selection can save collection energy, increase the speed of collection and reduce crew size. Most importantly, containers should be functional for the amount and type of materials and collection vehicles used. Containers should also be durable, easy to handle, and economical, as well as resistant to corrosion, weather and animals. In residential areas, where refuse is collected manually, standardised metal or plastic containers are typically required for waste storage. When mechanised collection systems are used, containers are specifically designed to fit the truck-mounted loading mechanisms. While evaluating residential waste containers, consider the following:

- efficiency, i.e., the containers should help maximise the overall collection efficiency.
- convenience, i.e., the containers must be easily manageable both for residents and collection crew.

- compatibility, i.e., the containers must be compatible with collection equipment.
- public health and safety, i.e., the containers should be securely covered and stored.
- ownership, i.e., the municipal ownership must guarantee compatibility with collection equipment.

(iv) **Collection crew** (see also Subsection 3.3.1)**:** The optimum crew size for a community depends on labour and equipment costs, collection methods and route characteristics. The size of the collection crew also depends on the size and type of collection vehicle used, space between the houses, waste generation rate and collection frequency. For example, increase in waste generation rate and quantity of wastes collected per stop due to less frequent collection result in a bigger crew size. Note also that the collection vehicle could be a motorised vehicle, a pushcart or a trailer towed by a suitable prime mover (tractor, etc.). It is possible to adjust the ratio of collectors to collection vehicles such that the crew idle time is minimised. However, it is not easy to implement this measure, as it may result in an overlap in the crew collection and truck idle time. An effective collection crew size and proper workforce management can influence the productivity of the collection system. The crew size, in essence, can have a great effect on overall collection costs. However, with increase in collection costs, the trend in recent years is towards:

- decrease in the frequency of collection;
- increase in the dependence on residents to sort waste materials;
- increase in the degree of automation used in collection.

This trend has, in fact, contributed to smaller crews in municipalities.

(v) **Collection route** (see also Subsection 3.3.2)**:** The collection programme must consider the route that is efficient for collection. An efficient routing of collection vehicles helps decrease costs by reducing the labour expended for collection. Proper planning of collection route also helps conserve energy and minimise working hours and vehicle fuel consumption. It is necessary therefore to develop detailed route configurations and collection schedules for the selected collection system. The size of each route, however, depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such as railroad, embankments, rivers and roads with heavy traffic, can be considered to divide route territories. Routing (network) analyses and planning can:

- increase the likelihood of all streets being serviced equally and consistently;
- help supervisors locate or track crews quickly;
- provide optimal routes that can be tested against driver judgement and experience.

(vi) **Transfer station** (see also Section 3.4)**:** A transfer station is an intermediate station between final disposal option and collection point in order to increase the efficiency of the system, as collection vehicles and crew remain closer to routes. If the disposal site is far from the collection area, it is justifiable to have a transfer station, where smaller collection vehicles transfer their loads to larger vehicles, which then haul the waste long distances. In some instances, the transfer station serves as a pre-processing point, where wastes are dewatered, scooped or compressed. A centralised sorting and recovery of recyclable materials are also carried out at transfer stations (EPA, 1989). The unit cost of hauling solid wastes from a collection area to a transfer station and then to a disposal site decreases, as the size of the collection vehicle increases. This is due to various reasons such as the following:

- labour costs remain constant;
- the ratio of payload to vehicle load increases with vehicle size;

- the waiting time, unloading time, idle time at traffic lights and driver rest period are constant, regardless of the collection vehicle size.

LEARNING ACTIVITY 3.1

Find the current waste collection practice in your locality and state its role in waste management.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

Note that waste collection often proves to be the most costly component of any waste management system. However, with a proper collection system design and management, we can significantly reduce the costs. Consider the following criteria to evaluate, and make decisions about, collection systems:

- **Efficiency:** Do the services help minimise the cost per household?
- **Effectiveness:** Do the services satisfy the community needs?
- **Equity:** Do the services address equally the concerns of all social and demographic groups?
- **Reliability:** Do the services ensure consistency?
- **Safety and environmental impact:** Do the services ensure safety of workers, public health and protection of the environment?

Note also that various management arrangements, ranging from municipal services to franchised services and under various forms of contracts are, typically, in vogue for waste collection. One of the critical decisions to be made at the planning stage, therefore, is as to who – the public or private agencies – operates the collection system, though the final decision depends on the existing conditions and options for the local decision-makers (EPA, 1989).

3.2 STORAGE: CONTAINERS/COLLECTION VEHICLES

As mentioned in Unit 1, waste storage is an important component of a waste management system. Waste storage encompasses proper containers to store wastes and efficient transport of wastes without any spillage to transfer stations/disposal sites. We will analyse these two aspects of waste storage in Subsections 3.2.1 and 3.2.2.

3.2.1 Containers/storage bins

The design of an efficient waste collection system requires careful consideration of the type, size and location of containers at the point of generation for storage of wastes until they are collected. While single-family households generally use small containers, residential units, commercial units, institutions and industries require large containers. Smaller containers are usually handled manually whereas the larger, heavier ones require mechanical handling. The containers may fall under either of the following two categories:

(i) Stationary containers: These are used for contents to be transferred to collection vehicles at the site of storage.

(ii) Hauled containers: These are used for contents to be directly transferred to a processing plant, transfer station or disposal site for emptying before being returned to the storage site.

The desirable characteristics of a well-designed container are low cost, size, weight, shape, resistance to corrosion, water tightness, strength and durability (Phelps, et al., 1995). For example, a container for manual handling by one person should not weigh more than 20 kg, lest it may lead to occupational health hazards such as muscular strain, etc. Containers that weigh more than 20 kg, when full, require two or more crew members to manually load and unload the wastes, and which result in low collection efficiency.

Containers should not have rough or sharp edges, and preferably have a handle and a wheel to facilitate mobility. They should be covered to prevent rainwater from entering (which increases the weight and rate of decomposition of organic materials) into the solid wastes. The container body must be strong enough to resist and discourage stray animals and scavengers from ripping it as well as withstand rough handling by the collection crew and mechanical loading equipment. Containers should be provided with a lifting bar, compatible with the hoisting mechanism of the vehicle. The material used should be light, recyclable, easily moulded and the surface must be smooth and resistant to corrosion. On the one hand, steel and ferrous containers are heavy and subject to corrosion; the rust peels off exposing sharp edges, which could be hazardous to the collection crew. On the other, wooden containers (e.g., bamboo, rattan and wooden baskets) readily absorb and retain moisture and their surfaces are generally rough, irregular and difficult to clean.

Communal containers

Generally, the containers used for waste storage are communal/public containers. Figure 3.1 below shows a typical communal container, which a compactor collection vehicle (see Figure 3.5) can lift and empty mechanically:

Figure 3.1

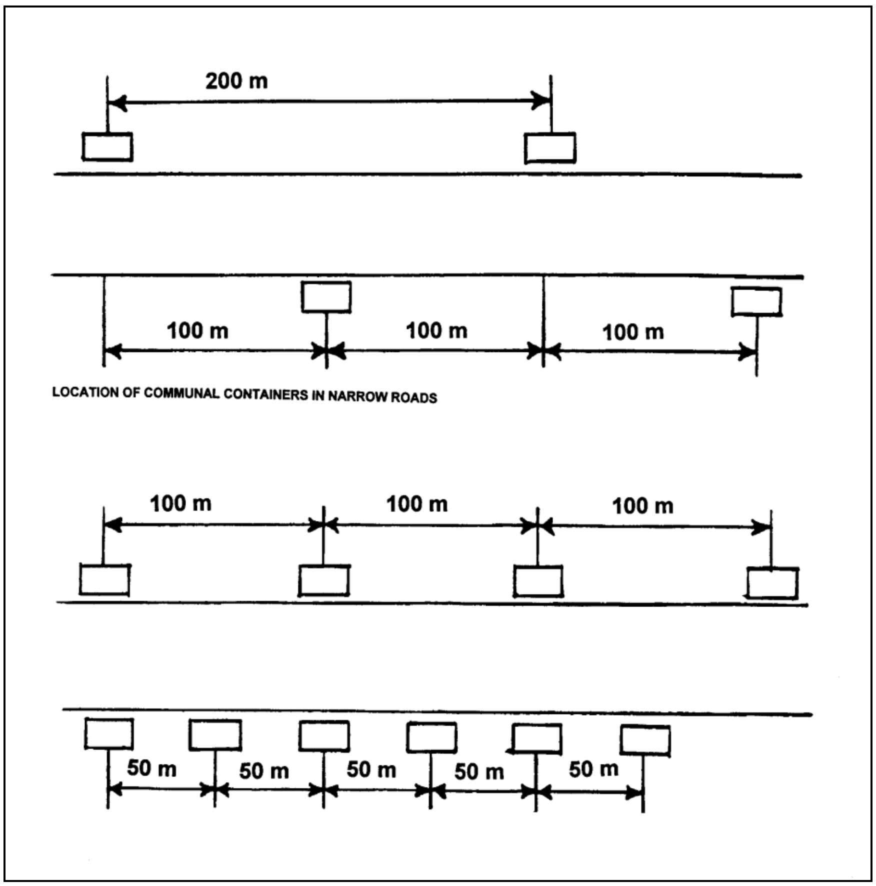
TYPICAL COMMUNAL CONTAINER

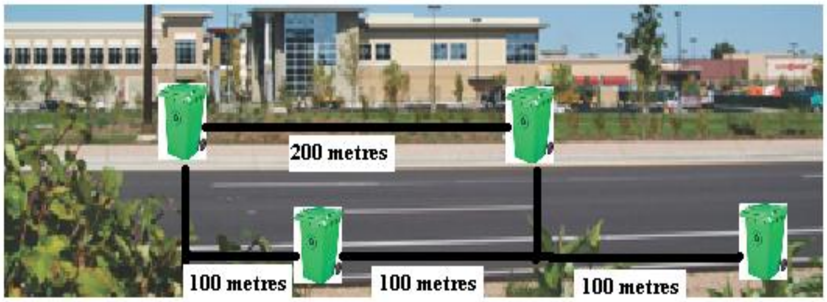
The use of communal containers is largely dependent on local culture, tradition and attitudes towards waste. Communal containers may be fixed on the ground (stationary) or movable (hauled). Movable containers are provided with hoists and tails compatible with lifting mechanism of collection vehicles and such containers have capacities of 1 – 4 m^3. The waste management authority must monitor, maintain and upgrade the communal containers. Note that in residential and commercial areas in India, the communal containers are often made of concrete.

In areas with very high waste generation rates, i.e., rates exceeding two truckloads daily, such as wet markets, large commercial centres and large business establishments, roll-on-roll or hoisted communal containers with capacities of 12 – 20 m^3 and a strong superstructure with wheels are used. Normally, the collection vehicle keeps an empty container as a replacement before it hauls the filled container. When a truck is used as a collection vehicle, the use of communal containers may be appropriate.

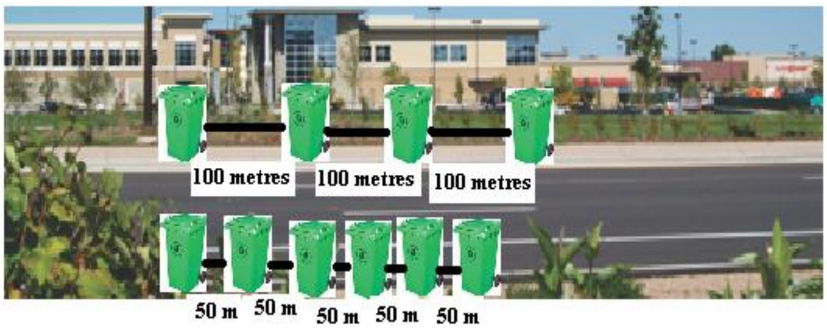
It is advisable to place the containers 100 – 200 m apart for economic reasons. The communal containers are usually staggered such that the effective distance of 100 m is maintained as shown in Figure 3.2:

Figure 3.2
Location of Communal Container





Location of communal containers in Narrow Roads



This means that the farthest distance the householder will have to walk is 50 meters. However, in narrow streets with low traffic, where the house owner can readily cross the street, a longer distance is advisable. If the collection vehicle has to stop frequently, say, at every 50 m or so, fuel consumption increases, and this must be avoided.

Disadvantages

The major disadvantage of communal containers is the potential lack of maintenance and upgrading. The residuals and scattered solid wastes emit foul odours, which discourage residents from using the containers properly. In addition, if fixed containers are built below the vehicle level, the collection crew may be held responsible for sweeping and loading the solid wastes into transfer containers before being loaded into the collection vehicle. Sweeping and cleaning the communal containers of residuals obviously impinge on the time of the crew members and take a longer time than if the wastes are placed in smaller containers. As fixed communal containers have higher rates of failure, their use is not advisable.

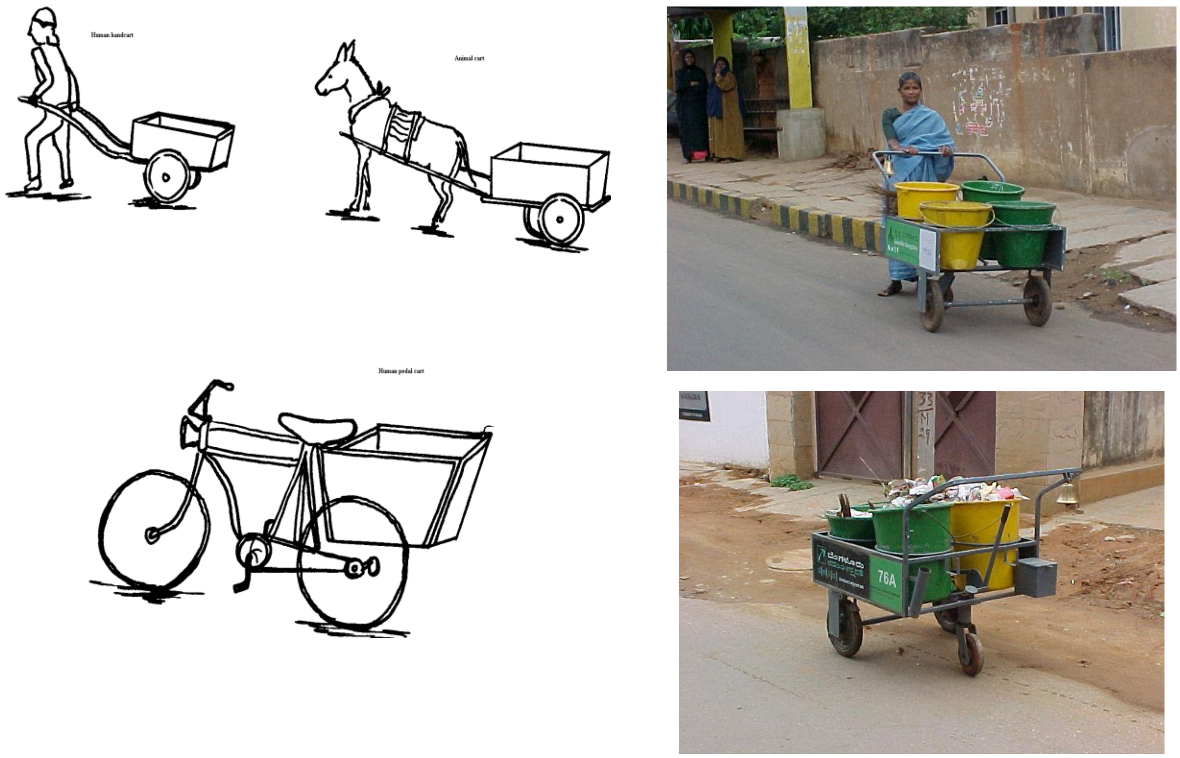
To overcome the problem of maintaining communal containers, individual residents should maintain their own containers and locate them in designated areas. The communal area must have water and drains to facilitate the cleaning of the containers. This practice has the advantage of reducing the number of collection stops and at the same time maintaining the householder's responsibility for cleaning them. The residents must also be properly educated on the importance of good housekeeping as the containers in the communal area are subject to vandalism. In the main, if communal containers are to be successful, the design of the containers, loading and unloading areas, and collection vehicle accessories should be co-ordinated.

3.2.2 Collection vehicles

Almost all collections are based on collector and collection crew, which move through the collection service area with a vehicle for collecting the waste material. The collection vehicle selected must be appropriate to the terrain, type and density of waste generation points, the way it travels and type and kind of material (UNEP, 1996). It also depends upon strength, stature and capability of the crew that will work with it. The collection vehicle may be small and simple (e.g., two-wheeled cart pulled by an individual) or large, complex and energy intensive (e.g., rear loading compactor truck). The most commonly used collection vehicle is the dump truck fitted with a hydraulic lifting mechanism. A description of some vehicle types follows:

(i) **Small-scale collection and muscle-powered vehicles:** These are common vehicles used for waste collection in many countries and are generally used in rural hilly areas. As Figure 3.3 illustrates, these can be small rickshaws, carts or wagons pulled by people or animals, and are less expensive, easier to build and maintain compared to other vehicles:

Figure 3.3
Small-scale Collection Vehicles: An Illustration



They are suitable for densely populated areas with narrow lanes, and squatter settlements, where there is relatively low volume of waste generated. Some drawbacks of these collection vehicles include limited travel range of the vehicles and weather exposure that affect humans and animals.

(ii) **Non-compactor trucks:** Non-compactor trucks are efficient and cost effective in small cities and in areas where wastes tend to be very dense and have little potential for compaction. Figure 3.4 illustrates a non-compactor truck:

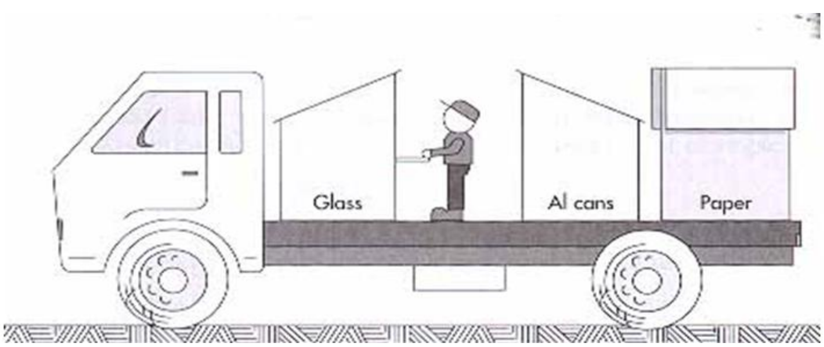
Figure 3.4
Non-compactor Trucks

When these trucks are used for waste collection, they need a dumping system to easily discharge the waste. It is generally required to cover the trucks in order to prevent residue flying off or rain soaking the wastes. Trucks with capacities of 10 – 12 m^3 are effective, if the distance between the disposal site and the collection area is less than 15 km. If the distance is longer, a potential transfer station closer than 10 km from the collection area is required. Non-compactor trucks are generally used, when labour cost is high. Controlling and operating cost is a deciding factor, when collection routes are long and relatively sparsely populated.

(iii) **Compactor truck:** Compaction vehicles are more common these days, generally having capacities of 12 – 15 m^3 due to limitations imposed by narrow roads. Although the capacity of a compaction vehicle, illustrated in Figure 3.4, is similar to that of a dump truck, the weight of solid wastes collected per trip is 2 to 2.5 times larger since the wastes are hydraulically compacted:

Figure 3.5
Compactor Truck

The success of waste management depends on the level of segregation at source. One of the examples for best collection method is illustrated in the figure below



A compactor truck allows waste containers to be emptied into the vehicle from the rear, front or sides and inhibits vectors (of disease) from reaching the waste during collection and transport. It works poorly when waste stream is very dense, wet, collected materials are gritty or abrasive, or when the roads are dusty. The advantages of the compactor collection vehicle include the following:

- containers are uniform, large, covered and relatively visually inoffensive;
- waste is set out in containers so that the crew can pick them up quickly;
- health risk to the collectors and odour on the streets are minimised;
- waste is relatively inaccessible to the waste pickers.

LEARNING ACTIVITY 3.2

What are the types of containers and collection vehicles in use in your locality?

Note:

a) Write your answer in the space given below.

b) Check your answer with the one given at the end of this Unit.

3.3 COLLECTION OPERATION

In Section 3.2, we introduced you to different types of containers and collection vehicles. We now discuss the movement of collection crew in terms of workforce efficiency and collection routes.

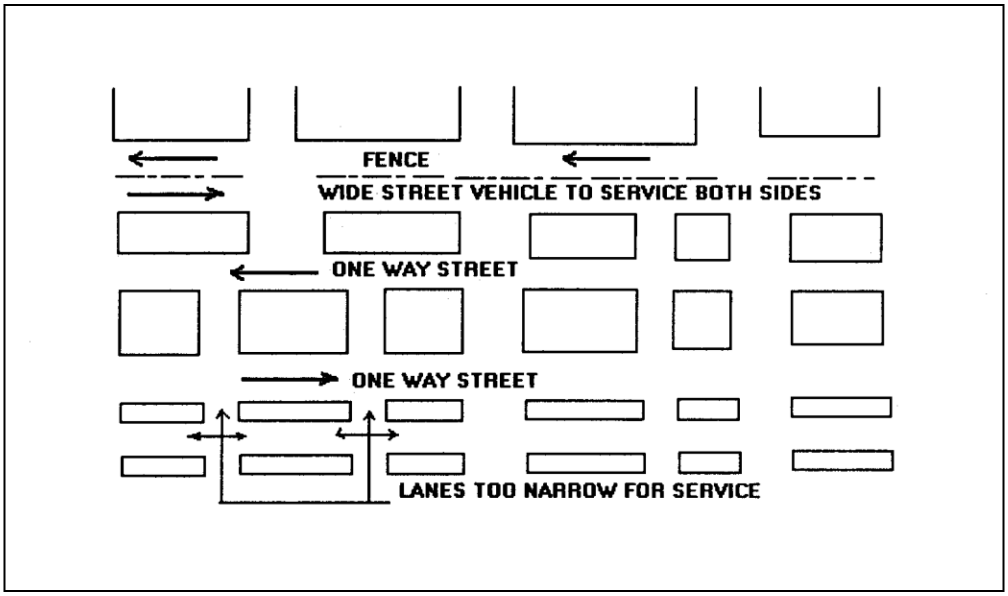
3.3.1 Movement of collection crew

In cultures such as India, Bangladesh, etc., solid waste collection is assigned to the lowest social group. More often, the collection crew member accepts the job as a temporary position or stopgap arrangement, while looking for other jobs that are considered more respectable.

