Solid and Hazardous Waste Management

UNIT- I

Introduction to Solid Waste Management

Syllabus:

Goals and objectives of solid waste management, Classification of Solid Waste - Factors Influencing generation of solid waste - sampling and characterization –Future changes in waste composition, major legislation, monitoring responsibilities, Terms related to ISWM like WTE, ULB, TLV etc. Measurement of NPK and Calorific value

Introduction:

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.

Solid Waste :

Conventionally waste can be defined any solid or liquid material that doesn't have any further use. As per Environment Public Health Act (EPHA, 1988) 'waste' includes:

a) Scrap material or an effluent arising from the application of any process,

b) Broken, worn out, contaminated or spoiled material have disposed off and

c) Discarded material shall be presumed to be waste unless the contrary is proved.

Garbage, sludge, refuse and other discarded solid materials resulting from industrial, residential and commercial activities and other operations are defined as solid waste. It does not include solids or dissolved material in domestic sewage or other pollutants like silt, dissolved or suspended solids in industrial wastewater effluents, dissolved materials in irrigation return flows or other common water pollutants (Leyes, 1993).

Solid waste management is defined as the discipline associated with control of generation, storage, collection, transport or transfer, processing and disposal of solid waste materials in a way that best addresses the range of public health, conservation, economic, aesthetic, engineering, and other environmental considerations.

Goals & Objectives of Solid Waste:

The primary goal of solid waste management is reducing and eliminating adverse impacts of waste materials on human health and the environment to support economic development and superior quality of life. This is to be done in the most efficient manner possible, to keep costs low and prevent waste build up.

- To establish and maintain an ongoing planning and plan implementation process to meet current and future needs for the service area based on the state's adopted hierarchy of waste management strategies
- classify solid wastes
- explain the functional elements of SWM and assess the current situation of SWM in India
- Explain the types of hazardous waste and its management
- To secure maximum public support for the regional solid waste planning and implementation process through public participation and education programs

Classification of Solid Waste:

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

1. Source of generation and
2. Type of Generation

Classification on the basis of source

1. **Residential:** This refers to wastes from dwellings, apartments, etc., and consists of leftover food, vegetable peels, plastic, clothes, ashes, etc.
2. **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.
3. **Institutional:** This mainly consists of paper, plastic, glasses, etc., generated from educational, administrative and public buildings such as schools, colleges, offices, prisons, etc.
4. **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).
5. **Industrial:** This mainly consists of process wastes, ashes, demolition and construction wastes, hazardous wastes, etc., due to industrial activities.
6. **Agricultural:** This mainly consists of spoiled food grains and vegetables, agricultural remains, litter, etc., generated from fields, orchards, vineyards, farms, etc.
7. **Open areas:** this includes wastes from areas such as Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.

Classification on the basis of type:

1. **Refuse**: it includes all types of rubbish and garbage.
2. **Garbage:** waste materials from kitchen waste, food, slaughter houses, canning and freezing industries can decompose easily are known as garbage.
3. **Rubbish:** it includes wastes material like paper, rubber, leather, wood, garden wastes metal, glass, ceramics, stones and soil.
4. **Ashes**: left over of heating and cooking or incineration of waste material is known as ash.

5. **Street wastes**: wastes collected during cleaning of streets, walkways, parks, playgrounds etc. It includes soil, paper, cardboard, plastics, leaves and vegetable matter in large quantities.
6. **Large wastes**: waste like parts or whole of automobile, furniture, refrigerator and other home appliances, trees, fires, demolition and construction wastes is considered as large waste.
7. **Industrial wastes:** waste originated from industries like chemicals, paints, fertilizer, pesticides, sand and explosives etc. It can be of hazards nature.
8. **Sewage sludge:** it includes sludge from primary and secondary settling tank and solids from screens etc.
9. **Mining wastes:** waste originated from mines which include mine dump, slug ropes and waste from coal mines like coal dust, fine coal and dirt.
10. **Agricultural wastes:** waste originated from animal farm like crop residue, cattle dung, manure etc.

Factors that influence the quantity of solid wastes generated include:

1. Geographic location
2. Season of the year
3. Collection frequency
4. Use of kitchen waste grinders
5. Characteristics of populace
6. Extent of salvaging and recycling
7. Public attitudes
8. Legislation

Following factors affect Municipal Solid Waste Generation Rates

1. Source reduction:

The waste reduction may occur through the design, manufacture, and packaging of products with minimum toxic content, the minimum volume of material, and longer useful life. Example: Improve product design to use less materials. Source reduction is the preferred approach.

Reuse:

Reusing product over and over again reduces the waste generation. Example: Using rechargeable batteries, reusable food containers, reusable glass instead of throwaway water bottles, etc.

Recycling:

Recycling is collecting materials that can be broken down and reprocessed to manufacture new items. Example: Household recycling products are - Paper products, Glass, Aluminium, Steel and Some plastics.

2. Effect of public attitudes and legislation on waste generation

Public Attitudes - Significant reduction in the quantities of solid wastes generated occur when and if people are willing to change of their own volition- their habits and lifestyles to conserve natural resources and to reduce the economic burdens associated with the management of solid wastes.

A program of continuing education is essential in bringing about a change in public attitudes.

Legislation Perhaps the most important factor affecting the generation of a certain type of wastes is the existence of local, state, and federal regulations concerning the use of specific materials.

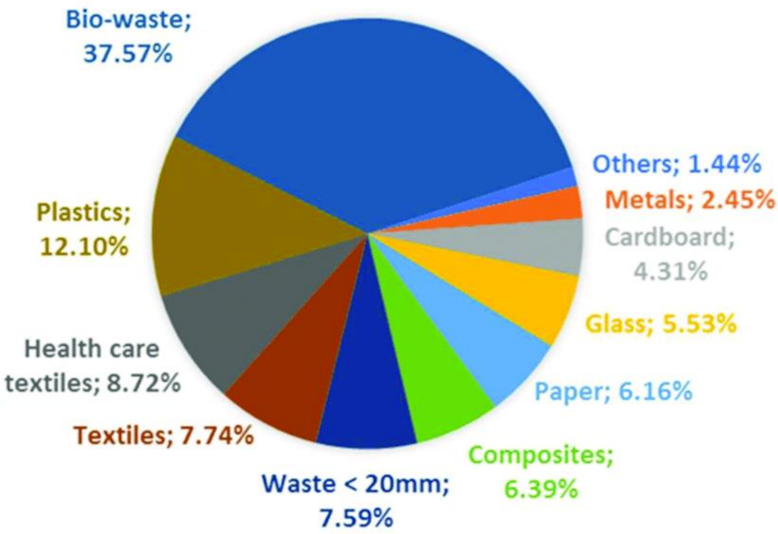
3. Effect of Geographic and physical factors on waste generation

Geographic and physical factors that affect the quantities of waste generated and collected include:

- geographical location: related primarily to the different climate that can influence both the amount generated and collection operation
- season of the year
- frequency of collection
- characteristics of population
- extent of salvage and recyling
- legislation
- public attitude

Waste Sampling and Characterization:

Waste Characterization: Waste characterization means finding out how much paper, glass, food waste, etc. is discarded in your waste stream. Waste characterization information helps in planning how to reduce waste, set up recycling programs, and conserve money and resources



Waste Sampling:

The individual components are separated, stored in bins and weighed. The weights are then expressed as a percent of the original sample. The density of the material is measured. The physical analysis is on a wet weight basis which helps in choosing the system for collection and processing.

Carruth and Klee have given the following method for determining the number of samples:

$$n=(Z.S /d)^2$$

Where -

n = number of samples required

Z = standard normal deviate for the confidence level desired

S = estimated standard deviation (transformed basis)

d = sensitivity (transformed basis)

At 90% confidence, Z = 1.645, S = 0.1413

Waste sampling is done in 3 ways:

1. Physical Analysis
2. Chemical Analysis
3. Biological Analysis

1. **Physical Analysis:**
   The sample so collected should be sorted out physically into various ingredients such as paper, glass, plastics, etc. on a sorting platform. The individual components are separated, stored in bins and weighed. The weights are then expressed as a percent of the original sample.
   The density of the material is measured. The physical analysis is on a wet weight basis which helps in choosing the system for collection and processing. A large organic content indicates the necessity for frequent collection and removal. The larger amount of paper indicates that waste can be thermally treated. Plastics in high concentration indicate possible problems in their disposal. A large percentage of ash indicates that putrefaction will not readily occur and that collection frequency could be less. In such a case, sanitary landfilling would be a better method.
   Changes in Physical Characteristics of City Refuse in Pune, India

Characteristics	Years	
	1970[23] (%)	1978[60] (%)
Compostable material	67.00	60.66
Paper	8.74	7.00
Glass	0.58	0.67
Rags	1.63	4.21
Plastics	0.72	0.89
Metals	0.59	0.77

2. **Chemical Analysis :**
   From the mass used for physical analysis a 500 gms sample is taken for moisture determination and heated overnight at 1000C1000C to obtain weight loss. This loss is expressed as a percentage of total weight. Normally moisture content is determined as soon as the sample is collected which helps in the choice of processing and disposal methods

3. **Biological Analysis :**
   Refuse as it is produced does not normally contain human intestinal parasites. In India and other developing countries, it is common to find refuse lying at such points where it is liable to come in contact with material containing parasites. In cities, which do not have a sewerage system, night- soil is often deposited along with refuse which transmits parasites.

Future Changes in Waste Composition:

- Due to
  I. growth in population
  II. changing lifestyles
  III. consumption patterns

  not only the quantity of waste generated is further increasing but quality and composition of waste is also changing particularly.
- A noticeable change in composition is observed that as the standards of living improve the proportion of paper and plastics increases – in many developing countries it has doubled in one decade.

Laws related to solid waste

1962	Atomic Energy Act
1986	Environmental (Protection) Act
1989	Hazards Waste (Management and Handling) Rules
1996	Chemical Accidents (Emergency Planning, Preparedness and Response) Rules
1998	Biomedical Waste (Management and Handling) Rules
1999	Recycled Plastic manufactured & usage Rules
1999	Solid Waste Management in Class 1 cities in India-Guided by Supreme Court Of India
2000	Municipal Solid Waste (Management and Handling) Rules
2001	Batteries (Management and Handling) Rule

Terminology in ISWM (Integrated Solid Waste Management)

WTE (Waste to Energy):

This process is called waste to energy (WTE). It recycles the energy and the metals contained in the MSW while most of the remaining ash by-product can be beneficially used for the maintenance of landfill sites or for building roads and other construction purposes.

ULB (Urban Local Bodies):

According to the 12th Schedule of the 74th Constitution Amendment Act of 1992, urban local bodies (ULBs) are responsible for keeping cities and towns clean.

TLV (Threshold limit value):

The threshold limit value (TLV) is defined as the concentration in air that may be breathed in without harmful effects for five consecutive eight-hour working days

Measurement of NPK

The N(Nitrogen), P(Phosphorous), and K(Potassium) value of the sample are determined by absorption light of each nutrient.

Measurement of Calorific Value

the calorific value can be calculated. For other foods (e.g. meat products), it is measured using a device called a "bomb calorimiter". Essentially, you put the food in a chamber filled with pure oxygen and burn it, measuring the amount of heat (i.e. energy) that is generated.

UNIT- II

Syllabus:

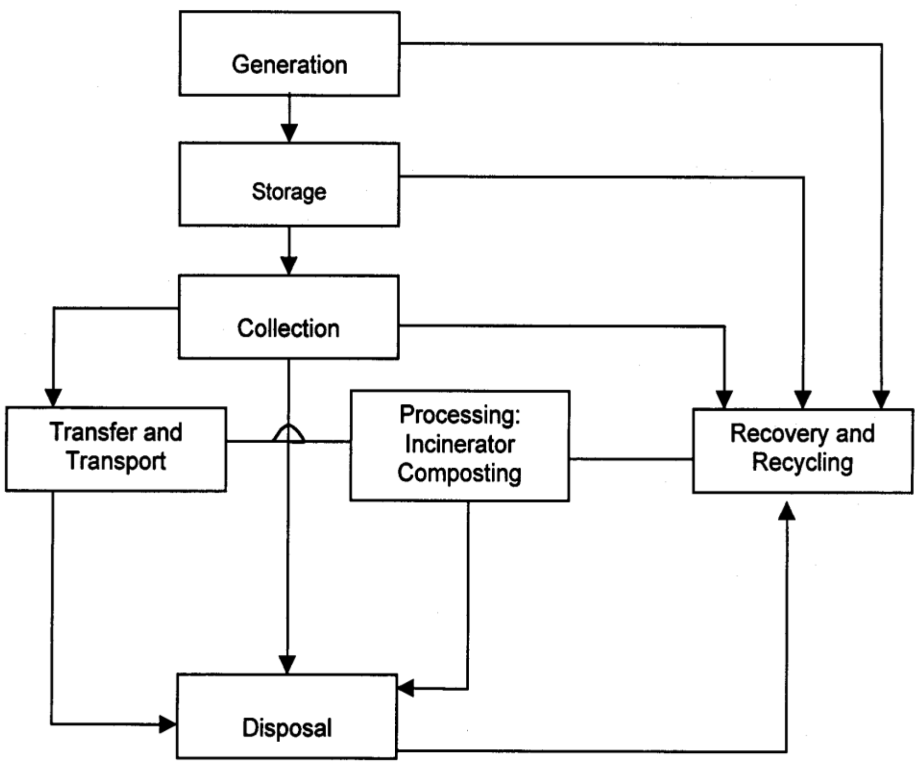
Basic Elements in Solid Waste Management:

Elements and their inter relationship – principles of solid waste management- onsite handling, storage and processing of solid waste

Collection of Solid Waste:

Type and methods of waste collection systems, analysis of collection system - optimization of collection routes– alternative techniques for collection system.

Elements of Solid Waste Management:



Generation of Solid Waste

Generally, the solid waste is generate by the community like residential or industrial or hospitals etc.

Storage of MSW

It is common practice in India to collect wastes in plastic buckets and deposit it in community bins located near the houses. Wastes collected during the cleaning of streets are also disposed off in community bins

Collection of MSW

The functional element of collection includes gathering of solid waste and recyclable materials and their transport to the location where the collection vehicle is emptied. Collection programs in different communities vary greatly depending on waste types collected, community characteristics, economics, and the desires of their residents. Data concerning waste sources, waste composition, and total volumes are critical for the proper planning of a collection program. In India, urban bodies spend ~ Rs.500 – 1500 per ton on solid waste management, out of which 60-70% of the amount is spent on collection, 20-30% on transportation and hardly any fund on treatment and disposal

Segregation of Solid Waste

Segregation means separation of waste into biodegradable (food waste, vegetable and fruit peels etc.), non-biodegradable (polythene bags, plastic, metal scraps, needles, syringe, plastic and glass bottles etc.) and recyclable (paper, cardboard, metals, glass, plastics etc.) It protects human health and the environment by removing the harmful pollutants from the waste stream and conserve natural resources

Transportation of Solid Waste

During transportation of waste, it should be covered to avoid exposure and spillage in environment. There should be separate cabin for driver for the protection of his health

Disposal of Solid Waste

The waste collected from municipalities is finally transferred to disposal site which may be a landfill site, incinerator or other disposal facilities like composting plant. Safe disposal of MSW is very important for safety of environment, wildlife and public health. An efficient waste management system is generally that which provide a landfill for ecologically sound disposal of waste that can't be reduced, recycled, composted, combusted or processed further

Open dumping and Burning

Solid wastes disposed off on roadside and in low lying areas are called an open dumping. The open dumps attract flies, insects, rodents, birds and also produce odours because they remain uncovered. It causes pollution of ground water and soil as well as health problems. Burning of waste is a common practice at open dumping site. It is prohibited in law and causing various types of pollution especially air pollution

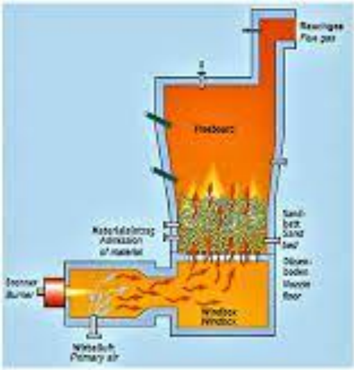
Composting

During composting process bacteria, fungi and other microbes break down organic materials to stable and usable organic substances called compost (Bernal et al., 2009 and Bundela et al., 2010). Compost is a good fertilizer because it contains various essential elements for plant.

In India, composting is carried out on small fraction i.e. 10-12% of total waste because it needs segregation and sorting which is not widely practiced.

Incineration

It is burning of solid waste in a closed chamber at very high temperature with excess air. During incineration various types of gaseous pollutants like CO_2, CO, NO_x, SO_x etc. and fly ash in the form of suspended particulate matter are emitted into the atmosphere. The ash produced during incineration should be disposed off into sanitary landfill.


Flue gas
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bett
Sand
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Admission
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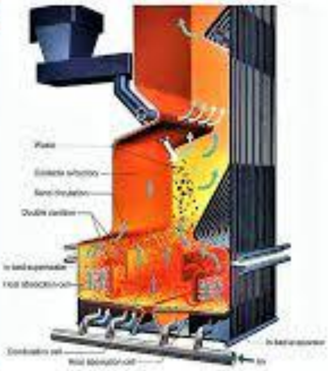
Burner
Windbox
Primary air



PRINCIPLES OF SOLID WASTE MANAGEMENT

- The first and vital principle of waste management refers to the 3 R's, Reuse, Recycle, Reduce.

- The waste hierarchy is represented in the form of a pyramid because the basic premise is the promotion of integrated methods to prevent waste generation.

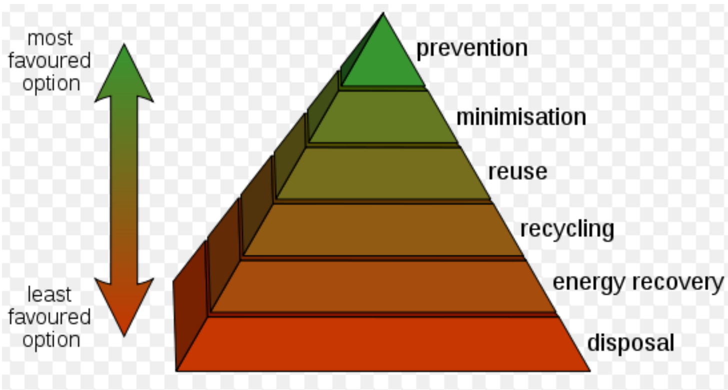


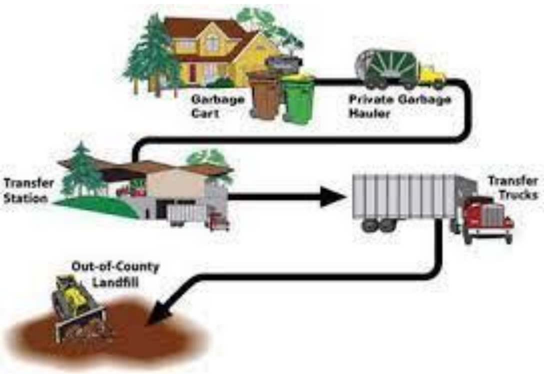
Fig: Waste management hierarchy

- The next step includes material restoration, waste conversion, and energy production techniques.
- he final and the last step is the disposal of the remaining wastes that can't be processed further. It includes incineration or disposing of the landfills.

On-site Handling and Storage

Refers to activities associated with the handling of SW until they are placed in the containers used for storage before collection [curb collection, direct haul, transfer stations]
On-site handling methods and principles involve public attitude and individual belief, and ultimately affects the public health. It is an activity associated with the handling of solid waste until it is placed in the containers used for its storage before collection. This may take place at any time before, during or after storage.

Importance of on-site handling of solid waste:
- reduce volume of waste generated
- alter physical form
- recover usable materials



Factors considered for On-site Storage

- Types of containers used depend on characteristics of SW collected, collection frequency, and space available for the placement of containers. Residential area can have refuse bags of 7-10 L and rubbish bins of 20-30 L capacity. Container must be standardized to suit collection equipment.

- Location can be either at the rear of/beside the house, alleys or at the basement of apartments

- Public health: Waste to be removed periodically to avoid spread of diseases

- Aesthetics: Must be clean, shielded from public view

On- site handling methods:
- sorting
- shredding
- grinding
- composting

On- Site Storage

The first phase to manage solid waste is at home level. It requires temporary storage of refuse on the premises. The individual householder or businessman has responsibility for onsite storage of solid waste

For individual homes, industries, and other commercial centers, proper on-site storage of solid waste is the beginning of disposal, because unkept or simple dumps are sources of nuisance, flies, smells and other hazards.There are four factors that should be considered in the onsite storage of solid waste. These are the type of container to be used, the location where the containers are to be kept, public health, and the collection method and time.

1. Storage containers

Garbage and refuse generated in kitchens and other work areas should be collected and stored in properly designed and constructed water-proof garbage cans (waste bins). The cans or receptacles can be constructed from galvanized iron sheet or plastic materials. They should have tightly fitting covers.

They must be of such size that, when full, they can be lifted easily by one man. They should be located in a cool place on platforms at least 30 cm above ground level. After putting in garbage, they should be kept covered. The bins must be emptied at least daily and maintained in clean conditions. A typical example of garbage can, constructed from galvanized iron sheet, dimensions: diameter 45 cm and height 75 cm, is shown in figure 1 below.

An adequate number of suitable containers should be provided with proper platforms with receptacles stand. The number may depend on the amount, type and establishments where the need arises. Suitable containers should be watertight, rust-resistant, with tight-fitting covers, fire-resistant, adequate in size, light in weight, with side handles and washable.

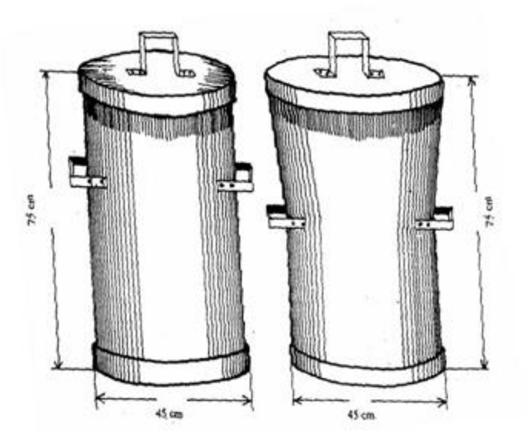


Figure 1. Typical Garbage Can with Tightly Fitting Cover

2. Container Size (capacity)

Consideration should be given for the size of the loaded container that must be hauled to the collection vehicle or to the disposal site.

Therefore, container size for:-
- ash: up to 80 to 128 liters
- mixed refuse: should not exceed 120 to 128 liters
- rubbish up to 200 liters
- kitchen waste is 40 liters
- garbage is 48 to 80 liters

Plastic liners for cans and wrapping for garbage reduce the need for cleaning of cans and bulk containers, and keep down odors, rat and fly breeding. Galvanized metal is preferable for

garbage storage because it is resistant to corrosion. Plastic cans are light in weight but are easily gnawed by rats. Bulk containers are recommended where large volumes of refuse are generated, such as at hotels, restaurants, apartment houses, and shopping centers.
A concrete platform provided with a drain to an approved sewer with a water faucet at the site facilitates cleaning.

On- site processing

Importance of on-site processing:
- reduces volume of waste generated
- alters physical form
- recovers usable materials

Factors that should be considered in evaluating on-site processing are capabilities, reliability, environmental effects, ease of operation, etc

Collection of Solid Waste

Collection Components:

1. **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.

2. **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**.**

3. **Storage containers:** 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.

4. **Collection crew:** 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.

5. **Collection route:** 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.
6. **Transfer station:** 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.

Methods of Waste Collection Systems:

1. **Residential:** Curb / Kerb and backyard collection; set-out and set-back containers; house-to-house collection from bags

2. **Commercial – Industrial** (12 m3): Large movable and stationary containers and compactors

3. **Collection frequency**: For residential – everyday or once in two days, whereas for commercial/ communal – daily collection should be ensured.

4. For food wastes, the maximum time should not exceed
   - The normal time for the accumulation of waste in the container
   - Time for fresh garbage to putrefy and emit foul odour
   - Length of fly-breeding cycle

Collection services:

People must understand that a good refuse-collection service requires citizen cooperation in the provision and use of proper receptacles in order to keep the community clean and essentially free of rats, flies, and other vermin.

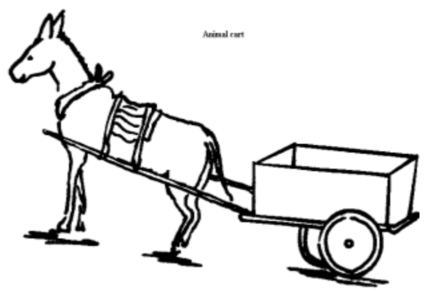
There are four types of collection services:

I. Curb (curb side): The home owner is responsible for placing and returning the empty container. Never entirely satisfactory.

II. Set-out (block collection): Owner is responsible for returning the container. The full containers are brought or set at the collection site by the crew. Bins are not left out on the street for long periods.

III. Backyard carrying service (door to door collection): Collection crews that go along with the collection vehicle are responsible for bringing out stored solid waste from the dwelling units. It is the only satisfactory system in which the householder does not get involved.

IV. Alleys: a narrow street or path between buildings in a town. That is difficult to get the container and also to the vehicle that will collect the waste..



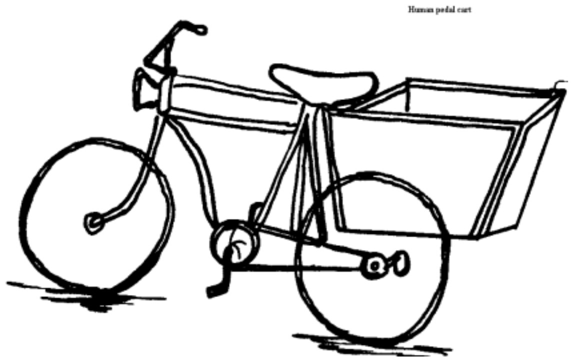
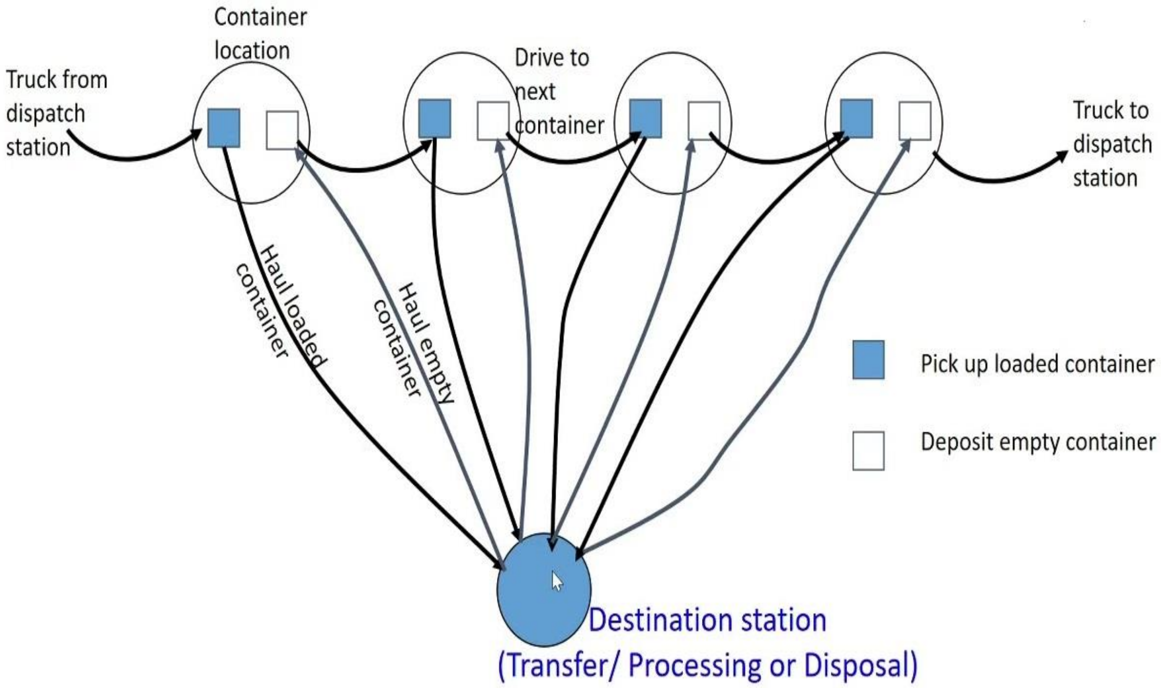


Fig: Small-scale Collection Vehicles

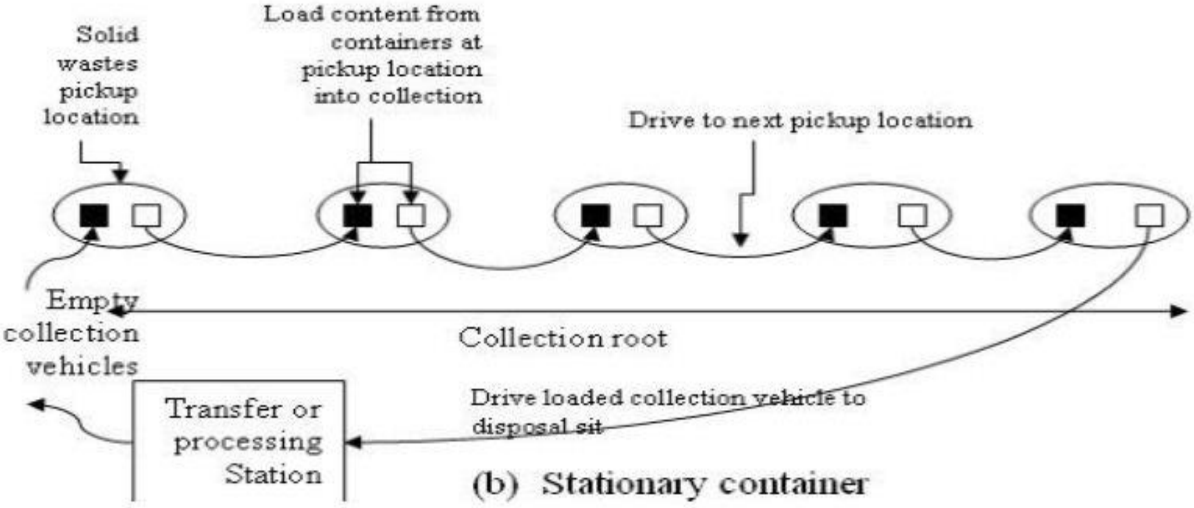
Fig: Compactor Trucks

Types of Collection Systems:

1. **Hauled Container System:** Hauled to disposal sites, emptied, and returned to original location or some other location. It can be a hoist truck, tilt frame container or trash trailer. In general, this type of system is suitable for areas with high waste generation.



2. **Stationary Container System:** The container used to store waste remains at the point of generation, except when moved to curb or other location to be emptied. It can a mechanized system or manually loaded collection vehicle.

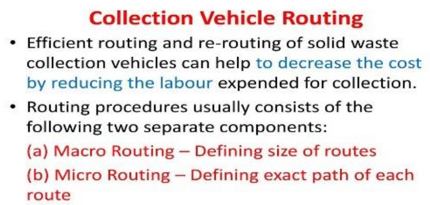


Analysis of collection System:

a. Load count analysis –basically involves counting of the individual loads over a specified time period. If possible, weighing the load will be very important**.**
b. Weight -volume analysis- measuring the volume of the truck and weight of each load will give ample data. Although the technique is expensive, it is used to: draw a system boundary round the unit to be studied; identify what occurrences affect generation rates; identify the rate of generation associated with different activities using the data available; determine the quantity of waste generated, stored and collected

Optimization of 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



Collection Vehicle Routing

- Efficient routing and re-routing of solid waste collection vehicles can help to decrease the cost by reducing the labour expended for collection.
- Routing procedures usually consists of the following two separate components:
  (a) Macro Routing – Defining size of routes
  (b) Micro Routing – Defining exact path of each route

(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.

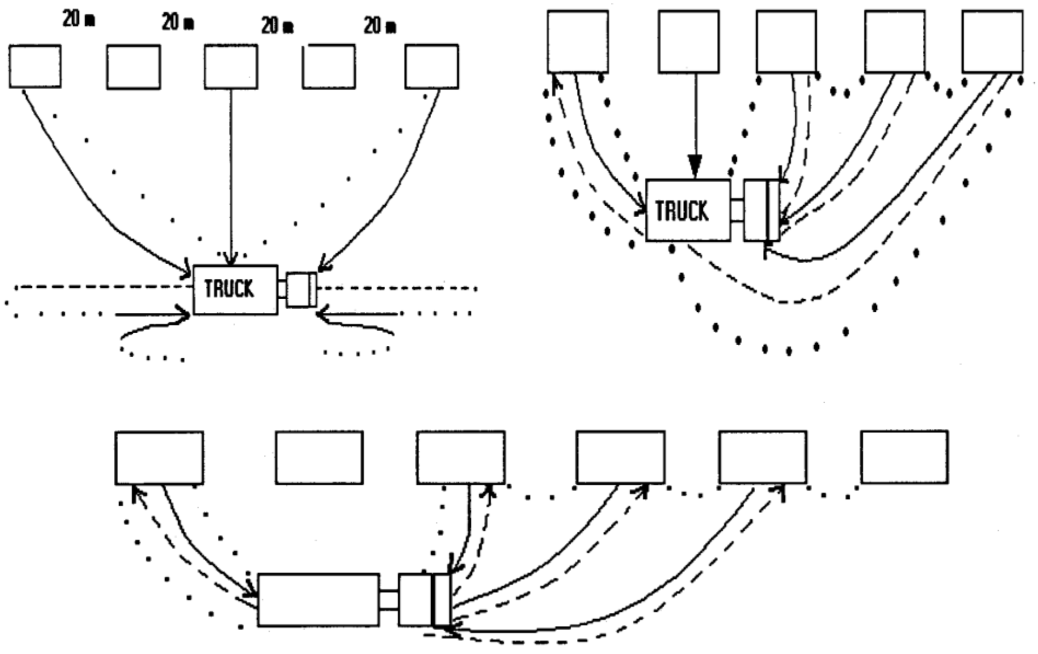


Fig: Collection Vehicle Routing

Waste Collection System design

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 x D)/W

where, C = Vehicle capacity (m3); D = Waste density (kg/m3) and W = Waste generation/residence (kg/service)

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

E = N x 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 (t1), time for hauling and other travel (t2) and collection route time (t3).

- **Administrative and break time (t1):**

t1 = 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 (t2):**

t2 = (n x 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 (t3):**

t3 = n x E

where variables have been previously defined.

Length of workday (t):

t = t1 + t2 +t3

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 x F)/(N x n x 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

UNIT- III

Syllabus:

Transfer, Transport and Transformation of Waste:

Need for transfer operation, compaction of solid waste - transport means and methods, transfer station types and design requirements. Unit operations used for separation and transformation: shredding - materials separation and recovery, source reduction and waste minimization

Introduction:

Waste transfer stations play an important role in a community's total waste management system, serving as the link between a community's solid waste collection program and a final waste disposal facility. While facility ownership, sizes, and services offered vary significantly among transfer stations, they all serve the same basic purpose—consolidating waste from multiple collection vehicles into larger, high-volume transfer vehicles for more economical shipment to distant disposal sites. In its simplest form, a transfer station is a facility with a designated receiving area where waste collection vehicles discharge their loads. The waste is often compacted, then loaded into larger vehicles (usually transfer trailers, but intermodal containers, railcars, and barges are also used) for long-haul shipment to a final disposal site—typically a landfill, waste to-energy plant, or a composting facility. No long-term storage of waste occurs at a transfer station; waste is quickly consolidated and loaded into a larger vehicle and moved off site, usually in a matter of hours.

Need for Transfer Operation:

The nationwide trend in solid waste disposal has been toward construction of larger, more remote, regional landfills. Economic considerations, heavily influenced by regulatory and social forces, are compelling factors leading to this result.

Transfer stations are used to collect the refuse at a central location and to reload the wastes into a vehicle where the cost per kilogram-kilometer ton-mile will be less for the movement of the ultimate waste to the disposal site. Transfer stations are employed when the disposal site is situated at significant distance from the point of collection.

A transfer station can reduce the cost of transporting refuse by reducing manpower requirement and total kilometers.When a collection vehicle goes directly to the disposal site,the entire crew, driver plus laborers, are idle. For a transfer vehicle, only one driver is needed. As the distance from the centers of solid waste generation increases, the cost of direct haul to a site increases. Ideally, the transfer station should be located at the center of the collection service area.

A transfer station may include stationary compactors, recycling bins, material recovery facility, transfer containers and trailers, transfer packer trailers, or mobile equipment.

A transfer station should be located and designed with drainage of paved areas and adequate water hydrants for maintenance of cleanliness and fire control and other concerns like land scaling, weight scales, traffic, odor, dust, litter, and noise control. Transporting vehicles could be a modern packer truck (trailer), motor-tricycles, animal carts (appropriate for developing countries), hand carts and tractors.

Transfer and transport station should provide welfare facilities for workers (lockers, toilets, showers); small stores for brooms, shovels, cleaning materials, lubricants, parking facilities for hand trucks, sweepers, refuse collectors, and office and telephone for the district inspector.

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.

Compaction of Solid Waste:

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.

Types of Transfer Station:

(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.

Formulas for Determining Transfer Station Capacity :

Stations with Surge Pits

Based on 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:

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

Direct Dump Stations

$C = Nn \times P_t \times F \times 60 \times H_W / [(Pt/Pc) \times (W/Ln) \times Tc] + B$

Hopper Compaction Stations

$C = (Nn \times Pt \times F \times 60 \times H_W) / (Pt/Pc \times Tc) + B$

Push Pit Compaction Stations

$C = (Np \times Pt \times F \times 60 \times H_W) / [(Pt/Pc) \times (W/Lp) \times Tc] + Bc + B$

Where:

C - Station capacity (tons/day)
P_C - Collection vehicle payloads (tons)
L - Total length of dumping space (feet)
W - Width of each dumping space (feet)
H_W -Hours per day that waste is delivered
T_C -Time to unload each collection vehicle (minutes)
F -Peaking factor (ratio of number of collection vehicles received during an average 30-minute period to the number received during a peak 30-minute period)
P_t -Transfer trailer payload (tons)
N -Number of transfer trailers loading simultaneously
H_t -Hours per day used to load trailers (empty trailers must be available)
B -Time to remove and replace each loaded trailer (minutes)
Tt -Time to load each transfer trailer (minutes)
Nn -Number of hoppers
Ln -Length of each hopper
Lp -Length of each push pit (feet)
Np -Number of push pits
Bc Total cycle time for clearing each push pit and compacting waste into trailer

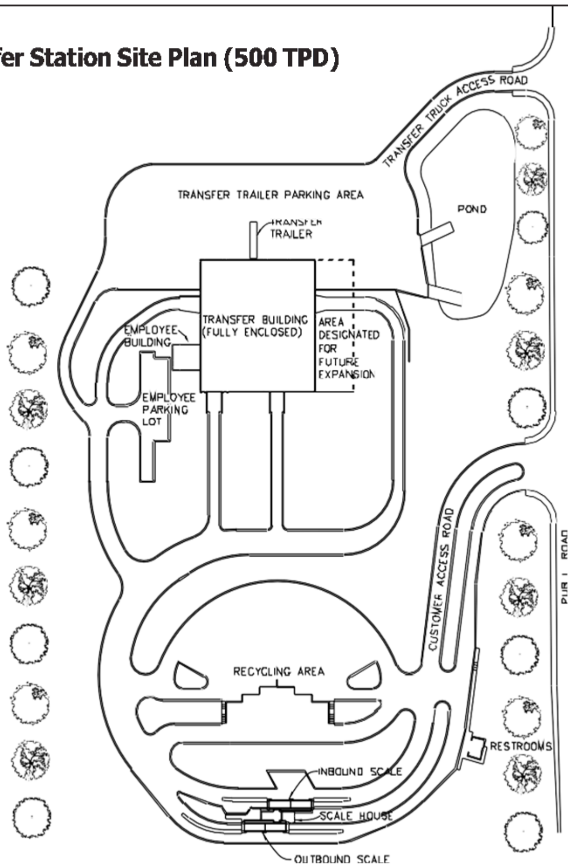


Figure 2
Transfer Station Site Plan (500 TPD)

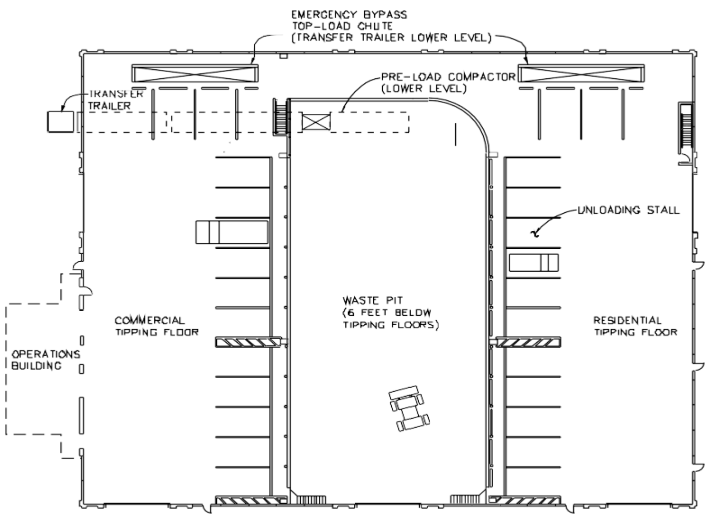
- **Road entrances and exits.** Including acceleration/deceleration lanes on public streets, and access points for waste arriving and departing from the transfer station. Some facilities have separate access for visitors and employees so these vehicles do not have to compete with lines of vehicles using the facility.
- **Traffic flow routes on site.** Often, separate routes are established for public use and for heavy truck use. Designers work to eliminate sharp turns, intersections, and steep ramps.
- **Queuing areas.** Queues can develop at the inbound scales, the tipping area, and the outbound scales. Queuing space should be clearly identified, and queues should not extend across intersections.
- **The scale house.** Incoming and outgoing loads are weighed and fees are collected.
- **Primary functions at the transfer station building.** Including tipping floor, tunnels, ramps, etc.
- **Buildings.** Including entrances and exits for vehicles and people.
- **Parking areas.** Employees, visitors, and transfer vehicles.
- **Public conveniences.** Such as separate tipping areas for the general public, recycling dropoff areas, a public education center, and restrooms.
- **Space for future expansion of the main transfer building.** Often, this area is shown as a dotted line adjacent to the initial building location.
- **Buffer areas.** Open space, landscaping, trees, berms, and walls that reduce impacts on the community.
- **Holding area.** For inspecting incoming loads and holding inappropriate waste loads or materials for removal.

Main Transfer Area Design

Most activity at a transfer station occurs within the main transfer building. Here, cars and trucks unload their waste onto the floor, into a pit, or directly into a waiting transfer container or vehicle. Direct loading can simplify operations, but limits the opportunity to perform waste screening or sorting. When not loaded directly, waste deposited onto the floor or into a pit is stored temporarily, then loaded into a transfer trailer, intermodal container, railcar, or barge. Most modern transfer stations have enclosed buildings. Some older and smaller facilities are partly enclosed (e.g., a building with three sides) or only covered (e.g., a building with a roof but no sides). Small rural facilities might be entirely open but surrounded by fences that limit access and contain litter.

Figure 3 shows the main transfer building for the site plan depicted in Figure 2. It shows a 40,000-square-foot building with a pit, separate tipping areas for public versus large trucks on either side of the pit, and a preload compactor to compact the waste before it is loaded into transfer trailers.

Figure 3
Main Transfer Building Floor Plan



Because the main transfer building is typically quite tall to accommodate several levels of traffic, it can often be seen easily from off-site locations. Therefore, the main transfer building should be designed to blend into or enhance the surrounding neighborhood.

Types of Vehicles That Use a Transfer Station

Traffic is frequently a transfer station's most significant community impact. Because the primary purpose of transfer stations is to provide more efficient movement of wastes, it is important to consider the following types of customers and vehicles that commonly use them.

- **Residents hauling their own wastes in cars and pickup trucks.** Residents regularly served by a waste collection service typically visit the transfer station less frequently than residents in unincorporated and rural areas not served by waste collection companies (or who elect not to subscribe to an available service). Residents typically deliver only a few pounds to a ton of waste per visit.
- **Businesses and industry hauling their own wastes in trucks.** Many small businesses such as remodeling contractors, roofers, and landscapers haul their own wastes to transfer stations. The vehicle type used and the waste amount delivered by businesses varies considerably.
- **Public or private waste hauling operations with packer trucks.** Packer trucks, which compact waste during the collection process, are commonly used on collection routes serving homes and businesses. Packer trucks typically visit many waste generators along their routes and unload when full, generally once or twice per day. Convenient access to a transfer station helps keep packer trucks on their collection routes. Packer trucks typically deliver 5 to 10 tons of waste per visit.
- **Public or private waste hauling operations with rolloff trucks.** Large rolloff containers are typically placed at businesses and industry and collected when they are full. A rolloff box is a large metal bin, often open at the top, that can be loaded onto a truck and hauled away to dispose of the waste. Rolloff boxes also are commonly used at transfer stations to receive yard waste, recyclables, and solid waste from the general public. A typical, large rolloff box measures 8 feet tall, 7 feet wide, and 22 feet long. Unlike packer trucks that operate on an extended route before traveling to the transfer station, rolloff trucks typically travel to one place, pick up a roll-off container, travel to and unload at the transfer station, and return the empty rolloff container to the place of origin. Because rolloff trucks handle many loads per day, convenient access to a transfer station is very important to their operations. Rolloff trucks typically deliver 2 to 8 tons per visit.
- **Transfer vehicles hauling waste from the transfer station.** Transfer trailers (similar to large interstate tractor-trailers) commonly haul consolidated waste from transfer stations to disposal facilities. Trains or barges are also used to haul waste from some large urban transfer stations (see text box). Transfer trailers typically haul 15 to 25 tons per trip, while trains and barges typically haul thousands of tons. Some stations

Unit operations used for separation and transformation

Introduction

- Separation, Processing and Transformation make up the fourth of the functional elements of solid waste management system
- the methods now used to recover source separated wastes materials include curb side collection and home owner delivery of separated materials to drop off and buy back centers.
- The further separation and processing of waste that have been source separated occur at MRF or at large integrated MR-TF.
- Chemical & biological transformation process are used to reduce the volume and weight of waste requiring disposal and to recover conversion products and energy in the form of heat.
- The most commonly used chemical transformation process is combustion which is used in conjunction with the recovery of energy in the form of heat.
- The most commonly used biological transformation process is aerobic composting.

Options for the separation of waste materials

- Separation is a necessary operation in the recovery of reusable materials from municipal solid waste. Separation can be accomplished either at the source of the generation or at MRFs.
- Waste separations at the source is usually accomplished by manual means, the number & types of components separated will depend on the waste diversion program. Additional separation and processing will be usually required before these materials can be reused or recycled.
- MRFs & MR-TFs are used for :
  - the further processing of source separated waste
  - the separation & recovery of reusable & recyclable materials from commingled MSW
  - improvement inequality (specification)
  - in the simplest term, AMRF can function as centralized facilities for the separations, cleaning & shipping of large volume of materials recovered from municipal solid waste

Options for the separation of waste materials

- The separation of waste materials from MSW can be accomplished manually or mechanically.
- Manual separation is used almost exclusively for the separation of waste at the source of generation. Many of the early MRFs built in 1970 s were designed to separate the waste components mechanically. Unfortunately, none of these early facilities is currently in operation, primarily because of mechanical problem.
- The currant trend is to design MRFs based on the integration of both manual and mechanical separation functions

Options for the separation of waste materials

Two types of MRF:

- MRF for Source – Separated Waste
- MRF for commingled MSW

- The sophistication of the MRF will depend on
  - the number and types of the components to be separated
  - the waste diversion goals established for the waste recovery program
  - the specifications to which the separated products must conform

Introduction to the Unit Operation Used for the Separation and Processing of Waste Materials

Size Reduction

- Size reduction is the unit operation in which as collected waste material are mechanically reduced in size

- The objective of size reduction is to obtain a final product that is **reasonably uniform** and **considerably reduced in size in comparison with its original form.**

- Note that size reduction does not necessarily imply volume reduction. In some situations, the total volume of the material after the size reduction may be greater than that of the original volume.

- Size reduction equipment used for the processing of wastes includes
  - Shredders
  - Glass crushers
  - Wood grinders

Shredders :

The shredders are useful machines for the volume reduction of bulky waste such as reams of paper, paper materials, bumpers, tires, refrigerators and the shredding of different materials such as scrap iron, aluminium, copper, plastic as well as municipal solid waste and industrial waste. The three most commonly used shredding devices used are:

1. Hammer Mill
2. Flail Mill
3. Shear Shredder

Introduction to the Unit Operation Used for the Separation and Processing of Waste Materials

- **Glass Crushers**
  - glass crushers are used to crush glass container and other glass products found in MSW
  - glass is often crushed after it has been separated to reduce storage and shipping costs
  - crushed glass can also be separated optically by color. However, because the equipment of the optical sorting of glass is expensive and on-line reliability of such equipment has not been good, optical sorting is not used commonly at present

- **Wood Grinders**
  - Typically, most wood grinders are wood chippers, used to shred large pieces of wood into chips, which can be used as a fuel and finer material which can be composted

Introduction to the Unit Operation Used for the Separation and Processing of Waste Materials

Screening

- Screening is used to separate mixtures of materials of different sizes
- The principal applications of screening devices in the processing of MSW include:
  - removal of oversized materials
  - removal of undersized materials
  - separation of waste into light combustible and heavy combustible
  - recovery of paper, plastic and other light materials from glass and metal
  - Separation of glass, girt and sand from combustible materials
  - Separation of rocks and oversized debris from soil excavated at construction sites
  - removal of oversized materials from combustion ash

Introduction to the Unit Operation Used for the Separation and Processing of Waste Materials

Screening

- The types of screen used most commonly for the separation of solid waste materials are
  - Vibrating screens
  - Rotary screens
  - Disc screens
    - self cleaning
    - adjustability with respect to the spacing of the discs on the drive shafts

Introduction to the Unit Operation Used for the Separation and Processing of Waste Materials

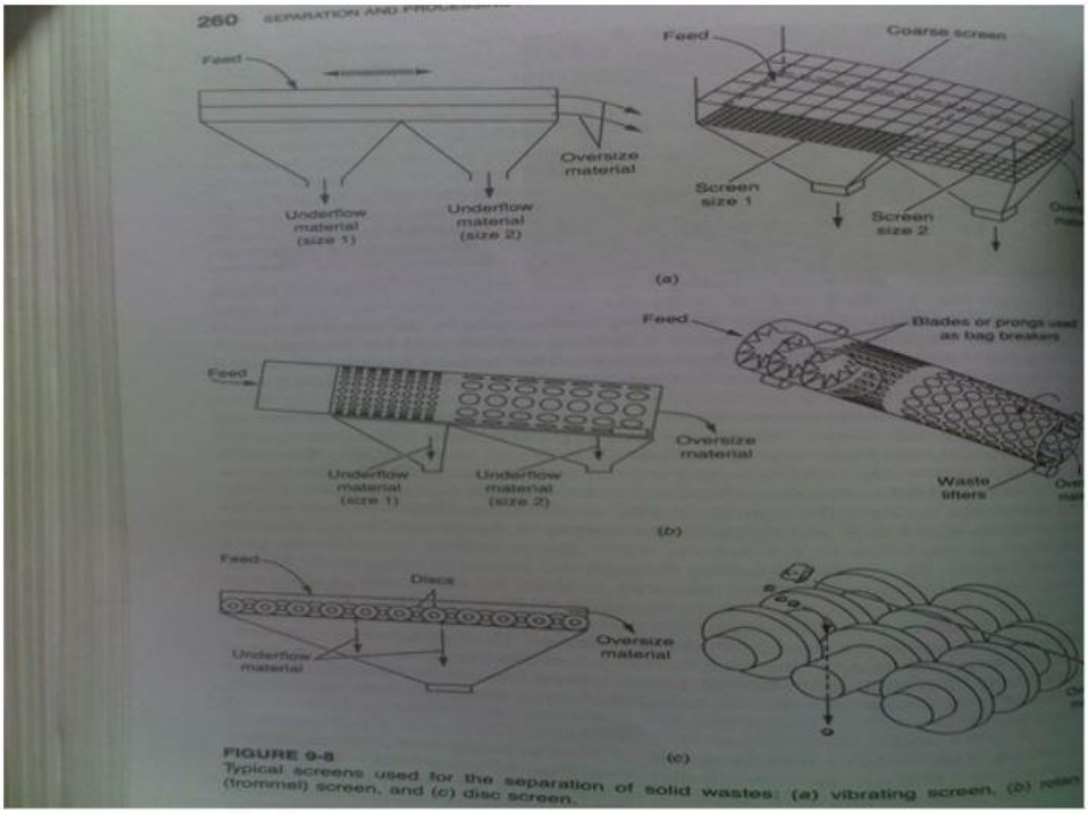


FIGURE 9-8
Typical screens used for the separation of solid wastes: (a) vibrating screen, (b) rotary (trommel) screen, and (c) disc screen.

Source reduction:

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).

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.

WASTE MINIMIZATION

Introduction:

Traditionally, waste is viewed as an unnecessary element arising from the activities of any industry. In reality, waste is a misplaced resource, existing at a wrong place at a wrong time. Waste is also the inefficient use of utilities such as electricity, water, and fuel, which are often considered unavoidable overheads. The costs of these wastes are generally underestimated by managers. It is important to realise that the cost of waste is not only the cost of waste disposal, but also other costs such as:

1. Disposal cost
2. Inefficient energy use cost
3. Purchase cost of wasted raw material
4. Production cost for the waste material
5. Management time spent on waste material
6. Lost revenue for what could have been a product instead of waste
7. Potential liabilities due to waste.

What is waste minimisation?

Waste minimisation can be defined as "systematically reducing waste at source". It means:

• Prevention and/or reduction of waste generated

• Efficient use of raw materials and packaging

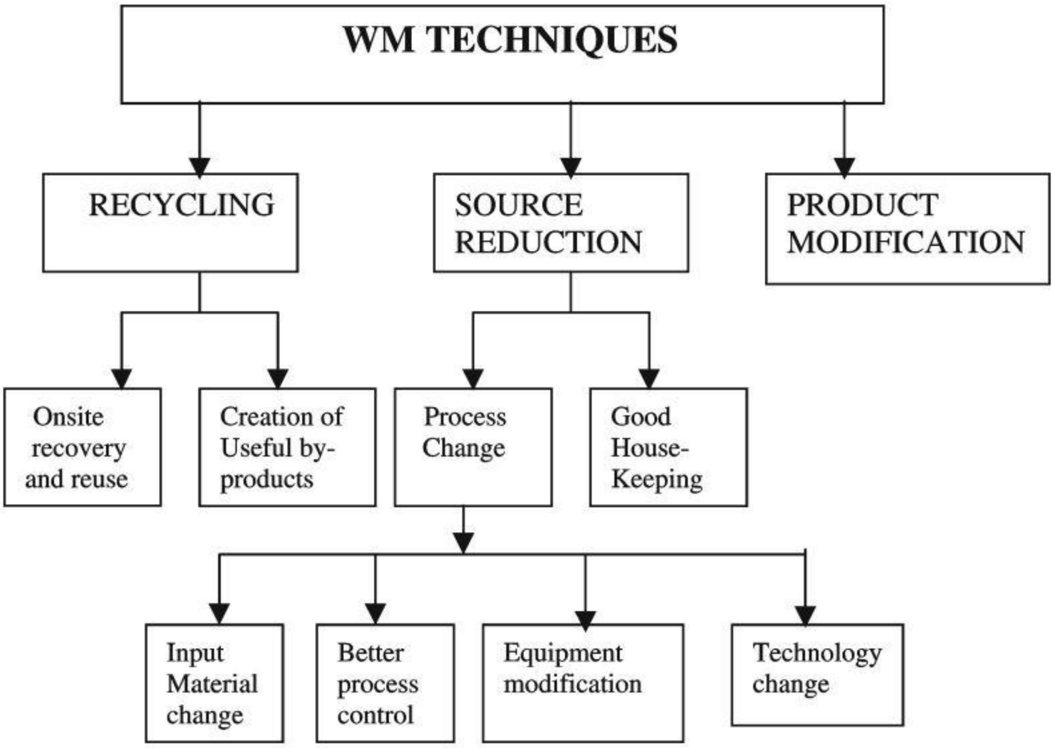
• Efficient use of fuel, electricity and water

• Improving the quality of waste generated to facilitate recycling and/or reduce hazard

• Encouraging re-use, recycling and recovery.

Waste minimisation is also known by other terms such as waste reduction, pollution prevention, source reduction and cleaner technology. It makes use of managerial and/or technical interventions to make industrial operations inherently pollution free It should be also clearly understood that waste minimization, however attractive, is not a panacea for all environmental problems and may have to be supported by conventional treatment/disposal solutions. Waste minimization is best practiced by reducing the generation of waste at the source itself. After exhausting the source reduction opportunities, attempts should be made to recycle the waste within the unit. Finally, modification or reformulation of products so as to manufacture it with least waste generation should be considered.