Apart from this cultural problem, the attitude of some SWM authorities affects collection operation. For example, some authorities still think that the collection of solid waste is mechanical, and therefore, the collection crew does not need any training to acquire special skills. As a result, when a new waste collector starts working, he or she is sent to the field without firm instruction concerning his or her duties, responsibilities and required skills. For an effective collection operation, the collection team must properly be trained. The collection crew and the driver of the collection vehicle must, for example, work as a team, and this is important to maintain the team morale and a sense of social responsibility among these workers.

You must also note that the movement of collection crew, container location and vehicle stopping point affect collection system costs. Figure 3.6 highlights the distance the collection crew will have to walk, if it were to serve the farthest point first or serve the point closest to the vehicle:

Figure 3.6
Effect of Container Location and Vehicle Stopping



The difference may be one or two minutes per collection stop, but it matters with the number of stops the crew will take in a working shift. Multiplying the minutes by the total number of crew working and labour cost depicts the amount of labour hours lost in terms of monetary value.

Generally, familiarity of the crew with the collection area improves efficiency. For example, the driver becomes familiar with the traffic jams, potholes and other obstructions that he or she must avoid. The crew is aware of the location of the containers and the vehicle stops. It is, therefore, important to assign each crew specific areas of responsibility. Working together also establishes an understanding of the strong and weak points of the team members and efficient work sequences. The collection operation must also observe a strict time schedule. Testing of new routes, new gadgets and vehicles is best carried out first in the laboratory and later in a pilot area. Testing of a new sequence using the whole service area could result in disorder and breakdown of the solid waste collection system. Studies show that it takes two hours to recover for every hour of a failed system.

Motion time measurement (MTM) technique

Motion time measurement (MTM) studies are now an integral part of the standard procedure in the development of solid waste collection systems. MTM is a technique to observe and estimate the movement of the collection crew with the help of stopwatches. The results thus gathered are tabulated as shown in Table 3.1 to determine the best sequence of activities that workers must follow in order to complete a repetitive task in the shortest possible time:

Table 3.1
MTM Study: Determination of Time, Distance and Number on Containers in Collection Route

	Time		**Odometer (Km)**	**Number of Containers**	**Collection time (Minute Second)**	**Trip time to next Station**
	Arrival	**Departure**				
Garage						
1 Station	::	::				
2 Station	::	::				
.	::	::				
.	::	::				
.	::	::				
20 Station	::	::				
Last Station	::	::				
Disposal Site	::	::				
Total	::	::				
Weight	With Load tonne		With Load tonne		With Load tonne	

Source: Phelps, et al., 1995

MTM also helps in deciding the best combination of equipment to maintain a desired level of output, reduce health problems related to the repetitive work sequence and predict the effects of changes in materials handled.

Sophisticated MTM studies involve hidden or open video cameras at different collection stops to record, replay and study the operation sequence of the collection crew. If the crew is conscious of being observed, they tend to work faster and reduce time wastage in unauthorised salvaging and other non-scheduled activities. Once the crew is familiar with the person(s) observing them, it begins to perform more credibly. In studies involving video cameras, therefore, the first two or three hours of observation are often neglected.

3.3.2 Collection vehicle routing

Efficient routing and re-routing of solid waste collection vehicles can help decrease costs by reducing the labour expended for collection. Routing procedures usually consist of the following two separate components:

(i) **Macro-routing:** Macro-routing, also referred to as route-balancing, consists of dividing the total collection area into routes, sized in such a way as to represent a day's collection for each crew. The size of each route depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such as railroad embankments, rivers and roads with heavy competing traffic, can be used to divide route territories. As much as possible, the size and shape of route areas should be balanced within the limits imposed by such barriers.

(ii) **Micro-routing:** Using the results of the macro-routing analysis, micro-routing can define the specific path that each crew and collection vehicle will take each collection day. Results of micro-routing analyses can then be used to readjust macro-routing decisions. Micro-routing analyses should also include input and review from experienced collection drivers.

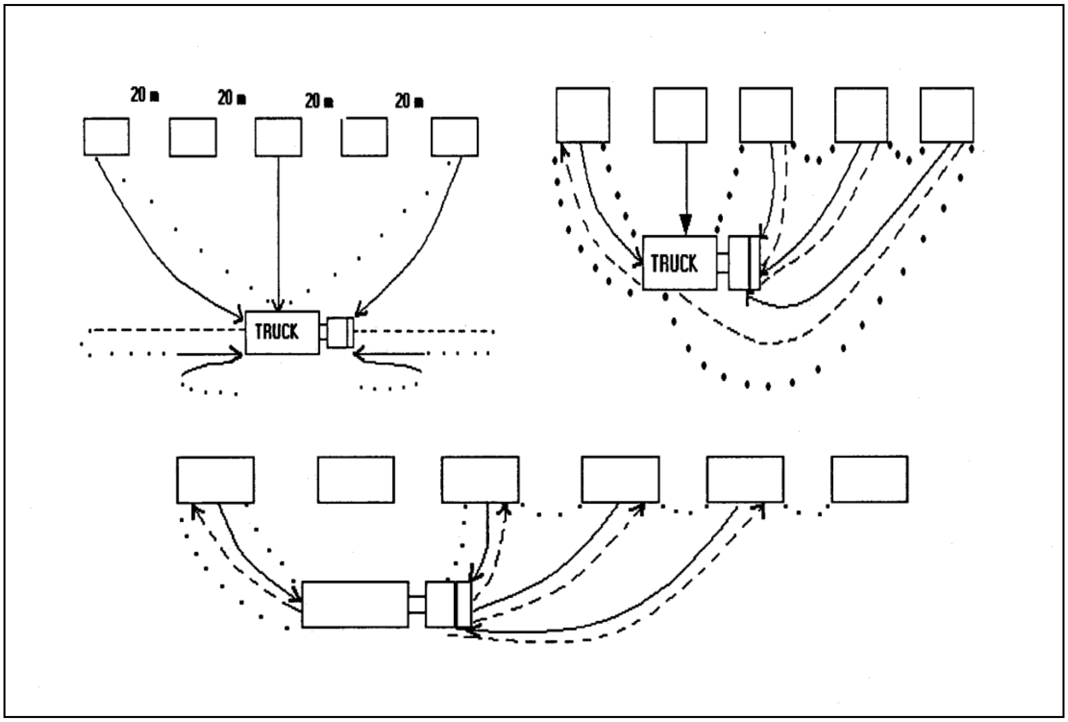
Districting is the other method for collection route design. For larger areas it is not possible for one institution to handle it then the best way is to sub divide the area and MSW collection districting plan can be made. This routing will be successful only when road network integrity is good and the regional proximity has been generated.

The heuristic (i.e., trial and error) route development process is a relatively simple manual approach that applies specific routing patterns to block configurations. The map should show collection, service garage locations, disposal or transfer sites, one-way streets, natural barriers and areas of heavy traffic flow. Routes should then be traced onto the tracing paper using the following rules:

- Routes should not be fragmented or overlapping. Each route should be compact, consisting of street segments clustered in the same geographical area.
- Total collection plus hauling time should be reasonably constant for each route in the community.
- The collection route should be started as close to the garage or motor pool as possible, taking into account heavily travelled and one-way streets.
- Heavily travelled streets should not be visited during rush hours.
- In the case of one-way streets, it is best to start the route near the upper end of the street, working down it through the looping process.
- Services on dead-end streets can be considered as services on the street segment that they intersect, since they can only be collected by passing down that street segment. To keep right turns at a minimum, (in countries where driving is left-oriented) collection from the dead-end streets is done when they are to the left of the truck. They must be collected by walking down, reversing the vehicle or taking a U-turn.
- Waste on a steep hill should be collected, when practical, on both sides of the street while vehicle is moving downhill. This facilitates safe, easy and fast collection. It also lessens wear of vehicle and conserves gas and oil.
- Higher elevations should be at the start of the route.
- For collection from one side of the street at a time, it is generally best to route with many anti-clockwise turns around blocks.
- For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the grid before looping anti-clockwise.
- For certain block configurations within the route, specific routing patterns should be applied. (Adapted from American Public Works Association, 1975.)

Based on the above rules, Figure 3.7 below illustrates a typical collection vehicle routing:

Figure 3.7 Collection Vehicle Route



Before we proceed any further, let us complete Learning Activity 3.3.

LEARNING ACTIVITY 3.3

State the rules that we need to keep in mind, while designing a collection route.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

3.4 TRANSFER STATION

Transfer station

As mentioned earlier in Section 3.1, transfer station is a centralised facility, where waste is unloaded from smaller collection vehicles and re-loaded into large vehicles for transport to a disposal or processing site. This transfer of waste is frequently accompanied by removal, separation or handling of waste. In areas, where wastes are not already dense, they may be compacted at a transfer station. The technical limitations of smaller collection vehicles and the low hauling cost of solid waste, using larger vehicles, make a transfer station viable. Also, the use of transfer station proves reasonable, when there is a need for vehicles servicing a collection route to travel shorter distances, unload and return quickly to their primary task of collecting the waste.

Limitations in hauling solid wastes are the main factors to be considered, while evaluating the use of transfer stations. These include the additional capital costs of purchasing trailers, building transfer stations and the extra time, labour and energy required for transferring wastes from collection truck to transfer trailer.

Consider also the following factors that affect the selection of a transfer station:

- Types of waste received.

- Processes required in recovering material from wastes.
- Required capacity and amount of waste storage desired.
- Types of collection vehicles using the facility.
- Types of transfer vehicles that can be accommodated at the disposal facilities.
- Site topography and access.

The main problem in the establishment of a transfer station, however, is securing a suitable site. Stored solid wastes and recyclable materials, if not properly handled, will attract flies and other insect vectors. Odours from the transferred solid wastes will also be a nuisance, if not properly controlled. In addition, the traffic and noise due to small and large collection vehicles, collectors, drivers, etc., invite the resentment of the communities living in the vicinity of transfer stations (EPA, 1995).

3.4.1 Types

Depending on the size, transfer stations can be either of the following two types:

(i) **Small to medium transfer stations:** These are direct-discharge stations that provide no intermediate waste storage area. The capacities are generally small (less than 100 tonnes/day) and medium (100 to 500 tonnes/day). Depending on weather, site aesthetics and environmental concerns, transfer operations of this size may be located either indoor or outdoor. More complex small transfer stations are usually attended during hours of operation and may include some simple waste and materials processing facilities. For example, it includes a recyclable material separation and processing centre. The required overall station capacity (i.e., the number and size of containers) depends on the size and population density of the area served and the frequency of collection.

(ii) **Large transfer stations:** These are designed for heavy commercial use by private and municipal collection vehicles. The typical operational procedure for a larger station is as follows:

- when collection vehicles arrive at the site, they are checked in for billing, weighed and directed to the appropriate dumping area;
- collection vehicles travel to the dumping area and empty the wastes into a waiting trailer, a pit or a platform;
- after unloading, the collection vehicle leaves the site, and there is no need to weigh the departing vehicle, if its weight (empty) is known;
- Transfer vehicles are weighed either during or after loading. If weighed during loading, trailers can be more consistently loaded to just under maximum legal weights and this maximises payloads and minimises weight violations.

Designs for larger transfer operations

Several different designs for larger transfer operations are common, depending on the transfer distance and vehicle type. Most designs, however, fall into one of the following three categories:

(i) **Direct-discharge non-compaction station:** In these stations, waste is dumped directly from collection vehicle into waiting transfer trailers and is generally designed with two main operating floors. In the transfer operation, wastes are dumped directly from collection vehicles (on the top floor) through a hopper and into open top trailers on the lower floor. The trailers are often positioned on scales so that dumping can be stopped when the maximum payload is reached. A stationary crane with a bucket is often used to distribute the waste in the trailer. After loading, a cover or tarpaulin is placed over the trailer top. However, some provision for waste storage during peak time or system interruptions should be developed. Because of the use of little hydraulic equipment, a shutdown is unlikely and this station minimises handling of waste.

(ii) **Platform/pit non-compaction station:** In this arrangement, the collection vehicles dump their wastes onto a platform or into a pit using waste handling equipment, where wastes can be temporarily stored, and if desired, picked through for recyclables or unacceptable materials. The waste is then pushed into open-top trailers, usually by front-end loaders. Like direct discharge stations, platform stations have two levels. If a pit is used, however, the station has three levels. A major advantage of these stations is that they provide temporary storage, which allows peak inflow of wastes to be levelled out over a longer period. Construction costs for this type of facility are usually higher because of the increased floor space. This station provides convenient and efficient storage area and due to simplicity of operation and equipment, the potential for station shutdown is less.

(iii) **Compaction station:** In this type of station, the mechanical equipment is used to increase the density of wastes before they are transferred. The most common type of compaction station uses a hydraulically powered compactor to compress wastes. Wastes are fed into the compactor through a chute, either directly from collection trucks or after intermediate use of a pit. The hydraulic ram of the compactor pushes waste into the transfer trailer, which is usually mechanically linked to the compactor (EPA, 1995). Compaction stations are used when:

- wastes must be baled for shipment;
- open-top trailers cannot be used because of size restrictions;
- site topography or layout does not accommodate a multi-level building.

The main disadvantage of a compaction facility is that the facility's ability to process wastes is directly dependent on the operative-ness of the compactor. Selection of a quality compactor, regular maintenance of the equipment, easy availability of spare parts and prompt availability of the service personnel are essential for the station's reliable operation.

3.4.2 Capacity

A transfer station should have enough capacity to manage and handle the wastes at the facility throughout its operating life. While selecting the design capacity of a transfer station, we must, therefore, consider trade-offs between the capital costs associated with the station and equipment and the operational costs. Designers should also plan adequate space for waste storage and, if necessary, waste processing. Transfer stations are usually designed to have 1.5 – 2 days of storage capacity. The collection vehicle unloading area is usually the waste storage area and sometimes a waste sorting area. When planning the unloading area, designers should allow adequate space for vehicle and equipment manoeuvring. To minimise the space required, the facility should be designed such that the collection vehicle backs into the unloading position. Adequate space should also be available for offices, employee facilities, and other facility-related activities (EPA, 1995). Factors that should be considered in determining the appropriate capacity of a transfer facility include:

- capacity of collection vehicles using the facility;
- desired number of days of storage space on tipping floor;
- time required to unload collection vehicles;
- number of vehicles that will use the station and their expected days and hours of arrival;
- waste sorting or processing to be accomplished at the facility;
- transfer trailer capacity;
- hours of station operation;
- availability of transfer trailers waiting for loading;
- time required, if necessary, to attach and disconnect trailers from tractors or compactors.

Transfer station capacity can be determined using the following formulae:

(i) **Pit stations:** Based on the rate at which wastes can be unloaded from collection vehicles:

$C = P_c \times (L/W) \times (60 \times H_w/T_c) \times F$

Based on rate at which transfer trailers are loaded:

$C = (P_t \times N \times 60 \times H_t)/(T_t + B)$

(ii) **Direct dump stations:** $C = (Nn \times Pt \times F \times 60 \times Hw)/ [((Pt/Pc) \times (W/Ln)) \times Tc + B]$

(iii) **Hopper compaction stations:** $C = (N_n \times P_t \times F \times 60 \times H_w)/[(P_t/P_c \times T_c) + B]$

(iv) **Push pit compaction station:** $C = (N_p \times P_t \times F \times 60 \times H_w)/[(P_t/P_c \times W/L_p \times T_c) + B_c + B]$

Where:

C = Station capacity (tonnes/day); P_c = Collection vehicle payload (tonnes); L = Total length of dumping space (feet); H_w = Hours per day that waste is delivered; T_c = Time (in minutes) to unload each collection vehicle; F = Peaking factor (ratio of the number of collection vehicles received during an average 30-minute period to the number received during a peak 30-minute period); L_p = Length of push pit (feet); N_p = Number of push pits; B_c = Total cycle time for clearing each push pit and compacting waste into trailer; P_t = Transfer trailer payload (tonnes); N = Number of transfer trailers loading simultaneously; H_t = Hours per day used to load trailers (minutes); B = Time to remove and replace each loaded trailer (minutes); T_t = Time to load each transfer trailer (minutes); N_n = Number of hoppers; L_n = Length of each hopper (feet).

These formulae are useful in estimating the capacity of various types of transfer stations (EPA, 1995) and should be adapted, as necessary, for specific applications.

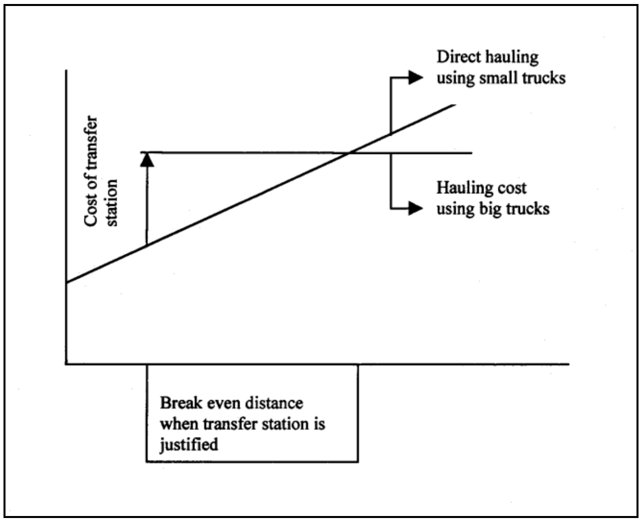
3.4.3 Viability

Transfer stations offer benefits such as lower collection costs (because crews waste less time travelling to the site), reduced fuel and maintenance costs for collection vehicles, increased flexibility in selection of disposal facilities, opportunity to recover recyclables or compostables at the transfer site and the opportunity to shred or scoop wastes prior to disposal. These benefits must be weighed against the costs to develop and operate the facility.

The classical approach to arrive at the economic viability of operating a transfer station, is to add the unit cost of the transfer station to the cost of hauling using large vehicles, and to compare this cost with the cost of hauling directly to the disposal site using the smaller vehicles that service the collection area. The cost of hauling using small vehicles is the sum of the depreciation cost of the vehicle, driver's salary, salary of the collection crew (if they are on standby waiting for the vehicle to return to the collection area) and fuel cost. The transfer station cost is the sum of the transfer station's depreciation cost and the operating and maintenance costs divided by the capacity of the station. The cost of using the large vehicle is the sum of the vehicle depreciation, fuel cost and driver's salary.

The cost-effectiveness of a transfer station depends on the distance of disposal site from the generation area, and a distance of 10 – 15 km is usually the minimum cost-effective distance (Phelps, et al., 1995). The distance between the disposal site and collection area is one of the principal variables in deciding whether to use a transfer station or haul the solid wastes directly from the collection area to the disposal site. Figure 3.8 illustrates the economic analysis involving the effect of the hauling distance on the collection cost:

Figure 3.8
Cost Analysis to Determine Viability of Transfer Station



Now, let us consider first the case in which the transfer station is located directly along the hauling route between the disposal site and the collection area. Let the unit cost of hauling using a small vehicle be *Rs. A/m3 km*. The cost of operation, maintenance, depreciation, loading and unloading at the transfer station be *Rs. B/m3* and the cost of hauling using large vehicles be *Rs. C/m3 km*. If the distance between the collection area and the transfer station is *X km* and the distance between the transfer station and the disposal site is *Y km*, then the distance between the collection area and the disposal site is *X + Y km*. Then, the total cost of hauling the solid wastes from the collection area to the disposal site using a transfer station is:

$$T = 2AX + B + 2CY$$

The factor 2 is added to account for the round trip, which effectively doubles the distance travelled. The total cost of hauling without the transfer station is:

$$T_1 = 2A(X + Y)$$

The transfer station is justified, when:

$$T < T_1$$

That is, the hauling cost using a transfer station is lower than the direct hauling costs between the collection area and the disposal site. Substituting the values of T and T_1 yields:

$$2AX + B + 2CY < 2AX + 2AY$$

or

$$Y > B/(2A - 2C)$$

Note that X cancels out. The distance between the potential transfer station site and the disposal site is the variable to consider. The distance between the collection area and the disposal site is important in deciding the utilisation of a transfer station, if X is equal to zero, in which case the transfer station is located right at the centroid of the collection area. Under normal conditions, the centroid of the collection area has a high land value, and it would be impractical to locate a solid waste transfer station in this area. Figure 3.8 shows the effect of the distance between the potential transfer station site and the disposal site on the hauling cost.

Consider a general case in which the transfer station is located away from the hauling route between the collection area and the disposal site. Let *Z* be the additional distance travelled by the vehicles. The cost *T*, when using a transfer station, is then equal to:

$$T = B + 2AX + 2AZ + 2CY + 2CZ$$

The cost of direct hauling from the collection area to the disposal site remains the same as previously defined. The use of a transfer station is justified, if:

$$B + 2AX + 2AZ + 2CY + 2AZ < 2AX + 2AY$$

or

$$Y > (B + 2CZ + 2AZ)/(2A - 2C)$$

Again, the decision whether or not to use a transfer station is independent of the distance between the collection area and the proposed transfer station.