Classification of Waste Minimization (WM) Techniques:



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:

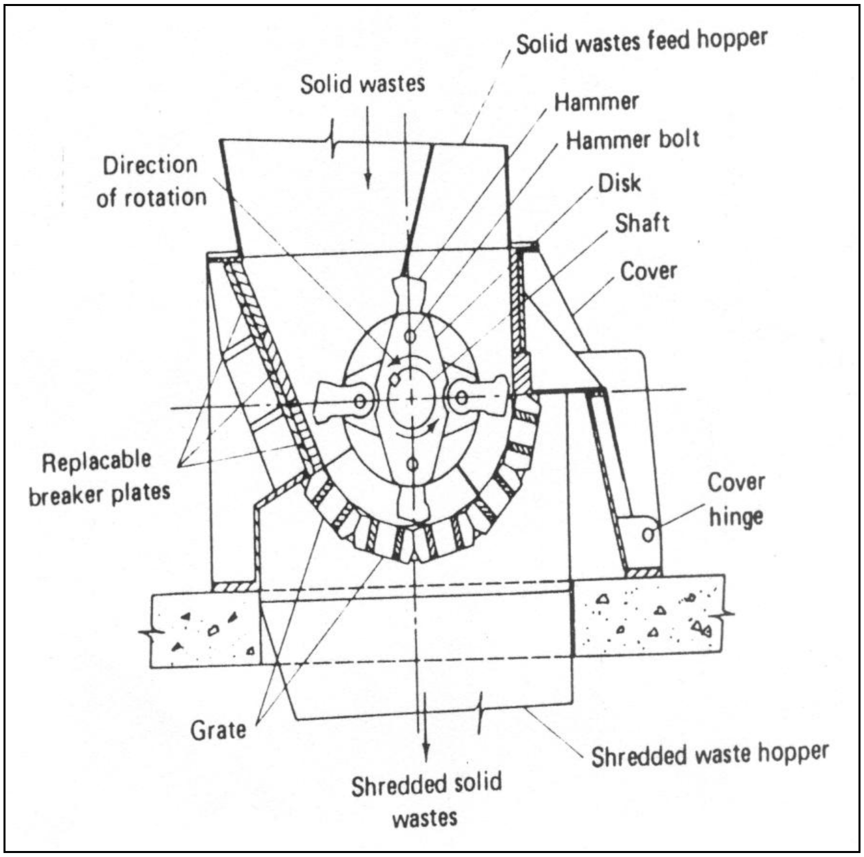
Table 5.2
Size Reduction Equipment

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:

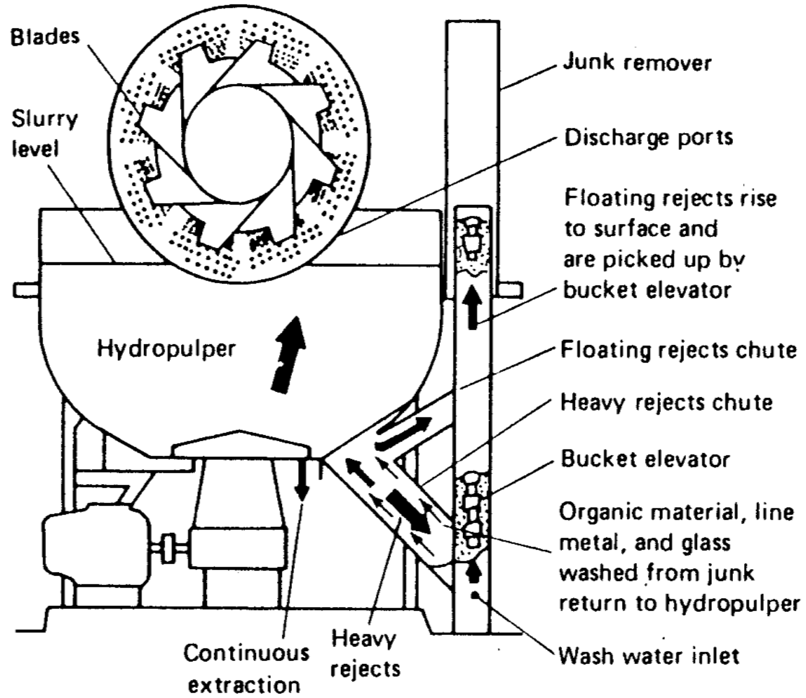
Figure 5.1
Hammer Mill: An Illustration



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.)

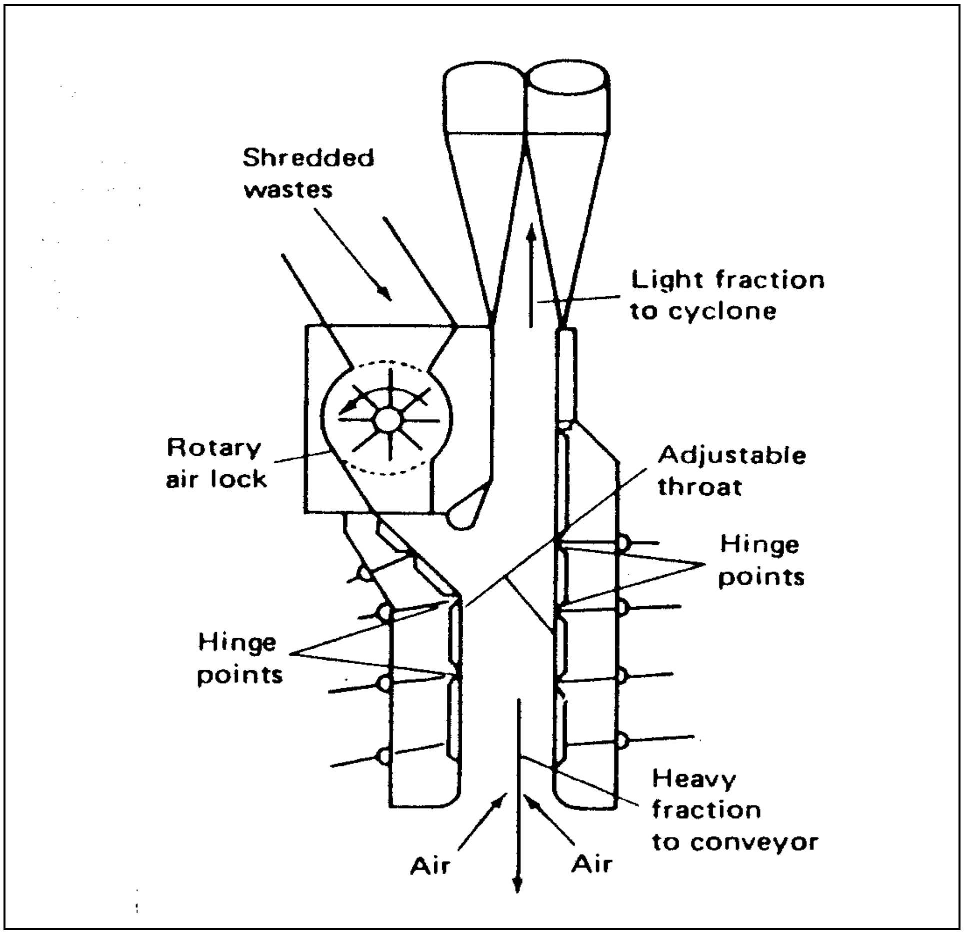
The most effective way of separation is manual sorting in households prior to collection. In many cities (e.g., Bangalore, Chennai, etc., in India), such systems are now routinely used. The municipality generally provides separate, easily identifiable containers into which the householder deposits segregated 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

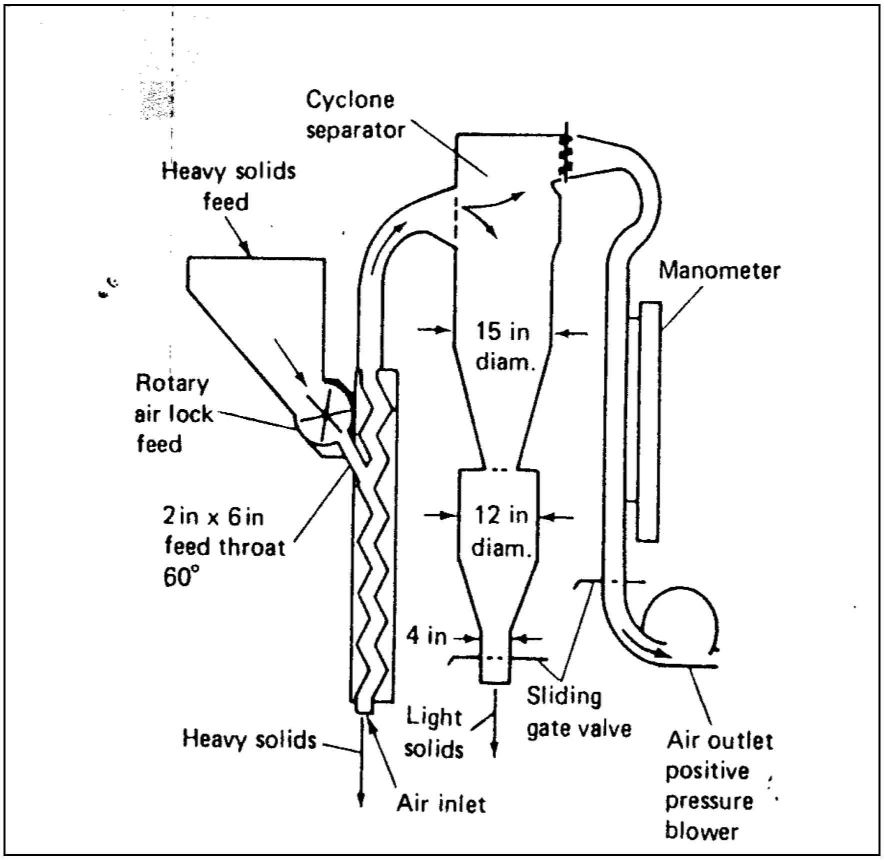


In this type, when the processed solid wastes are dropped into the vertical chute, the lighter material is carried by the airflow to the top while the heavier materials fall to the bottom of the chute. The control of the percentage split between the light and heavy fraction is accomplished by varying 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

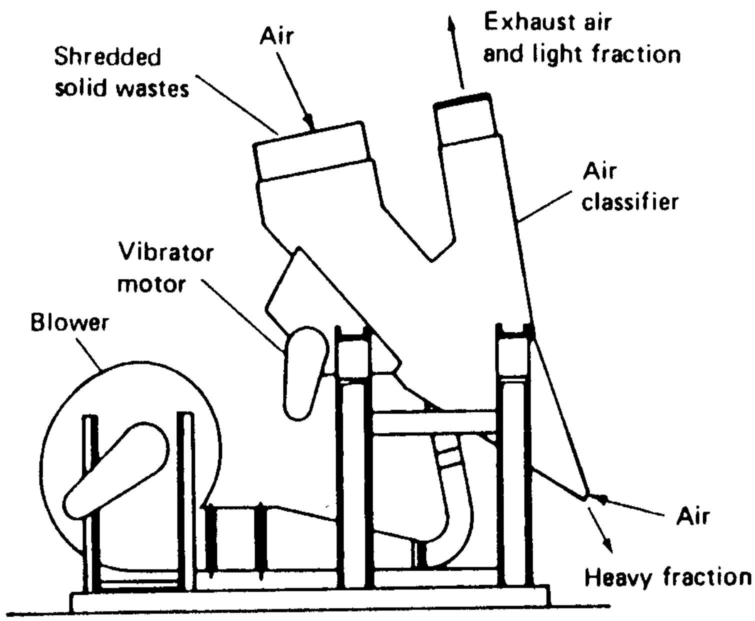
Zigzag Air Classifier



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

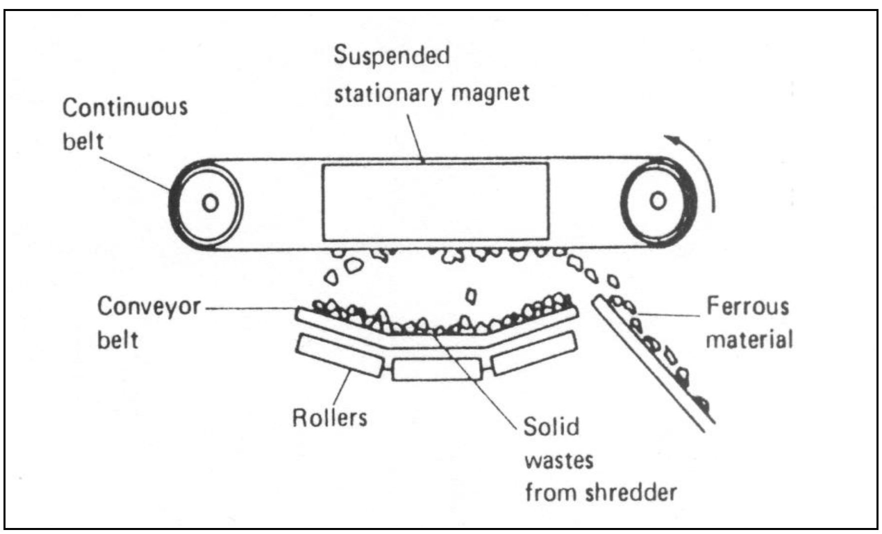
The most common method of recovering ferrous scrap from shredded solid wastes involves the use of magnetic recovery systems. Ferrous materials are usually recovered either after shredding or before air classification. When wastes are mass-fired in incinerators, the magnetic separator is used to remove 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:

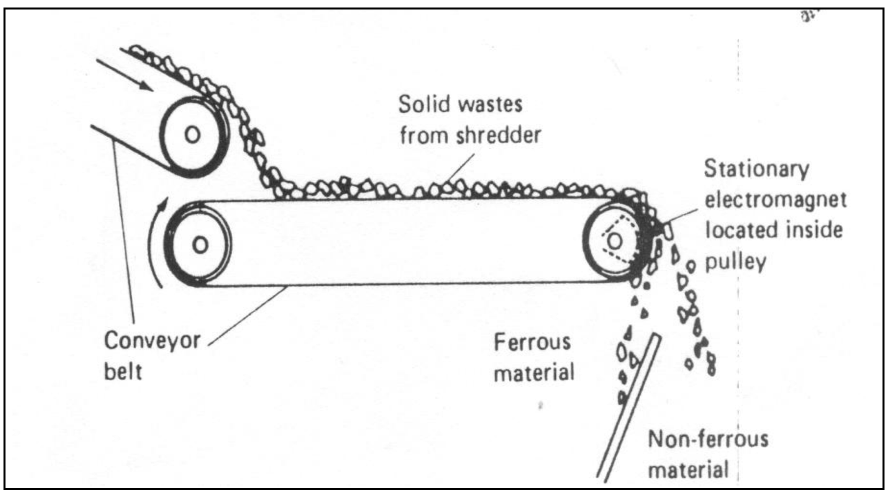
Figure 5.6
Suspended Type Permanent Magnetic Separator



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

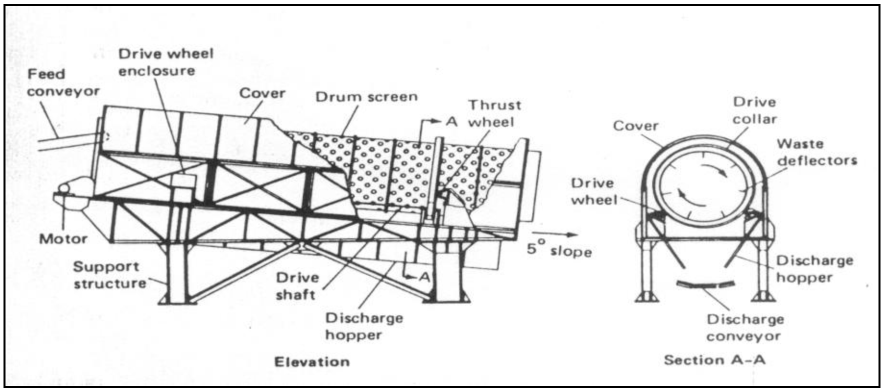
We must consider the following factors in the selection of magnetic separation equipment:

- 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

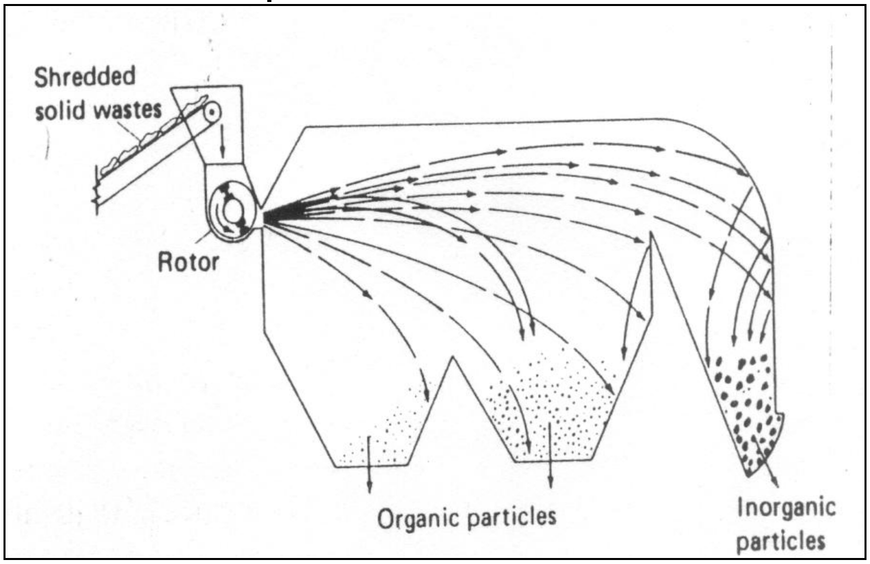
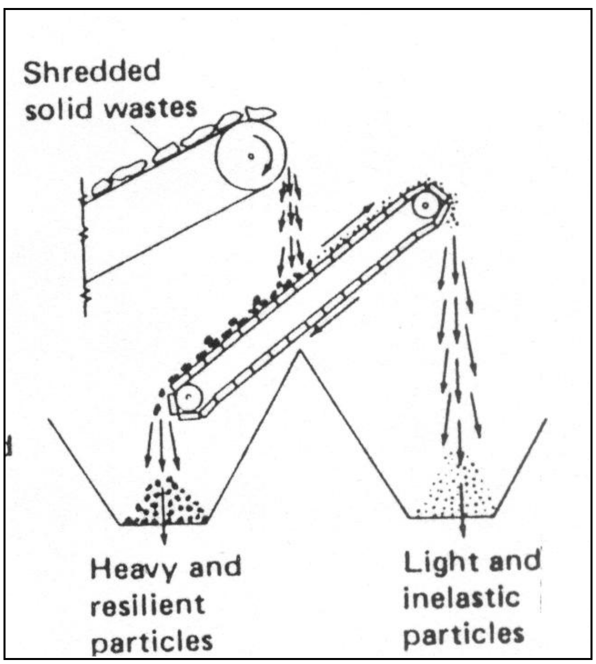


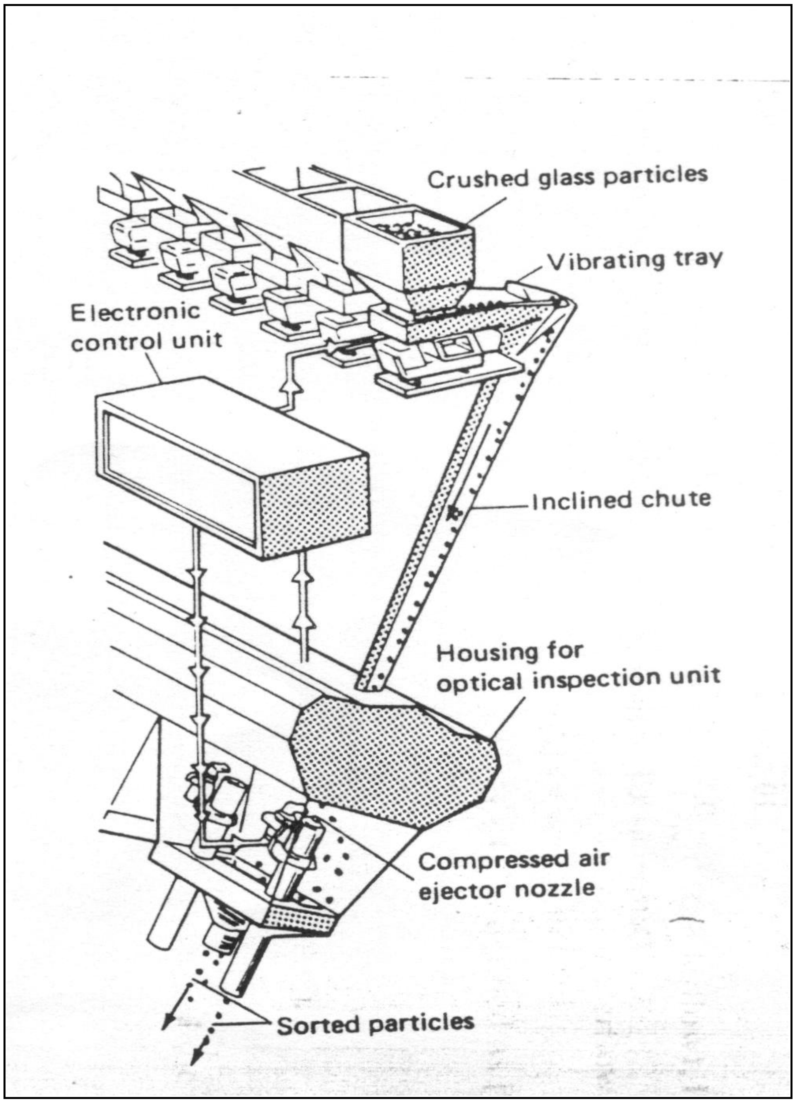
Figure 5.10
Inclined Conveyor Separator



(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:

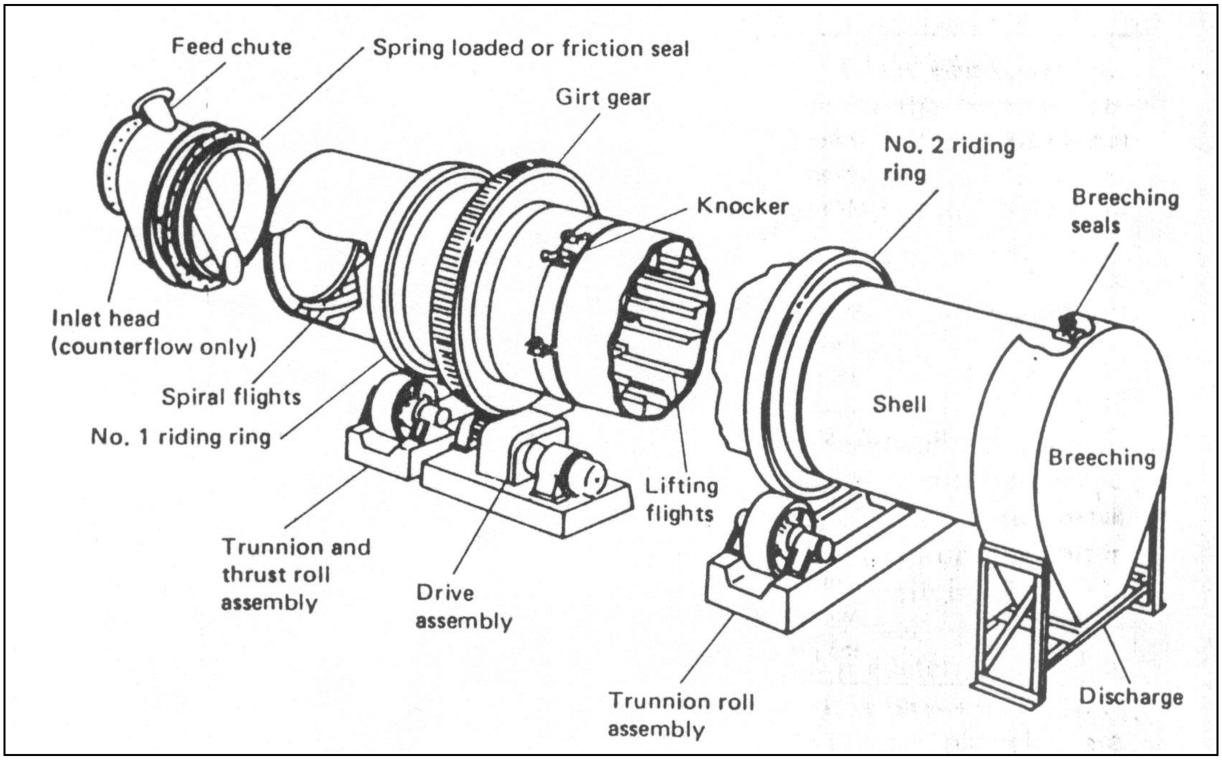
(i) **Convection drying:** In this method, hot air is in direct contact with the wet solid waste stream.

(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:

$$W_f = \frac{\text{Weight of sample}}{\text{Weight of material fed to the screen}}$$

$$= \frac{100 \times 1000 \times 0.08\ kg}{100 \times 1000\ kg}$$

$$= 0.08$$

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 × 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.

Lecture 7

Recovery of Biological Conversion Products: Compost and Biogas

STRUCTURE

OVERVIEW

In Unit 6, we discussed source reduction to reduce the volume and/or toxicity of solid wastes. In that context, we explained recycling of waste and its significance, which is the most widely recognised form of source reduction. We also discussed some of the commonly recycled materials (such as paper, glass, metals, plastics and tyres) and their processing techniques. One of the environmentally sound and beneficial means of recycling organic materials is composting, and this we will discuss in Unit 7.

Composting is the biochemical degradation of the organic fraction of solid waste material having a humus-like final product that could be used primarily for soil conditioning.

We will begin the Unit by discussing the physical, chemical and biological processes in composting along with their advantages. We will then touch upon the stages involved in composting, and subsequently, we will explain such composting technologies as windrow, aerated static pile, in-vessel and anaerobic composting. We will also discuss energy recovery through biogasification and deal with the factors affecting biogasification along with the types of digesters. We will close the Unit by discussing the environmental implications of composting and biogasification for land, water and air.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- discuss the processes and stages involved in composting, and use appropriate composting technologies;
- explain biogasification, identify its advantages and select appropriate digesters for biogasification;
- assess the environmental effects of composting and biogasification.
- Develop and operate a composting programme.

7.1 COMPOSTING

Biodegradation is a natural, ongoing biological process that is a common occurrence in both human-made and natural environments. In the broadest sense, any organic material that can be biologically decomposed is *compostable*. In fact, human beings have used this naturally occurring process for centuries to stabilise and recycle agricultural and human wastes. Today, however, composting is a diverse practice that includes a variety of approaches, depending on the type of organic materials being composted and the desired properties of the final product.

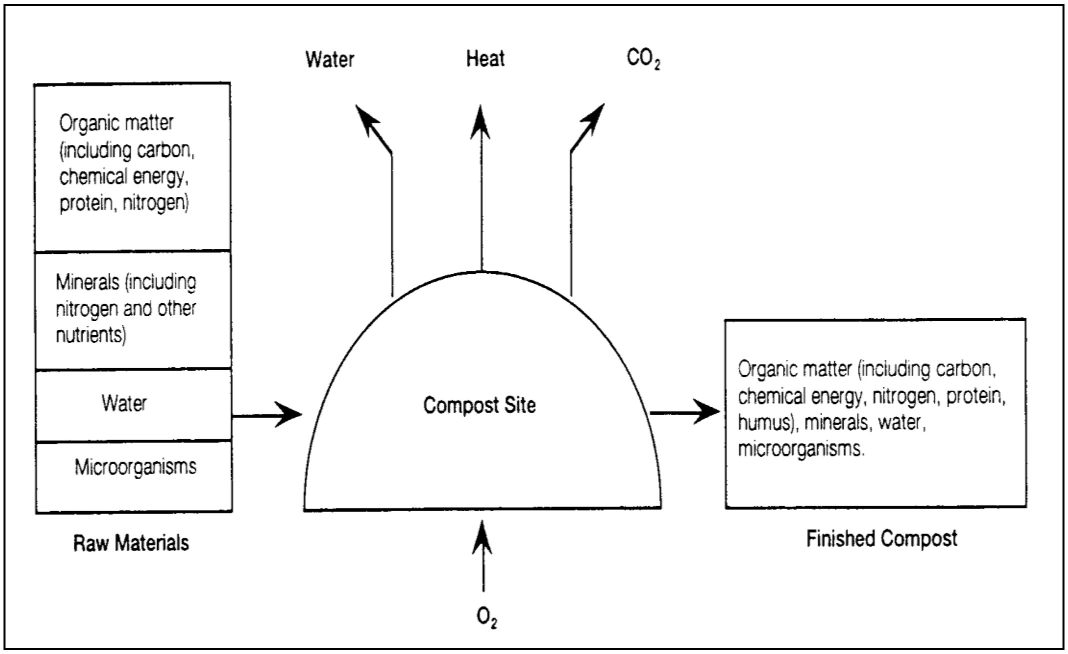
To derive the maximum benefit from the natural, but typically slow decomposition process (e.g., grass clippings left in the lawn or food scraps rotting in dustbins, etc.), it is necessary to control the environmental conditions during the composting process. The overall composting process can be explained as follows:

Organic matter + O_2 + *aerobic bacteria* $\rightarrow$ CO_2 + NH_3 + H_2O + *other end products* + *energy*

Compost is the end product of the composting process. The by-products of this process are carbon dioxide and water. Compost is peaty humus, dark in colour and has a crumbly texture, an earthy odour, and resembles rich topsoil. Composts will not have any resemblance in the physical form to the original waste from which it was derived. High-quality compost is devoid of weed seeds and organisms that may be pathogenic to humans, animals, or plants. Cured compost is also relatively stable and resistant to further decomposition by microorganisms.

A complete composting process is shown in Figure 7.1:

Figure 7.1
The Composting Process



As mentioned earlier, the composting process is an environmentally sound and beneficial means of recycling organic materials and not a means of waste disposal. And, it is important to view compostable materials as usable and not as waste requiring disposal. Before we discuss the composting process in detail, let us talk about the benefits of composting.

7.1.1 Benefits

Composting is one of the important components of solid waste management (SWM). It is a form of source reduction or waste prevention, as the materials are completely diverted from the disposal facilities and require no management or transportation. Community-yard trimming composting programme, source-separated organic composting and mixed municipal solid waste (MSW) composting constitute the various recycling processes. A major portion of municipal solid wastes in India contain up to 70% by weight of organic materials.

In addition, certain industrial by-products – those from food processing, agricultural and paper industries – are mostly composed of organic materials.

Composting, being an organic material, can significantly reduce waste stream volume. Diverting such materials from the waste stream frees up landfill space needed for materials that cannot be composted. Composting owes its current popularity to several factors, including increased landfill tipping fees, shortage of landfill capacity and increasingly restrictive measures imposed by regulatory agencies. In addition, recycling mandates indirectly encourage composting, as they consider it an acceptable strategy for achieving mandatory goals.

Composting may also offer an attractive economic advantage for communities where the costs of using other options are high. However, it is considered a viable option only when the compost can be marketed. In some cases, nevertheless, the benefits of reducing disposal needs through composting may be adequate to justify choosing this option, even if the compost is only used as a landfill cover. Compost, because of its high organic matter content, makes a valuable soil amendment and is used to provide nutrients for plants. When mixed with soil, compost promotes a proper balance between air and water in the resulting mixture, helps reduce soil erosion and serves as a slow-release fertiliser.

LEARNING ACTIVITY 7.1

Explain composting with examples.

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

7.1.2 Processes

Several factors contribute to the success of composting (see Figure 7.1), including physical, chemical, and biological processes (EPA, 1989 and 1995). Understanding these processes, therefore, is necessary for making informed decisions, when developing and operating a composting programme.

Biological processes

Microorganisms such as bacteria, fungi and actinomycetes as well as larger organisms such as insects and earthworms play an active role in decomposing the organic materials. As microorganisms begin to decompose the organic material, they break down organic matter and produce carbon dioxide, water, heat and humus (the relatively stable organic end product). This humus end product is compost.

Microorganisms consume some of the carbon to form new microbial cells, as they increase their population. They have, however, preferences on the type of organic material they consume. When the organic molecules they require are not available, they may become dormant or die. The chain of succession of different types of microbes continues, until there is little decomposable organic material left. At this point, the organic material that is remaining is termed *compost*. It is largely made up of microbial cells, microbial skeletons and by-products of microbial decomposition, and undecomposed particles of organic and inorganic origin. Decomposition may proceed slowly at first because of smaller microbial populations, but as populations grow in the first few hours or days, they rapidly consume the organic materials present in the feedstock. The number and kind of microorganisms are generally not a limiting environmental factor in composting non-toxic agricultural materials, yard trimmings, or municipal solid wastes, all of which usually contain an adequate diversity of microorganisms.

Under optimal conditions, composting proceeds through the following four phases (http://www.weblife.org/humanure/
Chapture3_9.html)

(i) **Mesophilic, or moderate-temperature phase:** Compost bacteria combine carbon with oxygen to produce carbon dioxide and energy. The microorganisms for reproduction and growth use some of the energy and the rest is generated as heat. When a pile of organic refuse begins to undergo the composting process, mesophilic bacteria proliferate, raising the temperature of the composting mass up to 44°C. This is the first stage of the composting process. These mesophilic bacteria can include *E. coli* and other bacteria from the human intestinal tract, but these soon become increasingly inhibited by the temperature, as the thermophilic bacteria take over in the transition range of 44°C – 52°C.

(ii) **Thermophilic, or high-temperature phase:** In the second stage of the process, the thermophilic microorganisms are very active and produce heat. This stage can continue up to about 70°C, although such high temperatures are neither common nor desirable in compost. This heating stage takes place rather quickly and may last only a few days, weeks, or months. It tends to remain localised in the upper portion of a compost pile where the fresh material is being added, whereas in batch compost, the entire composting mass may be thermophilic all at once. After the thermophilic heating period, the manure will appear to have been digested, but the coarser organic material will not be digested. This is when the third stage of composting, i.e., the cooling phase, takes place.

(iii) **Cooling phase:** During this phase, the microorganisms that were replaced by the thermophiles migrate back into the compost and digest the more resistant organic materials. Fungi and macroorganisms such as earthworms and sow bugs that break the coarser elements down into humus also move back in.

(iv) **Maturation or curing phase:** The final stage of the composting process is called curing, ageing, or maturing stage, and is a long and important one. A long curing period (e.g., a year after the thermophilic stage) adds a safety net for pathogen destruction. Many pathogens have a limited period of viability in the soil, and the longer they are subjected to the microbiological competition of the compost pile the more likely they will die a swift death. Immature compost can be harmful to plants. Uncured compost can, for example, produce phytotoxins (i.e., substances toxic to plants), robbing the soil of oxygen and nitrogen and contain high levels of organic acids.

Different communities of microorganisms predominate during the various composting phases. Initial decomposition is carried out by mesophilic microorganisms, which rapidly break down the soluble, readily degradable compounds. The heat they produce causes the compost temperature to rise rapidly. As the temperature rises above 40°C, the mesophilic microorganisms become less competitive and are replaced by thermophilic (heat loving) ones. At temperatures of 55°C and above, many microorganisms that are pathogenic to humans or plants are destroyed. Temperatures above 65°C kill many forms of microbes and limit the rate of decomposition. Compost managers use aeration and mixing to keep the temperature below this point. During the thermophilic phase, high temperatures accelerate the breakdown of proteins, fats, and complex carbohydrates like cellulose and hemicellulose, the major structural molecules in plants. As the supply of these high-energy compounds become exhausted, the compost temperature gradually decreases and mesophilic microorganisms once again take over the final phase of curing or maturation of the remaining organic matter.

The composting process, therefore, should cater to the needs of the microorganisms and promote conditions that will lead to rapid stabilisation of the organic materials. While several microorganisms are beneficial to the composting process and may be present in the final product, some microbes are potential pathogens to animals, plants or humans. These pathogenic organisms must be destroyed in the composting process before the compost is distributed in the market place. Most of this destruction takes place by controlling the temperature of composting operations.

Chemical processes

Several factors determine the chemical environment for composting. These include the presence of an adequate carbon food/energy source, a balanced amount of nutrients, the correct amount of water, adequate oxygen, appropriate pH and the absence of toxic constituents that could inhibit microbial activity (EPA, 1989 and 1995). Let us now describe each of these factors below:

(i) **Carbon/energy source:** For their carbon/energy source, microorganisms in the composting process rely on carbon in the organic material, unlike higher plants that rely on carbon dioxide and sunlight. The carbon contained in natural or human-based organic materials may or may not be biodegradable. The relative ease with which a material is biodegraded depends on the genetic makeup of the microorganisms present and the organic molecules that the organism decomposes.

Since most municipal and agricultural organics and yard trimmings contain an adequate amount of biodegradable forms of carbon, it is not a limiting factor in the composting process. As more easily degradable forms of carbon are decomposed, a small portion of the carbon is converted into microbial cells, and a significant portion is converted to carbon dioxide and lost to the atmosphere. As the composting process progresses, the loss of carbon results in a decrease in weight and volume of the feedstock. The less-easily decomposed forms of carbon will form the matrix for the physical structure of the final product.

(ii) **Nutrients:** Among the plant nutrients (i.e., nitrogen, phosphorus, and potassium), nitrogen is of greatest concern, because it is lacking in some plant materials. The carbon-nitrogen ratio, which is established on the basis of available carbon rather than total carbon, is considered critical in determining the rate of decomposition. Leaves, for example, are a good source for carbon, and fresh grass, manure and slaughterhouse waste are the sources for nitrogen. To aid the decomposition process, the bulk of the organic matter should be carbon with just enough nitrogen. In general, an initial ratio of 30:1 (C: N or Carbon: Nitrogen) is considered ideal. Higher ratios tend to retard the process of decomposition, while ratios below 25:1 may result in odour problems. As the composting process proceeds and carbon is lost to the atmosphere, this ratio decreases.

Finished compost should have ratios of 15 to 20:1. Adding 3 – 4 kg of nitrogen material for every 100 kg of carbon should be satisfactory for efficient and rapid composting. To lower the carbon to nitrogen ratios, nitrogen-rich materials such as yard trimmings, animal manures, or bio-solids are often added. Adding partially decomposed or composted materials (with a lower carbon: nitrogen ratio) as inoculums may also lower the ratio. As the temperature in the compost pile rises and carbon: nitrogen ratio falls below 25:1, the nitrogen in the fertiliser is lost as gas (ammonia) to the atmosphere. The composting process slows, if there is not enough nitrogen, and too much nitrogen may cause the generation of ammonia gas, which can create unpleasant odours.

(iii) **Moisture:** Water is an essential part of all forms of life, and the microorganisms living in a compost pile are no exception. Since most compostable materials have lower than ideal water content, i.e., 50 to 60% of total weight, the composting process may be slower than desired, if water is not added. However, it should not be high enough to create excessive free flow of water and movement caused by gravity. Excessive moisture and flowing water form leachate, which creates potential liquid management problems including water and air pollution (e.g., odour). For example, excess moisture impedes oxygen transfer to the microbial cells, can increase the possibility of developing anaerobic conditions and may lead to rotting and obnoxious odours. Microbial processes contribute moisture to the compost pile during decomposition. Although moisture is added, it is also being lost through evaporation. Since the amount of water evaporated usually exceeds the input of moisture from the decomposition processes, there is generally a net loss of moisture from the compost pile. In such cases, adding moisture may be necessary to keep the composting process performing at its peak.

Controlling the size of piles can minimise evaporation from compost piles, as piles with larger volumes have less evaporating surface/unit volume than smaller piles. The water added must be thoroughly mixed so that the organic fraction in the bulk of the material is uniformly wetted and composted under ideal conditions. Properly wetted compost has the consistency of a wet sponge. Systems that facilitate the uniform addition of water at any point in the composting process are preferable.

(iv) **Oxygen:** Composting is considered an aerobic process. Decomposition can occur under both aerobic (requiring oxygen) and anaerobic (lacking oxygen) conditions. The compost pile should have enough void space to allow free air movement so that oxygen from the atmosphere can enter the pile and the carbon dioxide and other gases emitted can be exhausted to the atmosphere. To maintain aerobic conditions, in which decomposition occurs at a fast rate, the compost pile is mechanically aerated or turned frequently to expose the microbes to the atmosphere and to create more air spaces by fluffing up the pile.

A 10 to 15% oxygen concentration is considered adequate, although a concentration as low as 5% may be sufficient for leaves. While higher concentrations of oxygen will not negatively affect the composting process, circulation of an excessive amount of air can cause problems. For example, excess air removes heat, which cools the pile and also promotes excess evaporation. In other words, excess air slows down the rate of composting. Excess aeration is also an added expense that increases production costs.

(v) **pH:** The pH factor affects the amount of nutrients available for the microorganisms, the solubility of heavy metals and the overall metabolic activity of the microorganisms. A pH between 6 and 8 is considered optimum, and it can be adjusted upward by the addition of lime, or downward with sulphur, although such additions are normally not necessary. The composting process itself produces carbon dioxide, which, when combined with water, produces carbonic acid, which could lower the pH of the compost. As the composting process progresses, the final pH varies, depending on the specific type of feedstock used and operating conditions. Wide swings in pH are unusual, since organic materials are naturally well buffered with respect to pH changes. Note that down swings in pH during composting usually do not occur.

What the foregoing discussion informs us is that the composition of material to be composted largely determines the chemical environment. In addition, several modifications can be made during the composting process to create an ideal chemical environment for the rapid decomposition of organic materials.

Physical processes

The physical environment in the compost process includes factors such as temperature, particle size, mixing and pile size (EPA, 1989 and 1995). Each of these is essential for the composting process to proceed in an efficient manner as described below:

(i) **Particle size:** As composting progresses, there is a natural process of size reduction and the particle size of the material being composted is critical. Because smaller particles usually have more surface area per unit weight, they facilitate more microbial activity on their surfaces, which leads to rapid decomposition. The optimum particle size has enough surface area for rapid microbial activity and also enough void space to allow air to circulate for microbial respiration. The feedstock composition can be manipulated to create the desired mix of particle size and void space. For instance, through particle size reduction, we can increase the desired combination of void space and surface area for garden trimmings or municipal solid wastes. To improve the aesthetic appeal of finished composts, we can carry out particle size reduction, after the composting process is completed.

(ii) **Temperature:** Composting can occur at a range of temperatures, and the optimum temperature range is between 32° and 60° C. Temperatures above 65° C are not ideal for composting as thermal destruction of cell proteins kill the organisms. Similarly, temperatures below the minimum required for a group of organisms affect the metabolic activity (i.e., regulatory machinery) of the cells. Temperatures can be lowered, if required, by either increasing the frequency of mechanical agitation or using airflow throttling, temperature feedback control or blowers controlled with timers. Mixing or mechanical aeration also provides air for the microbes.

When compost is at a temperature greater than 55° C for at least three days, pathogen destruction occurs. It is important that all portions of the compost material are exposed to such temperatures to ensure pathogen destruction throughout the compost. At these temperatures, weed seeds are also destroyed. After the complete pathogen destruction, temperatures may be lowered and maintained at slightly lower levels (51° to 55° C). Attaining and maintaining 55° C for three days is not difficult for in-vessel composting systems (see Subsection 7.1.4). However, to achieve pathogen destruction with windrow composting systems (see Subsection 7.1.4), the 55° C temperature level must be maintained for a minimum of 15 days, during which time the windrows must be turned at least five times. The longer duration and increased turning are necessary to achieve a uniform pathogen destruction in the entire pile. Care should be taken to avoid contact between materials that have achieved these minimum temperatures and materials that have not.

(iii) **Mixing:** Mixing of feedstock, water and inoculants is important and is done by turning or mixing the piles after composting has begun. Mixing and agitation distribute moisture and air evenly, and promote the breakdown of compost clumps. Excessive agitation of open vessels or piles, however, can cool them and retard microbial activity.

LEARNING ACTIVITY 7.2

Explain the significance of various processes in composting.

Note:

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

7.1.3 Stages

There are five basic stages involved in all composting practices, namely preparation, digestion, curing, screening or finishing, and storage or disposal. However, you must note that differences (among various composting processes) may occur in the method of digestion or in the amount of preparation and the finishing required. In choosing the type of process to be used and the amount of sophistication required, a number of criteria must be considered (Pavoni, et al., 1975). In what follows in this Subsection, we will study some of these criteria.

Preparation

This preparation phase of composting involves several steps, and these depend upon the sophistication of the plant and the amount of resource recovery practised. A typical preparation process, however, may include such activities as the sorting of recyclable materials, the removal of non-combustibles, the shredding, pulping, grinding and the adding of water sludge. Most plants utilise receiving equipment, which provides a steady flow of solid waste throughout the operation. Consistency of flow is accomplished by the use of storage hoppers and regulated conveyor system. After the solid wastes leave the receiving area, the bulky items, which could damage the grinders, are removed by hand. The separation of other non-compostable recyclable materials like glass, metal, rag, plastic, rubber and paper may be accomplished before or after comminution (i.e., reduction to small pieces or particles by pounding or abrading) by either hand or mechanical means. Those non-compostables, which are not salvaged, must be ultimately disposed of in a sanitary landfill.

After initial separation, most composting processes require the solid waste material to be reduced in particle size to facilitate handling, digestion and mixing of the product to provide more homogenous compost. The three major methods of comminution, which have been utilised in composting processes, include hammer mill, rasper/shredder and wet pulper, and the various equipment required are scales, receiving bins, conveyors, grinders and screens (see Unit 5 for details on equipment).

Since the refuse characteristics vary from one load to the next, a final step in the preparation phase of composting may be to adjust the moisture and nitrogen content of the solid waste to be composted. The optimum moisture content ranges from 45 to 55% of wet weight, while the optimum carbon to nitrogen ratio should be below 30%. The moisture and nutrient adjustments can be accomplished most efficiently through the addition of raw wastewater sludge. This increases the volume of composted material by 6 to 10%, in addition to accelerating the composting operation and producing a better final product in terms of nutrient contents.

Digestion

Digestion techniques are the most unique feature of the various composting processes and may vary from the backyard composting process to the highly controlled mechanical digester. Composting systems fall into the following two categories:

(i) windrow composting in open windrows;
(ii) mechanical composting in enclosed digestion chambers.

(See Subsection 7.1.4 for a discussion of the composting technologies.)

Curing

Organic materials, remaining after the first (rapid) phase of composting, decompose slowly, despite ideal environmental conditions. The second phase, which is usually carried out in windrows, typically takes from a few weeks to six months, depending on the outdoor temperatures, intensity of management and market specifications for maturity. With some system configurations, a screening step may precede the curing operation. During curing, the compost becomes biologically stable, with microbial activity occurring at a slower rate than that during actual composting. Curing piles may be either force-aerated or passive aerated with occasional turning. As the pile cures, the microorganisms generate less heat and the pile begins to cool.

Note that the cooling of piles does not always mean that the curing is complete. Cooling is merely a sign of reduced microbial activity, which can result from lack of moisture, inadequate oxygen within the pile, nutrient imbalance or the completion of the composting process. Curing may take from a few days to several months to complete. The cured compost is then marketed.

Screening or finishing

Compost is screened or finished to meet the market specifications. Sometimes, this processing is done before the compost is cured. One or two screening steps and additional grindings are used to prepare the compost for markets. During the composting operation, the compostable fraction separated from the non-compostable fraction, through screens, undergoes a significant size reduction. The non-compostable fraction retained on the coarse screen is sent to the landfill, while the compostable materials retained on finer screens may be returned to the beginning of the composting process to allow further composting. The screened compost may contain inert particles such as glass or plastic that may have passed through the screen. The amount of such inert materials depends on feedstock processing before composting and the composting technology used.

To successfully remove the foreign matter and recover the maximum compost by screening, the moisture content should be below 50%. Drying should be allowed only after the compost has sufficiently cured. If screening takes place before curing is complete, moisture addition may be necessary to cure the compost. The screen size used is determined by market specifications of particle size.

Storage or disposal

In the final analysis, regardless of the efficiency of the composting process, the success or failure of the operation depends upon the method of disposal. Even when a good market for compost exists, provision must be still made for storage. Storage is necessary because the use of composting is seasonal, with greatest demand during spring and winter. Therefore, a composting plant must have a 6-month storage area. For a 300 tonne per day plant, this will require about 6 hectares of storage area. Many composting operations combine their curing period with the storage period. The price at which compost can be sold depends on the benefit to be obtained from its use and the customers who are willing to make use of such benefits. Compost may be sold in bulk, finished or unfinished, as well as fortified with chemical fertilisers.

LEARNING ACTIVITY 7.3

Discuss briefly the basic steps involved in the composting practice.

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

During our discussion of the stages in the composting process, we frequently referred to various technologies used in the composting process. We will discuss four general categories of composting technologies in Subsection 7.1.4.

7.1.4 Technologies

The composting technologies – windrow, aerated static pile, in-vessel composting and anaerobic processing (EPA, 1989 and 1995) – vary in the method of air supply, temperature control, mixing/turning of the material, time required for composting, and capital and operating costs. Besides these general categories of composting technologies, there are also some supporting technologies, which include sorting, screening, and curing.

Let us discuss the four general categories of composting technologies, next.

Windrow composting

The windrow system is the least expensive and most common approach. Windrows are defined as regularly turned elongated piles, shaped like a haystack in cross section and up to a hundred meters or more in length. The cross-sectional dimensions vary with feedstock and turning equipment, but most municipal solid waste (MSW) windrows are 1.5 to 3 meters high and 3 to 6 meters wide as shown in Figure 7.2 below:

Figure 7.2
Windrow Composting

Windrows composed of MSW are usually required to be located on an impermeable surface, which greatly improves equipment handling under inclement weather conditions. The optimum size and shape of the windrow depends on particle size, moisture content, pore space and decomposition rate – all of which affect the movement of oxygen towards the centre of the pile.

Process control is normally through pile management, although forced aeration can also be used. Turning the pile re-introduces air into the pile and increases porosity so that efficient passive aeration from atmospheric air continues at all times. The windrow dimensions should allow conservation of the heat generated during the composting process and also allow air to diffuse to the deeper portions of the pile.

As mentioned earlier, windrows must be placed on a firm surface to turn the piles with ease. They may be turned as frequently as once per week, but more frequent turning may be necessary, if high proportions of bio-solids are present in the feedstock. Turning the piles also moves the materials from the pile surface to the core of the windrow, where they can undergo composting. Machines equipped with augers, paddles or tines are used for turning the piles. Some windrow turners can supplement piles with water, if necessary. When piles are turned, heat is released as steam to the atmosphere. If inner portions of the pile have low levels of oxygen, odours may result when this portion of the pile is exposed to the atmosphere. Piles with initial moisture content within the optimum range have a reduced potential for producing leachate. The addition of moisture from precipitation, however, increases this potential.

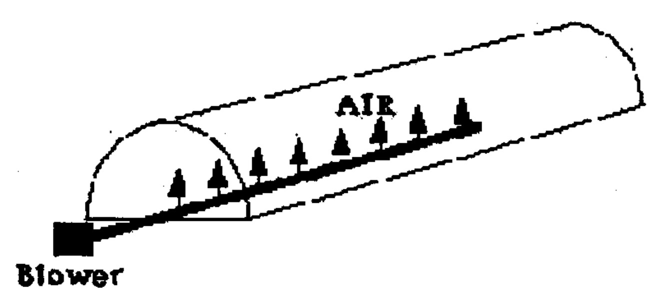
Any leachate or runoff created must be collected and treated or added to a batch of incoming feedstock to increase its moisture content. To avoid problems with leachate or runoff, piles can be placed under a roof, but doing so adds to the initial costs of the operation.

Aerated static pile composting

Aerated static pile composting is a non-proprietary technology that requires the composting mixture (i.e., a mixture of pre-processed materials and liquids) to be placed in piles that are mechanically aerated. The piles are placed over a network of pipes connected to a blower, as in Figure 7.3, which supplies the air for composting:

Figure 7.3

Aerated Static Pile Composting



Air can be supplied under positive or negative pressure. That is to say, the air supply blower either forces air into the pile or draws air out of it. Forcing the air into the pile generates a positive pressure system, while drawing air out of the pile creates a negative pressure. When the composting process is nearly complete, the piles are broken up for the first time since their construction. The compost is then taken through a series of post-processing steps. A timer or a temperature feedback system similar to a home thermostat controls the blowers.

Air circulation in the compost piles provides the needed oxygen for the composting microbes and prevents excessive heat build-up in the pile. Removing excess heat and water vapour cools the pile to maintain optimum temperature for microbial activity. A controlled air supply enables construction of large piles, which decreases the need for land. Odours from the exhaust air could be substantial, but traps or filters can be used to control them. The temperatures in the inner portion of a pile are usually adequate to destroy a significant number of the pathogens and weed seeds present. The surface of piles, however, may not reach the desired temperatures for destruction of pathogens because piles are not turned in the aerated static pile technology. This problem can be overcome by placing a layer of finished compost of 15 to 30 cms thick over the compost pile. The outer layer of finished compost acts as an insulating blanket and helps maintain the desired temperature for destruction of pathogens and weed seeds throughout the entire pile.

Aerated static pile composting systems have been used successfully for MSW, yard trimmings, bio-solids and industrial composting. Aerated static pile composting can also be done under a roof or in the open. Producing compost using this technology usually takes about 6 to 12 weeks. The land requirements for this method are lower than that of windrow composting.

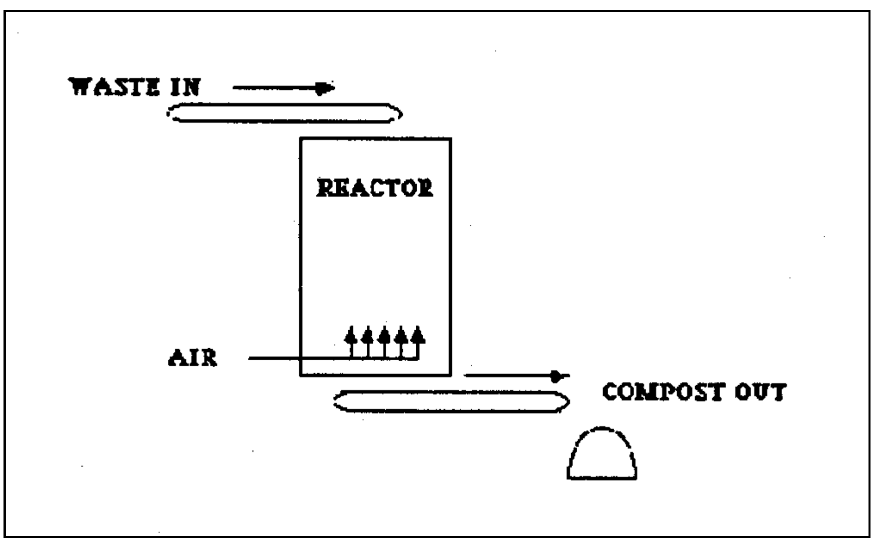
In-vessel composting system

In-vessel composting systems enclose the feedstock in a chamber or vessel that provides adequate mixing, aeration and moisture. Drums, digester bins and tunnels are some of the common in-vessel type systems. In-vessel systems vary in their requirements for pre-processing materials. For example, some require minimal pre-processing, while others require extensive MSW pre-processing. These vessels can be single- or multi-compartment units. In some cases, the vessel rotates, and in others, it is stationary and a mixing/agitating mechanism moves the material around. Most in-vessel systems are continuous-feed systems, although some operate in a batch mode. All in-vessel systems require further composting (curing) after the material has been discharged from the vessel.

A major advantage of in-vessel systems is that all environmental conditions can be carefully controlled to allow rapid composting. The material to be composted is frequently turned and mixed to homogenise the compost and promote rapid oxygen transfer. Retention times range from less than one week to as long as four weeks. These systems, if properly operated, produce minimal odours and little or no leachate. In-vessel systems enable exhaust gases from the vessel to be captured and are subjected to odour control and treatment. Some of the commonly used in-vessel systems are as follows (http://www.adeq.state.ar.us/solwaste/):

- **Vertical composting reactor:** It is generally over 4 meters high as illustrated in Figure 7.4, and can be housed in *silos* or other large structures:

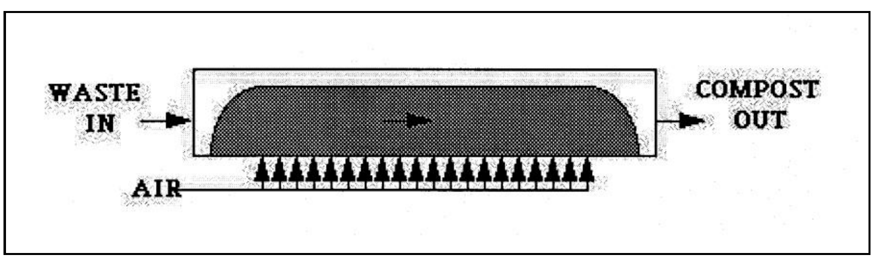
Figure 7.4
Vertical Composting Reactor



Organic material, typically fed into the reactor at the top through a distribution mechanism, moves by gravity to an unloading mechanism at the bottom. Process control is usually by pressure-induced aeration, where the airflow is opposite to the downward materials flow. The height of these reactors makes process control difficult due to the high rates of airflow required per unit of distribution surface area. Neither temperature nor oxygen can be maintained at optimal levels throughout the reactors, leading to zones of non-optimal activity. As with static pile composting, a stable porous structure is important in vertical reactors, which usually lack internal mixing. Tall vertical reactors have been successfully used in the sludge composting industry where uniform feedstock and porous amendments can minimise these difficulties in process control, but are rarely used for heterogeneous materials like MSW.

- **Horizontal composting reactors:** These avoid high temperature, oxygen and moisture gradients of vertical reactors by maintaining a short airflow pathway. They come in a wide range of configurations, including static and agitated, pressure and/or vacuum-induced aeration. Agitated systems generally use the turning process to move the material through the system in a continuous mode, while static systems require a loading and unloading mechanism. Material handling equipment may also shred to a certain degree, exposing new surfaces for decomposition, but excessive shredding may also reduce porosity. Aeration systems are usually set in the floor of the reactor and may use temperature and/or oxygen as control variables. Figure 7.5 illustrates a horizontal composting reactor:

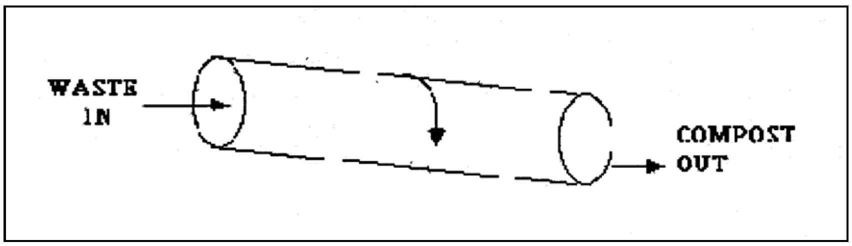
Figure 7.5
Horizontal Composting Reactor



Systems with agitation and bed depths less than two to three meters appear effective in dealing with the heterogeneity of MSW.