LEARNING ACTIVITY 3.4

Explain the role of a transfer station in solid waste management.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

3.5 WASTE COLLECTION SYSTEM DESIGN

After we identify appropriate options for collection, equipment and transfer, we must examine the various combinations of these elements to define system-wide alternatives for further analysis. Each should be evaluated for its ability to achieve the identified goals of the collection programme. Economic analysis will usually be a central focus of the system evaluation. This initial evaluation will lead to several iterations, with the differences between the alternatives under consideration becoming more narrowly focused with each round of evaluations (EPA, 1995). After comparing the alternative strategies, the various elements like crew and truck requirement, time requirement and cost involved are calculated. The various formulae used to calculate are:

(i) **Number of services/vehicle load (N):**

$N = (C \times D)/W$

where, C = Vehicle capacity (m^3); D = Waste density (kg/m^3)

and W = Waste generation/residence (kg/service)

(ii) **Time required collecting one load (E):**

$E = N \times L$

where, L = Loading time/residence, including on-route travel

(iii) **Number of loads/crew/day (n):**

The number of loads (n) that each crew can collect in a day can be estimated based on the workday length (t), and the time spent on administration and breaks (t_1), time for hauling and other travel (t_2) and collection route time (t_3).

- **Administrative and break time (t_1):**

  $t_1 = A + B$

  where, A = Administrative time (i.e., for meetings, paperwork, unspecified slack time) and B = Time for breaks and lunch

- **Hauling and other travel time (t_2):**

  $t_2 = (n \times H) - f + G + J$

  where, n = Number of loads/crew/day; H = Time to travel to disposal site, empty truck, and return to route; f = Time to return from site to route; G = Time to travel from staging garage to route and J = Time to return from disposal site to garage.

- **Time spent on collection route (t_3):**

  $t_3 = n \times E$

  where variables have been previously defined.

- **Length of workday (t):**

  $t = t_1 + t_2 + t_3$

  where t is defined by work rules and equations A through D are solved to find n.

(iv) **Calculation of number of vehicles and crews (K):**

$K = (S \times F)/(N \times n \times M)$

where, S = Total number of services in the collection area; F = Frequency of collection (numbers/week) and M = Number of workdays/week

(v) **Calculation of annual vehicle and labour costs:**

Vehicle costs = Depreciation + Maintenance + Consumables + Overhead + License + Fees + Insurance

Labour costs =

Drivers salary + Crew salaries + Fringe benefits + Indirect labour + Supplies + Overhead

LEARNING ACTIVITY 3.5

Work out the time required to dispose of the waste with density 400 kg/m3, with vehicle capacity of $12m^3$ and waste generation per residence is 2kg/service and loading time per residence is 2 minutes.

Note:

a) Write your answer in the space given below.

b) Check your answer with the one given at the end of this Unit.

3.6 RECORD KEEPING, CONTROL, INVENTORY AND MONITORING

For effective waste collection and, indeed, SWM, we must maintain records on the quantities of wastes collected and their variation within a week, month and year, as well as on established long-term trends in solid waste generation rates and composition, sources of wastes and the personnel collecting them. Long-term trends in solid waste generation rates and composition form the basis for planning, especially in budgeting for future vehicle requirements, allocating the collection vehicles and crew, building transfer stations, acquiring strategic lands and determining disposal options. Table 3.2 contains an illustration of a checklist of factors that affect the waste collection system:

Table 3.2
Checklist of Variables Affecting Collection System

Components	Factors to Consider	
Crew size	• labour cost • distance between containers • size and types of containers • loading accessories available in the truck • collection vehicle used	
Container type	• solid wastes generation rate • density of waste generation • street width • traffic volume • collection crew configuration • standard of living	
Collection accessory	• labour cost • protection of worker's health	
Vehicle size/type	• street width, traffic volume • solid waste generation rates • crew size • viability of a transfer station	
Collection route	• street width, traffic volume • direction of traffic flow • solid waste generation rates • spatial distribution of wastes • local topography	
Transfer station	• distance between disposal site and collection area • hauling cost for small and large trucks • cost of transferring the solid wastes from small to large trucks	

Source: Phelps, et al., 1995

Records of personnel and quantities of wastes collected are, when maintained, useful in determining the efficiency of the personnel and in correlating waste quantities with conditions in the service area. A time keeping system at the transfer or disposal site is a key element in improving the efficiency of collection system and planning an upgraded system. The timekeeping system determines if the crew were taking long rest periods, spending time salvaging or carrying out unauthorised activities. The performance of a particular crew in terms of the quantity of solid wastes collected per day could be compared with that of another collection crew working under similar conditions.

The composition of solid wastes should be measured at least once a year for major districts and possibly once every two years in residential areas with stagnant growth rates and development. Changes in composition affect the collection equipment and configuration of the collection system is important in designing the disposal system. Changes in an energy source (such as a shift to gas or electricity from wood or charcoal for cooking and heating), reduces the ash content of wastes, making the solid waste lighter, in which case, larger containers could be used. The same line of analysis holds true in specifying the collection vehicles. Comparison of the routes taken by various crew serving a particular area helps to identify the best hauling route. Although this route may be longer, it could be more economical in terms of hauling time. However, note that the best route often changes with the season.

All these decisions should be based on reliable data, without which the waste collection system will inevitably be ineffective. Proper interpretation of monitoring data allows the authority to adapt the proposed system to actual conditions. In some instances, it also allows management to identify areas, where the design is not realistic.

LEARNING ACTIVITY 3.6

Discuss the practice of record keeping and monitoring with the local civic authorities of your locality and write a short report.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

3.7 IMPLEMENTING COLLECTION AND TRANSFER SYSTEM

Implementing of collection and transfer system involves the following activities, which are important for success of the plan (EPA, 1995):

(i) **Finalising and implementing the system management plan:** For proper implementation of collection and transfer system, it is necessary to have clear organisational structures and management plans. The organisational structure should be simple, with a minimum of administrative and management layers between collection crews and top management. All workers in the department should clearly understand the department's mission and their roles. Through training, incentives and reinforcement by management, workers should be encouraged to be customer-oriented and team contributors. Feedback mechanisms must be introduced to help the crew review their performance and help managers monitoring the performance of crews, equipment, etc. It is also important to periodically review the management plans and structures, as implementation of collection services continues.

(ii) **Purchasing and managing equipment:** For purchasing equipment, most municipalities issue bid specifications. Detailed specifications include exact requirements for equipment sizes and capacities, power ratings, etc. Performance specifications often request that equipment be equivalent to certain available models and meet standards for capacity, speed, etc. Municipalities may either perform equipment maintenance themselves, contract with a local garage, or in some cases, contract with the vehicle vendor at the time of purchase. As part of the preventive maintenance programme, the collection crew should check the vehicle chassis, tyres and body daily and report any problems to maintenance managers. In addition, each vehicle should have an individual maintenance record that includes the following items:

- preventive maintenance schedule;
- current list of specific engine;
- a description of repairs and a list containing information on the repair date, mechanic, cost, type and manufacturer of repair parts and the length of time the truck was out of service, for each maintenance event.

(iii) **Hiring and training personnel:** As in all organisations, good personnel management is essential to an efficient, high-quality waste collection system. Authorities responsible for SWM should, therefore, strive to hire and keep well-qualified personnel. The recruitment programme should assess applicants' abilities to perform the types of physical labour required for the collection, equipment and methods used. To retain employees, management should provide a safe working environment that emphasises career advancement, participatory problem solving and worker incentives. Worker incentives should be developed to recognise and reward outstanding performance by employees. Ways to accomplish motivation include merit-based compensation, awards programme and a work structure. Feedback on employee performance should be regular and frequent.

Safety is especially important because waste collection employees encounter many hazards during each workday. As a result of poor safety records, insurance costs for many collection services are high. To minimise injuries, haulers should have an ongoing safety programme. This programme should outline safety procedures and ensure that all personnel are properly trained on safety issues. Haulers should develop an employee-training programme that helps employees improve and broaden the range of their job-related skills. Education should address such subjects as driving skills, first aid, safe lifting methods, identification of household hazardous wastes, avoidance of substance abuse and stress management.

(iv) **Providing public information:** Maintaining good communication with the public is important to a well-run collection system. Residents can greatly influence the performance of the collection system by co-operating in separation requirements, and by keeping undesirable materials from entering the collected waste stream. Commonly used methods of communicating information include brochures, articles in community newsletters, newspaper articles, announcements, and advertisements on radio and television, information attachments to utility bills (either printed or given separately) and school handouts. Communication materials should be used to help residents understand the community waste management challenges and the progress in meeting them. Residents should also be kept informed about issues such as the availability and costs of landfill capacity so that they develop an understanding of the issues and a desire to help meet their waste management needs.

(v) **Monitoring system cost and performance:** Collection and transfer facilities should develop and maintain an effective system for cost and performance reporting. Each collection crew should complete a daily report containing the following information:

- Total quantity hauled.
- Total distance and travel times to and from the disposal site.
- Amounts delivered to each disposal, transfer, or processing facility.
- Waiting time at sites.
- Number of loads hauled.
- Vehicle or operational problems needing attention.

Collected data should be used to forecast workloads, truck costs, identify changes in the generation of wastes and recyclables, trace the origin of problematic waste materials and evaluate crew performance. Just as the goals of a collection programme set its overall directions, a monitoring system provides the short-term feedback necessary to identify the corrections needed to achieve those goals.

In brief guidelines for planning waste collection and transport are given below:

- Analyse the quantum of waste generated with composition
- Capacity building of town municipalities with appropriate infrastructure and the knowledge of existing laws or regulations on waste collection, transport and safe disposal.
- Designate a para-state agency to oversee waste collection, transport and disposal to avoid confusion among para-state government agencies.
- Determine geographic scope of collection and transport services.
- Determine funding, equipment and labour needs.
- Determine the type and amount of waste to be processed

- Implement decentralised waste treatment through proven local techniques
- Deploy GPS (Global Positioning System) based trucks for waste collection and transport to minimise pilferages.
- Adopt spatial information system for the management
- Consider a transfer station that serves as a central location for activities to sort and recover waste.
- Implement decentralised waste management including all stakeholders with active participation of the public.

LEARNING ACTIVITY 3.7

Identify the activities necessary for successful implementation of collection and transfer system.

Note:

a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

3.8 THE CASE OF BANGALORE

In the Bangalore city (India), the waste collected through street sweeping is the main system of primary collection of wastes. However, recently efforts are being made for doorstep collection of waste through NGOs (Non-Governmental Organisations) and private contractors, but only about 5% of the population is covered under this system. The waste generated by the rest is collected from either the street or the dustbins. Other details regarding the collection process in Bangalore are given below:

(i) **Waste storage:** There are about 14,000 bottomless cement bins having 0.9 meters diameter and 0.6 cubic meter storage capacity and large masonry bins for depositing wastes at a distance of about 100 to 200 meters. Besides these, there are 1500 places, where the waste is deposited but no bins are kept on these sites. Recently, metal containers have been placed and at present 55 metal containers are in the city for the storage of waste in a more hygienic manner.

(ii) **Waste collection:** The frequency of removal of wastes varies from place to place, depending on the locality. Whichever system adapted in the area needs proper planning for collection, loading, unloading and transportation from transfer station and to the point of final disposal, considering traffic constraints, peak hour traffic, etc. An optimum collection schedule requires to be worked out where the number of premises or dumps is mentioned on a daily programme sheet, to be executed by the driver or supervisor in charge of collection. At present, it is estimated that there are about 4943 hotels/restaurants, which produce a large quantity of organic wastes in Bangalore. The silt and waste removed from drains get deposited along the roadside. The human and animal excreta also add to the mass getting deposited on streets. Mechanical sweeping or cleaning cannot work in Bangalore roads and footways because of obstructions due to the activities of hawkers, shop extensions, broken pavements, etc. Pedestrians, shops, goods vehicles carrying loose materials contribute to street littering of paper, used tickets, cigarette butts, etc., as well as vehicles dropping material during their movement (http://stratema.sigis.net/cupum/pdf/E1.pdf).

(iii) **Waste transportation:** Removal of garbage is a very important aspect of SWM, and the method of transportation is crucial. In essence, any breakdown in this system could create problems. Transportation implies conveyance from point of collection to the point of final disposal either directly or through a transfer system. In Bangalore, the transportation of waste is done by:

- engaging, departmentally, 82 trucks of the Corporation.
- engaging 129 vehicles, on contract, for layout and markets and 72 vehicles for transportation of waste. (In addition, the Bangalore Corporation has 13 dumper placers for transporting metallic containers of 2.5 to 3 tonnes capacity and 6 mini-compactors for transportation of waste.)

The clearing efficiency is 30 to 35%. The vehicles are open and the spillage of waste on the roads is a common feature. Each truck makes two trips to the dumpsite everyday. There are no transfer stations in Bangalore. The waste collected from the roads and bins is directly transported to the final disposal sites. There is no arrangement made for the primary collection of construction waste. The engineering division of the Corporation removes the unauthorised construction waste from time to time. There are 115 small and big vegetable, fruit and meat markets in the city. However, no special arrangements are made for the collection of waste from these markets.

LEARNING ACTIVITY 3.8

A collection vehicle is found to be able to service customers at a rate of 2 customers per minute. If actual time spent for collection is 4 hours per day, compute the number of customers served per day.

Calculate the number of collection vehicles a corporation ward with 10,000 houses (services) that are to be collected once per week. (The ward wants the collection on Mondays, Tuesdays, Thursdays, and Fridays, leaving Wednesdays for special projects and maintenance. A single collection vehicle can service 250 houses in a single day and still have time to take the full loads to the landfill.)

Note:

a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

SUMMARY

In this Unit, our focus was on waste collection systems. We discussed in detail the various components of waste collection system including collection frequency, storage containers, collection route and transfer station. We also discussed the viability of establishing and maintaining transfer stations. During the course of our discussion on the movement of collection vehicles and crew, we brought out the usefulness of the MTM technique to achieve efficiency in vehicle and crew movement. We also discussed the design, operation and implementation aspects of waste collection systems. We closed the Unit with the case study of Bangalore.

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Lecture 3

Model Answers to Learning Activities

LEARNING ACTIVITY 3.1

Bangalore Mahanagara Palike (BMP) undertakes the waste collection system in our locality.

Solid waste collection starts at the point of waste generation. Wastes are stored in bottomless concrete containers placed 100 meters apart for which covers are not provided. Wastes are collected in trucks of 4 to 5 tonnes capacity. Collection frequency is based on the requirement of the locality. Since our locality is mostly residential, collection of waste is done three times a week. The collection crew consists of a driver and two helpers. The collection route for our locality is entirely left to the driver's judgement.

Collection is often the most costly component of the solid waste management system and a proper collection system design and management can reduce the cost significantly. In terms of cost, the collection system in developing countries accounts for 70 – 80% of the total budget for solid waste management, the remaining 20 – 30% going for overheads. While making decisions for alternative collection systems, the services must be evaluated considering such factors as efficiency, effectiveness, equity, reliability, safety and environmental impacts.

LEARNING ACTIVITY 3.2

The types of containers used in our locality are uncovered bottomless concrete rings having 0.9 meters diameter and 0.6 cubic meter storage capacity. They are placed 100 – 200 meters apart. The collection vehicle used is a truck of 4 – 5 tonne capacity and is enclosed by an iron mesh at the top to prevent the spillage of wastes.

LEARNING ACTIVITY 3.3

The heuristic (trial and error) route development process is a relatively manual approach that applies specific routing patterns to block configurations. Routes are to be traced on the tracing paper by following certain rules. Routes should not be fragmented or overlapping. Each route should be compact, consisting of street segments clustered in the same geographical area. In streets with heavy traffic, wastes should not be collected during peak hours. Higher elevations should be at the start of the route. Waste on a steep hill should be collected, when practical, on both sides of the street while vehicle is moving downhill. This facilitates safe, easy and fast collection. In case of one-way streets, it is best to start near the upper end of the street, working down it through the looping process. Services on dead end streets can be considered as services on the street segment. To keep right turns at a minimum, collect the dead-end streets when they are to the left of the truck. They must be collected by walking down, backing down or making a U-turn.

LEARNING ACTIVITY 3.4

Transfer station is a centralised facility where waste is unloaded from smaller collection vehicles and reloaded into large vehicles for transport to a disposal or processing site. To determine whether a transfer system is viable for a particular community, the decision-makers should compare the costs and savings associated with the construction and operation of a transfer facility. The use of transfer station is a sound practice when there is a need for vehicles servicing a collection route to travel a shorter distance, unload and return quickly to their primary task of collecting the waste. There are 3 types of stations depending on the capacity, viz., small capacity (less than 100 tonnes/day), medium capacity (100 to 500 tonnes) and large capacity (more than 500 tonnes). Some of the factors that should be considered in determining the appropriate size of a transfer facility include the capacity of collection vehicles, time required to unload, waste sorting, hours of station operation and time required to connect and disconnect the trailers from compactors.

LEARNING ACTIVITY 3.5

Convert 400 kg/m^3 to tonnes, i.e. 400/1000 = 0.4 tonnes/m^3

(i) Number of services/vehicle load (N)

N = (C X D)/W
= (12 x 0.4)/2
= 2.4 ~ 2

(ii) Time required to collect the load

E = N x L
= 2 x 2
= 4 minutes

LEARNING ACTIVITY 3.6

The solid waste collection in our ward is undertaken by a private contract system, and Bangalore Mahanagara Palike (BMP), which has appointed a Medical Health officer, a Senior Health Inspector, a Junior Health Inspector and Sanitary *Daffedars*, assists the private contractor. They have employed *pourakarmikas* for sweeping and collection of wastes from households and containers. The Health Inspectors are in charge of the muster roll. Workers assemble at 6:30 a.m. in the morning at a specified place. Each worker is given the equipment and the section of the ward, which he or she has to clean. Work ends at 10:30 a.m. and the workers assemble at the same place to give their muster roll. From 11 a.m. to 1:30 p.m. gang work is carried out in a particular area or even a whole ward depending on the need. The need may be a clogged drain or clearing of black spots. The attendance of each of the workers is recorded at the field by the inspectors. There is another muster roll at 1:30 p.m. At present records are not maintained on the quantity of wastes collected and their variation. Once in a while, the contractor of our ward is asked to determine the quantity of waste generated per day.

LEARNING ACTIVITY 3.7

The activities responsible for successful implementation of collection and transfer systems are as follows:

- Finalising and implementing the system management plan.
- Purchasing and management of equipment.
- Hiring and training personnel.
- Providing public information.
- Monitoring system cost and performance.

LEARNING ACTIVITY 3.8

(i) If the crew can service 2 customers in one minute, then in 4 hours (i.e., 4 x 60 minutes) the crew can service:

$$\frac{2}{1} = \frac{X}{4 \times 60}$$

$X = 480$ customers per day.

(ii) The number of collection vehicles needed for a community is given by:

$$N = \frac{SF}{XW}$$

Where N = number of collection vehicles required; S = total number of households serviced = 10,000; F = collection frequency, number of collections per week = 1; X = number of households a single truck can service per day = 4 and W = number of workers per week = 250.

Therefore $N = \frac{10000 \times 1}{250 \times 4}$, i.e., the corporation ward requires ten collection vehicles.

Lecture 4

Waste Disposal

STRUCTURE

OVERVIEW

In Unit 3, we examined waste collection system that subsumes activities such as waste collection, storage and transportation. As a logical sequence, the wastes collected should properly be disposed of to avoid health and environmental hazards, and this is the focus of Unit 4. We will begin this Unit by explaining the key issues in waste disposal followed by disposal options and selection criteria. Then, we will discuss the engineered waste disposal option in detail and explain the principles, processes, environmental concerns and issues related to its design, construction and monitoring. Finally, we will present a case study of disposal option.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- assess key issues associated with waste disposal;
- evaluate the various options for disposal of wastes and their selection criteria;
- explain the design, operation and maintenance of sanitary landfill;
- determine the most viable disposal option for your locality.

4.1 KEY ISSUES IN WASTE DISPOSAL

Let us first get one thing very clear: there is no option but to dispose of wastes. Disposal is the final element in the SWM system. It is the ultimate fate of all solid wastes, be they residential wastes collected and transported directly to a landfill site, semisolid waste (sludge) from municipal and industrial treatment plants, incinerator residue, compost or other substances from various solid waste processing plants that are of no further use to society. It is, therefore, imperative to have a proper plan in place for safe disposal of solid wastes, which involves appropriate handling of residual matter after solid wastes have been processed and the recovery of conversion products/energy has been achieved. It follows that an efficient SWM system must provide an environmentally sound disposal option for waste that cannot be reduced, recycled, composted, combusted, or processed further (Ali, et al 1999).

However, in these days, indiscriminate disposal of wastes in many regions is very common, giving rise to such problems as:

- health hazards (e.g., residents in the vicinity of wastes inhale dust and smoke when the wastes are burnt; workers and rag pickers come into direct contact with wastes, etc.);
- pollution due to smoke;
- pollution from waste leachate and gas;
- blockage of open drains and sewers.

Clearly, safe disposal of solid wastes is important for safeguarding both public health and the environment.

Issues to be overcome

To achieve effective waste disposal, we must overcome the following the constraints:

(i) **Municipal capacities:** With the increasing volume of waste generation, collection of wastes gets more attention than disposal. Furthermore, in India, only a few municipalities seem to have the required experience or capacity for controlled disposal. Some municipalities may have identified disposal sites but still only few may actively manage them. In some places, contracting out waste disposal is seen as a solution. But, municipalities are not equipped to deal with the problems associated with it, such as issues of privatisation and monitoring of the contract.

(ii) **Political commitment:** SWM is more than a technical issue, as any successful programme needs effective political and governmental support. This is rarely a priority of government authorities, unless there is a strong and active public interest as well as international interventions.

(iii) **Finance and cost recovery:** Development of a sanitary landfill site represents a major investment and it generally receives less priority over other resource demands. And, even when establishment costs are secured for a disposal site, recurrent costs to maintain it always pose problems.

(iv) **Technical guidelines:** Standards established for waste disposal in one country need not necessarily be appropriate for another, due to reasons such as climatic conditions, resources availability, institutional infrastructure, socio-cultural values, etc. In the absence of adequate data and/or the means of collecting/acquiring it, officials often struggle to plan a safe and economically viable disposal option.

(v) **Institutional role and responsibility:** A disposal site may be located outside the boundary of a town and may serve more than one town. This necessitates the co-ordination of all authorities concerned, and the roles and responsibilities of different departments need to be clearly defined and accepted by all concerned.