- **Rotating drum:** Rotating drum reactors (see Figure 7.6) take the trade-off between reactor cost and compost residence time to an even further extreme than the horizontal or vertical in-vessel systems. These reactors, also known as digesters, retain the material for only a few hours or days:

Figure 7.6
Rotating drum



While the tumbling action can help homogenise and shred materials, the short residence time usually means the processing is more physical than biological. While rotating drums can play an important role in MSW composting, they are normally followed by other biological processing, which may include in-vessel, static pile and/or windrow systems.

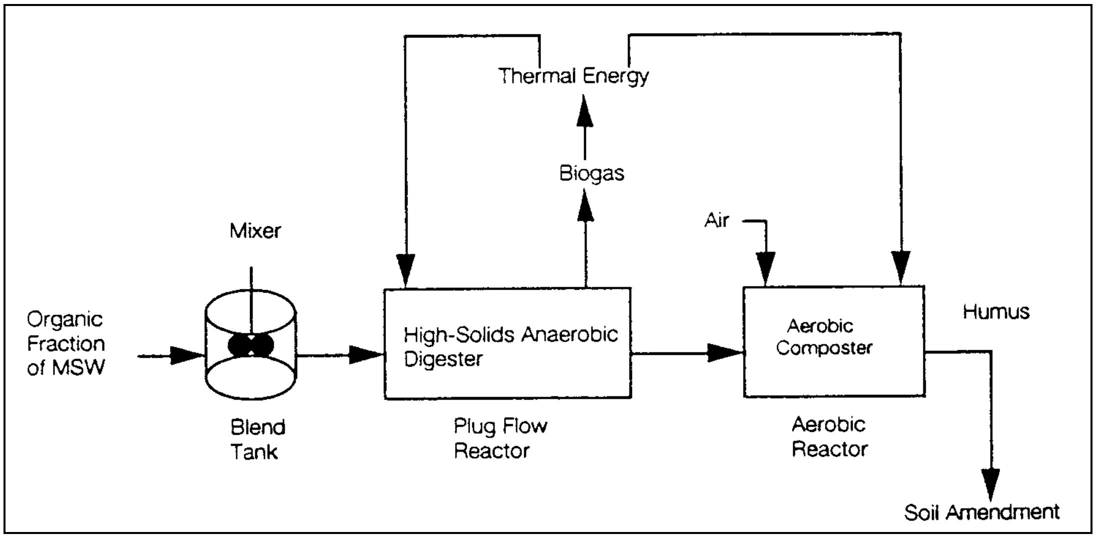
Anaerobic composting

In anaerobic processes, facultative bacteria break down the organic materials in the absence of oxygen and produce methane and carbon dioxide. Anaerobic systems, if configured efficiently, will generate sufficient energy in the form of methane to operate the process and have enough surpluses to either market as gas or convert to electricity. Conventional composting systems, on the other hand, need significant electrical or mechanical energy inputs to aerate or turn the piles. Several approaches are available for anaerobic digestion of feedstock.

Single-stage digesters contain the entire process in one airtight container. In this system, the feedstock is first shredded, and before being placed in the container, water and possibly nutrients are added to the previously shredded material. A single-stage digester may contain agitation equipment, which continuously stirs the liquefied material. The amount of water added and the presence or absence of agitation equipment depend on the particular research demonstration or proprietary process employed.

The two-stage digestion involves circulating a liquid supernatant from a first stage digester, containing the materials, to a second-stage digester. This circulation eliminates the need for agitation equipment and provides the system operator with more opportunity to carefully control the biological process. Figure 7.7 schematically illustrates an anaerobic digester with an aerobic compost curing:

Figure 7.7
Anaerobic Digester with Aerobic Compost Curing



As digestion progresses, a mixture of methane and carbon dioxide is produced. These gases are continuously removed from both first- and second-stage digesters and are either combusted on-site or directed to off-site gas consumers. A portion of the recovered gas may be converted to thermal energy by combustion, which is then used to heat the digester. A stabilised residue remains, when the digestion process is completed. The residue is either removed from the digester with the mechanical equipment or pumped out as a liquid. It is chemically similar to compost, but contains more moisture. Conventional dewatering equipment can reduce the moisture content enough to handle the residue as a solid. The digested residue may require further curing by windrow or static pile composting. We will explain the process of anaerobic digestion and energy production through it in Section 7.2. But, first let us work out Learning Activity 7.4.

LEARNING ACTIVITY 7.4

Explain anaerobic composting process.

Note:

a) Write your answer in the space given below.

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

Let us look at the brief process of backyard composting which can also be done with kitchen and garden waste.

Backyard Composting using dry leaves can be done with a little time and effort even with wastes from the kitchen. Any pile of waste organic matter will rot. To produce good compost for one's own garden following steps are to be followed.

- Choose a compost bin which can be of wood, cement, brick or plastic.
- Place the bin on a leveled, well-drained surface as it does not require base. Earthworm and other micro-organisms enter the bin from the base of bin through the soil and act on compost.

Note: Avoid wood bins that may be chemically treated to keep micro-organisms at bay.

- Carbon nitrogen ratio in the bin should be 25:1.

Note: Carbon-rich organic matters are brown colored waste products that include hay, saw dust, old leaves, cardboard, newspaper and straw. Nitrogen-rich organic matters are green colored products that include green grass, manure, coffee, weeds, and vegetable peels.

- Bottom layer of bin should be around six inches of carbon-rich matter like hay, straw etc. Then top of it be covered with a three-inch layer of nitrogen-rich organic waste like vegetable scraps, manure etc.
- Water each layer in the bin.
- Add these layers alternately till it becomes say four to five feet high.
- Shred all the waste into smaller particles that you dump in the pile which makes decomposition process faster. A sample pile composition could be four parts of fruit and vegetable scraps, two parts of cow dung, one part of shredded paper, and one part dry leaves.
- Protect the pile from rain. To avoid sogginess of the contents cover the pile and see to it that contents are not too dry either.
- Enssure only biodegradable organic component are added.
- Proper decomposition occurs in presence of proper air and water. Don't saturate the pile with excess water. Turn the contents of the compost bin thoroughly using a shovel. This will aerate its contents, prevent it from stinking and hasten decomposition. It is advisable to mix the compost once in one or two weeks. Under proper temperature and moisture conditions, earthworms and other microbes will do the decomposition.
- If these steps are properly followed then would be ready in six months.
- Spread around two inches of compost on the soil until it mixes well. Though the compost is spread on the top layer of the soil, it releases nutrients to the layers lying underneath.

Check your compost quality: Smell sweet like earth, dark in colour and crumbly.

Caution: Do not dump diseased or infected plants and vegetables as they may survive even in the bin. Meat, dairy products, bones and fish attract rodents and other undesired creatures to your bin. Also, dog, cat or pig feces should not be put in the pile. However, chicken or cow dung is beneficial in a compost bin. Refrain from adding chemically-treated plants from your garden.

Monitoring compost: Touch the pile. If it is warm, it means microbes are doing their job. If it is not warmer than temperature outside then feed kitchen waste and manure to the pile. It will increase decomposition. Keep the pile moist and not dry. Air is necessary for organisms working on your pile. Insert some tree branches in the pile so that they can be occasionally shaken to allow air circulation. Air and moisture act as pile's lifelines. If pile is still not decomposing, it means too much carbon and too little nitrogen is present in the pile.

The Indian scenario

The first significant development in composting as a systemised process took place in India in 1925, when a process involving the anaerobic degradation of leaves, refuse, animal manure and sewerage were placed in pits. The materials were placed in layers and the pit wall conserved some of the heat of degradation, resulting in high temperature than when composting was carried out in the open. This process (often referred as Indore process) took approximately six months to produce usable compost. Following this, the Indian Council of Agricultural Research (ICAR) improved the method by laying down alternate layers of waste and sewage and this system (referred to as the Bangalore process) is still being used in India. In India, the high humid degradation that occurs in the land requires a large amount of humus for maintaining soil-fertility, and for that reason, composting is an ideal method for recycling organic wastes.

7.2 BIOGASIFICATION

Biogas is a mixture of gases composed of methane (CH_4) 40 – 70 vol.%, carbon dioxide (CO_2) 30 – 60 vol.%, other gases 1 – 5 vol.% including, hydrogen (H_2) 0 – 1 vol.% and hydrogen sulphide (H_2S) 0 – 3 vol.%. It originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. The natural generation of biogas is an important part of the biogeochemical carbon cycle.

Methanogens (methane producing bacteria) are the last link in a chain of microorganisms, which degrade organic material and return the decomposition products to the environment. In this process, biogas is generated, which is a source of renewable energy. As is the case with any pure gas, the characteristic properties of biogas are pressure and temperature dependency. It is also affected by moisture content. Well-functioning biogas systems can yield a whole range of benefits for their users, the society and the environment in general. Some of the important benefits are as follows:

- production of energy (heat, light, electricity);
- transformation of organic waste into high quality fertiliser;
- improvement of hygienic conditions through reduction of pathogens, worm eggs and flies;
- reduction of workload in firewood collection and cooking;
- environmental advantages through protection of soil, water, air and woody vegetation;
- micro-economical benefits through energy and fertiliser substitution, additional income generation and increasing yields of animal husbandry and agriculture;
- macro-economic benefits through decentralised energy generation, import substitution and environmental protection.

What we can deduce from the list above, is that biogas technology can substantially contribute to energy conservation and development, if the economic viability and social acceptance of biogas technology are favourable.

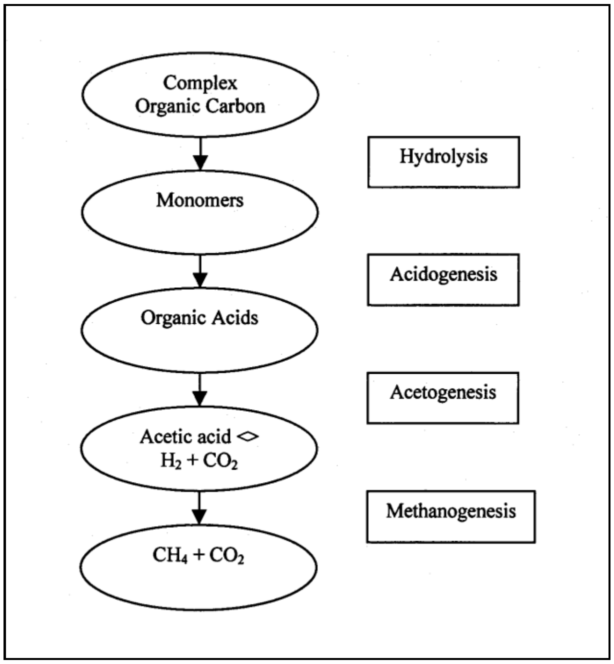
Biogasification or Biomethanation is the process of conversion of organic matter in the waste (liquid or solid) to BioMethane (sometimes referred to as "Biogas" with high energy density) and manure (bio compost) by microbial action in the absence of air, known as "anaerobic processing or digestion."

In Subsections 7.2.1 to 7.2.3, we will discuss the various processes, environmental requirements and digesters associated with it (http://www3.gtz.de/gate/).

7.2.1 Anaerobic processing

Anaerobic processing of organic material is a two-stage process, where large organic polymers are fermented into short-chain volatile fatty acids. These acids are then converted into methane and carbon dioxide. The metabolic stages in biogasification are illustrated in Figure 7.8.

Figure 7.8
Biogasification of Organic Waste: Metabolic Stages



Note that both the organic polymers fermentation process and acid conversion occur at the same time, in a single-phase system. And, the separation of the acid-producing (acidogenic) bacteria from the methane producing (methanogenic) bacteria results in a two-phase system (McDougall, et. al., 2001).

The main feature of anaerobic treatment is the concurrent waste stabilisation and production of methane gas, which is an energy source. The retention time for solid material in an anaerobic process can range from a few days to several weeks, depending upon the chemical characteristics of solid material and the design of the biogasification system (e.g., single stage, two stage, multi- stage, wet or dry, temperature and pH control).

In the absence of oxygen, anaerobic bacteria decompose organic matter as follows:

Organic matter + anaerobic bacteria $\rightarrow CH_4 + CO_2 + H_2S + NH_3$ *+ other end products + energy*

The conditions for biogasification need to be anaerobic, for which a totally enclosed process vessel is required. Although this necessitates a higher level of technology than compared to composting, it allows a greater control over the process itself and the emission of noxious odours. Greater process control, especially of temperature, allows a reduction in treatment time, when compared to composting. Since a biogas plant is usually vertical, it also requires less area than a composting plant.

Biogasification is particularly suitable for wet substrates, such as sludges or food waste, which present difficulties in composting, as the lack of structural material restricts air circulation. The anaerobic process is used sometimes to digest sewage sludge, and this has been extended to fractions of household solid waste.

In contrast to aerobic processes (i.e., composting), biogasification is mildly exothermic. Thus, the heat needs to be supplied to maintain the process temperature, especially for thermophilic processes. The advantage of high temperature is that the reaction will occur at a faster rate, and so a shorter residence time is required in the reactor vessel.

According to the solid content of the material digested and the temperature at which the process operates, the various biogasification processes can be classified as under:

- **Dry anaerobic digestion:** In dry anaerobic digestion, semi-solid wastes are digested to produce biogas in a single stage, either as a batch process or a continuous process. It takes place at a total solid concentration of over 25%, and below this level of solid, the process is described as wet digestion. With regard to temperature, the processes are either described as mesophilic (operating between 30 and 40°C) or thermophilic (operating between 50 and 65°C), and anaerobic microorganisms have optimum growth rates within these temperature ranges. The dry fermentation process means that only little process water has to be added or heated, which favours thermophilic operation. No mixing equipment is necessary, and crust formation is not possible due to the relatively solid nature of the digester contents. This anaerobic process usually takes between 12 and 18 days, followed by several days in post-digestion for residue stabilisation and maturation.

- **Wet anaerobic digestion:** In its simplest form, this process consists of a single stage in a completely mixed mesophilic digester, operating at a total solid content of around 3 – 8%. To produce this level of dilution, a considerable amount of water has to be added and heated, and then removed after the digestion process. This method is routinely used to digest sewage sludge, and animal and household wastes. The single-stage wet process can suffer from several practical problems such as the formation of a hard scum layer in the digester and difficulty in keeping the content completely mixed.

  The major problem with the single-stage process is that the different reactions in the process cannot be separately optimised. The acidogenic microorganisms grow fast and lower the pH of the reaction mixture, whereas the methanogens, which grow slowly, have a pH optimum around 7.0. The development of the two-stage digestion process solves this problem as hydrolysis and acidification occur in the first reactor vessel, kept at a pH of around 6.0 and methanogenesis occurs in the second vessel, operated at a pH of 7.5 – 8.2. The whole process can run with a retention time of 5 to 8 days. (We will discuss single-stage and two-stage digesters in Subsection 7.2.2.)

Maturing or refining

The residues of both wet and dry biogasification processes require extensive maturing under aerobic conditions. However, we can considerably reduce this period through effective aeration. The maturation processes facilitate the release of entrapped methane, elimination of phytotoxins (i.e., substances that are harmful for plant growth, such as volatile organic acids) and reduce the moisture content to an acceptable level. These residues contain a high level of water – even the dry process residue contains around 65% water.

Filtering or pressing can reduce excess water, and further drying can be achieved using waste heat from the gas engine, if the biogas is burnt onsite to produce electricity. The digested residue, initially anaerobic, will also contain many volatile organic acids and reduced organic materials. These need to be matured aerobically to oxidise and stabilise the compounds, in the process similar to the maturation of aerobic compost, prior to sale as compost or disposal as residue. Odour production is measured as the total amount of volatile organics produced per tonne of bio-waste during composting and the final aerobic maturation after anaerobic digestion.

Factors affecting biogasification

As with composting, a number of environmental factors (Phelps, et al., 1995) influence biogasification, some of which are listed below:

- **Temperature:** A temperature range of about 25 – 40°C (mesophilic) is generally optimal. It can be achieved without additional heating, thus being very economical. In some cases, additional energy input is provided to increase temperature to 50° – 60°C (thermophilic range) for greater gas production. Often digesters are constructed below ground to conserve heat.
- **pH and alkalinity:** pH close to neutral, i.e., 7, is optimum. At lower pH values (below 5.5), some bacteria carrying out the process are inhibited. Excess loading and presence of toxic materials will lower pH levels to below 6.5 and can cause difficulties. When pH levels are too low, stopping the loading of the digester and/or use of time is recommended. The presence of alkalinity between 2500 and 5000 mg/L will provide good buffering against excessive pH changes.
- **Nutrient concentration:** An ideal C: N ratio of 25:1 is to be maintained in any digester. It is an important parameter, as anaerobic bacteria need nitrogen compound to grow and multiply. Too much nitrogen, however, can inhibit methanogenic activity. If the C: N ratio is high, then gas production can be enhanced by adding nitrogen, and if the C: N ratio is low, it can be increased by adding carbon, i.e., adding chicken manure, etc., which reduces

the possibility of toxicity. Anaerobic digestion not only breaks down plant materials into biogas, but also releases plant nutrients, such as nitrogen (N), potassium (K) and phosphorous (P), and converts them into a form that can be easily absorbed by plants.

- **Loading**: When any digester is designed, the main variable to be defined is the internal volume. The digester volume is related to, as Fulford (1998) shows, two other parameters, and these are feed rate (Q, measured in m^3/day) and hydraulic loading or retention time (R, measured in days). The feed rate (Q) is given by the mass of total solid (m, kg) fed daily, divided by the proportion of total solid (TS) in the mixed slurry (as summing the density of feed is 1000 kg/m^3).

$$Q = \frac{m}{TS \times 1000} \text{ or } Q = \frac{m}{TS\% \times 10} \ m^3/day$$

The retention time (R) of any digester is given by the volume of the digester pit (V, m^3), divided by the volume of the daily feed (Q, m^3/day).

$$R = \frac{V}{Q} days$$

The loading rate, r (kg. VS/m^3/day) of a digester is defined as the mass of volatile solids added each day per unit volume of digester. This is related to mass feed rate:

$$r = \frac{m \times VS}{Q} \text{ or } r = \frac{m \times VS\%}{Q \times 100} kg\ VS/m^3/day$$

The typical values for the loading rate are between 0.2 and 2.0 kg VS/m^3/day.

- **Effect of toxins:** The main cause of biogas plants receiving flak is the presence of toxic substance. Chlorinated hydrocarbons, such as chloroforms and other organic solvents, are particularly toxic to biogas digestion. If the digester has been badly poisoned, it may be difficult to remove the toxins without removing most of the bacteria. In that case, the digester must be emptied, cleaned with plenty of water and refilled with fresh slurry.

7.2.2 Types of digesters

In the anaerobic digestion process, the organic matter in mixtures of sludges is converted biologically, under anaerobic conditions, to a variety of products including methane (CH_4) and carbon dioxide (CO_2). The process is carried out in an airtight reactor, where wastes in the form of sludges are introduced continuously or intermittently and retained in the reactor for varying periods. The microbiology of anaerobic digestion and the optimum environmental considerations for the microorganisms can be achieved by selecting the proper type of digester.

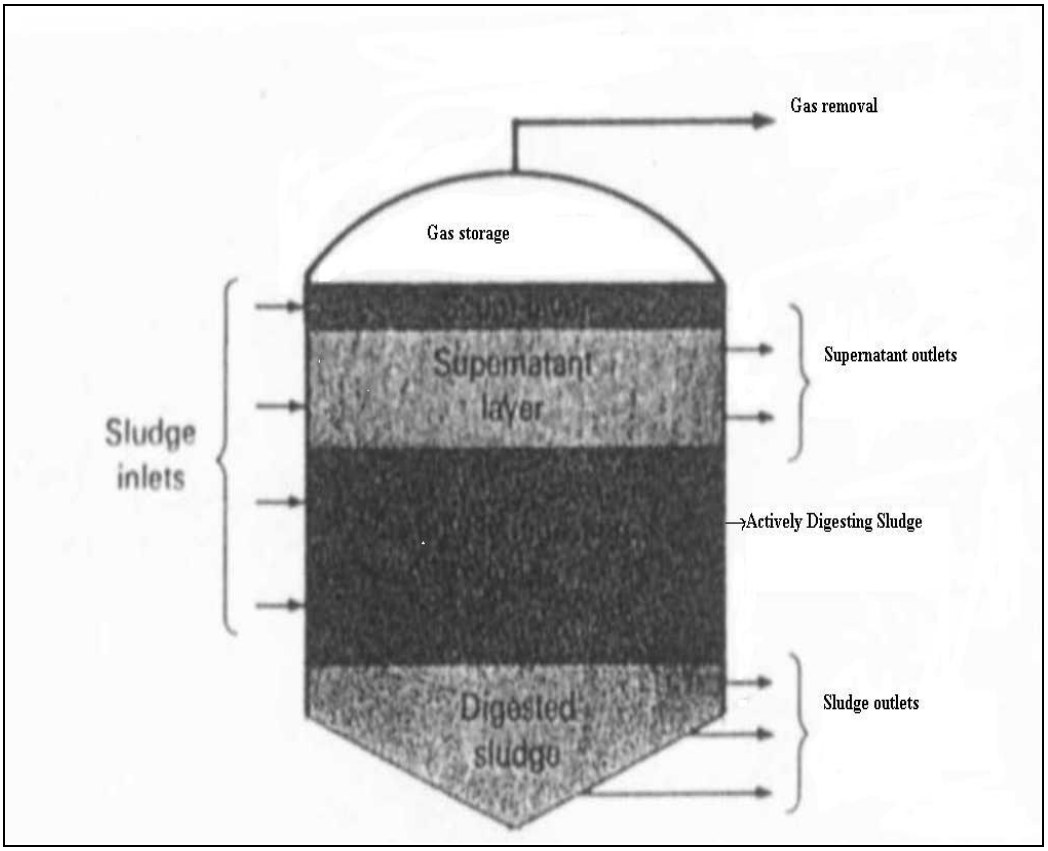
Against this background, we explain below the operation and physical facilities for anaerobic digestion in single-stage digester (standard rate and high rate) and two-stage digester (Tchobanoglous and Burton, 1996), which generally operate in a mesophilic range, i.e., between 30 and 38°C:

(i) **Standard rate single-stage digester:** In a single stage digester, the untreated waste sludge is directly added to the zone, where the sludge is actively digested and the gas is being released. The sludge is heated by means of an external heat exchanger.

As the gas rises to the surface, it lifts sludge particles and other minerals such as grease oil and fats, ultimately giving rise to the formation of scum layer. As a result of digestion, the sludges stratify by forming a supernatant layer above the digesting sludge and become more mineralised, i.e., the percentage of fixed solid increases. Due to stratification and lack of mixing, the standard rate process is used principally for small installations. Detention time for standard rate processes vary from 30 to 60 days.

Figure 7.9 illustrates a single-stage digester:

Figure 7.9
Standard Rate Single-Stage Digester



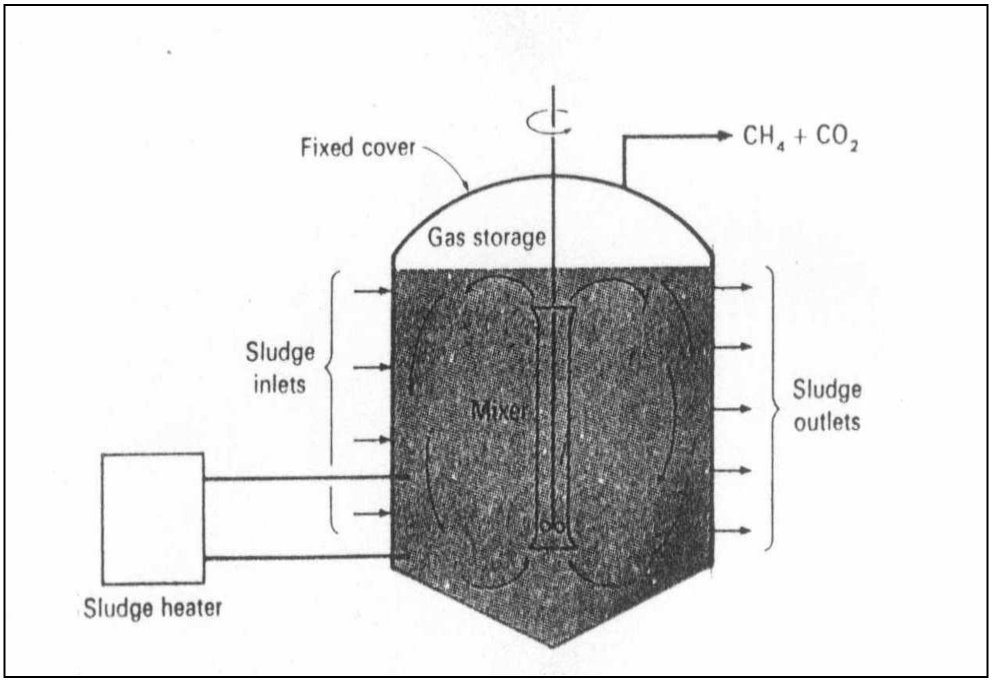
(ii) **High rate single-stage digester:** The single-stage high rate digester differs from the single-stage standard rate digester in that the solid-loading rate is much greater. The sludge is mixed intimately by gas recirculation, mechanical mixing, pumping or draft tube mixer and heated to achieve optimum digestion rates.

With the exception of higher loading rates and improved mixing, there are only a few differences between standard rate and high rate digester. The mixing equipment should have a greater capacity and should reach the bottom of the tank, which should be deeper to aid the mixing process.

Digestion tank may have fixed roof or floating covers along with gasholder facility, which provide extra gas storage capacity. The required detention time for a high rate digestion is typically 15 days or less.

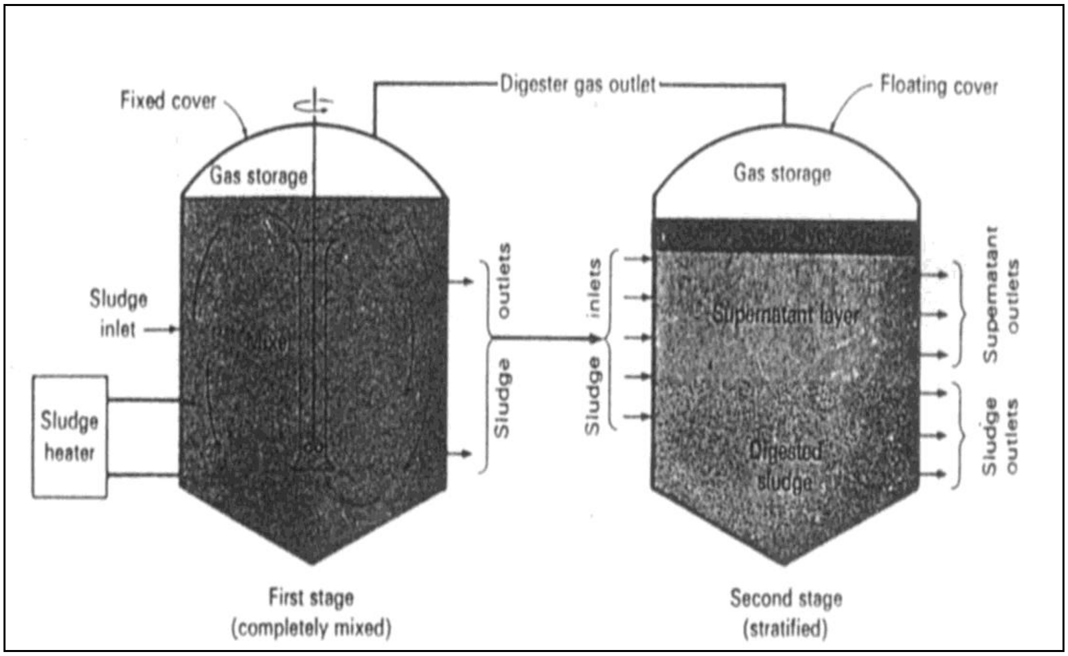
Figure 7.10 illustrates a high rate single-stage digester.

Figure 7.10
High Rate Single-Stage Digester



(iii) **Two-stage digester:** The combination of the two digesters, mentioned above, is known as a two-stage digester. The first stage digester is a high rate complete mix digester used for digestion, mixing and heating of waste sludge, while the primary function of a second stage is to separate the digested solid from the supernatant liquor, and in the process, additional digestion and gas production may occur. The tanks are made identical, in which case either one may be the primary digester. They may have fixed roofs or floating covers along with gasholder facility. Figure 7.11 below illustrates a two-stage digester:

Figure 7.11
Two-Stage Digester



7.2.3 Biogas plants in India

In India, the dissemination of large-scale biogas plants began in the mid-seventies, and the process has become consolidated with the advent of the National Project on Biogas Development (NPBD), initiated by the Ministry of Non-Conventional Energy Sources (http://mnes.nic.in) in 1981, which has been continuing since, with the following objectives:

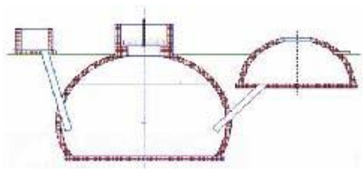
- to provide fuel for cooking purposes and organic manure to rural households through biogas plants;
- to mitigate the drudgery of rural women, reduce pressure on forest and accentuate social benefits;
- to improve sanitation in villages by linking toilets with biogas plants.