(vi) **Location:** The accessibility of a disposal site, especially its distance from town, is an important factor in site selection, especially when staff and public do not have a strong incentive to use it, when compared to indiscriminate dumping. Site selection is perhaps the most difficult stage in the development of suitable disposal option.

LEARNING ACTIVITY 4.1

Identify waste disposal constraints faced by municipal authorities of your locality.

Note:

a) Write your answer in the space given below.

b) Check your answer with the one given at the end of this Unit.

4.2 DISPOSAL OPTIONS AND SELECTION CRITERIA

The most common disposal option practised currently in many countries is either uncontrolled dumping or dumping with moderate control. The environmental costs of uncontrolled dumping include breeding of disease causing vectors (e.g., flies, mosquitoes and rodents), pollution, odour and smoke. In Subsection 4.2.1, we will discuss some of the options available for waste disposal. However, it should be noted that the option selected for waste disposal must mesh with the existing socio-cultural milieu, infrastructure, etc., and this we will discuss in Subsection 4.2.2.

4.2.1 Disposal options

In this Subsection, we will touch upon some the options available for waste disposal, and in that respect, we will consider the following:

(i) **Uncontrolled dumping or non-engineered disposal:** As mentioned, this is the most common method being practised in many parts of the world, and India is no exception. In this method, wastes are dumped at a designated site without any environmental control. They tend to remain there for a long period of time, pose health risks and cause environmental degradation. Due to the adverse health and environmental impact associated with it, the non-engineered disposal is not considered a viable and safe option.

(ii) **Sanitary landfill:** Unlike the non-engineered disposal, sanitary landfill is a fully engineered disposal option in that the selected location or wasteland is carefully engineered in advance before it is pressed into service. Operators of sanitary landfills can minimise the effects of leachate (i.e., polluted water which flows from a landfill) and gas production through proper site selection, preparation and management. This particular option of waste disposal is suitable when the land is available at an affordable price, and adequate workforce and technical resources are available to operate and manage the site. We will discuss this option in detail in Section 4.3.

(iii) **Composting:** This is a biological process of decomposition in which organisms, under controlled conditions of ventilation, temperature and moisture, convert the organic portion of solid waste into humus-like material. If this process is carried out effectively, what we get as the final product is a stable, odour-free soil conditioner. Generally, the option of composting is considered, when a considerable amount of biodegradable waste is available in the waste stream and there is use or market for composts. Composting can be either centralised or small-scale. Centralised composting plants are possible, if adequate skilled workforce and equipments are available. And, small-scale composting practices can be effective at household level, but this needs public awareness. We will discuss composting processes, methods, technologies and environmental consequences in detail in Unit 7.

(iv) **Incineration:** This refers to the controlled burning of wastes, at a high temperature (roughly 1200 – 1500°C), which sterilises and stabilises the waste in addition to reducing its volume. In the process, most of the combustible materials (i.e., self-sustaining combustible matter, which saves the energy needed to maintain the combustion) such as paper or plastics get converted into carbon dioxide and ash. Incineration may be used as a disposal option, when land filling is not possible and the waste composition is highly combustible. An appropriate technology, infrastructure and skilled workforce are required to operate and maintain the plant. We will discuss in detail the process, technology and environmental concerns of incineration, which is generally limited to hospital and other biological wastes, in Unit 8.

(v) **Gasification:** This is the partial combustion of carbonaceous material (through combustion) at high temperature (roughly 1000°C) forming a gas, comprising mainly carbon dioxide, carbon monoxide, nitrogen, hydrogen, water vapour and methane, which can be used as fuel. We will discuss the aspects of energy recovery, including gasification and refuse-derived fuel (RDF), described below, in Unit 8.

(vi) **Refuse-derived fuel (RDF):** This is the combustible part of raw waste, separated for burning as fuel. Various physical processes such as screening, size reduction, magnetic separation, etc., are used to separate the combustibles (see Unit 8 for details).

(vii) **Pyrolysis:** This is the thermal degradation of carbonaceous material to gaseous, liquid and solid fraction in the absence of oxygen. This occurs at a temperature between 200 and 900°C. The product of pyrolysis is a gas of relatively high calorific value of 20,000 joules per gram with oils, tars and solid burned residue (Ali, et al 1999).

Relative merits of some options

Having touched upon several disposal options, let us now present the merits and demerits of some of them in Table 4.1:

Table 4.1
Relative Merits of Disposal Options

Disposal Option → **↓Sustainability Indicator**	**Non-engineered Disposal**	**Sanitary Landfill**	**Composting**	**Incineration**
Volume reduction	×	×	×	√
Expensive	×	√	√	√
Long term maintenance	√	√	×	×
By product recovery	×	√	√	√
Adaptability to all wastes	√	√	×	×
Adverse environmental effect	√	√	×	√

Source: http//ces.iisc.ernet.in/energy/SWMTR/TR85.html

4.2.2 Selection criteria

With the help of proper frameworks and sub-frameworks, we can assess the effectiveness of each of the waste disposal options (see Subsection 4.2.1). While a framework represents an aid to decision-making and helps to ensure the key issues are considered, a sub-framework explains how and why the necessary information should be obtained (Ali, et al 1999). A framework contains a list of issues and questions pertaining to the technical, institutional, financial, social and environmental features of a waste disposal system to assess the capacity of a disposal option to meet the requirements. For example, an appraisal of waste disposal option must include the following:

(i) **Technical:** This feature, involving efficient and effective operation of the technology being used, evaluates the following components of a SWM system:

- composition of wastes, e.g., type, characteristics and quantity.
- existing practices, e.g., collection, transport, and recycling process.
- siting, e.g., location of disposal site, engineering material, etc.
- technology, e.g., operation, maintenance, technical support, etc.
- impact, e.g., anticipated by-product, requirement for their treatment and disposal, etc.

(ii) **Institutional:** This involves the ability and willingness of responsible agencies to operate and manage the system by evaluating the following:

- structures, roles and responsibilities, e.g., current institutional frameworks.
- operational capacity, e.g., municipal capacities, local experience and staff training.
- incentives, e.g., management improvement and waste disposal practices.
- innovation and partnership.

(iii) **Financial:** This assesses the ability to finance the implementation, operation and maintenance of the system by evaluating the following:

- financing and cost recovery, e.g., willingness to raise finance for waste management.
- current revenue and expenditure on waste management.
- potential need for external finance for capital cost.

(iv) **Social:** This helps in avoiding adverse social impact by evaluating the following:

- waste picking, which has an impact on livelihood and access to waste pickers.

- health and income implication.
- public opinions on the existing and proposed system.

(v) **Environmental:** This means setting up an environment friendly disposal system by evaluating the following:

- initial environmental risks, i.e., impact of existing and proposed disposal option.
- long-term environmental risks, i.e., long-term implication (future impacts).

LEARNING ACTIVITY 4.2

Considering the selection criteria, suggest the best disposal option for your locality.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

We touched upon the various disposal options alongside the selection criteria for disposal options. One such option we mentioned is engineered disposal, often referred to as sanitary landfill. Although in several countries, uncontrolled dumping is still the most prevalent disposal option, sanitary landfill is gradually taking precedence as the ill effects of uncontrolled dumping are increasing. This being so, we will discuss the principle, processes, design, construction and monitoring aspects of sanitary landfill next.

4.3 SANITARY LANDFILL

The term landfill generally refers to an engineered deposit of wastes either in pits/trenches or on the surface. And, a sanitary landfill is essentially a landfill, where proper mechanisms are available to control the environmental risks associated with the disposal of wastes and to make available the land, subsequent to disposal, for other purposes. However, you must note that a landfill need not necessarily be an engineered site, when the waste is largely inert at final disposal, as in rural areas, where wastes contain a large proportion of soil and dirt. This practice
is generally designated as non-engineered disposal method. When compared to uncontrolled dumping, engineered landfills are more likely to have pre-planned installations, environmental monitoring, and organised and trained workforce. Sanitary landfill implementation, therefore, requires careful site selection, preparation and management.

The four minimum requirements you need to consider for a sanitary landfill are:

(i) full or partial hydrological isolation;
(ii) formal engineering preparation;
(iii) permanent control;
(iv) planned waste emplacement and covering.

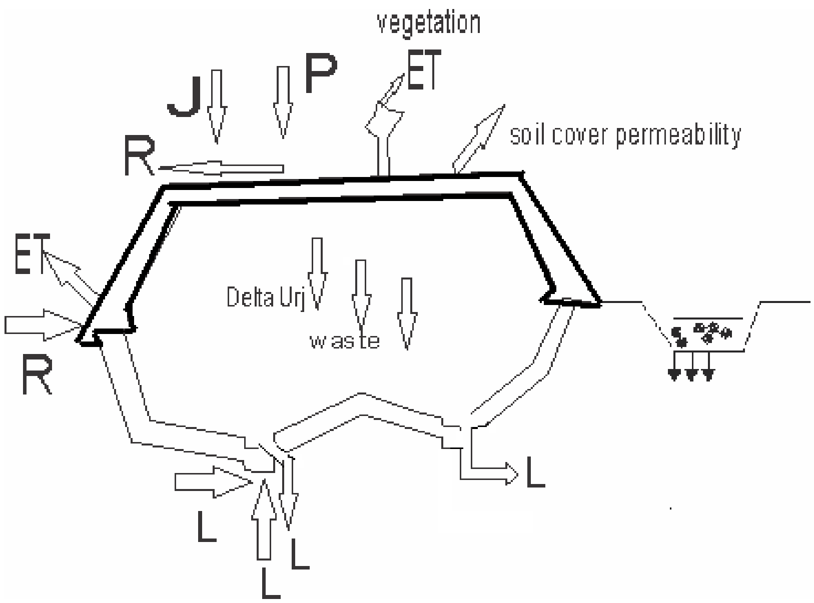
Against this background, let us now discuss the principles, processes and operation of sanitary landfills.

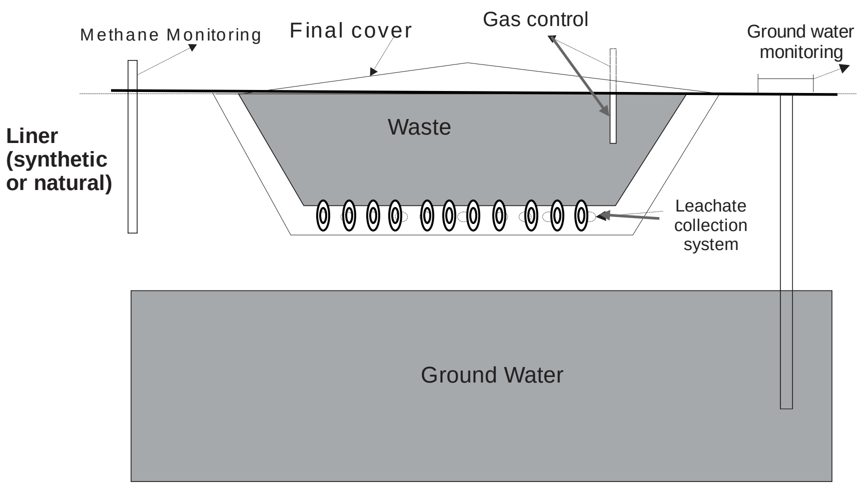
4.3.1 Principle

The purpose of land filling is to bury or alter the chemical composition of the wastes so that they do not pose any threat to the environment or public health. Landfills are not homogeneous and are usually made up of cells in which a discrete volume of waste is kept isolated from adjacent waste cells by a suitable barrier. The barriers between cells generally consist of a layer of natural soil (i.e., clay), which restricts downward or lateral escape of the waste constituents or leachate.

Land filling relies on containment rather than treatment (for control) of wastes. If properly executed, it is a safer and cheaper method than incineration (see Unit 8). An environmentally sound sanitary landfill comprises appropriate liners for protection of the groundwater (from contaminated leachate), run-off controls, leachate collection and treatment, monitoring wells and appropriate final cover design (Phelps, 1995). Figure 4.1 below gives a schematic layout of sanitary landfill along with its various components:

Figure 4.1
Schematic Layout of Sanitary Landfill





Design components in a subtitle D Landfill

P: precipitation; J: irrigation or leachate recirculation; R: surface runoff; R: runoff from external areas; ET: actual evapotranspiration;* $P_i = P+J+R^*- R-ET+/ \Delta Us$*; Us: water contents in soil; Uw: water content in waste; S: water added in sludge disposal; b: water production (if>0) or consumption (if <0) caused by biological degradation of organic matter; Is/Ig: water from natural aquifers;* $L=Pi+S+Ig+b +/-\Delta Uw$*; L: total leachate production; Li: infiltration into aquifers; Lr: leachate collected by drains.*

Before we take up landfill processes for discussion in Subsection 4.3.2, let us touch upon the phases in the life cycle of a landfill, and these are:

- **Planning phase**: This typically involves preliminary hydro-geological and geo-technical site investigations as a basis for actual design.

- **Construction phase**: This involves earthworks, road and facility construction and preparation (liners and drains) of the fill area.

- **Operation phase (5 – 20 years):** This phase has a high intensity of traffic, work at the front of the fill, operation of environmental installations and completion of finished sections.

- **Completed phase (20 – 100 years):** This phase involves the termination of the actual filling to the time when the environmental installations need no longer be operated. The emissions may have by then decreased to a level where they do not need any further treatment and can be discharged freely into the surroundings.

- **Final storage phase:** In this phase, the landfill is integrated into the surroundings for other purposes, and no longer needs special attention.

4.3.2 Landfill processes

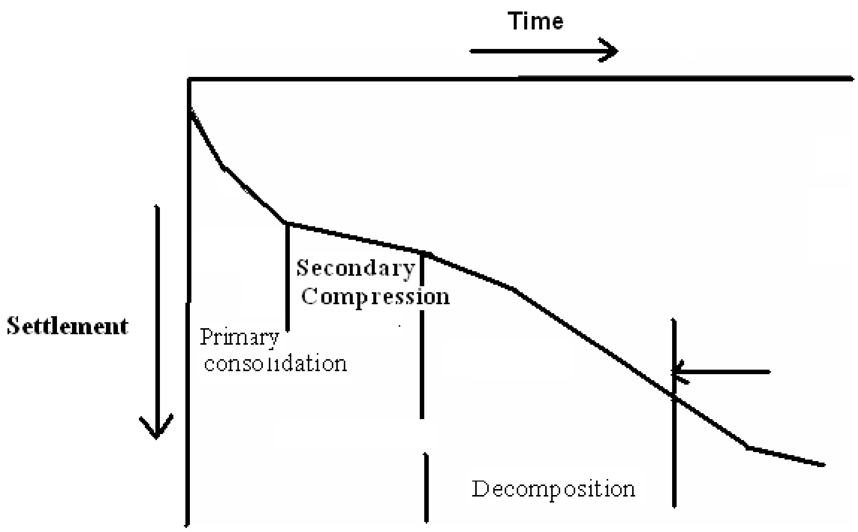
The feasibility of land disposal of solid wastes depends on factors such as the type, quantity and characteristics of wastes, the prevailing laws and regulations, and soil and site characteristics. Let us now explain some of these processes.

(i) **Site selection process and considerations:** This requires the development of a working plan – a plan, or a series of plans, outlining the development and descriptions of site location, operation, engineering and site restoration. Considerations for site include public opinion, traffic patterns and congestion, climate, zoning requirements, availability of cover material and liner as well, high trees or buffer in the site perimeter, historic buildings, and endangered species, wetlands, and site land environmental factors, speed limits, underpass limitations, load limits on roadways, bridge capacities, and proximity of major roadways, haul distance, hydrology and detours.

(ii) **Settling process:** The waste body of a landfill undergoes different stages of settling or deformation. Figure 4.2 below illustrates these stages:

Figure 4.2

Settling Processes in Landfill



The three stages shown in the figure above are described below:

- **Primary consolidation:** During this stage, a substantial amount of settling occurs. This settlement is caused by the weight of the waste layers. The movement of trucks, bulldozers or mechanical compactors will also enhance this process. After this primary consolidation, or short-term deformation stage, *aerobic degradation* processes occur.

- **Secondary compression:** During this stage, the rate of settling is much lower than that in the primary consolidation stage, as the settling occurs through compression, which cannot be enhanced.

- **Decomposition:** During the degradation processes, organic material is converted into gas and leachate. The settling rate during this stage increases compared to the secondary compression stage, and continues until all decomposable organic matter is degraded. The settling rate, however, gradually decreases with the passage of time.

To appropriately design protective liners, and gas and leachate collection systems, it is, therefore, necessary to have a proper knowledge of the settling process of wastes.

(iii) **Microbial degradation process:** The microbial degradation process is the most important biological process occurring in a landfill. These processes induce changes in the chemical and physical environment within the waste body, which determine the quality of leachate and both the quality and quantity of landfill gas (see Subsection 4.3.2). Assuming that landfills mostly receive organic wastes, microbial processes will dominate the stabilisation of the waste and therefore govern landfill gas generation and leachate composition. Soon after disposal, the predominant part of the wastes becomes *anaerobic*, and the bacteria will start degrading the solid organic carbon, eventually to produce carbon dioxide and methane. The *anaerobic degradation* process undergoes the following stages:

- Solid and complex dissolved organic compounds are hydrolysed and fermented by the fermenters primarily to volatile fatty acids, alcohols, hydrogen and carbon dioxide.
- An acidogenic group of bacteria converts the products of the first stage to acetic acid, hydrogen and carbon dioxide.
- Methanogenic bacteria convert acetic acid to methane and carbon dioxide and hydrogenophilic bacteria convert hydrogen and carbon dioxide to methane.

The biotic factors that affect methane formation in the landfill are pH, alkalinity, nutrients, temperature, oxygen and moisture content.

Enhancement of degradation

Enhancement of the degradation processes in landfills will result in a faster stabilisation of the waste in the landfill, which enhances gas production, and we can achieve this by:

- **Adding partly composted waste:** As the readily degradable organic matter has already been decomposed aerobically, the rapid acid production phase is overcome, and the balance of acid and methane production bacteria can develop earlier and the consequent dilution effect lowers the organic acid concentration.

- **Recirculating leachate:** This may have positive effects since a slow increase in moisture will cause a long period of gas production. During warmer periods, recirculated leachate will evaporate, resulting in lower amounts of excess leachate.

LEARNING ACTIVITY 4.3

Do you think a sanitary landfill is possible to manage wastes in your locality? List at least three reasons to support your answer.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

We mentioned earlier that microbial degradation of waste under anaerobic conditions induces gas emission and leachate formation. We will explain this further, next.

Landfill gas and leachate

Leachate and landfill gas comprise the major hazards associated with a landfill. While leachate may contaminate the surrounding land and water, landfill gas can be toxic and lead to global warming and explosion leading to human catastrophe (Phelps, 1995). (Note that global warming, also known as greenhouse effect, refers to the warming of the earth's atmosphere by the accumulation of gases (e.g., methane, carbon dioxide and chlorofluorocarbons) that absorbs reflected solar radiation.) The factors, which affect the production of leachate and landfill gas, are the following:

- **Nature of waste:** The deposition of waste containing biodegradable matter invariably leads to the production of gas and leachate, and the amount depends on the content of biodegradable material in the waste.
- **Moisture content:** Most micro-organisms require a minimum of approximately 12% (by weight) moisture for growth, and thus the moisture content of landfill waste is an important factor in determining the amount and extent of leachate and gas production.
- **pH:** The methanogenic bacteria within a landfill produce methane gas, which will grow only at low pH range around neutrality.
- **Particle size and density:** The size of waste particle affects the density that can be achieved upon compaction and affects the surface area and hence volume. Both affect moisture absorption and therefore are potential for biological degradation.
- **Temperature:** An increase in temperature tends to increase gas production. The temperature affects the microbial activity to the extent that it is possible to segregate bacteria, according to their optimum temperature operating conditions.

Note that the composition of waste, which varies with region and climate (season), determines the variation in pollution potential. Carbohydrates comprise a large percentage of biodegradable matter within municipal waste, the overall breakdown of which can be represented by the following equation:

$$\underset{\text{(Carbohydrate)}}{C_6H_{12}O_6} \xrightarrow{\text{(Bacteria)}} \underset{\text{(Methane)}}{CH_4} + \underset{\text{(Carbon dioxide)}}{CO_2} + \text{Biomass} + \text{Heat}$$

Let us now discuss landfill leachate and gas emission in detail along with their composition and adverse effects.

4.4 LANDFILL GAS EMISSION

Landfill gas contains a high percentage of methane due to the anaerobic decomposition of organic matter, which can be utilised as a source of energy. In Subsections 4.4.1 to 4.4.4, we will explain the composition and properties, risks, migration and control of landfill gas.

4.4.1 Composition and properties

We can predict the amount and composition of the gas generated for different substrates, depending on the general anaerobic decomposition of wastes added. Climatic and environmental conditions also influence gas composition. Due to the heterogeneous nature of the landfill, some acid-phase anaerobic decomposition occurs along with the methanogenic decomposition. Since aerobic and acid-phase degradation give rise to carbon dioxide and not methane, there may be a higher carbon dioxide content in the gas generated than what would otherwise be expected. Furthermore, depending on the moisture distribution, some carbon dioxide goes into solution. This may appear to increase (artificially) the methane content of the gas measured in the landfill. A typical landfill gas contains a number of components such as the following, which tend to occur within a characteristic range:

- **Methane:** This is a colourless, odourless and flammable gas with a density lighter than air, typically making up 50 – 60% of the landfill gas.
- **Carbon dioxide:** This is a colourless, odourless and non-inflammable gas that is denser than air, typically accounting for 30 – 40%.
- **Oxygen:** The flammability of methane depends on the percentage of oxygen. It is, therefore, important to control oxygen levels, where gas abstraction is undertaken.
- **Nitrogen:** This is essentially inert and will have little effect, except to modify the explosive range of methane.

It is difficult to convert the amount of gas measured to the maximum landfill gas production value because gas is withdrawn from a small part of the landfill only, referred to as *zone of influence* during measurement. In other words, it is very difficult to determine this zone and relate it to the whole landfill area.

4.4.2 Hazards

Landfill gas consists of a mixture of flammable, asphyxiating and noxious gases and may be hazardous to health and safety, and hence the need for precautions. Some of the major hazards are listed below:

- **Explosion and fire:** Methane is flammable in air within the range of 5 – 15% by volume, while hydrogen is flammable within the range of 4.1 – 7.5% (in the presence of oxygen) and potentially explosive. Fire, occurring within the waste, can be difficult to extinguish and can lead to unpredictable and uncontrolled subsidence as well as production of smoke and toxic fumes.
- **Trace components:** These comprise mostly alkanes and alkenes, and their oxidation products such as aldehydes, alcohols and esters. Many of them are recognised as toxicants, when present in air at concentrations above occupational exposure standards.

- **Global warming:** Known also as greenhouse effect, it is the warming of the earth's atmosphere by the accumulation of gases (methane, carbon dioxide and chlorofluorocarbons) that absorbs reflected solar radiation.

4.4.3 Migration

During landfill development, most of the gas produced is vented to the atmosphere, provided the permeable intermediate cover has been used. While biological and chemical processes affect gas composition through methane oxidation, which converts methane to carbon dioxide, physical factors affect gas migration. The physical factors that affect gas migration include:

- **Environmental conditions:** These affect the rate of degradation and gas pressure build up.
- **Geophysical conditions:** These affect migration pathways. In the presence of fractured geological strata or a mineshaft, the gas may travel large distances, unless restricted by the water table.
- **Climatic conditions:** Falling atmospheric pressure, rainfall and water infiltration rate affect landfill gas migration.

The proportion of void space in the ground, rather than permeability, determines the variability of gas emission. If the escape of landfill gas is controlled and proper extraction system is designed, this gas can be utilised as a source of energy. If landfill gas is not utilised, it should be burnt by means of flaring. However, landfill gas utilisation can save on the use of fossil fuels since its heating value is approximately 6 kWh/m^3 and can be utilised in internal combustion engines for production of electricity and heat.

It is important that landfill gas is extracted during the operation phase. It is extracted out of the landfill by means of gas wells, which are normally drilled by auger and are driven into the landfill at a spacing of 40 – 70 m. In addition, horizontal systems can be installed during operation of the landfill. The gas wells consist mainly of perforated plastic pipes surrounded by coarse gravel and are connected with the gas transportation pipe with flexible tubing. The vacuum necessary for gas extraction and transportation is created by means of a blower. The most important factors influencing planning and construction of landfill gas extraction systems are settling of waste, water tables in landfills and gas quality.

4.4.4 Control

To control gas emission, it is necessary to control the following:

- waste inputs (i.e., restrict the amount of organic waste).
- processes within the waste (i.e., minimise moisture content to limit gas production).
- migration process (i.e., provide physical barriers or vents to remove the gas from the site and reduce gas pressure). Note that since gas migration cannot be easily prevented, removal is often the preferred option. This is done by using vents (extraction wells) within the waste or stone filled vents, which are often placed around the periphery of the landfill site. Some of the gas collection systems include impermeable cap, granular material, collection pipes and treatment systems.

LEARNING ACTIVITY 4.4

Identify adverse effects of landfill gas and list appropriate control measures.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

4.5 LEACHATE FORMATION

Leachate can pollute both groundwater and surface water supplies. The degree of pollution will depend on local geology and hydrogeology, nature of waste and the proximity of susceptible receptors. Once groundwater is contaminated, it is very costly to clean it up. Landfills, therefore, undergo siting, design and construction procedures that control leachate migration.

4.5.1 Composition and properties

Leachate comprises soluble components of waste and its degradation products enter water, as it percolates through the landfill. The amount of leachate generated depends on:

- water availability;
- landfill surface condition;
- refuse state;
- condition of surrounding strata.

The major factor, i.e., water availability, is affected by precipitation, surface runoff, waste decomposition and liquid waste disposal. The water balance equation for landfill requires negative or zero ("Lo") so that no excess leachate is produced. This is calculated using the following formula:

$Lo = I - E - aW$

i.e. $I - E < aW$

where, Lo = free leachate retained at site (equivalent to leachate production minus leachate leaving the site); I = total liquid input;
E = evapotranspiration losses; a = absorption capacity of waste;
W = weight of waste disposed.

Common toxic components in leachate are ammonia and heavy metals, which can be hazardous even at low levels, if they accumulate in the food chain. The presence of ammoniacal nitrogen means that leachate often has to be treated off-site before being discharged to a sewer, since there is no natural bio-chemical path for its removal (Ali, et al., 1995). Leachate composition varies with time and location. Table 4.2 shows a typical leachate properties and composition at various stages of waste decomposition:

Table 4.2
Properties and Composition of Leachate at Various Stages of Decomposition (mg/l except pH)

Components	Fresh wastes	Aged wastes	Wastes with high moisture
pH	6.2	7.5	8.0
COD	23800	1160	1500
BOD	11900	260	500
TOC	8000	465	450
Volatile acid (as C)	5688	5	12
NH_3-N	790	370	1000
NO_3-N	3	1	1.0
Ortho-P	0.73	1.4	1.0
Cl	1315	2080	1390
Na	9601	300	1900
Mg	252	185	186
K	780	590	570
Ca	1820	250	158
Mn	27	2.1	0.05
Fe	540	23	2.0
Cu	0.12	0.03	-
Zn	21.5	0.4	0.5
Pb	0.40	0.14	-

Source: *Ali et al., 1995*

4.5.2 Leachate migration

It is generally difficult to predict the movement of escaped leachate accurately. The main controlling factors are the surrounding geology and hydrogeology. Escape to surface water may be relatively easy to control, but if it escapes to groundwater sources, it can be very difficult both to control and clean up. The degree of groundwater contamination is affected by physical, chemical and biological actions. The relative importance of each process may change, however, if the leachate moves from the landfill to the sub-surface region.

4.5.3 Control

The best way to control leachate is through prevention, which should be integral to the site design. In most cases, it is necessary to control liquid access, collection and treatment, all of which can be done using the following landfill liners:

- **Natural liners:** These refer to compacted clay or shale, bitumen or soil sealants, etc., and are generally less permeable, resistant to chemical attack and have good sorption properties. They generally do not act as true containment barriers, because sometimes leachate migrates through them.
- **Synthetic (geo-membrane) liners:** These are typically made up of high or medium density polyethylene and are generally less permeable, easy to install, relatively strong and have good deformation characteristics. They sometimes expand or shrink according to temperature and age.

Note that natural and geo-membrane liners are often combined to enhance the overall efficiency of the containment system. Some of the leachate collection systems include impermeable liner, granular material, collection piping, leachate storage tank; leachate is trucked to a wastewater treatment facility.

4.5.4 Treatment

Concentrations of various substances occurring in leachate are too high to be discharged to surface water or into a sewer system. These concentrations, therefore, have to be reduced by removal, treatment or both. The various treatments of leachate include:

- **Leachate recirculation**: It is one of the simplest forms of treatment. Recirculation of leachate reduces the hazardous nature of leachate and helps wet the waste, increasing its potential for biological degradation.
- **Biological treatment:** This removes BOD, ammonia and suspended solids. Leachate from land filled waste can be readily degraded by biological means, due to high content of volatile fatty acids (VFAs). The common methods are aerated lagoons (i.e., special devices which enhance the aerobic processes of

degradation of organic substances over the entire depth of the tank) and activated sludge process, which differs from aerated lagoons in that discharged sludge is recirculated and is often used for BOD and ammonia removal. While under conditions of low COD, rotating biological contactors (i.e., biomass is brought into contact with circular blades fixed to a common axle which is rotated) are very effective in removing ammonia. In an anaerobic treatment system, complex organic molecules are fermented in filter. The common types are anaerobic filters, anaerobic lagoon and digesters.

- **Physicochemical treatment:** After biological degradation, effluents still contain significant concentrations of different substances. Physicochemical treatment processes could be installed to improve the leachate effluent quality. Some of these processes are flocculation-precipitation. (Note that addition of chemicals to the water attracts the metal by floc formation). Separation of the floc from water takes place by sedimentation, adsorption and reverse osmosis.

LEARNING ACTIVITY 4.5

State how you would control and treat leachate.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

4.6 ENVIRONMENTAL EFFECTS OF LANDFILL

The environmental effects of a landfill include wind-blown litter and dust, noise, obnoxious odour, vermin and insects attracted by the waste, surface runoff and inaesthetic conditions. Gas and leachate problems also arise during the operation phase and require significant environmental controls. In what follows, we will describe some of the major environmental effects below:

(i) Wind-blown litter and dust are continuous problems of the ongoing landfill operation and a nuisance to the neighbourhood. Covering the waste cells with soil and spraying water on dirt roads and waste in dry periods, in combination with fencing and movable screens, may minimise the problem of wind-blown litter and dust. However, note that the problem will remain at the tipping front of the landfill.

(ii) Movement of waste collection vehicles, emptying of wastes from them, compactors, earthmoving equipment, etc., produce noise. Improving the technical capability of the equipment, surrounding the fill area with soil embankments and plantations, limiting the working hours and appropriately training the workforce will help minimise noise pollution.

(iii) Birds (e.g., scavengers), vermin, insects and animals are attracted to the landfill for feeding and breeding. Since many of these may act as disease vectors, their presence is a potential health problem.

(iv) Surface run-off, which has been in contact with the land filled waste, may be a problem in areas of intense rainfall. If not controlled, heavily polluted run-off may enter directly into creeks and streams. Careful design and maintenance of surface drains and ditches, together with a final soil cover on completed landfill sections, can help eliminate this problem.

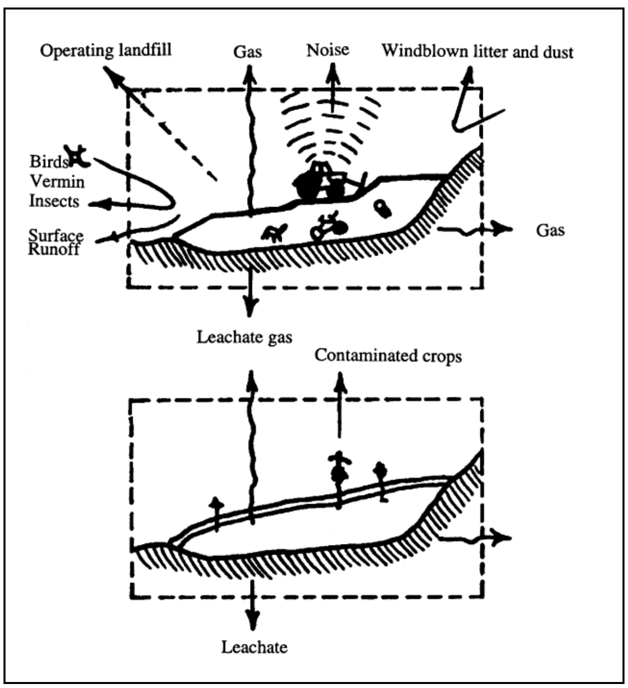
(v) An operating landfill, where equipment and waste are exposed, appears inaesthetic. This problem may be reduced by careful design of screening soil embankments, plantings, rapid covering and re-vegetation of filled sections.

(vi) Gas released, as a result of degradation or volatilisation of waste components, causes odour, flammability, health problems and damage of the vegetation (due to oxygen depletion in the root zone). The measures to control this include liners, soil covers, passive venting or active extraction of gas for treatment before discharge into the atmosphere.

(vii) Polluted leachate appears shortly after disposal of the waste. This may cause groundwater pollution and pollution of streams through sub-surface migration. Liners, drainage collection, treatment of leachate, and groundwater and downstream water quality monitoring are necessary to control this problem.

Figure 4.3 gives a summary of the environmental emissions from a sanitary landfill:

Figure 4.3
Environmental Emissions from a Sanitary Landfill



Besides the emissions shown in Figure 4.3, incidental events such as flooding, fires, landslides and earthquakes result in severe environmental impacts, and may require preventive measures with respect to landfill site selection, design and operation. In the main, to minimise adverse environmental impacts due to sanitary landfill, proper attention must be paid to the environmental aspects at all stages and phases of landfill management, viz., site selection, design, construction, operation and maintenance (Ali, et al., 1995).

Regulations for Landfills:

Regulations include restrictions on distances from airports, flood plains, and fault areas, as well as limitations on construction in wetlands and others. Prevention of contamination of groundwater and land resources requires synthetic liner. (Hutzler, 2004). Adequate buffer with the restricted activities around the landfill.

LEARNING ACTIVITY 4.6

Compare sanitary landfill and uncontrolled dumping from the point of view of public health and the environment.

Note:

a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

4.7 LANDFILL OPERATION ISSUES

Once a potential site has been identified/selected, an assessment of design aspects, including costs for civil works, begins. Important issues to be looked into in this regard are land requirements, types of wastes that are handled, evaluation of seepage potential, design of drainage and seepage control facilities, development of a general operation plan, design of solid waste filling plan and determination of equipment requirements.

With this in view, we will discuss some important factors required for successful implementation and operation of a sanitary landfill in Subsections 4.7.1 to 4.7.3.

4.7.1 Design and construction

The design and construction process involves site infrastructure, i.e., the position of the buildings, roads and facilities that are necessary to the efficient running of the site and site engineering, i.e., the basic engineering works needed to shape the site for the reception of wastes and to meet the technical requirements of the working plan (Phelps, 1995). At the outset, however, the potential operator and the licensing authority should agree upon a working plan for the landfill. The disposal license includes the design, earthworks and procedures in the working plan.

What are the processes involved in design and construction? We will study these below:

(i) **Site infrastructure:** The size, type and number of buildings required at a landfill depend on factors such as the level of waste input, the expected life of the site and environmental factors. Depending on the size and complexity of the landfill, buildings range from single portable cabins to big complexes. However, certain aspects such as the following are common:

- need to comply with planning, building, fire, health and safety regulations and controls;
- security and resistance to vandalism;
- durability of service and the possible need to relocate accommodation during the lifetime of the site operations;
- ease of cleaning and maintenance;
- availability of services such as electricity, water, drainage and telecommunication.

Paying some attention to the appearance of the site entrance is necessary, as it influences the perception of the public about the landfill site. All landfill sites need to control and keep records of vehicles entering and leaving the site, and have a weighbridge to record waste input data, which can be analysed by a site control office. Note that at small sites, the site control office can be accommodated at the site itself.

(ii) **Earthworks:** Various features of landfill operations may require substantial earthworks, and therefore, the working plan must include earthworks to be carried out before wastes can be deposited. Details about earthworks gain significance, if artificial liners are to be installed, which involves grading the base and sides of the site (including construction of 25 slopes to drain leachate to the collection areas) and the formation of embankments. Material may also have to be placed in stockpiles for later use at the site. The cell method of operation requires the construction of cell walls. At some sites, it may be necessary to construct earth banks around the site perimeter to screen the landfill operations from the public. Trees or shrubs may then be planted on the banks to enhance the screening effect. The construction of roads leading to disposal sites also involves earthworks.

(iii) **Lining landfill sites:** Where the use of a liner is envisaged, the suitability of a site for lining should be evaluated at the site investigation stage. However, they should not be installed, until the site has been properly prepared. The area to be lined should be free of objects likely to cause physical damage to the liner, such as vegetation and hard rocks. If synthetic liner materials are used, a binding layer of suitable fine-grained material should be laid to support the liner. However, if the supporting layer consists of low permeable material (e.g., clay), the synthetic liner must be placed on top of this layer. A layer of similar fine-grained material with the thickness of 25 – 30 cm should also be laid above the liner to protect it from subsequent mechanical and environmental damage. During the early phase of operation, particular care should be taken to ensure that the traffic does not damage the liner. Monitoring the quality of groundwater close to the site is necessary to get the feedback on the performance of a liner.

(iv) **Leachate and landfill gas management:** The basic elements of the leachate collection system (i.e., drain pipes, drainage layers, collection pipes, sumps, etc.) must be installed immediately above the liner, before any waste is deposited. Particular care must also be taken to prevent the drain and collection pipes from settling. During landfill operations, waste cells are covered with soil to avoid additional contact between waste and the environment. The soil layers have to be sufficiently permeable to allow downward leachate transport. Landfill gas is not extracted before completion, which includes construction of final cover, of the waste body. Extraction wells (diameter 0.3 to 1.0 m) may be constructed during or after operation.

(v) **Landfill capping:** Capping is required to control and minimise leachate generation (by minimising water ingress into the landfill) and facilitate landfill gas control or collection (by installing a low permeability cap over the whole site). A cap may consist of natural (e.g., clay) or synthetic (e.g., poly-ethylene) material with thickness of at least 1 m. An uneven settlement of the waste may be a major cause of cap failure. Designs for capping should, therefore, include consideration of leachate and landfill gas collection wells or vents. For the cap to remain effective, it must be protected from agricultural machinery, drying and cracking, plant root penetration, burrowing animals and erosion.

4.7.2 Operation

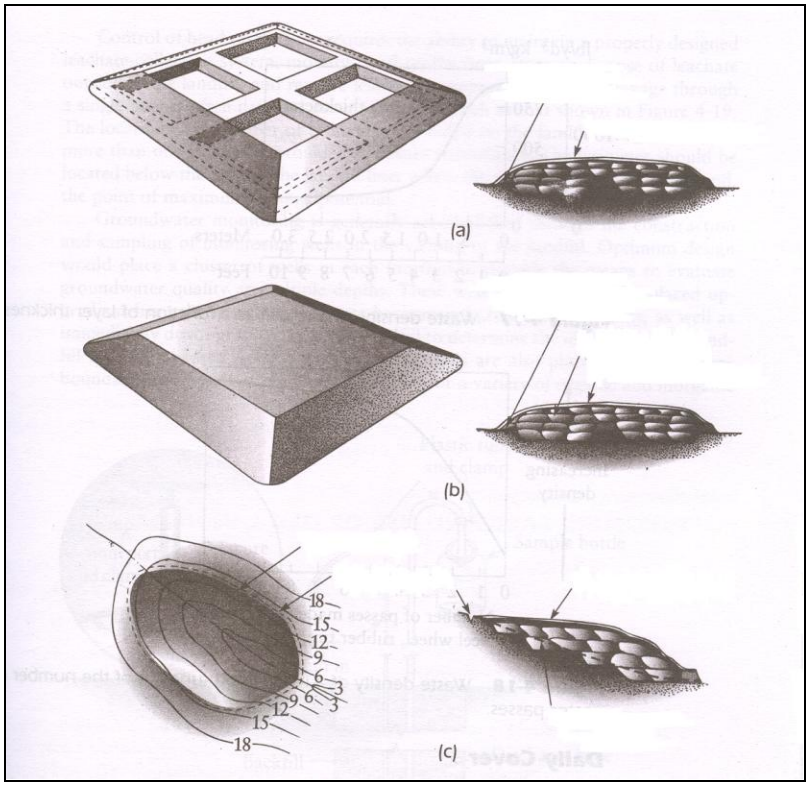
To secure public acceptability, landfill operations require careful planning and determination of the extent of environmental effects. The basic factor influencing the planning of site operations is the nature and quantity of incoming wastes. The various aspects of this include the following:

(i) **Methods of filling:** The following variations in land filling techniques are available (Burner and Kelly, 1972):

- **Trench method:** This involves the excavation of a trench into which waste is deposited, and the excavated material is then used as cover.
- **Area method:** Wastes may be deposited in layers and so form terraces over the available area. However, with this type of operation, excessive leachate generation may occur, which may render the control difficult.
- **Cell method:** This method involves the deposition of wastes within pre-constructed bounded area. It is now the preferred method in the industrialised world, since it encourages the concept of progressive filling and restoration. Operating a cellular method of filling enables wastes to be deposited in a tidy manner, as the cells serve both to conceal the tipping operation and trap much of the litter that has been generated.
- **Canyon/depression:** This method refers to the placing of suitable wastes against lined canyon or ravine slide slopes. (Slope stability and leachate gas emission control are critical issues for this type of waste placement.)

Figure 4.4 illustrates the land filling methods touched upon above:

Figure 4.4
Commonly Used Land Filling Methods



(a) trench (b) area and (c) canyon/depression methods

(ii) **Refuse placement:** The working space should be sufficiently extensive to permit vehicles to manoeuvre and unload quickly and safely without impeding refuse spreading, and allow easy operation of the site equipment. Depositing waste in thin layers and using a compactor enables a high waste density to be achieved. Each progressive layer should not be more than 30 cm thick. The number of passes by a machine over the waste determines the level of compaction.

(iii) **Covering of waste:** At the end of each working day, all exposed surfaces, including the flanks and working space, should be covered with a suitable inert material to a depth of at least 15 cm. This daily cover is considered essential, as it minimises windblown litter and helps reduce odours. Cover material may be obtained from on-site excavations or inert waste materials coming to the site. Pulverised fuel ash or sewage sludge can also be used for this purpose.

(iv) **Site equipment and workforce orientation:** The equipment most commonly used on landfill sites includes steel wheeled compactors, tracked dozers, loaders, earthmovers and hydraulic excavators. Scrapers are used for excavating and moving cover materials. In addition to appropriate equipment, proper training must be ensured for the workforce. They should be competent, and adequately supervised; training should include site safety and first aid. Since a landfill site may pose dangers to both site operators and users, it is necessary to lay down emergency plans and test them from time to time (Phelps, 1995).

4.7.3 Monitoring

Landfill represents a complex process of transforming polluting wastes into environmentally acceptable deposits. Because of the complexity of these processes and their potential environmental effects, it is imperative to monitor and confirm that the landfill works, as expected. A monitoring scheme, for example, is required for collecting detailed information on the development of leachate and landfill gas within and beyond a landfill. The scheme should be site specific, drawn at the site investigation stage and implemented. Monitoring is generally done for the following:

(i) **Leachate/gas:** Monitoring of leachate/gas plays a vital role in the management of landfills. Data on the volume of leachate/gas and their composition are essential for proper control of leachate/gas generation and its treatment. Knowledge of the chemical composition of leachate/gas is also required to confirm that attenuation processes within the landfill are proceeding as expected. Various systems for monitoring the leachate level are in use, and are mostly based on pipes installed prior to land filling. Note that small bore perforated plastic pipes are relatively cheaper and easier to install, but have the disadvantage of getting damaged faster during infilling. Placing pipes within a column or tyres may, however, offer some protection.