Against the estimated potential of 12 million biogas plants, 2.9 million families, and 2700 communities, institutional and night soil-based biogas plants were set up by December 1999 (http://www.teriin.org/renew/tech/biogas/). This is estimated to have helped in saving 3 million tonnes of fuel wood per year and manure containing nitrogen equivalent to 0.7 million tonnes of urea. There are various biogas plant models approved by NPDB for implementation. All these models are based on the basic designs available: floating metal drum type, fixed masonry dome type, and FLEXI, a portable model made of rubberised nylon fabric, which has been approved for promotion in hilly and other terrains. Some of the NPDB approved models are as follows:

- **KVIC floating drum:** Based on *Gramalakshmi III*, the first workable prototype of a biogas plant – created by Jashbhai Patel, a Gandhian worker in the early 1950s – *Khadi* and Village Industries Commission (KVIC) developed this model in the early 1960s. This model has an underground cylindrical digester with inlet and outlet connections at the bottom on either side of a masonry wall. An inverted metal drum, which serves as the gasholder, rests on a wedge type support on top of the digester and, as the gas begins to accumulate, the drum starts rising in height. The weight of the drum applies pressure on the gas to make it pass through the pipeline to the point of use. As the gas flows out, the drum gradually moves down. Due to this smooth two-way motion, the gas remains at constant pressure, which ensures efficient use of gas. Though KVIC has been a very popular model since the beginning, it has two major drawbacks: the plant cost is very high and the metal gasholder has to be painted regularly for protecting it against corrosion, which means high running cost.
- **Deenbandhu:** Action for Food Production (AFPRO), a voluntary organisation based in New Delhi developed this model in 1984. *Deenbandhu* has probably been the most significant development in the entire biogas programme of India, as the cost of the plant was nearly 50% less than that of the KVIC plant, and this brought the biogas technology within the reach of even the poorer sections of the population. The cost reduction was achieved by minimising the surface area through joining the segments of two spheres of different diameters at their bases (Figure 7.12). This structure acts as a digester, and pressure is exerted on the slurry, which is pushed into a displacement chamber. Once the gas is drawn from the outlet, the slurry

again enters the digester. The brick masonry dome, which is fixed, requires skilled workmanship and quality material to ensure no leakage.

Figure 7.12
Deenbandhu



- **Pragati:** The United Socio-Economic Development and Research Programme (UNDARP), a Pune-based NGO (non-government organisation) developed this model, which is a combination of KVIC and *Deenbandhu* designs. In this model, the lower part of the digester is semi-spherical in shape with a conical bottom. However, instead of a fixed dome, it has a floating drum acting as gas storage chamber. The spread of *Pragati* model has been confined mainly to the state of Maharashtra.
- **KVIC plant with ferro-cement digester:** The Structural Engineering Research Centre, Ghaziabad, has developed the ferro-cement digester design in order to overcome the problems encountered in construction of traditional models of biogas plants. In this digester, layers of thin steel wire mesh, distributed throughout, are impregnated with rich mortar. Ferro-cement (i.e., concrete made of welded mesh, sand and cement) as a building material offers several advantages like 10 to 15% reduction in cost over KVIC digesters, usage of locally available material, less labour and little or no maintenance. The only limitation though is ferro-cement is vulnerable to damage due to the impact of pointed loads, which, however, can be easily repaired.
- **KVIC plant with fiber reinforced plastic (FRP) gasholder:** FRP is used in place of metal in the floating drum gasholder. Contact Moulding Process, a technique of moulding without the application of external pressure, is adopted to manufacture the FRP. It employs one of the less expensive types of moulds, resulting in lower cost of the plant. The major advantage of FRP is its resistance to corrosion, which saves the recurring expenditure on painting the drum.

- **FLEXI:** Developed by Swastik Rubber Products Ltd., Pune, this is a portable model in which the digester is made of rubberised nylon fabric. The model is particularly suitable for hilly areas, where high transportation cost of construction materials, such as cement and bricks substantially increases the cost of installing the regular type of biogas plants.

Components of biogas plant

A typical biogas plant has the following components:

- a digester in which the slurry (e.g., dung mixed with water) is fermented;
- an inlet tank used to mix the feed and let it into the digester;
- a gas holder/dome in which the generated gas is collected;
- an outlet tank to remove the spent slurry;
- distribution pipeline(s) to carry the gas into the kitchen;
- a manure pit, where the spent slurry is stored.

LEARNING ACTIVITY 7.5

Do you suggest biogasification approach for MSW? Give reasons.

Note:

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

So far, we studied the importance and benefits of composting and biogasification. In Section 7.3, we will examine the effects they may have on the environment.

7.3 COMPOSTING AND BIOGASIFICATION: ENVIRONMENTAL EFFECTS

The compost produced and slurry from biogas plants is often used as a soil amendment in a variety of applications, after ascertaining the quality of the product. Since the product is used for a variety of purposes, contaminants in the compost could be detrimental to the environment (EPA, 1989 and 1995). This is particularly true when one considers that the environmental pollutants are easily minimised through simple treatment procedures (i.e., waste segregation, proper turning and sufficient composting time). In the main, composting facilities of solid waste with manure, sewage sludge and residue from processing create some significant environmental considerations including the following:

(i) **Water impacts:** Water runoff from garden waste composting facilities could contain large concentration of nutrients (i.e., nitrates and phosphorous), volatile organics and metals that cause algal blooms in the nearby surface water. Retention basins may be used at facilities to limit water runoff. Water impacts are not generally expected to be serious at yard waste composting facilities. Municipal waste composting, sludge composting and co-composting involve a large amount of potential contaminants, and water impact could be greater at these facilities. Leachate from MSW compost facilities can contain high concentration of nutrients (e.g., nitrate and phosphorous), volatile organics and metals. Leachate could affect both surface and ground water.

(ii) **Land impacts:** At garden waste composting facilities, soil may become more acidic, due to the presence of certain leaves and pine needles in the compost pile. Nitrogen depletion may also occur, which can be limited by proper turning. MSW and co-composting facilities carry the potentially harmful impacts of acids, and organic and metal contamination. Again careful pre-processing to divert much of the potentially hazardous materials from the compost facility is an important quality control procedure.

(iii) **Odour pollution:** Odour is one of the most frequent problems at composting facilities. Frequent turning of compost piles has proven to be effective in limiting odour problems. When in-vessel systems are used, odour control devices (e.g., air scrubber, etc.) can minimise the problem.

(iv) **Health impact:** The primary public health concerns associated with composting operation result from:

- drinking contaminated water;
- toxins in the finished product (applied on land);
- pathogens.

Nitrate contamination of drinking water can affect the oxygen-carrying capacity of the blood in infants, e.g., blue baby syndrome (methemoglobinemia) and in elderly, but again under proper composting conditions, this risk can be minimised. Insects and vermin can spread pathogens. Note that because of the high temperature achieved during the normal composting operations, pathogens found in manure, sewage sludge or municipal waste are usually destroyed. There are risks to workers as well (e.g., aggravation of respiratory problem). However, proper training and health monitoring as well as proper apparel and equipment can minimise these risks.

LEARNING ACTIVITY 7.6

List the environmental implications of composting.

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

Indian Scenario of Biogasification

Biogas reverses the supply chain of energy at the regional scale and highly feasible to Indian climate conditions. This helps in converting organic fractions (constitute 60-70% of the total) of solid wastes generated in urban area in an environmentally sound way through anaerobic digestion, while meeting the energy demand in sustainable way.

Similarly, Bio compost produced through aerobic process aid in transferring biodegradable organic materials back to the soil to complete the bio-cycle. This compost can sustain the soil humus resulting in sustained yields thus reducing the demand for chemical fertilizers.

Not only these the other useful products of this process based on feed stock used increases and includes power, steam, dry ice separated from biogas can be used for refrigeration, compressed natural gas, pipeline gas, cooking gas and bio compost. This is beneficial clean development mechanism (CDM) as well.
Its process in brief involves simpler stages to convert waste to biogas and compost. It can also be used as major MSW process in tropical regions of India.

As biomethanogenesis decomposes organic matter with production of useful energy products, anaerobic digestion of organic matter is receiving increased attention. Treatment and recovery of methane in reactors would reduce this source of atmospheric methane. An attractive option for treatment of the organic fraction of these wastes is to separately treat organic fraction by composting and applying the stabilized residues in land as a soil amendment. The residues would reduce water needs and prevent erosion.

SUMMARY

In this Unit, we discussed the benefits and environmental effects of composting, a biochemical degradation of the organic fraction of solid waste material having humus-like final product that could be used primarily for soil conditioning, and biogas. We began the Unit by describing some of the benefits of composting. We then explained the physical, chemical and biological processes in composting. In that context, we said that while the mesophilic, thermophilic, cooling and curing phases are involved in the biological processes, the carbon/energy content, nutrients, oxygen, moisture and pH influence the chemical process and particle size, temperature and mixing affect the physical process. We also discussed the stages (preparation, digestion, curing or finishing and storage and disposal) and the technologies (windrow, aerated static pile, in-vessel and anaerobic) of composting processes. Following this discussion, we described biogasification, another process for recovery of biological conversion, and anaerobic processing, including the factors affecting biogasification, types of digesters and the biogas plants in India. Finally, we closed the Unit by examining the impact of composting and biogasification on the environment.

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Lecture 7

Model Answers to Learning Activities

LEARNING ACTIVITY 7.1

Composting is the transformation of organic material (e.g., plant matter) through decomposition into a soil-like material called compost. Invertebrates (e.g., insects and earthworms) and microorganisms (e.g., bacteria and fungi) help in transforming the material into compost. Composting is a natural form of recycling, which continually occurs in nature. Decomposition occurs naturally wherever plants grow. Creating ideal conditions can encourage this natural decomposition. The microorganisms and invertebrates fundamental to the composting process require oxygen and water to successfully decompose the material. The end products of the process are soil-enriching compost, carbon dioxide, water and heat. For example, composting of organic wastes such as vegetable wastes produce an organic manure, which is good for garden plants.

LEARNING ACTIVITY 7.2

There are 3 processes of composting, viz., biological, chemical and physical. In biological processes, microorganisms such as bacteria, fungi and actinomycetes break down the organic matter present in the waste. As microorganisms begin to decompose the organic material, the carbon in it is converted to by-products like carbon dioxide and water and a humic end product called compost. Inoculum is added in case of a lack of microbial organisms. If all conditions are ideal for a given microbial population to perform at its maximum potential, composting will occur rapidly. The chemical environment is largely determined by the composition of material to be composted. Several factors determine the chemical environment for composting: carbon energy source, the correct amount of water, adequate oxygen, appropriate pH and the absence of toxic constituents that could inhibit microbial activity. A physical environment is essential for the composting process to proceed efficiently. This includes factors such as temperature, particle size, mixing and pile size. Smaller particle size is preferred, as it has more surface per unit weight, and therefore, facilitates more microbial activity, which leads to rapid decomposition. The optimum temperature range is between 32^0C and 60^0C. Temperature above 65^0C is not ideal for composting. Mixing is done to distribute moisture and air evenly and promote the breakdown of compost clumps.

LEARNING ACTIVITY 7.3

There are 5 basic stages involved in all composting practices, namely, preparation, digestion, curing, screening and finishing and storage or disposal. Preparation consists of sorting the recyclables, removal of non-combustibles, shredding, pulping, grinding and the addition of water sludge. There are 5 techniques of digestion, viz., windrow, aerated, static pile, in-vessel composting and anaerobic processing. These techniques vary in the method of air supply, temperature control, mixing/turning of the material, time required for composting and capital and operating costs. The amount of curing necessary at the initial stabilisation depends on the proposed use of the composted material. If the compost is to be pelletised and/or bagged, it must be completely stable before being finished. The amount of finishing required is also dependent on the final marketing of the compost. Regrinding and rescreening is done, so as to make the compost uniform in size. The efficiency of the composting process, i.e., the success or failure of the operation, depends on the method of disposal. Even where a good compost market exists, provisions must still be made for storage because the use of composting is seasonal, with greatest demand during the spring and fall.

LEARNING ACTIVITY 7.4

In the anaerobic composting process, facultative bacteria break down the organic materials in the absence of oxygen and produce methane and carbon dioxide. Single-stage digesters contain the entire process in one airtight container. The feedstock is first shredded, and before being placed in the container, water and possible nutrients are added to the previously shredded material. The single-stage digester may contain agitation equipment, which continuously stirs the liquefied material. As digestion progresses, a mixture of methane and carbon dioxide is produced. These gases are continuously removed from both first- and second-stage digesters and are either combusted on-site or directed to off-site gas consumers. A stabilised residue remains, when the digestion process is completed, which can be removed either by mechanical equipment or pumped out as a liquid. The digested residue may require further curing by windrow or static pile composting.

LEARNING ACTIVITY 7.5

Yes, I suggest biogasification of municipal solid waste. Biogasification is an effective way of recovery of waste in the form of biogas, which is a source of renewable energy. The benefits that can be accrued from biogas are production of energy, transformation of organic waste into high quality manure/fertiliser, improvement of hygienic conditions through reduction of pathogens, worm eggs and flies, environmental advantages through protection of soil, water, air and woody vegetation, etc. Also, biogas is much more convenient to use than traditional fuels such as firewood, dried dung and even kerosene. Biogasification is particularly suitable for wet substrates, such as sludges or food waste, which present difficulties in composting.

LEARNING ACTIVITY 7.6

Although compost has been used for a variety of purposes, contaminants in the compost could be detrimental to the environment and public health as they affect the water (i.e., eutrophication and leaching to surface and groundwater), the land (i.e., acidic soil, nitrogen depletion in soil, impacts of acids, organic and metal contamination), the air (i.e., odour) and health (i.e., drinking of contaminated water, toxins in the finished product and pathogens).

Lecture 8

Incineration and Energy Recovery

STRUCTURE

OVERVIEW

In Unit 7, we discussed the recovery of energy through composting and biogasification. Yet another means of energy recovery is thermal treatment of solid wastes, which is also regarded as pre-treatment of waste prior to final disposal. Thermal treatment includes both the burning of mixed MSW (municipal solid waste) in incinerators and the burning of selected parts of the waste stream as fuel. In this Unit (i.e., Unit 8), we will deal with incineration and energy recovery. We will begin the Unit with an introduction to the process and objectives of incineration. Then, we will take up the issues that are to be considered while planning an incineration facility. We will, subsequently, discuss various incineration technologies such as mass burning system, refuse derived fuel (RDF) system, modular incineration and fluidised bed incineration. Then, we will explain energy generation, i.e., generation of steam and electricity, and cogeneration of steam and electricity. Emission of air pollutants being a major concern of incineration facilities, and we will also discuss the various gaseous pollutants and their control measures (equipment). Finally, we will discuss the environmental impacts of incineration on land, water and aesthetics.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- discuss incineration processes;
- list the objectives of incineration;
- plan an incineration facility;
- explain various incineration technologies;
- identify emissions from incinerators and their control;
- estimate the energy generation potential of wastes;
- assess the environmental impacts of incineration.

8.1 INCINERATION: AN INTRODUCTION

Incineration is a chemical reaction in which carbon, hydrogen and other elements in the waste mix with oxygen in the combustion zone and generates heat. The air requirements for combustion of solid wastes are considerable. For example, approximately 5000 kg of air is required for each tonne of solid wastes burned. Usually, excess air is supplied to the incinerator to ensure complete mixing and combustion and to regulate operating temperature and control emissions. Excess air requirements, however, differ with moisture content of waste, heating values and the type of combustion technology employed. The principal gas products of combustion are carbon dioxide, carbon monoxide, water, oxygen and oxides of nitrogen.

Many incinerators are designed to operate in the combustion zone of 900°C – 1100°C. This temperature is selected to ensure good combustion, complete elimination of odours and protection of the walls of the incinerator. Incinerator systems are designed to maximise waste burn out and heat output, while minimising emissions by balancing the oxygen (air) and the three "Ts", i.e., time, temperature and turbulence. Complete incineration of solid wastes produces virtually an inert residue, which constitutes about 10% of the initial weight and perhaps a larger reduction in volume. The residue is generally landfilled.

The incineration facility along with combustion of waste emits air pollutants (i.e., fine particulate and toxic gases), which are an environmental concern, and, therefore, their control is necessary. Other concerns relating to incineration include the disposal of the liquid wastes from floor drainage, quench water, scrubber effluents and the problem of ash disposal in landfills because of heavy metal residues. By optimising the combustion process, we can control the emission of combustible, carbon-containing pollutants (EPA 1989 and 1995). Oxides of nitrogen and sulphur, and other gaseous pollutants are not considered a problem because of their relatively smaller concentration.

Having introduced you to incineration, we will touch upon the combustion of various elements of waste materials and the objectives of incineration in Subsections 8.1.1 and 8.1.2, respectively.

8.1.1 Combustion of waste material

Table 8.1 shows the major elements that constitute solid wastes and the end products of combustion:

Table 8.1
Major Elements of Solid Wastes

Elements		End Products (Gases)
Carbon (C)	Combustion Process	Carbon dioxide (CO_2)
Hydrogen (H)		Water (H_2O)
Oxygen (O)		
Nitrogen (N)		Nitrogen (N_2)
Sulphur (S)		Sulphur dioxide (SO_2), other gaseous compounds and ash

Table 8.2 gives the information about several components of solid waste mixtures on the basis of proportion:

Table 8.2
Ultimate Analysis of Combustible Component

Percent by Weight (dry basis)						
Component	**Carbon**	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulphur**	**Ash**
Food waste	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	6.0
Plastic	60.0	7.2	22.8	--	--	10.0
Textile	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	--	2.0	--	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Garden trimmings	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.
Dirt, ash, brick, etc.	26.3	3.0	2.0	0.5	0.2	68.0

Source: Tchobanoglous et al (1977, 1993)

In case energy values in KJ/kg or BTU/1b are not available, we can calculate them approximately from the data in Table 8.2 above and the Dulong formula given below:

Energy value (BTU/lb) = 145.4 C + 620 (H – 1/8 O) + 41S

$$\text{Energy value (BTU/lb)} = 145.4\,C + 620\,(H - 1/8\,O) + 41S \qquad \textbf{Equation 8.1}$$

where C, H, O, and S are in percent by weight (dry basis) and can be converted to KJ/kg by: ***BTU/lb x 2.326 = KJ/kg***

8.1.2 Incineration objectives

The purpose of incineration is to combust solid wastes to reduce their volume to about one-tenth, without producing offensive gases and ashes (Phelps, et al., 1995). That is to say, incineration of solid wastes aims at the following (McDougall, et al., 2001):

- **Volume reduction:** Depending on its composition, incineration reduces the volume of solid wastes to be disposed of by an average of 90%. The weight of the solid wastes to be dealt with is reduced by 70 – 75%. This has both environmental and economic advantages since there is less demand for final disposal to landfill, as well as reduced costs and environmental burdens due to transport, if a distant landfill is used.
- **Stabilisation of waste:** Incinerator output (i.e., ash) is considerably more inert than incinerator input (i.e., solid wastes), mainly due to the oxidation of the organic components of the waste stream. This leads to a reduction of landfill management problems (since the organic fraction is responsible for landfill gas production) and the organic compounds present in landfill leachate.
- **Recovery of energy from waste (EFW):** This represents a valorisation method, rather than just a pre-treatment of waste prior to disposal. Energy recovered from burning the wastes is used to generate steam for use in on-site electricity generation or export to local factories or district heating schemes. Combined heat and power plants increase the efficiency of energy recovery by producing electricity as well as utilising the residual heat. Solid waste incineration can replace the use of fossil fuels for energy generation. As a large part of the energy content of solid wastes comes from truly renewable resources (e.g., biomass), there should be a lower overall net carbon dioxide production than that from burning fossil fuels, since carbon dioxide is absorbed in the initial growing phase of the biomass.
- **Sterilisation of waste:** This is of primary importance in the incineration of clinical or biomedical waste. Incineration of solid wastes will also ensure destruction of pathogens prior to final disposal in a landfill.

The prevalence of incineration practice and the actual approach that it takes vary across regions and reflect the relative importance attached to the different objectives discussed. Volume reduction for both environmental and economic reasons and sterilisation of waste has historically been the important objectives of incineration. Due to the growing concern over the production of landfill gas and the organic compounds in leachate from landfill receiving untreated waste, it is likely that the future will see more emphasis on using incineration for stabilising wastes for subsequent landfilling. Landfill gas and leachate arise principally from the organic fraction of solid wastes, which will be effectively converted to gases and mineralised ash by incineration.

LEARNING ACTIVITY 8.1

State how incineration helps in the management 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.

Now, we discuss the planning aspects pertaining to siting and sizing an incineration facility.

8.2 PLANNING AN INCINERATION FACILITY

Incineration of solid wastes is becoming an increasingly important aspect of solid waste management, as communities look for alternatives to rapidly filling landfills (or disappearing landfill sites). Modern incineration facilities are no longer simple garbage burners. Instead, they are designed to produce steam and electricity and can be used as a complement to source reduction, recycling and composting programmes. However, strategic long- term planning is essential for developing a successful incineration facility. In other words, it is important to develop an understanding of a variety of issues in the planning process, including the following:

(i) **Facility ownership and operation:** One of the first planning decisions that local officials make is about the entity that will actually own the facility and oversee its operation. This decision is based largely on the amount of financial risk the community is willing to assume and the time and resources available. Some of the procurement options, in this context, are:

- **Full service approach:** In this system, the community specifies only the process type and the performance required, and hires a (single) firm to design, construct and operate the plant.
- **Merchant plants:** In this type of system, in which waste is accepted on weight basis, a private firm designs, constructs, owns and operates the facility.
- **Turnkey approach:** In this system, a single company designs and builds the plant, according to the communities' specifications, and the community or a different contractor owns and operates the plant.

(ii) **Energy market:** Waste incineration facilities differ from most government services in that they generate a product as well as energy, which are sold for revenue. Steam and electricity are the energy products at incineration facilities, depending on the particular design.

(iii) **Marketing steam:** The primary end uses of steam from waste incineration facilities are industrial and institutional heating and cooling systems. Marketing of steam products involves identifying these industries and institutions within the region. Industrial and institutional steam users include textile, paper and pulp, food processing, leather, chemical producers, hospitals, etc. Planning must include proper backup to guarantee a consistent supply and steam demand variation (often caused by changing seasons).

(iv) **Marketing electricity:** Incineration facilities generating electricity are referred to as *co-generators* as they provide electricity in addition to that generated by the local electric utility. Besides the plant that uses the electricity generated for its operation, customers for electricity include nearby industries and public, and private utilities. It must be equipped to give a consistent supply and must compete with other co-generators in selling energy.

(v) **Facility siting:** Siting the incineration facility is one of the most important tasks to be undertaken and a variety of social and technical hurdles have to be negotiated. The important aspects in this context are the following:

- **Effect on residents:** Residents will be concerned with the health effects associated with incinerator plant, decreased property value and increased traffic (e.g., due to truck movement).
- **Environmental impact:** Incineration has the potential to create a variety of environmental concerns like air, water and noise pollution and ash disposal.

- **Development plans:** It is important to evaluate future land use plans at the possible site.
- **Proximity to waste source:** Transportation cost is one of the most significant expenditures in waste management system.
- **Proximity to energy market:** The energy products will have to be delivered to buyers. The location of power line must be considered.
- **Logistic concerns:** Area zoning and access route must be considered.
- **Residual ash disposal:** Access to a secure landfill is necessary.

(vi) **Facility sizing:** Proper plant sizing results from careful evaluation of a wide variety of criteria such as:

- **Waste supply:** This is the most fundamental sizing factor and measures are usually taken to guarantee a waste supply for the facility. Waste flow control ordinances are often used to ascertain the quantity of waste. When properly planned, waste flow control can benefit both incineration facility and alternative waste management programme, by diverting the relevant portions of the waste stream (e.g., recyclables to the recycling programme and combustibles to incineration facility).
- **Alternative waste management programme:** In addition to waste flow control agreements, future source reduction, recycling and composting programmes are directly related to facility design. When sizing the incineration facility, it is important, therefore, to account for the type and amount of materials that will be diverted from the facility.
- **Waste stream characteristics:** Good combustion depends on the accuracy of waste stream data. Planning of incineration facility requires waste stream assessment to develop an accurate picture of the quantity and composition of the waste stream. From a technical standpoint, the waste stream data will be used to ascertain the heating value of the waste, which helps in plant operation.

- **Planning for facility disruption:** Accounting for downtime is an important facility planning criteria. Most incineration facilities are designed to operate continuously (i.e., 24 hours a day), but both scheduled (e.g., maintenance) and unscheduled (e.g., equipment failure) downtime situations are likely to occur. Storage space must be available for the waste that continues to arrive during downtime. If these capabilities are not built into the system, provisions must be made to send waste to a landfill or an alternative facility.
- **Facility financing:** Depending upon the procurement approach selected, incineration facility will require extensive financing agreements.
- **Time frame:** The time required to plan, develop and construct a facility will vary, but at least 5 to 8 years are required to bring a new facility from the early planning stages to in-service.

Long-term planning within the local government is the key for successful facility design and operation. By understanding all issues and dedicated workforce, waste combustion can become a positive component of waste management system (EPA 1989 and 1995).

LEARNING ACTIVITY 8.2

List the various planning stages of thermal treatment.

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

In order to assess the technical feasibility of the use of an incinerator, we will have to look into the various technologies that are available. In Section 8.3, we will examine some of these technologies.

8.3 INCINERATION TECHNOLOGIES

The four incineration technologies covered in this Section are mass burning system, refuse derived fuel system, modular incineration and fluidised bed incineration. The two most widely used and technically proven incineration technologies are mass-burning incineration and modular incineration. Fluidised-bed incineration has been employed to a lesser extent, although its use has been expanding and experience with this relatively new technology has increased. Refuse-derived fuel production and incineration has also been used, with limited success. Some facilities have been used in conjunction with pyrolysis, gasification and other related processes that convert solid waste to gaseous, liquid, or solid fuel through thermal processing (UNEP 1996). In Subsections 8.3.1 to 8.3.4, we will discuss the four incineration technologies.

8.3.1 Mass-burning system

Mass-burning systems are the predominant form of MSW incineration. A mass-burn facility typically consists of a reciprocating grate combustion system and a refractory-lined, water-walled steam generator. Mass-burn systems generally consist of either two or three incineration units ranging in capacity from 50 to 1,000 tonnes per day. That is to say, the facility capacity ranges from about 100 – 150 to 2,000 – 3,000 tonnes per day. These facilities can accept refuse that has undergone little preprocessing other than the removal of oversized items. Although this versatility makes mass-burn facilities convenient and flexible, local programmes to separate household hazardous wastes (e.g., cleaners and pesticides) and recover certain materials (e.g., iron scrap) are necessary to help ensure environmentally viable incineration and resource conservation.