(ii) **Groundwater:** A continued groundwater-monitoring programme for confirming the integrity of the liner system is essential. At an early stage of site preparation, therefore, a number of monitoring boreholes need to be provided around the site. However, the location, design and number of boreholes depend on the size of the landfill, proximity to an aquifer, geology of the site and types of wastes deposited. Installation of a double liner system can make the monitoring exercise more accurate and easier to perform. Water should be regularly flushed through the secondary leachate collection system. In case this water is polluted, the primary leachate barrier will be damaged, and if repair is not considered possible, the leachate collected must be transported to the leachate treatment facility.

LEARNING ACTIVITY 4.7

Explain the need for monitoring sanitary landfills.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

4.8 WASTE DISPOSAL: A CASE STUDY OF BANGALORE

One of the critical concerns of a municipal corporation is planning for a proper waste disposal in response to the increasing volume and hazardous nature of urban wastes. When wastes are disposed unhygienically, they do spoil the aesthetic value of the city as well as create problems such as breeding of pathogenic organisms, which serve as carriers of diseases (Attarwalla, 1993, Areivala, 1971). Some of the principal problems associated with disposal of solid wastes can be categorised as under:

- Diseases, i.e., rats, flies and other pests feed on the wastes and carry diseases.
- Air/noise pollution, e.g., increase in vehicular traffic, smoke, fly ash and odours.
- Ground and surface water pollution, e.g., runoff during the monsoon season causes surface water pollution, while percolation often causes groundwater contamination.
- Unaesthetic appearance because of litter (Gotoh, 1989).

However, we can minimise or satisfactorily deal with these problems through competent engineering and planning, selecting appropriate waste disposal sites and methods of operation, and making SWM strategies essentially local (see also http://stratema.sigis.net/cupum/pdf/E1.pdf).

Against this backdrop, let us now assess the scenario in Bangalore. About two-thirds of the waste (about 1600 tonnes/day) in the Bangalore city is getting dumped in the outskirts of the city. As there are no sanitary landfills in the city for proper dumping of waste, it is merely transported to the outskirts and disposed of in any abandoned open land, usually along public highways (Vagale, 1997). The Bangalore Mahanagara Palike (BMP) along with the Karnataka State Pollution

Control Board (KSPCB) has, however, identified 9 abandoned quarries around the city for sanitary landfills. Table 4.3 contains the list of these sites:

Table 4.3
Solid Waste Disposal Sites Identified by the BMP

Sl No.	Name of site	Area (acres)
1	B. Narayanpura	10.15
2	Vibuthipura	8.01
3	Devanachikkanahalli	6.09
4	Sarakki	2.00
5	Hongasandra	4.02
6	Lakkasandra	10.04
7	Hennur	10.00
8	Kudittally	0.36
9	Adugodi	2.00
10	Mavalipura	35

Source: Department of SWM, Bangalore Mahanagara Palike, Bangalore, 1998

Of the sites listed in Table 4.3, only 3 have been selected after an assessment of suitability, viz. B. Narayanpura (situated about 10 km northeast of the city in Krishnarajapura hobli), Hennur (situated at a distance of about 9 km north of the city) and Devanachikkanahalli (situated about 10 km to the southeast of the city). These sites were selected on the basis of the geo-technical assessment carried out after a site visit and review of data. However, a periodical assessment of ground water and air quality, before and during the process of land filling, is necessary.

SUMMARY

In this Unit, we discussed some of the problems associated with the indiscriminate disposal of wastes and the key issues involved in safe disposal. In this context, we said that safe disposal is constrained by various issues such as inadequate municipal capacity, lack of political commitment, lack of finance, insufficient technical guidelines and lack of accountability of individuals and institutions. We, then, discussed some of the salient features of waste disposal including various disposal options such as uncontrolled dumping, sanitary landfill, composting, incineration, gasification, refuse-derived fuel and pyrolysis, and their selection criteria (i.e., technical, institutional, financial, social and environmental). Having given a background of waste disposal options, we discussed in detail sanitary landfill in terms of principle, processes, environmental effects, design, construction, operation and monitoring. We closed the Unit by giving a case study of Bangalore.

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Lecture 4

Model Answers to Learning Activities

LEARNING ACTIVITY 4.1

Based on a general observation, some of the constraints municipal authorities in our locality face with regard to effective waste disposal include poor political back up, inadequate infrastructure, insufficient funds and lack of public support. Let me explain these below:

(i) Waste disposal is as much a technical issue as a political one. For example, an elected representative, called a Corporator, administers a municipal ward, and is responsible for the general upliftment of the ward. But, generally, waste disposal is not considered a priority issue. However, our locality, and indeed, Bangalore is just awakening to the importance of waste disposal, and the Bangalore Agenda Task Force appointed by the State government has introduced a programme called the *Swachha Bangalore*. This programme involves door-to-door collection of solid waste. But, this is merely a temporary solution as the city, requires an integrated waste management system. In the main, for any programme to be successful, sufficient political and governmental backing is necessary.

(ii) In our locality, importance is given to waste collection and not waste disposal. Due to the inadequate infrastructure, the municipality is unable to give sufficient importance to waste disposal.

(iii) Waste disposal is a costly process and sufficient funds are not available to the municipality to adopt latest techniques such as pyrolysis, gasification, etc.

(iv) Public support is essential for the success of any waste management programme. For example, people must stop dumping wastes indiscriminately on roadsides and in drains. Indiscriminate dumping makes waste collectors' work tedious and time consuming.

LEARNING ACTIVITY 4.2

Based on technical (i.e., composition of waste, existing practices and technology), social (i.e., health and income implication, and public opinions) and environmental (i.e., initial and long-term environmental risks) aspects, the best disposal option for our locality is composting. This is due to the fact that our locality is predominantly residential, generating mostly biodegradable wastes, and composting does not need long-term maintenance. Nor does it cause any adverse environmental effects.

LEARNING ACTIVITY 4.3

No, a sanitary landfill is not possible to manage wastes in our locality mainly because:

- it is not economically feasible for a small locality such as ours;
- composition of waste is mostly biodegradable;
- sufficient land is not available for setting up a landfill site.

LEARNING ACTIVITY 4.4

Typical landfill gases include methane, carbon dioxide, oxygen and nitrogen, and these adversely impact on public health and the environment. For example:

- Methane is flammable in air and can lead to unpredictable and uncontrolled subsidence and production of smoke and toxic fumes.
- Trace components such as aldehydes, alcohol and esters are toxicants when present in air at concentrations above occupational exposure standards.
- The landfill gases lead to global warming as these absorb reflected solar radiations.

It is vital that these emissions are controlled, and we can achieve this by controlling:

- waste inputs (i.e., restrict the amount of organic wastes);
- processes within the waste (i.e., minimise the moisture content to limit gas production);
- the migration process (i.e., put physical barriers or vents to remove the gas from the site and reduce gas pressure).

Since gas emissions cannot be easily prevented, removal by vents within the waste or stonewalled vents is the preferred option.

LEARNING ACTIVITY 4.5

The best way to control leachate is through prevention, which can be done with natural liners and synthetic liners.

- Natural liners, such as compacted clay or shale, bitumen or soil sediments, are less permeable, resistant to chemical attack and have good sorption properties.
- Synthetic (geo-membranes) liners such as high density or medium density polyethylene, are less permeable, easy to install and relatively strong and have good deformation characteristics.

Natural and synthetic liners can be combined to improve the efficiency of the containment system. The various treatments used to treat leachates are leachate recirculation, biological treatment (e.g., aerated lagoons, activated sludge process, rotating biological contactors, anaerobic treatments that include anaerobic filters, anaerobic lagoons and digesters) and physico-chemical treatment (e.g., flocculation-precipitation process).

LEARNING ACTIVITY 4.6

A sanitary landfill is essentially an engineered waste disposal option, where the environmental risk is controlled at an appropriate and acceptable level. But, if it is not properly managed, it can cause the following problems: (i) noise pollution due to vehicles such as earthmovers, compactors, etc., (ii) scavenger birds, vermins, insects, etc., are attracted to the landfill for breeding and they constitute potential health problems, (iii) leachates, if not treated or controlled, may pollute groundwater and surface water and (iv) gas released, due to degradation or volatilisation of waste components, causes problems such as odour, flammability and damage to health and the environment.

Uncontrolled disposal is a non-engineered waste disposal method in which wastes are dumped at a designated point without any environmental control, and it (i) causes odour problems due to the putrification of biodegradable wastes, (ii) provides a breeding place for disease vectors such as flies, mosquitoes, etc, and (iii) causes visual pollution, etc.

When properly managed, a landfill is a better and safer option of disposing wastes than uncontrolled dumping. Also, it is adaptable to all kinds of wastes and there is potential for by-product recovery.

LEARNING ACTIVITY 4.7

Landfill is a complex reactor where physical, chemical and biological processes transform polluting wastes into environmentally acceptable deposits. Due to the complexity of these processes and their potential environmental effects, monitoring is needed to confirm that the landfill works as expected. Knowledge of the chemical composition of leachate and gas is required, as leachates may contain toxic substances and, if not prevented, may contaminate the groundwater. Landfill gases that may be flammable, asphyxiating and noxious, pose a health hazard. A continued groundwater-monitoring programme is essential for confirming the integrity of the liner system.

Lecture 5

Waste Processing Techniques

STRUCTURE

OVERVIEW

In Unit 4, we discussed conventional and engineered waste disposal options, and also mentioned that through proper processing, we would be able to recover resource and energy from wastes. In Unit 5, we will explain some of the important techniques used for processing solid wastes for the recovery of materials, and their design criteria. The processing techniques we will be discussing in this Unit include mechanical and chemical volume reduction, component separation, and drying and dewatering.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- identify the purpose of waste processing;
- explain the processing techniques for reducing the volume and size of wastes;
- carry out separation of various components;
- discuss the need for dewatering and drying of wastes;
- assess technical viability of various processing techniques.

5.1 PURPOSE OF PROCESSING

The processing of wastes helps in achieving the best possible benefit from every functional element of the solid waste management (SWM) system and, therefore, requires proper selection of techniques and equipment for every element. Accordingly, the wastes that are considered suitable for further use need to be paid special attention in terms of processing, in order that we could derive maximum economical value from them.

The purposes of processing, essentially, are (Tchobanoglous et al., 1993):

(i) **Improving efficiency of SWM system:** Various processing techniques are available to improve the efficiency of SWM system. For example, before waste papers are reused, they are usually baled to reduce transporting and storage volume requirements. In some cases, wastes are baled to reduce the haul costs at disposal site, where solid wastes are compacted to use the available land effectively. If solid wastes are to be transported hydraulically and pneumatically, some form of shredding is also required. Shredding is also used to improve the efficiency of the disposal site.

(ii) **Recovering material for reuse:** Usually, materials having a market, when present in wastes in sufficient quantity to justify their separation, are most amenable to recovery and recycling. Materials that can be recovered from solid wastes include paper, cardboard, plastic, glass, ferrous metal, aluminium and other residual metals. (We will discuss some of the recovery techniques later in Section 5.3.)

(iii) **Recovering conversion products and energy:** Combustible organic materials can be converted to intermediate products and ultimately to usable energy. This can be done either through incineration, pyrolysis, composting or bio-digestion. Initially, the combustible organic matter is separated from the other solid waste components. Once separated, further processing like shredding and drying is necessary before the waste material can be used for power generation. (We will explain these energy recovery techniques in Units 7 and 8.)

Having described the need for waste processing, we now discuss how waste processing is actually carried out.

5.2 MECHANICAL VOLUME AND SIZE REDUCTION

Mechanical volume and size reduction is an important factor in the development and operation of any SWM system. The main purpose is to reduce the volume (amount) and size of waste, as compared to its original form, and produce waste of uniform size. We will discuss the processes involved in volume and size reduction along with their selection criteria, equipment requirement, design consideration, etc., in Subsections 5.2.1 and 5.2.2.

5.2.1 Volume reduction or compaction

Volume reduction or compaction refers to densifying wastes in order to reduce their volume. Some of the benefits of compaction include:

- reduction in the quantity of materials to be handled at the disposal site;
- improved efficiency of collection and disposal of wastes;
- increased life of landfills;
- Economically viable waste management system.

However, note the following disadvantages associated with compaction:

- poor quality of recyclable materials sorted out of compaction vehicle;
- difficulty in segregation or sorting (since the various recyclable materials are mixed and compressed in lumps);
- Bio-degradable materials (e.g., leftover food, fruits and vegetables) destroy the value of paper and plastic material.

Equipment used for compaction

Based on their mobility, we can categorise the compaction equipment used in volume reduction under either of the following:

(i) **Stationary equipment:** This represents the equipment in which wastes are brought to, and loaded into, either manually or mechanically. In fact, the compaction mechanism used to compress waste in a collection vehicle, is a stationary compactor. According to their application, stationary compactors can be described as light duty (e.g., those used for residential areas), commercial or light industrial, heavy industrial and transfer station compactors. Usually, large stationary compactors are necessary, when wastes are to be compressed into:

  - steel containers that can be subsequently moved manually or mechanically;

- chambers where the compressed blocks are banded or tied by some means before being removed;
- chambers where they are compressed into a block and then released and hauled away untied;
- transport vehicles directly.

(ii) **Movable equipment:** This represents the wheeled and tracked equipment used to place and compact solid wastes, as in a sanitary landfill.

Table 5.1 below lists the types of commonly-used compaction equipment and their suitability:

Table 5.1
Types of Compaction Equipment

Location or Operation	Type of Compactor Stationary/residential	Remarks
Solid waste generation points	Vertical	Vertical compaction ram may be used; may be mechanically or hydraulically operated, usually hand-fed; wastes compacted into corrugated box containers, or paper or plastic bags; used in medium and high-rise apartments.
	Rotary	Ram mechanism used to compact waste into paper or plastic bags on rotating platform, platform rotates as containers are filled; used in medium and high-rise apartments.
	Bag or extruder	Compactor can be chute fed; either vertical or horizontal rams; single or continuous multi-bags; single bag must be replaced and continuous bags must be tied off and replaced; used in medium and high-rise apartments.

Location or Operation	Type of Compactor Stationary/residential	Remarks
	Under counter	Small compactors used in individual residences and apartment units; wastes compacted into special paper bags; after wastes are dropped through a panel door into a bag and door is closed, they are sprayed for odour control; button is pushed to activate compaction mechanism.
	Stationary/commercial	Compactor with vertical and horizontal ram; wastes compressed into steel containers; compressed wastes are manually tied and removed; used in low, medium and high-rise apartments, commercial and industrial facilities.
Collection	Stationary/packers	Collection vehicles equipped with compaction mechanism.
Transfer and/or processing station	Stationary/transfer trailer	Transfer trailer, usually enclosed, equipped with self-contained compaction mechanism.
	Stationary low pressure	Wastes are compacted into large containers.
	Stationary high pressure	Wastes are compacted into dense bales or other forms.
Disposal site	Movable wheeled or tracted equipment	Specially designed equipment to achieve maximum compaction of wastes.
	Stationary/track mounted	High-pressure movable stationary compactors used for volume reduction at a disposal site.

Source: Tchobanoglous, et al., (1993)

Let us now move on to the discussion of compactors used in the transfer station.

Compactors

According to their compaction pressure, we can divide the compactors used at transfer stations as follows:

(i) **Low-pressure (less than 7kg/cm^2) compaction:** This includes those used at apartments and commercial establishments, bailing equipment used for waste papers and cardboards and stationary compactors used at transfer stations. In low-pressure compaction, wastes are compacted in large containers. Note that portable stationary compactors are being used increasingly by a number of industries in conjunction with material recovery options, especially for waste paper and cardboard.

(ii) **High-pressure (more than 7kg/cm^2) compaction:** Compact systems with a capacity up to 351.5 kg/cm^2 or 5000 lb/in^2 come under this category. In such systems, specialised compaction equipment are used to compress solid wastes into blocks or bales of various sizes. In some cases, pulverised wastes are extruded after compaction in the form of logs. The volume reduction achieved with these high-pressure compaction systems varies with the characteristics of the waste. Typically, the reduction ranges from about 3 to 1 through 8 to 1.

When wastes are compressed, their volume is reduced, which is normally expressed in percentage and computed by equation 5.1, given below:

$$\text{Volume Reduction (\%)} = \frac{V_i - V_f}{V_i} \times 100 \qquad \textbf{Equation 5.1}$$

The compaction ratio of the waste is given in equation 5.2:

$$\text{Compaction ratio} = \frac{V_i}{V_f} \qquad \textbf{Equation 5.2}$$

where V_i = volume of waste before compaction, m^3 and V_f = volume of waste after compaction, m^3

The relationship between the compaction ratio and percent of volume reduction is important in making a trade-off analysis between compaction ratio and cost. Other factors that must be considered are final density of waste after compaction and moisture content. The moisture content that varies with location is another variable that has a major effect on the degree of compaction achieved. In some stationary compactors, provision is made to add moisture, usually in the form of water, during the compaction process.

Selection of compaction equipment

To ensure effective processing, we need to consider the following factors, while selecting compaction equipment:

- Characteristics such as size, composition, moisture content, and bulk density of the waste to be compacted.
- Method of transferring and feeding wastes to the compactor, and handling.
- Potential uses of compacted waste materials.
- Design characteristics such as the size of loading chamber, compaction pressure, compaction ratio, etc.
- Operational characteristics such as energy requirements, routine and specialised maintenance requirement, simplicity of operation, reliability, noise output, and air and water pollution control requirement.
- Site consideration, including space and height, access, noise and related environmental limitations.

5.2.2 Size reduction or shredding

This is required to convert large sized wastes (as they are collected) into smaller pieces. Size reduction helps in obtaining the final product in a reasonably uniform and considerably reduced size in comparison to the original form. But note that size reduction does not necessarily imply volume reduction, and this must be factored into the design and operation of SWM systems as well as in the recovery of materials for reuse and conversion to energy.

In the overall process of waste treatment and disposal, size reduction is implemented ahead of:

- land filling to provide a more homogeneous product. This may require less cover material and less frequent covering than that without shredding. This can be of economic importance, where cover material is scarce or needs to be brought to the landfill site from some distance.
- recovering materials from the waste stream for recycling.
- baling the wastes – a process sometimes used ahead of long distance transport of solid wastes – to achieve a greater density.
- making the waste a better fuel for incineration waste energy recovery facilities. (The size reduction techniques, coupled with separation techniques such as screening, result in a more homogeneous mixture of relatively uniform size, moisture content and heating value, and thereby improving the steps of incineration and energy recovery. We will discuss incineration in Unit 8.)
- reducing moisture, i.e., drying and dewatering of wastes (see Section 5.4 for a discussion on drying and dewatering).