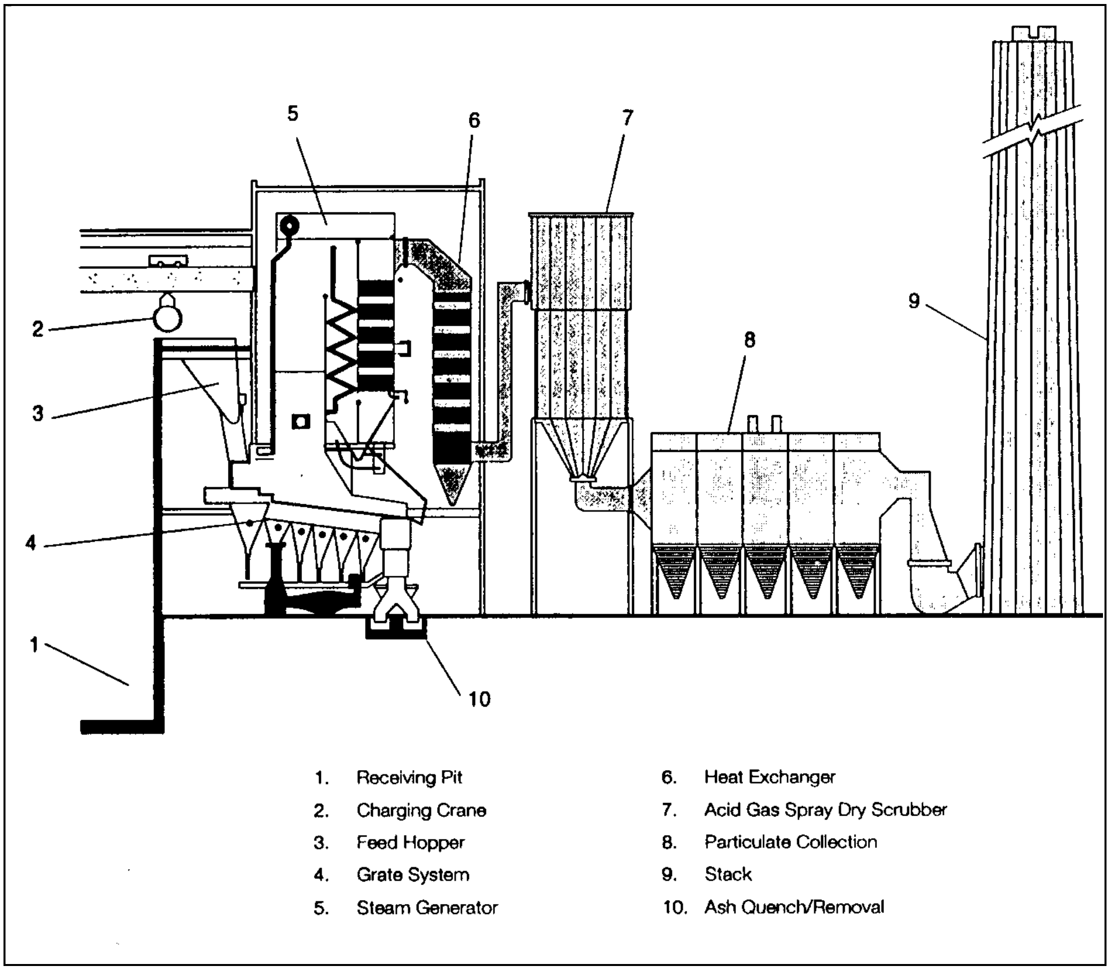
Because of the larger facility size, an incineration unit is specially designed to efficiently combust the waste to recover greater quantities of steam or electricity for revenue. To achieve this greater combustion and heat recovery efficiency, the larger field-erected incinerators are usually in-line furnaces with a grate system. The steam generator generally consists of refractory-coated water wall systems, i.e., walls comprised of tubes through which water circulates to absorb the heat of combustion. In a water wall system, the boiler is an integral part of the system wall, rather than a separate unit as is in a refractory system.

Mass-burning of waste can also be achieved by the use of a rotary kiln. Rotary kilns use a turning cylinder, either refractor or water wall design, to tumble the waste through the system. The kiln is reclined, with waste entering at the high elevation end and ash and non-combustibles leaving at the lower end.

The waste intake area usually includes a tipping floor, pit, crane and sometimes conveyors. Trucks enter the tipping floor and tip their wastes either onto the floor itself, or directly into the pit. When wastes are tipped onto the floor, a front-end loader or a bulldozer is used to push them into the pit or onto a conveyor. From a feed chute, MSW is continuously fed to a grate system, which moves the waste through a combustion chamber using a tumbling motion. A travelling or reciprocating grate may follow rotary combustors to further complete combustion.

At least two combustor units are included to provide a level of redundancy and to allow waste processing at a reduced rate during periods of scheduled and unscheduled maintenance. Mass-burn facilities today generate a higher quality of steam (i.e., pressure and temperature), which is then passed through a turbine generator to produce electricity or through an extraction turbine to generate electricity as well as provide process steam for heating or other purposes. Figure 8.1 below illustrates a typical mass-burn facility:

Figure 8.1
Typical Mass-Burn Facility



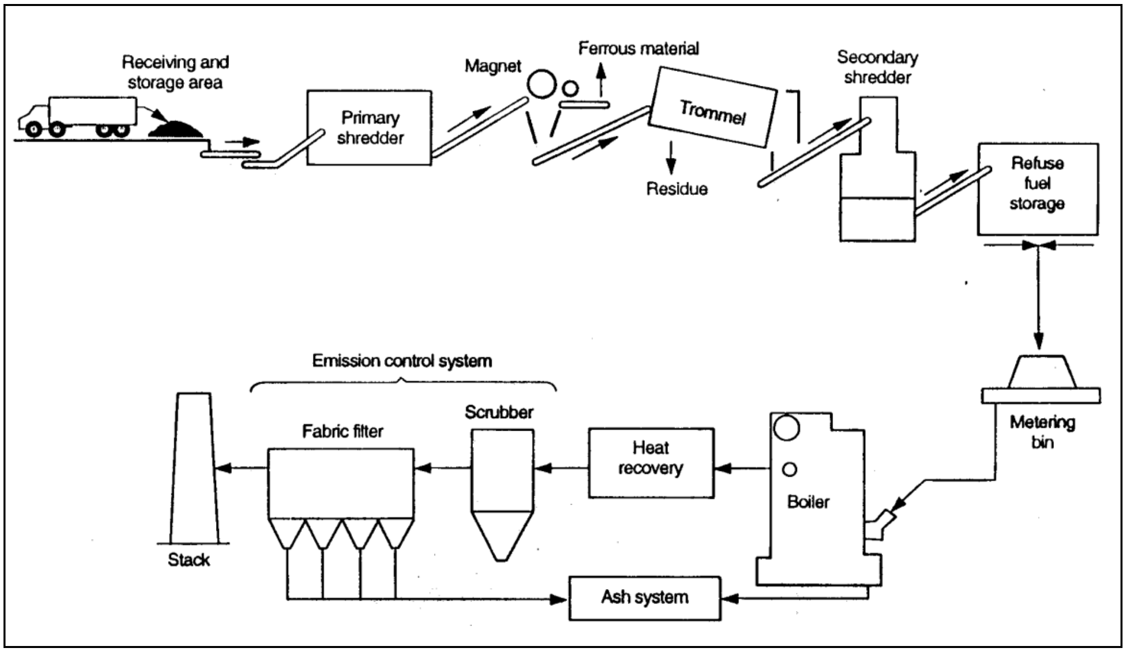
8.3.2 Refuse derived fuel (RDF) system

Refuse-derived fuel (RDF) refers to solid wastes in any form that is used as fuel. The term RDF, however, is commonly used to refer to solid waste that has been mechanically processed to produce a storable, transportable and more homogeneous fuel for combustion. RDF systems have two basic components: RDF production and RDF incineration.

RDF production facilities make RDF in various forms through material separation, size reduction and pelletising. Although RDF processing has the advantage of removing recyclables and contaminants from the combustion stream, on an average, capital costs per tonne for incineration units that use RDF are higher than for other incineration options. RDF production plants like mass-burn incinerators characteristically have an indoor tipping floor. Instead of being pushed onto a pit, the waste in an RDF plant is typically fed onto a conveyor, which is either below grade or hopper fed. In some plants, the loader doing the feeding will separate corrugated and bulky items, like carpets.

Once on the conveyor, the waste travels through a number of processing stages, usually beginning with magnetic separation. The processing steps are tailored to the desired products, and typically include one or more screening stages, using trammel or vibrating screens, shredding or hammer milling of waste with additional screening steps, pelletising or baling of burnable wastes, and, depending on the local recycling markets and the design of the facility, a manual separation line. A typical RDF facility scheme is given in Figure 8.2 below:

Figure 8.2
Typical Simplified RDF Facility



There are two primary types of systems in operation, and these are:

(i) **Shred-and-burn systems:** Shred-and-burn systems are the simplest form of RDF production. The process system typically consists of shredding the MSW to the desired particle size that allows effective feeding to the combustor and magnetic removal of ferrous metal, with the remaining portion delivered to the combustor. There is no attempt to remove other non-combustible materials in the MSW before combustion. This, in essence, is a system with minimal processing and removal of non-combustibles.

(ii) **Simplified process systems:** This is a system that removes a significant portion of the non-combustibles. A simplified process system involves processing the MSW to produce an RDF with a significant portion of the non-combustibles removed before combustion. The MSW process removes more than 85% of the ferrous metals, a significant percentage of the remaining non-combustible (i.e., glass, nonferrous metals, dirt, sand, etc.), and shreds the material to a nominal particle top size of 10 to 15 cm to allow effective firing in the combustion unit.

Depending on the type of combustor to be used, a significant degree of separation can be achieved to produce a high-quality RDF (i.e., low ash), which typically results in the loss of a higher percentage of combustibles when compared to systems that can produce a low-quality fuel (i.e., slightly higher ash content) for firing in a specially designed combustor. These types of systems recover over 95% of the combustibles in the fuel fraction.

8.3.3 Modular incineration

Modular incinerator units are usually prefabricated units with relatively small capacities between 5 and 120 tonnes of solid waste per day. Typical facilities have between 1 and 4 units with a total plant capacity of about 15 to 400 tonnes per day. The majority of modular units produce steam as the sole energy product. Due to their small capacity, modular incinerators are generally used in small communities or for commercial and industrial operations.

Their prefabricated design gives modular facilities the advantage of a shorter construction time. Modular combustion systems are usually factory-assembled units consisting of a refractory-lined furnace and a waste heat boiler. Both units can be pre-assembled and shipped to the construction site, which minimises field installation time and cost. Adding modules or units, installed in parallel can increase facility capacity. For example, a 200 tonne-per-day facility may consist of 4 units, a 50-tonne-per-day consists of 2 units and a 100 tonne-per-day consists of 1 unit. The number of units may depend on the fluctuation of waste generation for the service area and the anticipated maintenance cycle of the units.

Modular incinerators employ a different process from that of mass-burn incinerators, typically involving two combustion chambers, and combustion is typically achieved in two stages.

The first stage may be operated in a condition in which there is less than the theoretical amount of air necessary for complete combustion. The controlled air condition creates volatile gases, which are fed into the secondary chamber, mixed with additional combustion air, and under controlled conditions, completely burned. Combustion temperatures in the secondary chamber are regulated by controlling the air supply, and when necessary, through the use of an auxiliary fuel. The hot combustion gases then pass through a waste heat boiler to produce steam for electrical generation or for heating purposes. The combustion gases and products are processed through air emission control equipment to meet the required emission standards.

In general, modular incineration systems are a suitable alternative and may, for smaller-sized facilities, be more cost-effective than other incinerators. But modular incineration has become less common, partly due to concerns over the consistency and adequacy of air pollution controls.

8.3.4 Fluidised-bed incineration

Fluidised-bed incineration of MSW is typically medium scale, with processing capacity from 50 to 150 tonnes per day. In this system, a bed of limestone or sand that can withstand high temperatures, fed by an air distribution system, replaces the grate. The heating of the bed and an increase in the air velocities cause the bed to bubble, which gives rise to the term *fluidised*. There are two types of fluidised-bed technologies, viz., bubbling bed and circulating bed. The differences are reflected in the relationship between air flow and bed material, and have implications for the type of wastes that can be burned, as well as the heat transfer to the energy recovery system.

Unlike mass-burn incinerators, fluidised-bed incinerators require front-end pre-processing, also called fuel preparation. They are generally associated with source separation because glass and metals do not fare well in these systems and also they can successfully burn wastes of widely varying moisture and heat content, so that the inclusion of paper and wood, which are both recyclable and burnable, is not a crucial factor in their operation (and thus paper can be extracted for higher-value recycling).

Fluidised-bed systems are more consistent in their operation than mass burn and can be controlled more effectively to achieve higher energy conversion efficiency, less residual ash and lower air emissions. In general, however, these systems appear to operate efficiently on smaller scales than mass-burn incinerators, which may make them attractive in some situations. For this reason, fluidised-bed technology may be a sound choice for high-recycling cities in developing countries when they first adopt incineration.

Let's see Indian Scenario in adopting incineration technology

Indian scenario in selection of Incineration technology

The absence of a well planned, scientific system of waste management (including waste segregation at source) coupled with ineffective regulation leading to waste burning. The left-over waste at the dumping yards generally contains high percentage of inerts (>40%) and of puterscible organic matter (30-60%). It is common practice of adding the road sweepings to the dust bins. Papers and plastics are mostly picked up and only such fraction which is in an unrecoverable form remains in the refuse. Paper normally constitutes 3-7% of refuse while the plastic content is normally less than 1%. The calorific value on dry weight basis (High Calorific Value) varies between 800-1100 k-cal/kg. Self sustaining combustion cannot be obtained for such waste and auxiliary fuel will be required. Incineration, therefore, has not been preferred in India so far. The only incineration plant installed in the country is at Timarpur, Delhi way back in the year 1990 has been lying inoperative due to mismatch between the available waste quality and plant design. This made the government of Delhi to assure increased efforts in segregation of household MSW at source collection. However, with the growing problems of waste management in the urban areas and the increasing awareness about the ill effects of the existing waste management practices on the public heath, the urgent need for improving the overall waste management system and adoption of advanced, scientific methods of waste disposal, including incineration, is imperative.

Out of most recent Waste to energy technologies adopted in India such as Biomethanation, landfill with gas recovery, gasification/pyrolysis, incineration and composting; incineration is selected as last option.

LEARNING ACTIVITY 8.3

State the advantages and disadvantages of mass-burning 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.

The benefit of incineration is a substantial reduction in the weight and volume of waste, and generation of revenue from energy production known as "waste-to-energy" (WTE), which can partially offset the cost of incineration. Keeping this in view, we will discuss the various options of energy generation from waste.

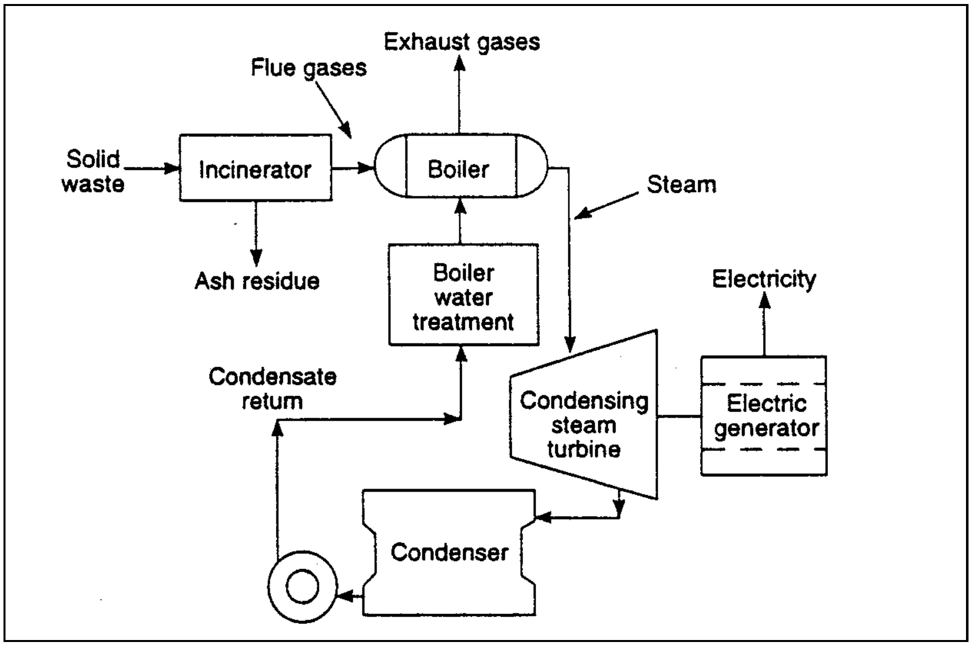
8.4 ENERGY RECOVERY

Most of the MSW incineration currently practice energy recovery in the form of steam, which is used either to drive a turbine to generate electricity or directly for heating or cooling. In the past, it was common to simply burn MSW in incinerators to reduce its volume and weight, but energy recovery has become more prevalent (EPA 1989 and 1995).

In waste-to-energy (WTE) plants, heat from the burning waste is absorbed by water in the wall of the furnace chamber, or in separate boilers. Water when heated to the boiling point changes to steam. At this point, the steam is used either for heating or to turn turbines to generate electricity. The amount of energy recovered from waste is a function of the amount of waste combusted, energy value of the waste stream and the efficiency of the combustion process (UNEP 1996). The three basic types of waste-to-energy incineration are:

(i) **Generation of electricity:** Electricity is the most common form of energy produced and sold from WTE facilities constructed today. By directing the steam produced from a WTE system through a turbine generator, electricity can be produced and sold. A process flow diagram of an electrical generation system is shown in Figure 8.3:

Figure 8.3
Incinerator and Electrical Generation System



Since electric utilities can receive power 24 hours a day and are usually very stable financially, public utilities have attractive markets for power produced from WTE systems. Of the electricity produced in incineration facilities, about one-fifth is used at the facility for general operations, and the remainder is sold to public and private utilities or nearby industries. In many countries, utilities provide a stable market for electricity generated from incinerators. The availability of purchasers and rates for electricity sales will, however, vary by region.

(ii) **Steam generation**: Steam is used widely in a variety of industrial applications. Steam generated in incineration facilities can also be used directly by a customer for manufacturing operations. Steam generated in an incinerator is supplied to a customer through a steam line, and a separate line sometimes returns the condensed steam. It can be used to drive machinery such as compressors, for space heating and generating electricity. Industrial plants, dairies, cheese plants, public utilities, paper mills, tanneries, breweries, public buildings and many other businesses use steam for heating and air conditioning.

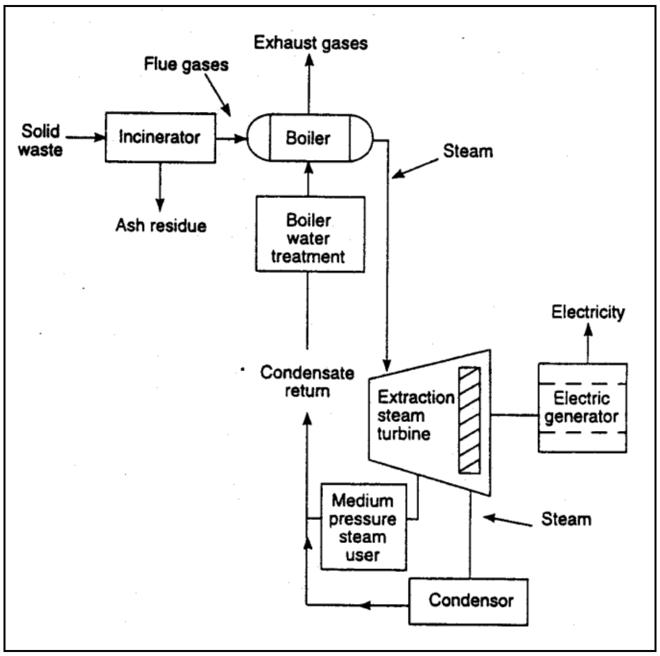
When assessing potential markets for steam, it is important to consider a market's proximity to the WTE facility and the quantity of steam produced. Proximity is important because steam cannot usually be economically transported more than one or two miles. The WTE facility, therefore, should be as close as possible to the potential market. The advantages of transmitting steam over a long distance to an end user must be weighed against energy losses that will occur in transmission. Installation of a pipeline connecting the facility and the customer can also be prohibitively expensive in certain circumstances. High-temperature hot water may be an option for overcoming the transmission limitation for steam.

Anticipated steam quantity and quality are interrelated parameters, and must be carefully projected when assessing steam markets. The prospective user will most likely have an existing process requiring steam at a specific temperature and pressure. The quantity of steam produced from a given amount of waste will decrease, as the steam temperature and pressure increase, but the equipment using the steam will operate more efficiently. To ensure the continuing availability of high quantity and quality steam, supplementary fuels, such as natural gas, may occasionally be used, but this will result in an increase in the operating costs.

(iii) **Co-generation:** Co-generation refers to combined production of steam and electricity and can occur in two ways. If the energy customer requires steam conditions (pressure and temperature) that are less than the incineration plant's design specifications, a turbine-generator is used to produce electricity and thus reduce steam conditions to appropriate levels for the customer. If the steam purchaser cannot accept all the steam produced by the facility, the excess can be converted to electricity. In co-generation, high-pressure steam is used first to generate electricity; the steam leaving the turbine is then used to serve the steam users. Co-generation (Figure 8.4) provides greater overall energy efficiency, even though the output of the major energy product – whether electricity or steam – may be less than that generated by producing one type of energy alone.

Co-generation allows flexibility, so that seasonal variations in steam demand can be offset by increases in electricity production, and can provide the project a financial base by selling electricity, should the steam customer become unavailable.

Figure 8.4
Co-generation System for Producing Electricity and Steam



LEARNING ACTIVITY 8.4

Describe the three types of waste-to-energy incineration.

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

The major risks of incinerators are the potential emission of contaminants into the air through exhaust stack or into the water through ash leachate. Proper planning to minimise these problems as well as public education and involvement that directly address these issues are essential for a successful incineration programme. In Section 8.5, we will summarise the various air pollutants from the incineration process and their control equipment.

8.5 AIR EMISSION AND ITS CONTROL

The operation of the combustion process plays an important role in the formation of pollutants, which are carbon monoxide, NO_x (oxides of nitrogen), hydrocarbons and other volatile organic compounds. It also produces gaseous stream containing dust, acid gases (HCl, SO_x, HF), heavy metals and traces of dioxins (McDougall, et al., 2001). The majority of modern incinerators, however, produce less particulate and gaseous pollutants than their predecessors. Also, emissions from incinerators are controlled by a combination of measures that use both the pollution prevention approach and various control equipment. We will describe the main gaseous pollutants and their control measures, respectively, in Subsections 8.5.1 and 8.5.2.

8.5.1 Gaseous pollutants

The various gaseous pollutants formed due to incineration processes are:

- **Carbon dioxide (CO_2):** This is one of the main products of incineration, and the other main product is water. At low concentrations, CO_2 has no short-term toxic or irritating effect, as it is abundant in the atmosphere and necessary for plant life and is not generally considered a pollutant. Nevertheless, due to the high increase in global concentration of CO_2, it has been recognised as one of the gases responsible for global warming.
- **Carbon monoxide (CO):** An incomplete combustion of carbon due to the lack of oxygen forms CO. This gas is toxic, as it reacts with the haemoglobin in the blood, causing a decrease of available oxygen to the organisms. This lack of oxygen produces headache, nausea, suffocation and eventually death. Carbon monoxide in the flue gas is used to monitor the incomplete combustion of the other emissions, such as un-burnt hydrocarbons and provide information on the performance of the incinerator.
- **Sulphur oxides (SO_x):** The emission of SO_x is a direct result of the oxidation of sulphur present in solid waste, but other conditions such as the type of

incinerator used and its operating conditions also influence its production. Approximately 90% of SO_x emissions are SO_2 and 10% are SO_3. In the atmosphere, most of the SO_2 is transformed into SO_3, which leads to the production of H_2SO_3 (sulphurous acid) and H_2SO_4 (sulphuric acid), increasing the acidity of rain. At high concentrations, it causes eye, nose and throat irritation, and other respiratory problems.

- **Nitrogen oxides (NO_x):** This is predominantly formed during the incineration process. However, they oxidise to NO_2 in the atmosphere. NO_x is formed from two main sources – thermal NO_x and fuel NO_x. In thermal formation, the oxygen and nitrogen react in the air. Fuel NO_x is formed during the reactions between oxygen and nitrogen in the fuel. Nitrogen oxides are important, as they participate in several processes in atmospheric chemistry. They are precursors of the formation of ozone (O_3) and preoxy acetal nitrate (PAN). These photochemical oxidants are responsible for smog formation and cause acid rain.
- **Particulates:** This is formed during the combustion process by several mechanisms. The turbulence in the combustion chambers may carry some ash into the exhaust flow. Other inorganic materials present in the waste volatilise at combustion temperature and later condense downstream to form particles or deposits on ash particles. The main component of fly ash is chemically inert silica; but it may also contain toxic metal and organic substances.
- **Hydrochloric acid (HCl):** Hydrochloric acid results from the high concentration of chlorine containing materials (e.g., some type of plastics like polyvinyl chloride) in solid waste. Chlorine easily dissolves in water to form HCl. Its presence in the gaseous state may increase the acidity of local rain and ground water, which can damage exposed and unprotected metal surfaces, erode buildings and may affect the mobilisation of heavy metals in soil.
- **Hydrogen fluoride (HF):** Hydrogen fluoride is more toxic and corrosive than HCl, although its presence in the emissions from solid waste incinerators occurs in much smaller quantities. It is formed due to the presence of trace amounts of fluorine in the waste.

- **Heavy metals (Hg, Cd, Pb, Zn, Cu, Ni, Cr):** Solid waste contains heavy metals and metallic compounds in the combustible and incombustible fractions. During the incineration process, metals may vaporise directly or form oxides or chlorides at high temperatures in the combustion zone. They condensate over other particles and leave the incineration process in the flue gas.

- **Dioxins and furans:** Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) have been detected in the emissions from solid waste incinerators. Dioxins can be formed in all combustion processes, where organic carbon, oxygen and chlorine are present, although the processes by which they are formed during incineration are not completely understood. The concern over dioxins and furans has increased after a number of animal studies have shown that for some species, they are carcinogenic and highly toxic, even at very low levels of exposure.

8.5.2 Gas-cleaning equipment

The technologies employed to carry out the necessary flue gas cleaning include:

- **Electrostatic precipitators (ESP):** These are used for particle control. ESP use electric forces to move the particle flowing out of the gas stream on to the collector electrodes. The particles get a negative charge, when they pass through an ionised field. The electric field that forces the charged particles to the walls comes from discharged electrodes maintained at high voltage in the centre of the flow lane.

  When particles are collected, they must be carefully removed to avoid their entry into the gaseous stream. This is achieved by knocking them loose from the plates and by intermittent and continuous washing with water. The removal efficiency is more than 99% with a low-pressure drop. Particle size and other physical characteristics such as gas stream temperature, flue gas volume, moisture content, gas stream composition, particle composition and particle surface characteristics affect the performance of the equipment. ESP’s come in one- or two-stage designs and can have different configurations: plate wire, flat plate and tubular. These configurations can be wet or dry, depending on the method of dust collection.

- **Fabric filters:** In fabric filtration, the gas flows through a number of filter bags placed in parallel, leaving the dust captured by the fabric. Extended operation of fabric filters requires periodic cleaning of the cloth surface. After a new fabric goes through a number of cycles of use and cleaning, it forms a residual cake of dust that becomes the filter medium, which is responsible for highly efficient filtering of small particles that characterises fabric filter. They are widely accepted for controlling particulate matter.

  The type of cloth fabric limits the temperature of operation of fabric cloth: cotton is least resistant (82°C) while fabric glass is the most resistant (277°C). This temperature requirement makes the use of a cooling system necessary for the gas, before it enters the equipment, but it is also necessary that the temperature of the exhaust gas stream be maintained above the dew point because liquid particles block the pores in the fabric very quickly. The major difference between different configurations of fabric filters is the cleaning method used during operating cycles such as shaker, reverse-air and pulse-jet cleaning.

- **Scrubbers:** Scrubbers are used to control particulate matter and acid gases leaving the incinerator. Particulates and gases are removed from the gas stream mainly by absorption and adsorption. The particles are moved to the vicinity of the water droplets and collide with each other. The particles adhere to the liquid media and precipitate to the bottom of the unit containing the dust particle from the gas phase. In addition to removing entrapped particulate matter, scrubbers can also remove gases by absorption and adsorption. Any other type of particulate control equipment does not possess this capability of scrubber. It can remove particles of size 0.1 to 200μm efficiently. The various types of scrubbers can be dry, semi-dry or wet, depending on the composition of flue gas.

✍ LEARNING ACTIVITY 8.5

Describe the mechanism of an electrostatic precipitator.

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

8.6 ENVIRONMENTAL CONCERNS

In Section 8.5, we discussed the various air pollutants emitted from an incinerator and their control equipment. Apart from air pollution, there are other environmental concerns related to incineration (EPA 1989 and 1995), some of which are touched upon below:

(i) **Water pollution:** Wastewater in an incineration facility can be generated in various forms. These include tipping floor runoff system wash water, ash quench water and water from pollution control systems. These systems also deal with normal problems experienced by all large industrial facilities, including sanitary wastewater disposal and surface-water runoff. For most incineration facilities, wastewater can be recycled in a closed-loop system. In these systems, water from floor drains, ash dewatering, water softener recharge and other process wastewaters are collected and stored in a tank. This water is then reused for ash quenching. Sanitary waste can be directed to municipal sewer systems. In some cases, regulatory authorities may require that the waste stream be pretreated before discharge.

(ii) **Land-retained pollution:** Land-retained pollutants originate as stack or fugitive emissions and are of increasing concern. Bioaccumulation and subsequent ingestion from food is an indirect exposure route resulting from land-retained emissions. To provide better understanding of land-retained pollutants, it may be desirable to establish baseline contaminant levels, before incineration plant construction so that changes in those levels throughout the plant's operating lifetime can be monitored.

(iii) **Residue disposal:** An incineration facility and its emission control system produce a variety of residues such as large quantity of bottom ash, the unburned and not burnable materials discharged from the incinerator at the end of the burning cycle. The process also produces a lighter emission known as fly ash. Fly ash consists of products in particulate form, which are either produced as a result of the chemical decomposition of burnable materials or are unburned (or partially burned) materials drawn upward by thermal air currents in the incinerator and trapped in pollution control equipment. Fly ash normally comprises only a small proportion (ranging from 10 to 20%) of the total volume of residue from an incineration facility.

Constituents in both ash and scrubber product vary, depending on the materials burned. In systems burning a homogeneous fuel such as coal, oil, or tires, the level of pollutants in residues may be relatively constant. Systems burning a more heterogeneous mixture, such as municipal, industrial, or medical waste may experience wide swings in the chemical composition of residues. The major constituents of concern in municipal waste combustion ash are heavy metals, particularly lead, cadmium and mercury. These metals may impact human health and the environment; if improperly handled, stored, transported, disposed of or reused.