Equipment used for size reduction

Table 5.2 lists the various equipment used for size reduction:

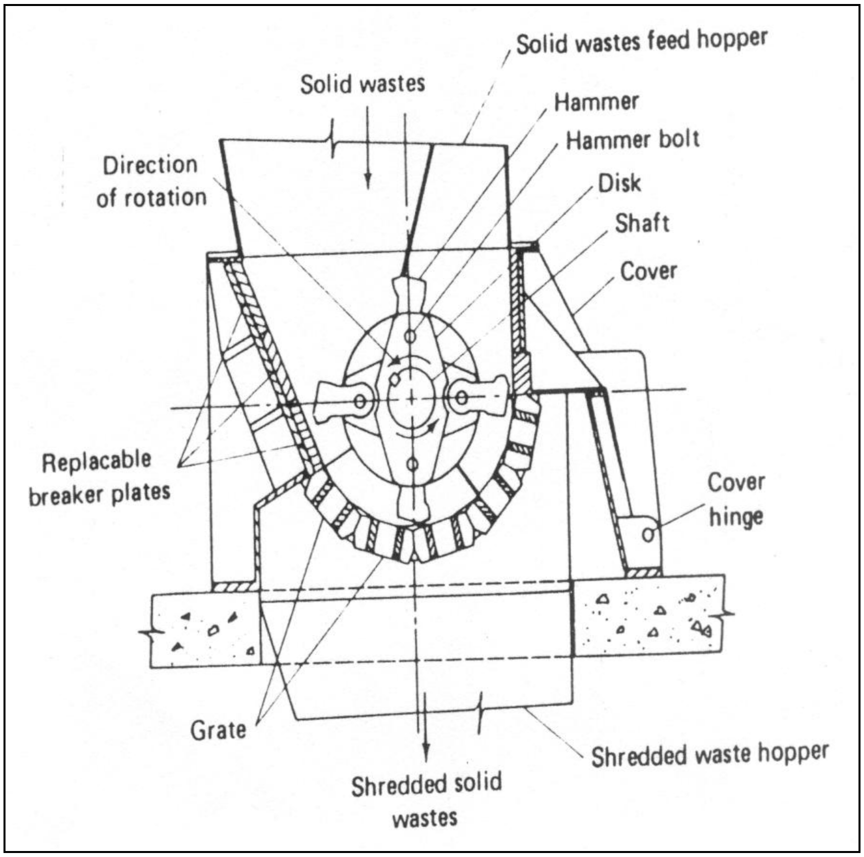
Table 5.2
Size Reduction Equipment

Type	Mode of action	Application
Small grinders	Grinding, mashing	Organic residential solid wastes
Chippers	Cutting, slicing	Paper, cardboard, tree trimmings, yard waste, wood, plastics
Large grinders	Grinding, mashing	Brittle and friable materials, used mostly in industrial operation
Jaw crushers	Crushing, breaking	Large solids
Rasp mills	Shredding, tearing	Moistened solid wastes
Shredders	Shearing, tearing	All types of municipal wastes
Cutters, Clippers	Shearing, tearing	All types of municipal wastes
Hammer mills	Breaking, tearing, cutting, crushing	All types of municipal wastes, most commonly used equipment for reducing size and homogenizing composition of wastes
Hydropulper	Shearing, tearing	Ideally suited for use with pulpable wastes, including paper, wood chips. Used primarily in the papermaking industry. Also used to destroy paper records

The most frequently used shredding equipment are the following:

(i) **Hammer mill:** These are used most often in large commercial operations for reducing the size of wastes. Hammer mill is an impact device consisting of a number of hammers, fastened flexibly to an inner disk, as shown in Figure 5.1, which rotates at a very high speed:

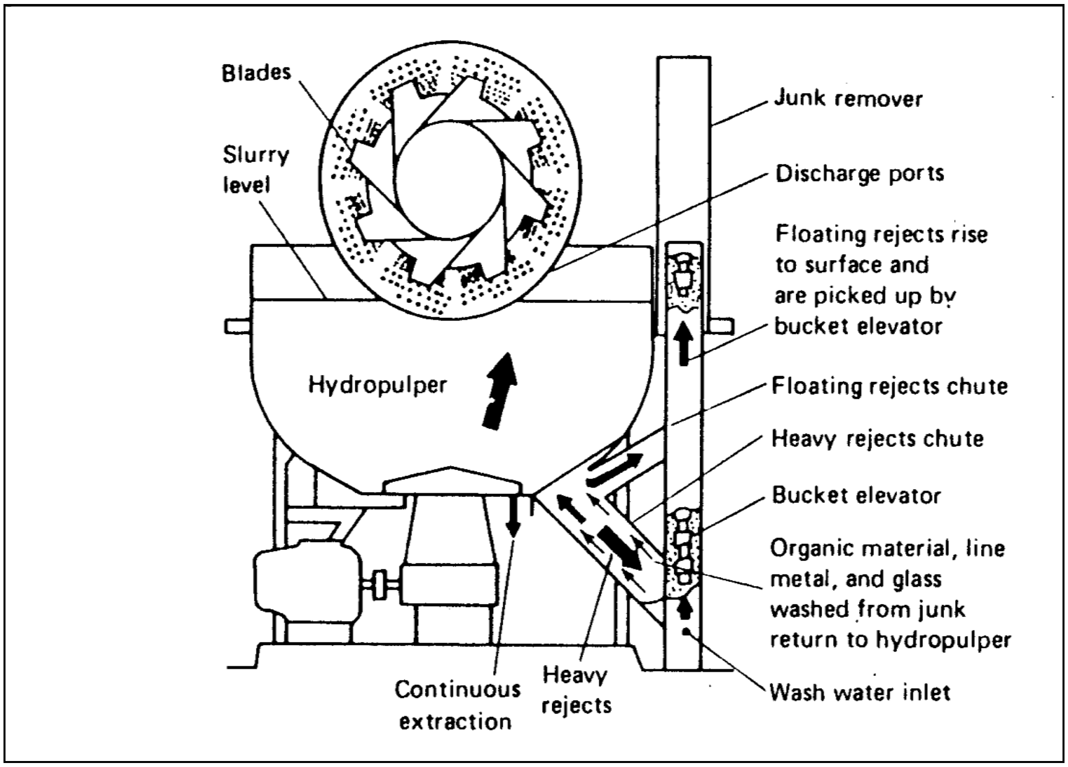
Figure 5.1
Hammer Mill: An Illustration



Solid wastes, as they enter the mill (see Figure 5.1), are hit by sufficient force, which crush or tear them with a velocity so that they do not adhere to the hammers. Wastes are further reduced in size by being struck between breaker plates and/or cutting bars fixed around the periphery of the inner chamber. This process of cutting and striking action continues, until the required size of material is achieved and after that it falls out of the bottom of the mill.

(ii) **Hydropulper:** An alternative method of size reduction involves the use of a hydropulper as shown in Figure 5.2:

Figure 5.2
Hydropulper: An Illustration



Solid wastes and recycled water are added to the hydropulper. The high-speed cutting blades, mounted on a rotor in the bottom of the unit, convert pulpable and friable materials into slurry with a solid content varying from 2.5 to 3.5%. Metal, tins, cans and other non-pulpable or non-friable materials are rejected from the side of the hydropulper tank. The rejected material passes down a chute that is connected to a bucket elevator, while the solid slurry passes out through the bottom of the pulper tank and is pumped to the next processing operation.

Selection of size reduction equipment

The factors that decide the selection of size reduction equipment include the following:

- The properties of materials before and after shredding.
- Size requirements for shredded material by component.
- Method of feeding shredders, provision of adequate shredder hood capacity (to avoid bridging) and clearance requirement between feed and transfer conveyors and shredders.
- Types of operation (continuous or intermittent).
- Operational characteristics including energy requirements, routine and specialised maintenance requirement, simplicity of operation, reliability, noise output, and air and water pollution control requirements.
- Site considerations, including space and height, access, noise and environmental limitations.
- Metal storage after size reduction for the next operation.

LEARNING ACTIVITY 5.1

Explain the difference between compaction and size reduction and their importance in SWM.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

Besides mechanical techniques of compaction and shredding to reduce the volume and size of wastes, there are also chemical processes through which we can reduce the volume of wastes, which we will touch upon next.

Chemical volume reduction

Chemical volume reduction is a method, wherein volume reduction occurs through chemical changes brought within the waste either through an addition of chemicals or changes in temperature. Incineration is the most common method used to reduce the volume of waste chemically, and is used both for volume reduction and power production. These other chemical methods used to reduce volume of waste chemically include *pyrolysis*, *hydrolysis* and chemical conversions. (We will discuss incineration and related issues in Unit 8.)

Note that prior to size or volume reduction, which we discussed in Section 5.2, component separation is necessary to avoid the problem of segregating or sorting recyclable materials from the mixed and compressed lumps of wastes and the poor quality of recyclable materials sorted out of compaction vehicles. We will discuss component separation in Section 5.3.

5.3 COMPONENT SEPARATION

Component separation is a necessary operation in which the waste components are identified and sorted either manually or mechanically to aid further processing. This is required for the:

- recovery of valuable materials for recycling;
- preparation of solid wastes by removing certain components prior to incineration, energy recovery, composting and biogas production. (Note that these are discussed in Units 8 and 9.)

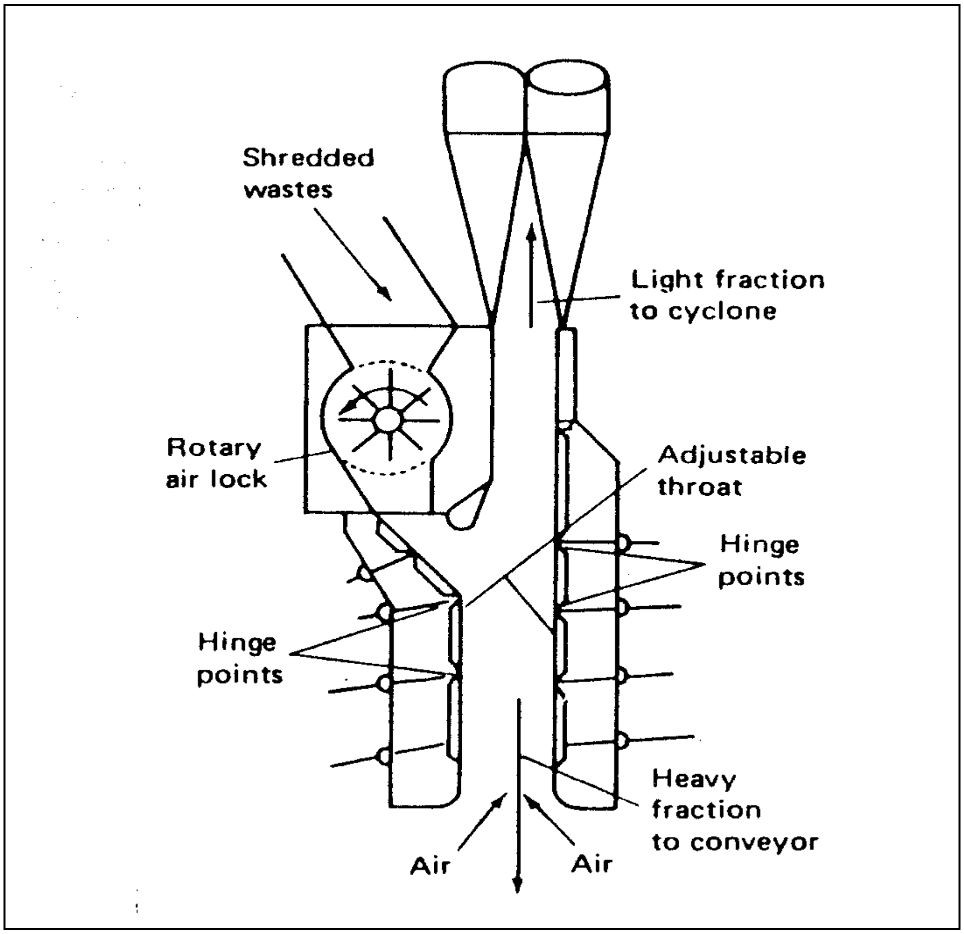
The most effective way of separation is manual sorting in households prior to collection. In many cities (e.g., Bangalore, Chennai, etc., in India), such systems are now routinely used. The municipality generally provides separate, easily identifiable containers into which the householder deposits segregated recyclable materials such as paper, glass, metals, etc. Usually, separate collections are carried out for the recyclable material. At curbside, separate areas are set aside for each of the recyclable materials for householders to deliver material – when there is no municipal collection system. In case the separation is not done prior to collection, it could be sorted out through mechanical techniques such as air separation, magnetic separation, etc., to recover the wastes. We will discuss some of these techniques in Subsections 5.3.1 to 5.3.4.

5.3.1 Air separation

This technique has been in use for a number of years in industrial operations for segregating various components from dry mixture. Air separation is primarily used to separate lighter materials (usually organic) from heavier (usually inorganic) ones. The lighter material may include plastics, paper and paper products and other organic materials. Generally, there is also a need to separate the light fraction of organic material from the conveying air streams, which is usually done in a cyclone separator. In this technique, the heavy fraction is removed from the air classifier (i.e., equipment used for air separation) to the recycling stage or to land disposal, as appropriate. The light fraction may be used, with or without further size reduction, as fuel for incinerators or as compost material. There are various types of air classifiers commonly used, some of which are listed below:

(i) **Conventional chute type:** This, as shown in Figure 5.3, is one of the simplest types of air classifiers:

Figure 5.3
Conventional Chute Type

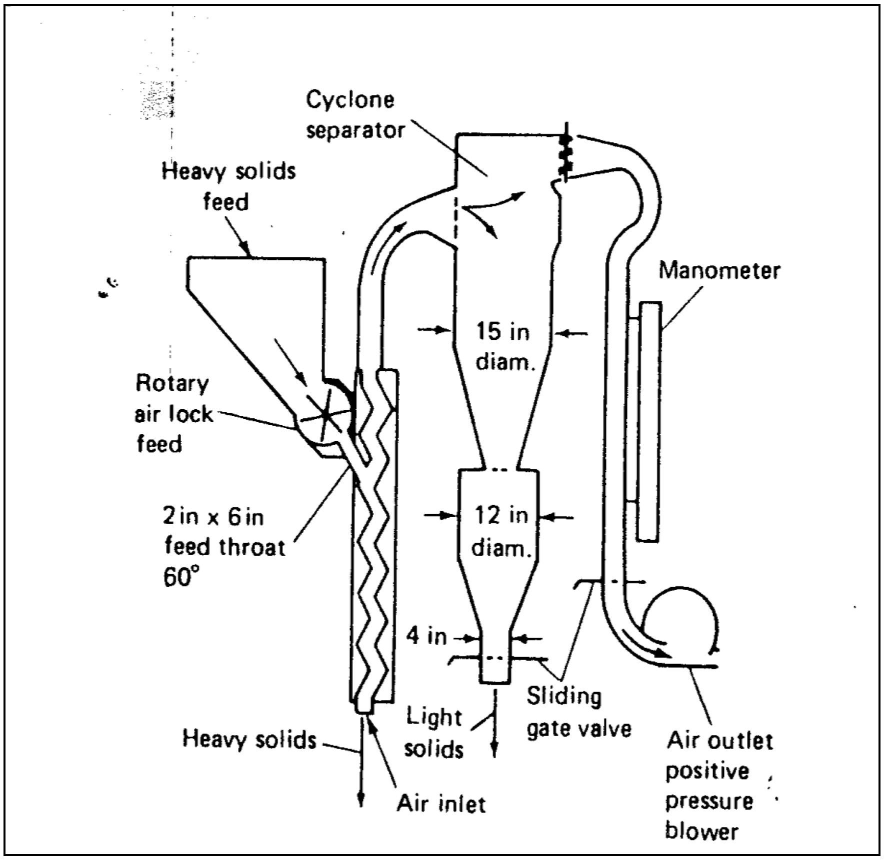


In this type, when the processed solid wastes are dropped into the vertical chute, the lighter material is carried by the airflow to the top while the heavier materials fall to the bottom of the chute. The control of the percentage split between the light and heavy fraction is accomplished by varying the waste loading rate, airflow rate and the cross section of chute. A rotary air lock feed mechanism is required to introduce the shredded wastes into the classifier.

(ii) **Zigzag air classifier:** An experimental zigzag air classifier, shown in Figure 5.4 below, consists of a continuous vertical column with internal zigzag deflectors through which air is drawn at a high rate:

Figure 5.4

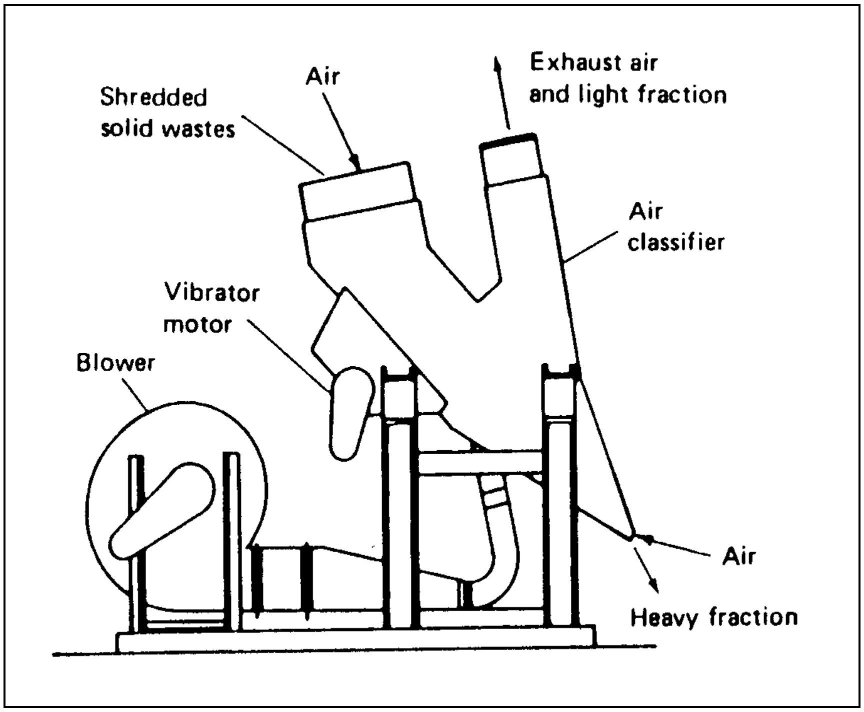
Zigzag Air Classifier



Shredded wastes are introduced at the top of the column at a controlled rate, and air is introduced at the bottom of the column. As the wastes drop into the air stream, the lighter fraction is fluidised and moves upward and out of column, while the heavy fraction falls to the bottom. Best separation can be achieved through proper design of the separation chamber, airflow rate and influent feed rate.

(iii) **Open inlet vibrator type:** Figure 5.5 below illustrates this type of air classifier:

Figure 5.5
Open Inlet Vibrator



In this type of air classifier, the separation is accomplished by a combination of the following actions:

- **Vibration:** This helps to stratify the material fed to the separator into heavy and light components. Due to this agitation, the heavier particles tend to settle at the bottom as the shredded waste is conveyed down the length of the separator.
- **Inertial force:** In this action, the air pulled in through the feed inlet imparts an initial acceleration to the lighter particle, while the wastes travel down the separator as they are being agitated.
- **Air pressure:** This action refers to the injection of fluidising air in two or more high velocity and low mass flow curtains across the bed. A final stripping of light particles is accomplished at the point where the heavy fraction discharges from the elutriators. It has been reported that the resulting separation is less sensitive to particle size than a conventional vertical air classifier, be it of straight or zigzag design. An advantage of

this classifier is that an air lock feed mechanism is not required and wastes are fed by gravity directly into the separator inlet.

Selection of air separation equipment

The factors that are to be considered for selecting air separation equipment include the following:

- Characteristics of the material produced by shredding equipment including particle size, shape, moisture content and fibre content.
- Material specification for light fraction.
- Methods of transferring wastes from the shredders to the air separation units and feeding wastes into the air separator.
- Characteristics of separator design including solids-to-air ratio, fluidising velocities, unit capacity, total airflow and pressure drop.
- Operational characteristics including energy requirement, maintenance requirement, simplicity of operation, proved performance and reliability, noise output, and air and water pollution control requirements.
- Site considerations including space and height access, noise and environmental limitations.

So far, we have studied the separation of solid waste components by air separation. We will next learn about the separation of wastes based on their magnetic properties.

5.3.2 Magnetic separation

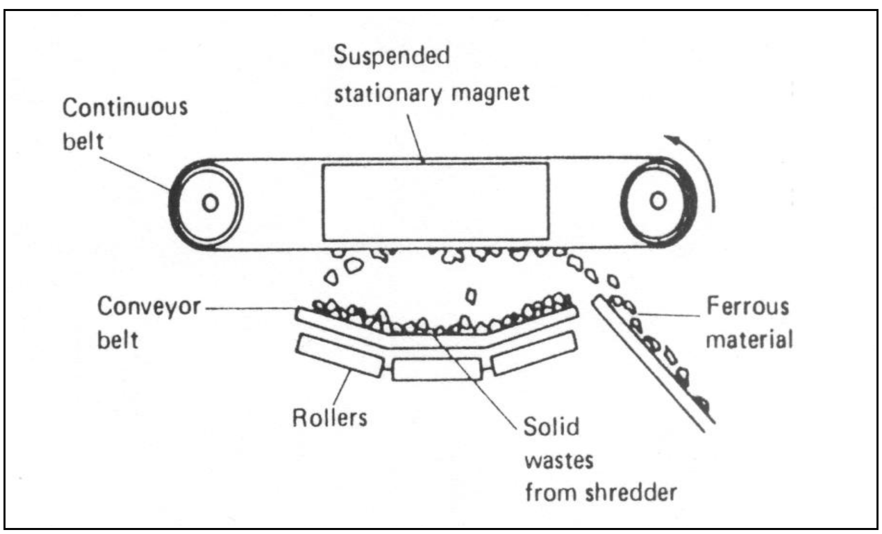
The most common method of recovering ferrous scrap from shredded solid wastes involves the use of magnetic recovery systems. Ferrous materials are usually recovered either after shredding or before air classification. When wastes are mass-fired in incinerators, the magnetic separator is used to remove the ferrous material from the incinerator residue. Magnetic recovery systems have also been used at landfill disposal sites. The specific locations, where ferrous materials are recovered will depend on the objectives to be achieved, such as reduction of wear and tear on processing and separation equipment, degree of product purity achieved and the required recovery efficiency.

Equipment used for magnetic separation

Various types of equipment are in use for the magnetic separation of ferrous materials. The most common types are the following:

(i) **Suspended magnet:** In this type of separator, a permanent magnet is used to attract the ferrous metal from the waste stream. When the attracted metal reaches the area, where there is no magnetism, it falls away freely. This ferrous metal is then collected in a container. Figure 5.6 shows a typical suspended magnet:

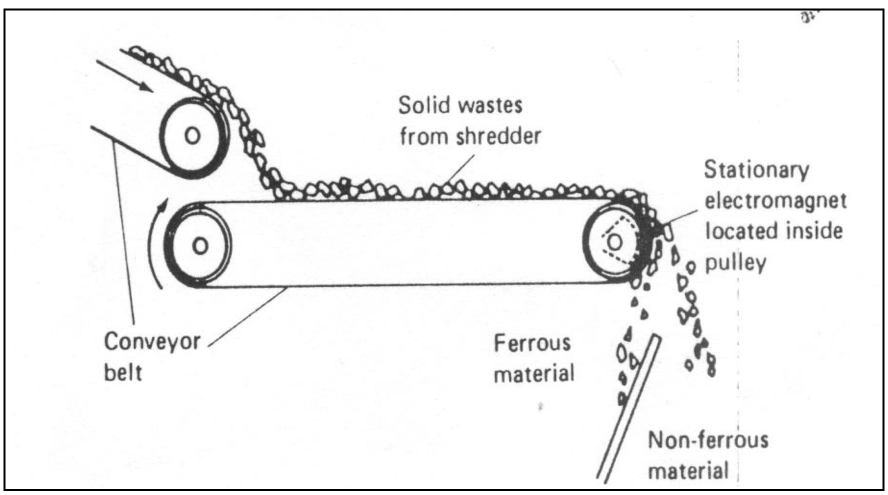
Figure 5.6
Suspended Type Permanent Magnetic Separator



This type of separation device is suitable for processing raw refuse, where separators can remove large pieces of ferrous metal easily from the waste stream.

(ii) **Magnetic pulley:** This consists of a drum type device containing permanent magnets or electromagnets over which a conveyor or a similar transfer mechanism carries the waste stream. The conveyor belt conforms to the rounded shape of the magnetic drum and the magnetic force pulls the ferrous material away from the falling stream of solid waste. Figure 5.7 illustrates this type of magnetic separator:

Figure 5.7
Pulley Type Permanent Magnetic Separator



Selection of magnetic separation equipment

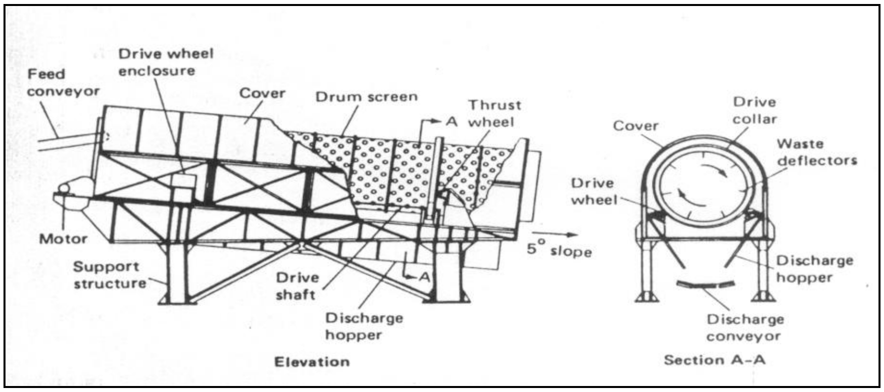
We must consider the following factors in the selection of magnetic separation equipment:

- Characteristics of waste from which ferrous materials are to be separated (i.e., the amount of ferrous material, the tendency of the wastes to stick to each other, size, moisture content, etc.)
- Equipment used for feeding wastes to separator and removing the separated waste streams.
- Characteristics of the separator system engineering design, including loading rate, magnet strength, conveyor speed, material of construction, etc.
- Operational characteristics, including energy requirements, routine and specialised maintenance requirements, simplicity of operation, reliability, noise output, and air and water pollution control requirements.
- Locations where ferrous materials are to be recovered from solid wastes.
- Site consideration, including space and height, access, noise and environmental limitations.

5.3.3 Screening

Screening is the most common form of separating solid wastes, depending on their size by the use of one or more screening surfaces. Screening has a number of applications in solid waste resource and energy recovery systems. Screens can be used before or after shredding and after air separation of wastes in various applications dealing with both light and heavy fraction materials. The most commonly used screens are rotary drum screens and various forms of vibrating screens. Figures 5.8 shows a typical rotary drum screen:

Figure 5.8
Rotary Drum Screen



Source: Tchobanoglous, et al., (1977)

Note that rotating wire screens with relatively large openings are used for separation of cardboard and paper products, while vibrating screens and rotating drum screens are typically used for the removal of glass and related materials from the shredded solid wastes.

Selection of screening equipment

The various factors that affect the selection of screens include the following:

- Material specification for screened component.
- Location where screening is to be applied and characteristics of waste material to be screened, including particle size, shape, bulk, density and moisture content.
- Separation and overall efficiency.
- Characteristics screen design, including materials of construction, size of screen openings, total surface screening area, oscillating rate for vibrating screens, speed for rotary drum screens, loading rates and length.
- Operational characteristics, including energy requirements, maintenance requirements, simplicity of operation, reliability, noise output and air and water pollution control requirements.

- Site considerations such as space and height access, noise and related environmental limitations.

The efficiency of screen can be evaluated in terms of the percentage recovery of the material in the feed stream by using Equation 5.3:

$$\text{Recovery } (\%) = \frac{U \times W_u}{F \times W_f} \times 100 \qquad \textbf{Equation 5.3}$$

$$W_f = \frac{\text{Weight of sample}}{\text{Weight of material fed to the screen}} \qquad \textbf{Equation 5.4}$$

$$W_u = \frac{\text{Weight of sample in underflow}}{\text{Total weight of material in underflow}} \qquad \textbf{Equation 5.5}$$

where U = weight of material passing through screen (underflow) kg/h; F = weight of material fed to the screen, kg/h; W_u = weight fraction of material desired size in underflow; W_f = weight fraction of material of desired size in feed.

The effectiveness of the screening operation can be determined by:

Effectiveness = recovery × rejection

where, rejection = 1 – recovery of undesired material

$$= 1 - \frac{U(1 - W_u)}{F(1 - W_f)}$$

Therefore, the effectiveness of screen is:

$$\text{Effectiveness} = \frac{U \times W_u}{F \times W_f} \times \left[1 - \frac{U(1 - W_u)}{F(1 - W_f)}\right]$$

LEARNING ACTIVITY 5.2

Given that 100 tonne/h of solid waste is applied to a rotary screen for the removal of glass prior to shredding, determine the recovery efficiency and effectiveness of the screen, based on the following experimental data:

The percentage of glass in solid waste = 8 %
Total weight of material in under flow = 10 tonne/h
Weight of glass in screen underflow = 7.2 tonne/h

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at the end of this Unit.

5.3.4 Other separation techniques

Besides the mechanical techniques we studied earlier for segregating wastes, there are others. A description of some of these other separation techniques is given below:

(i) **Hand-sorting or previewing:** Previewing of the waste stream and manual removal of large sized materials is necessary, prior to most types of separation or size reduction techniques. This is done to prevent damage or stoppage of equipment such as shredders or screens, due to items such as rugs, pillows, mattresses, large metallic or plastic objects, wood or other construction materials, paint cans, etc.

(ii) **Inertial separation:** Inertial methods rely on ballistic or gravity separation principles to separate shredded solid wastes into light (i.e., organic) and heavy (i.e., inorganic) particles. Figures 5.9 and 5.10 illustrate the modes of operation of two different types of inertial separators:

Figure 5.9
Ballistic Inertial Separator

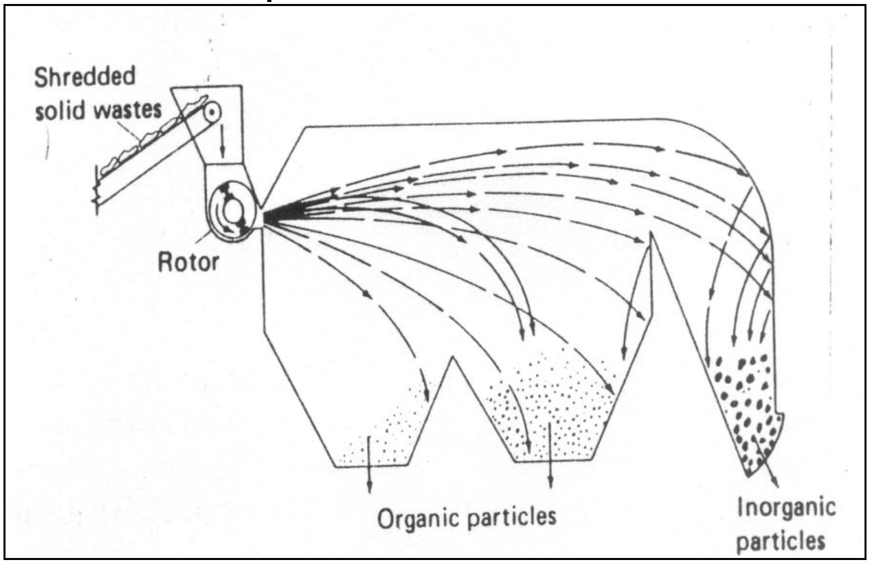
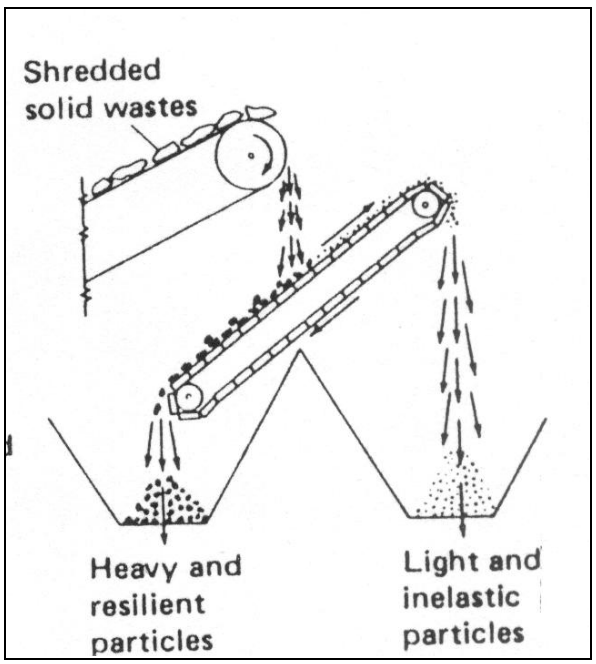


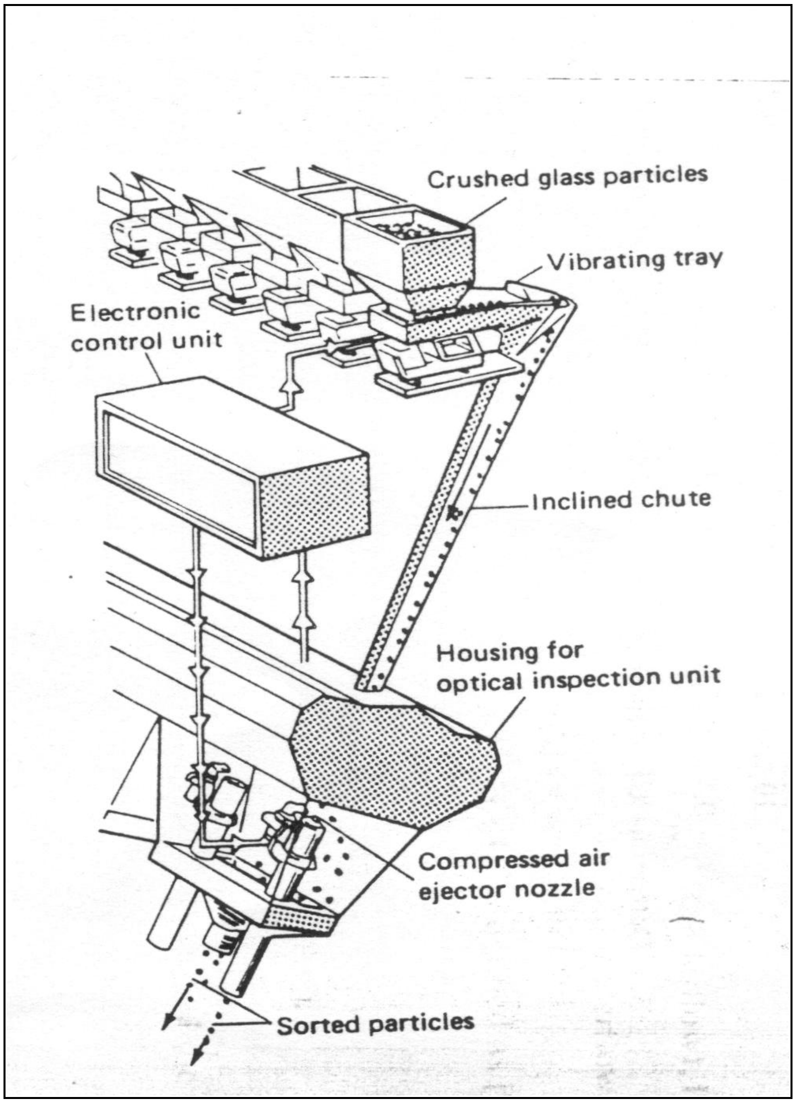
Figure 5.10
Inclined Conveyor Separator



(iii) **Flotation:** In the flotation process, glass-rich feedstock, which is produced by screening the heavy fraction of the air-classified wastes after ferrous metal separation, is immersed in water in a soluble tank. Glass chips, rocks, bricks, bones and dense plastic materials that sink to the bottom are removed with belt scrappers for further processing. Light organic and other materials that float are skimmed from the surface. These materials are taken to landfill sites or to incinerators for energy recovery. Chemical adhesives (flocculants) are also used to improve the capture of light organic and fine inorganic materials.

(iv) **Optical sorting:** Optical sorting is used mostly to separate glass from the waste stream, and this can be accomplished by identification of the transparent properties of glass to sort it from opaque materials (e.g., stones, ceramics, bottle caps, corks, etc.) in the waste stream. Optical sorting involves a compressed air blast that removes or separates the glasses – plain or coloured. An optical sorting machinery is, however, complex and expensive. Consider Figure 5.11 shows a simplified scheme of electronic sorter for glass:

Figure 5.11
Simplified Scheme of Electronic Sorter



Source: Tchobanoglous, et al., (1993)

So far, we discussed component separation through air classifiers, magnetic separators, screens, and hand sorting, flotation, optical sorting and inertial separators. In case, however, the waste consists of moisture, we need to remove it for efficient management. It is in this regard that drying and dewatering are considered the most appropriate means of removal of moisture. We will study this next.

5.4 DRYING AND DEWATERING

Drying and dewatering operations are used primarily for incineration systems, with or without energy recovery systems. These are also used for drying of sludges in wastewater treatment plants, prior to their incineration or transport to land disposal. The purpose of drying and dewatering operation is to remove moisture from wastes and thereby make it a better fuel. Sometimes, the light fraction is *pelletised* after drying to make the fuel easier to transport and store, prior to use in an incinerator or energy recovery facility.

Table 5.3 shows the range of moisture content for municipal solid waste components:

Table 5.3
Moisture Content of
Municipal Solid Waste Components

Component	Moisture (in percent)	
	Range	Typical
Food wastes	50 – 80	70
Paper	4 – 10	6
Cardboard	4 – 8	5
Plastics	1 – 4	2
Textiles	6 – 15	10
Rubber	1 – 4	2
Leather	8 – 12	10
Garden trimmings	30 – 80	60
Wood	15 – 40	20
Glass	1 – 4	2
Tin cans	2 – 4	3
Nonferrous metals	2 – 4	2
Ferrous metals	2 – 6	3
Dirt, ashes, brick, etc.	6 – 12	8
Municipal solid wastes	15 – 40	20

Source: Tchobanoglous, et al., (1993)

5.4.1 Drying

The following three methods are used to apply the heat required for drying the wastes:

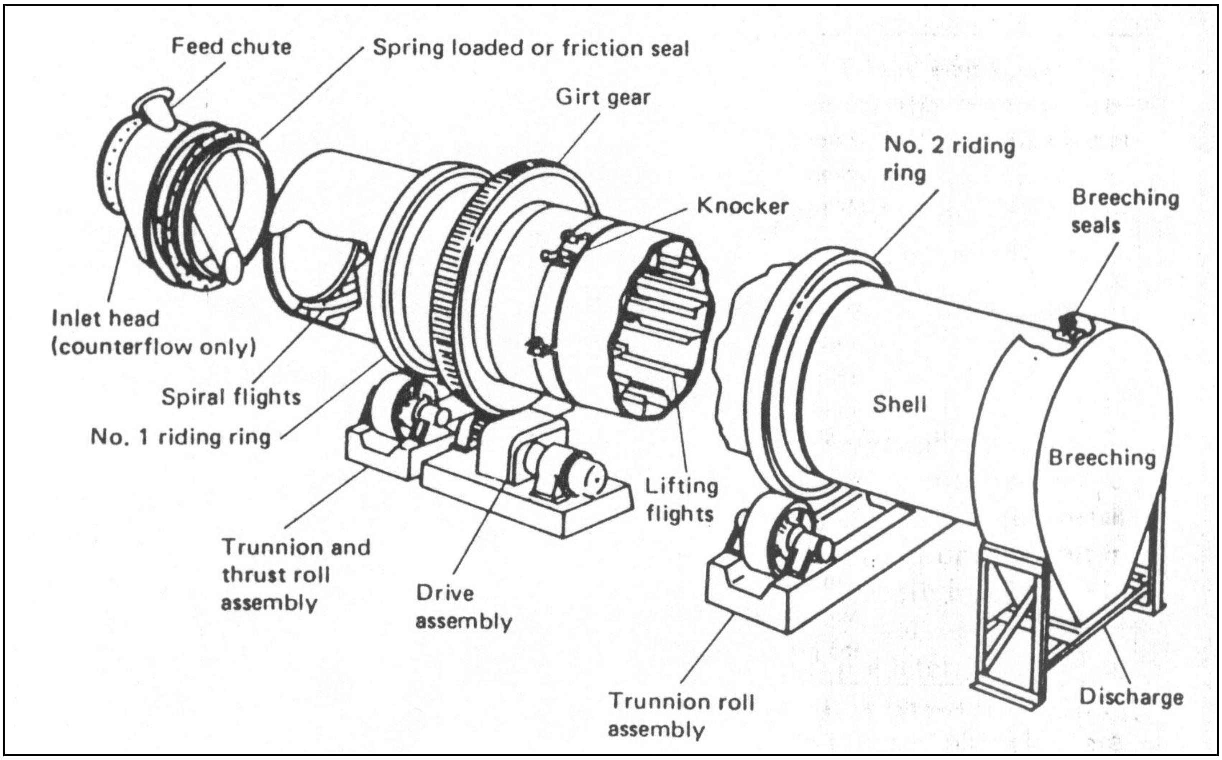
(i) **Convection drying:** In this method, hot air is in direct contact with the wet solid waste stream.

(ii) **Conduction drying:** In this method, the wet solid waste stream is in contact with a heated surface.

(iii) **Radiation drying:** In this method, heat is transmitted directly to the wet solid waste stream by radiation from the heated body.

Of these three methods, convection drying is used most commonly. Figure 5.12 illustrates a rotary drum dryer used in the cement industry:

Figure 5.12
Countercurrent Direct-Heat Rotary Drum Dryer
(Bartlett-Snow)



Source: Tchobanoglous, et al., (1977)

As Figure 5.12 illustrates, a rotary drum dryer is composed of a rotating cylinder, slightly inclined from the horizontal through which the material to be dried and the drying gas are passed simultaneously. The drying of material in a direct rotary dryer occurs in the following stages:

- Heating the wet material and its moisture content to the constant-rate drying temperature.
- Drying the material substantially at this temperature.
- Heating of material to its discharge temperature and evaporation of moisture remaining at the end of the stage.

The retention time in the rotary drum is about 30 – 45 minutes. The required energy input will depend on the moisture content, and the required energy input can be estimated by using a value of about 715 KJ/kg (or 1850 Btu/1b) of water evaporated. Some of the factors, we need to consider in the selection of a drying equipment that include the following:

- Properties of material to be dried.
- Drying characteristics of the materials, including moisture content, maximum material temperature and anticipated drying time.
- Specification of final product, including moisture content.
- Nature of operation, whether continuous or intermittent.
- Operational characteristics, including energy requirements, maintenance requirements, simplicity of operation, reliability, noise output and air and water pollution control requirements.
- Site considerations such as space and height access, noise and environmental limitations.

5.4.2 Dewatering

Dewatering is more applicable to the problem of sludge disposal from wastewater treatment of plants, but may also be applicable in some cases to municipal/industrial waste problems. When drying beds, lagoons or spreading on land are not feasible, other mechanical means of dewatering are used. The emphasis in the dewatering operation is often on reducing the liquid volume. Once dewatered, the sludge can be mixed with other solid waste, and the resulting mixture can be:

- incinerated to reduce volume;
- used for the production of recoverable by-products;
- used for production of compost;
- buried in a landfill.

Centrifugation and filtration are the two common methods for the dewatering of sludge. Sludges with solid content of a few percent can be thickened to about 10 – 15% in centrifugation and about 20 – 30% in pressure filtration or vacuum filtration.

LEARNING ACTIVITY 5.3

List the methods of drying.

Note:
a) Write your answer in the space given below.
b) Check your answer with the one given at this end of this Unit.

SUMMARY

In this Unit, we discussed various processing techniques that are used in SWM system to improve the efficiency of operation, recovery of resources, i.e., usable materials, and recovery of conversion product and energy. We began our discussion with the importance of processing techniques and the nature of equipment involved for the purpose. Subsequently, we discussed mechanical volume and size reduction techniques and touched upon chemical volume reduction. We also explained some component separation techniques (air separation, magnetic separation, screening, etc.). We closed the Unit with a discussion on drying and dewatering, i.e., the processing techniques used for removing varying amounts of moisture present in solid wastes.

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Lecture 5

Model Answers to Learning Activities

LEARNING ACTIVITY 5.1

Compaction of wastes is the method in which waste is densified so as to reduce its volume. This is done to improve the efficiency of collection and disposal of wastes. Compaction is done to increase the useful life of landfills and to reduce the quantity of material handled at the disposal site. It also brings down the cost involved in waste management.

Size reduction refers to the conversion of solid wastes into smaller portions. This helps to obtain the final product in reasonably uniform and considerably reduced size in comparison to the original form. It is important in the recovery of materials for reuse and for conversion to energy. In order to make a better fuel for incineration waste energy recovery facilities, size reduction is practised. It is also used prior to moisture reduction, drying and dewatering.

LEARNING ACTIVITY 5.2

1 tonne = 1000 kg

The weight fraction of the glass in the feed is given by the equation:

$$W_f = \frac{\text{Weight of sample}}{\text{Weight of material fed to the screen}}$$

$$= \frac{100 \times 1000 \times 0.08 \text{ kg}}{100 \times 1000 \text{ kg}}$$

$$= 0.08$$

Weight fraction of glass in screen underflow is given by:

$$W_u = \frac{\text{Weight of sample in underflow}}{\text{Total weight of material in underflow}}$$

$$= \frac{7.2 \times 1000\ kg}{10 \times 1000}$$

$$= 0.72$$

Recovery efficiency is given by the equation:

$$Recovery\ (\%) = \frac{Uw_u}{Fw_u}$$

$$= \frac{10 \times 1000 \times 0.72 \times 100}{100 \times 1000 \times 0.08}$$

$$= 90\%$$

Effectiveness is given by the equation:

Effectiveness = recovery $\times$ rejection

$$= \frac{U \times W_u}{F \times W_f} \times 1 - \frac{U(1 - W_u)}{F\ (1 - W_f)}$$

$$= \frac{(10 \times 1000)(0.72)}{(100 \times 1000 \times 0.08)} \times 1 - \frac{10 \times 1000(1 - 0.72)}{100 \times 1000(1 - 0.08)}$$

$$= 0.87$$

LEARNING ACTIVITY 5.3

The heat required for drying can be applied by the following methods:

(i) Convection drying in which hot air is in direct contact with the wet solid waste stream.

(ii) Conduction drying in which wet solid waste stream is in contact with a heated surface.

(iii) Radiation drying in which heat is transmitted directly to the wet solid waste stream by radiation from the heated body.