(iv) **Noise pollution:** Truck traffic is the greatest source of noise pollution in incineration plant operations. Well-maintained and responsibly operated trucks will help minimise this problem. Local ordinances may restrict truck traffic to certain hours of the day and to specified truck corridors. Under these conditions, noise pollution should not be a significant factor. Noise resulting from plant operations and air handling fans associated with the combustion and emission control equipment is also a potential problem. Noise levels are likely to be the highest in front of waste tipping floor doors, ash floor doors and the vicinity of air emission stacks. Walls, fences, trees and landscaped earthen barriers can serve to reduce noise levels.

(v) **Aesthetic impact:** Proper site landscaping and building design can help minimise or prevent negative aesthetic impacts. Such impacts are much less problematic, if the facility is sited in an industrial area and not adjacent to residential or commercial districts. Local zoning ordinances may ensure that aesthetic impacts are minimised. Keeping the process building at negative pressure can prevent undesirable odours from escaping outside of the building. Also, the use of internal air for combustion in the plant processes will destroy most odours.

Some facilities may emit visible steam or vapour plumes. Smoke, resulting from improper conditions in the combustion chamber, can also be problematic. Air emission stacks and cooling towers may also be unappealing anomalies in the skyline of some areas. If external lights on buildings prove objectionable to neighbours, perimeter lights (on stands) directed towards the plant may be preferable.

SUMMARY

Incineration is a chemical reaction by which carbon, hydrogen and other elements in the waste combine with oxygen in the combustible air and generate heat. In this Unit, we discussed the objectives and issues to be considered while planning an incineration facility. In this context, we discussed the various incineration processes and technologies such as mass burn, refuse derive fuel, modular incineration and fluidised bed incineration. We said that the product of incineration is heat that can be utilised for the generation of steam and electricity. We also pointed out that the amount of energy recovered is a function of the amount of waste combusted, the energy value of the waste stream and the efficiency of the combustion process. We then discussed energy generation. We also discussed the various air pollutants emitted out of an incineration facility and the equipment used for their control namely scrubbers, electrostatic precipitators and fabric filters. Finally, we listed some of the impacts of incinerators on the environment.

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Lecture 8

Model Answers to Learning Activities

LEARNING ACTIVITY 8.1

Incineration is the controlled high temperature oxidation of primarily organic compounds to produce carbon dioxide and water. Incineration of municipal solid waste can reduce its volume by more than 90%. Incineration reduces financial expenses that are necessary to carry waste to the landfill site. Due to the reduction in haul distance, fuel cost is reduced. The thermal conversion products that can be derived from solid wastes include heat and gas, which can be recovered. The low level heat remaining in the gases after heat recovery can also be used to preheat the combustion air, boiler makeup water or solid waste fuel. Overall incineration increases the efficiency of solid waste management by producing less waste and reducing cost.

LEARNING ACTIVITY 8.2

Strategic long-term planning is necessary for developing a successful incineration facility. This includes:

- Facility ownership and operation (full service approach, merchant plants and turnkey approach).
- Energy market (marketing steam and marketing electricity).
- Facility siting (effect on residents, environmental impact, development plans, proximity to waste source, proximity to energy market, logistic concern and residual ash disposal).
- Facility sizing (waste supply, alternative waste management programme, waste stream characteristics, planning for facility disruption, facility financing and time frame).

LEARNING ACTIVITY 8.3

Mass-burning system has several advantages. Apart from being the widely technically proven incineration technology, a mass-burn facility can accept refuse that has undergone little preprocessing other than the removal of oversized items. This provides advantages such as convenience and flexibility. Due to the large facility size, the incineration unit can be used to recover greater quantities of steam and electricity. The steam generated is of higher quality, which is then passed through a turbine to produce electricity or through an extraction turbine to generate electricity as well as provide process steam for heating purposes. One of the disadvantages of mass-burn facility is that a local programme is needed to separate household hazardous wastes and recover certain materials (e.g., iron scrap) so as to help ensure environmentally viable incineration and resource conservation. Other disadvantages include increased cost of construction and land space.

LEARNING ACTIVITY 8.4

The three basic types of waste-to-energy (WTE) incineration involve the generation of electricity, steam or the cogeneration of both electricity and steam. Electricity is the most common form of energy produced and sold from WTE facilities. By directing the steam produced from a WTE system through turbine generator, electricity can be produced and sold. The second method uses steam generated from incineration facilities directly by a customer for manufacturing operations. This steam can be used to drive machinery such as compressors, for space heating and generating electricity. Cogeneration involves the combined production of steam and electricity. In cogeneration, high-pressure steam is used first to generate electricity; the steam leaving the turbine is used to serve the steam users.

LEARNING ACTIVITY 8.5

Electrostatic precipitators (ESP) are used for particle control. ESP uses electric forces to move the particle flowing out of the gas stream on to the collector electrodes. The particles get a negative charge, when they pass through an ionised field. The electric field forces the charged particles to the walls. The particles that are collected are removed by knocking them loose from the plates and by intermittent and continuous washing with water. The removal efficiency is 99%.

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.

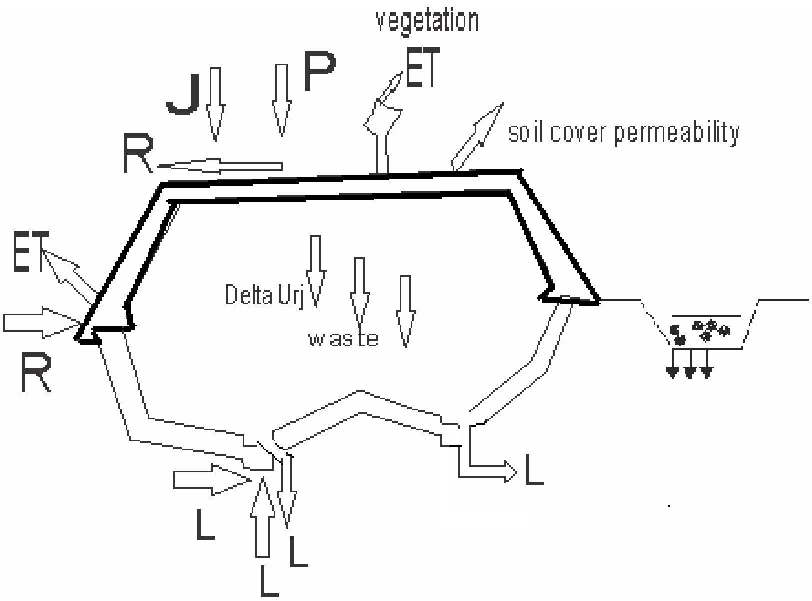
Against this background, let us now discuss the principles, processes and operation of sanitary landfills.

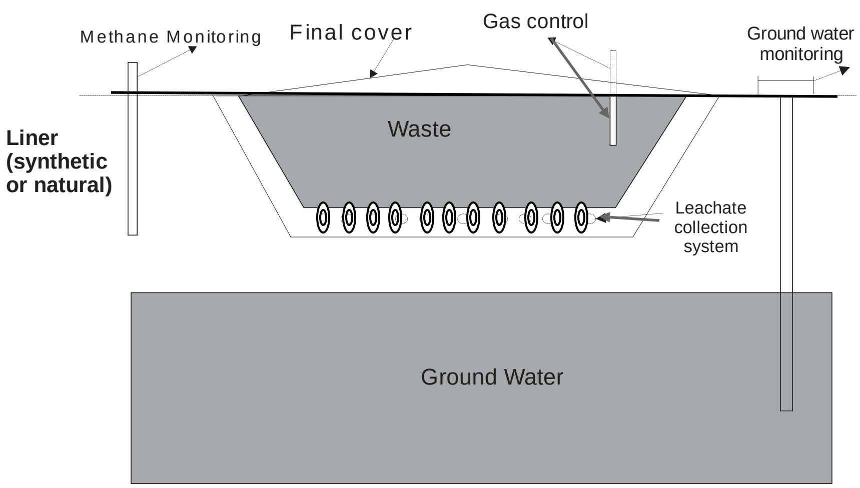
4.3.1 Principle

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+/ ΔUs; 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 +/-ΔUw; 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

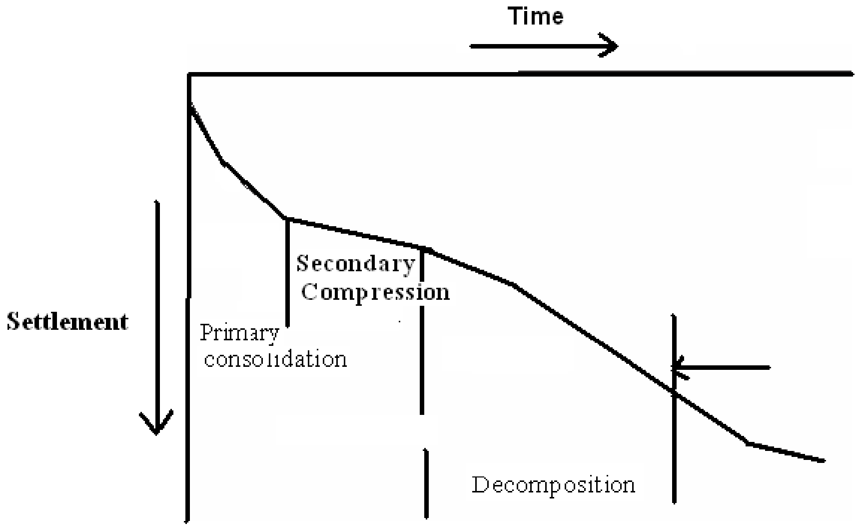
The feasibility of land disposal of solid wastes depends on factors such as the type, quantity and characteristics of wastes, the prevailing laws and regulations, and soil and site characteristics. Let us now explain some of these processes.

(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.

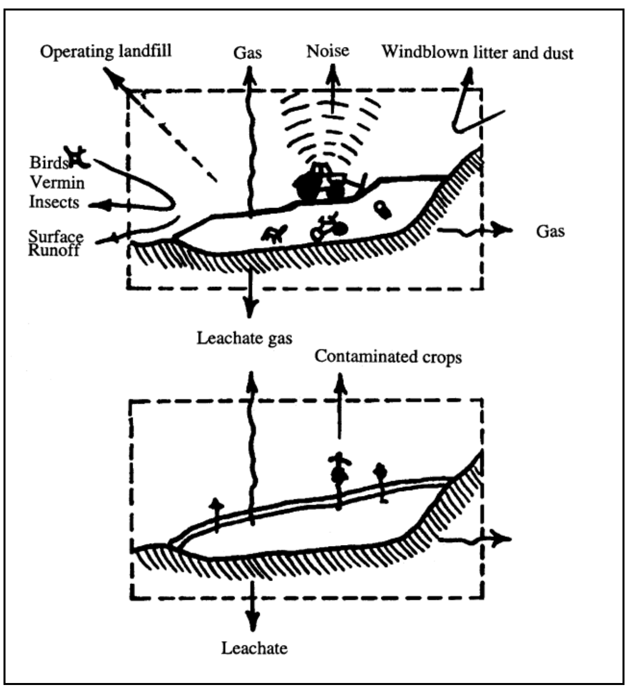
(v) An operating landfill, where equipment and waste are exposed, appears inaesthetic. This problem may be reduced by careful design of screening soil embankments, plantings, rapid covering and re-vegetation of filled sections.

(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

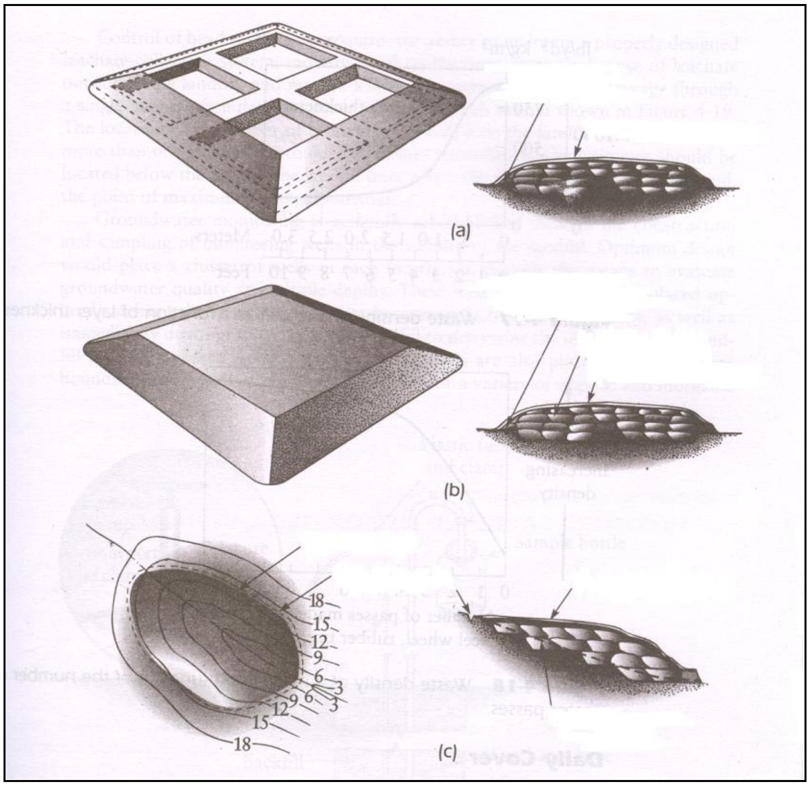
To secure public acceptability, landfill operations require careful planning and determination of the extent of environmental effects. The basic factor influencing the planning of site operations is the nature and quantity of incoming wastes. The various aspects of this include the following:

(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

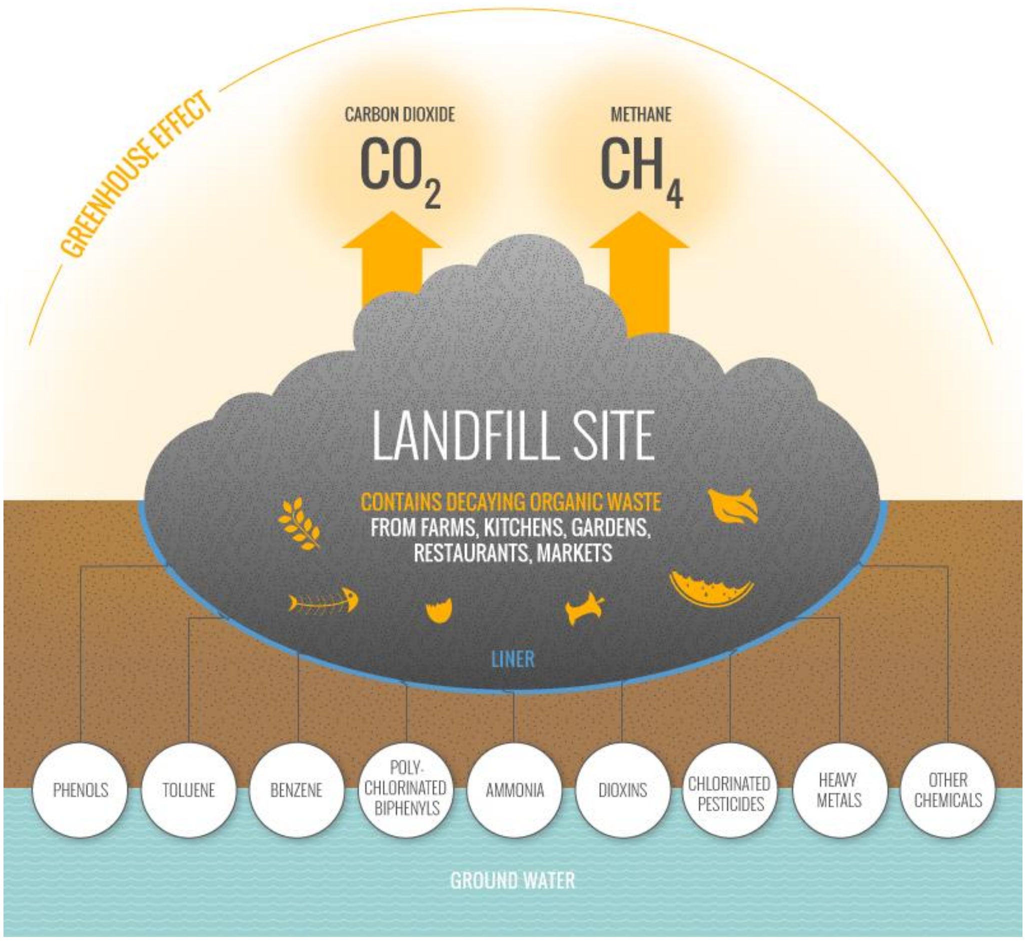
A sanitary landfill is essentially an engineered waste disposal option, where the environmental risk is controlled at an appropriate and acceptable level. But, if it is not properly managed, it can cause the following problems: (i) noise pollution due to vehicles such as earthmovers, compactors, etc., (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.



LANDFILL DESIGN - OVERVIEW

ABSTRACT

This module gives an overview of landfill design, with some perspective on design calculations as well.

IITM-EWRE

Solid and Hazardous Waste Management

Source for graphic above: Gazasia – Landfill Sites
www.gazasia.com

Introduction

We have looked at Landfills in Module 1, which dealt with Municipal Solid Waste. In this module, we can look at landfills in a more detailed manner.

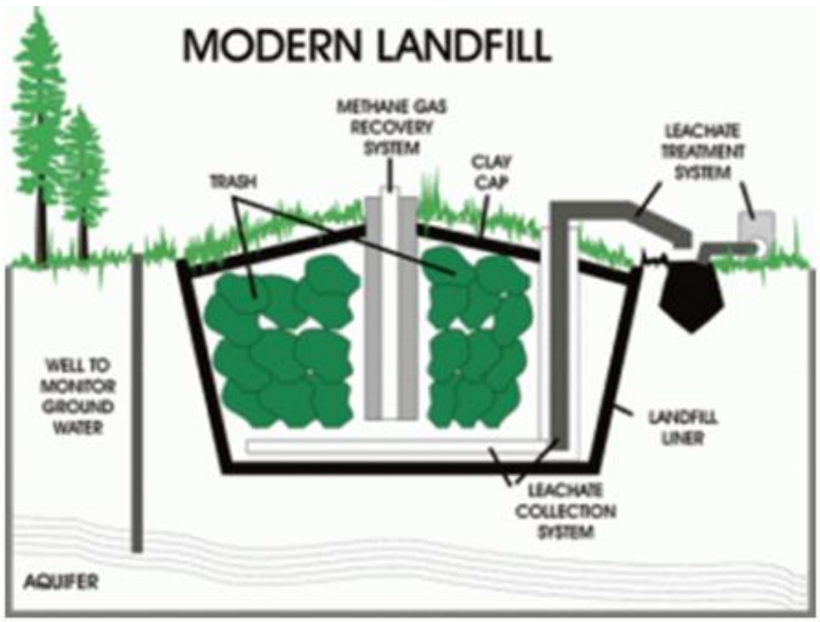


Fig. 1: Schematic diagram of a landfill
Source: www.waynegov.com

Operating requirements for a solid waste landfill:

- Detection and exclusion of hazardous waste from the facility
- Use of appropriate cover material for the landfill
- Disease vector control
- Control of gas production (especially those which can combust readily)
- Monitoring of air and groundwater quality
- Access to facility
- Run-on and run-off control systems
- Restricting liquids entering the landfill
- Record keeping requirements

Site selection criteria for a sanitary landfill:

- Land area and volume must be sufficient enough so that the landfill can serve for the projected number of years.
- The slope of the region should not be very steep.
- Irrigation pipelines and water supply wells should not be situated close to the boundary of the landfill.
- Residential development should be planned away from the landfill site.
- Unstable areas posing seismic risks should be avoided.
- The depth to groundwater and proximity to water wells must be thoroughly analyzed.
- The visual impact of the landfill must be minimized (landscaping, aesthetic development of landfill).
- Agricultural land should not be used for landfill development.
- The landfill must not cause flood hazard in the event of heavy rainfall.

Liner systems

Landfill liners are designed to create a barrier between the waste and the environment, and to drain the leachate to collection and treatment facilities. Liners may be single, composite, or double. Selection of liner is based on chemical compatibility, stress-strain characteristics, survivability and permeability.

I. Single liner

Single liners consist of a clay liner, a geosynthetic clay liner or a geomembrane. Single liners are sometimes used in landfills containing construction debris. Clay liner is easily available and is durable. Synthetic geo-membranes are composed of polymers such as: Thermoplastics (PVC); crystalline thermoplastics (HDPE, LDPE); thermoplastic elastomers (chlorinated polyethylene, chlorylsulphonated polyethylene); elastomers (neoprene, ethylene propene diene monomer).

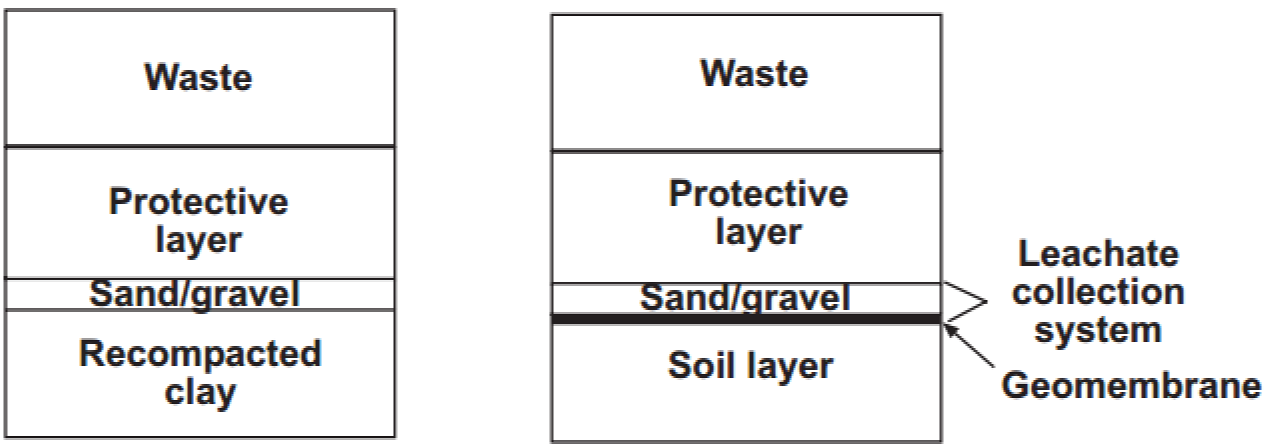


Fig. 2: Single liner system

Source: The Ohio State University Extension Factsheet. *Landfill Types and Liner Systems*.

II. Composite liner

A composite liner consists of a geomembrane in combination with a clay liner. These are more effective at limiting leachate migration into the subsoil.

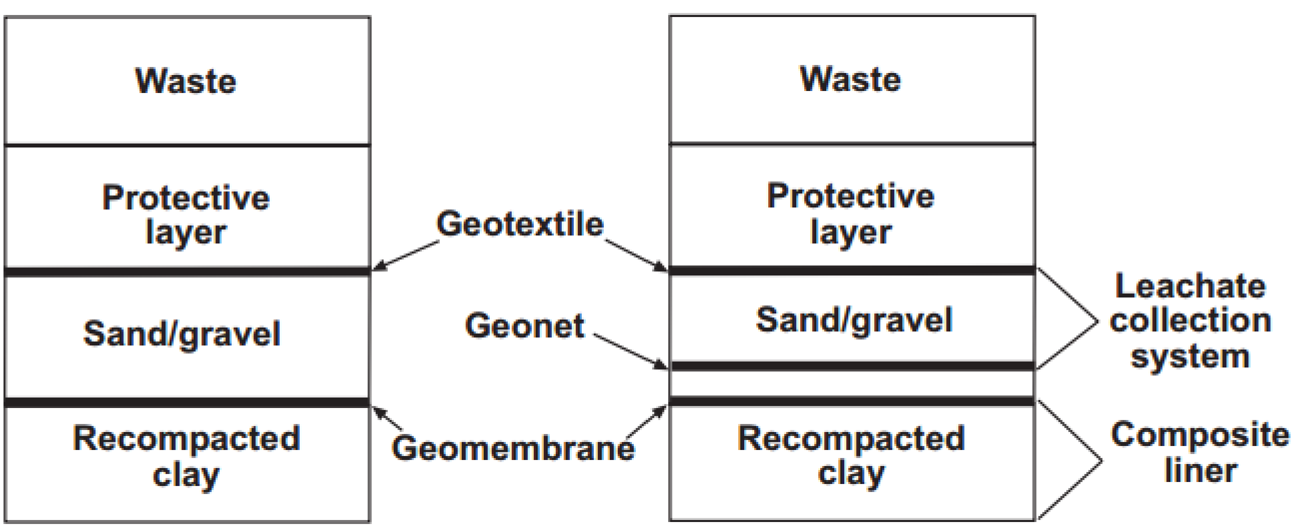


Fig. 3: Composite liner system

Source: The Ohio State University Extension Factsheet. *Landfill Types and Liner Systems*.

III. Double liner

A double liner consists of either two single liners, two composite liners, or a single and a composite liner. The upper (primary) liner collects the leachate, while the lower (secondary) liner acts as a leak detection system. Double liners are to be used in MSW landfills, and especially in hazardous waste landfills. A double liner is more resistant to stress cracking and increased strain due to tensile yield.

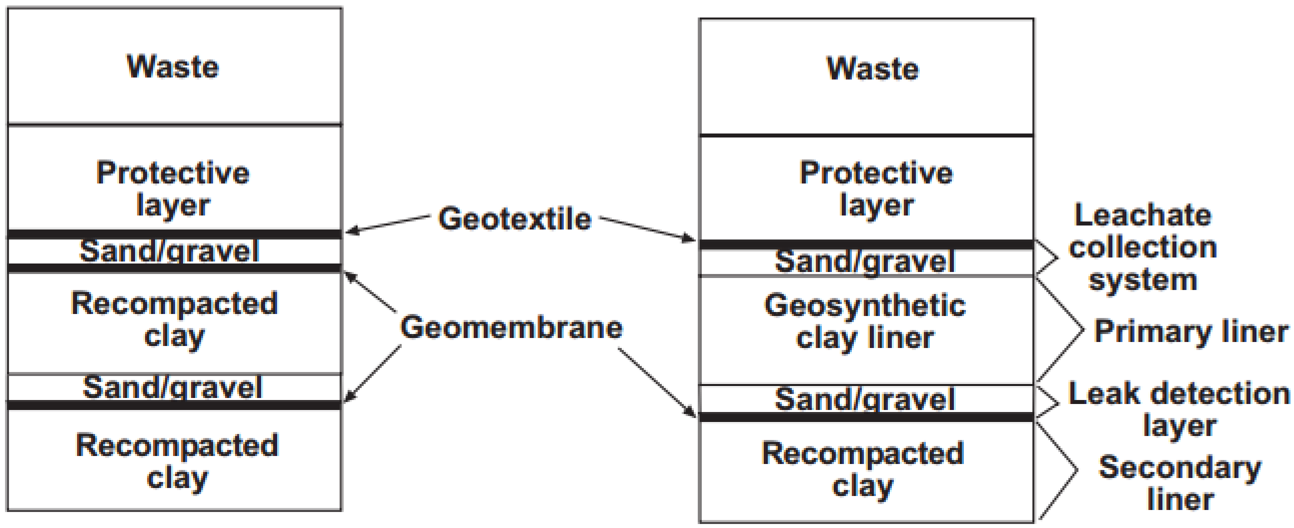


Fig. 4: Double liner system

Source: The Ohio State University Extension Factsheet. *Landfill Types and Liner Systems*.

Definitions:

- Geotextile: A permeable fabric made of plastic threads that separates the base of the landfill from the underlying soil. It allows water to pass through it but prevents soil from coming into the base.
- Geomembrane: A synthetic membrane with very low permeability that controls the movement of fluid in any engineering structure or system.
- Landfill cover: A daily cover of compacted soil or earth is applied on top of the waste deposited in a landfill. This cover minimizes the interaction between waste and the surrounding environment. It also reduces odours.

Leachate generation and control

Integrated into all liner systems is a leachate collection system. This collection system is composed of sand and gravel, or a geo-net. A geo-net is a plastic net like drainage blanket. In this layer is a series of leachate collection pipes to drain the leachate from the landfill – to holding tanks for storage and eventual treatment. In double-liner systems, the upper drainage layer is the leachate collection system, and the lower drainage layer is the leak detection system. The leak detection layer contains a second set of drainage pipes. The presence of leachate in these pipes serves to alert landfill management if the primary liner has a leak. The leachate collection and removal system (LCR) also contains a sump (which is the lowest point in the composite liner system) in addition to the parts mentioned above.

The rate of percolation of leachate through the liner is controlled by the hydraulic activity of the liner, the head of the leachate on top of the liner, and the total area of the liner. The leakage through a composite liner can be described the following equation (Darcy's Law):

$$Q = KA\frac{dH}{dL}$$

Where Q is the volume of flow per unit time through a column of cross-sectional area A; the flow occurs under a pressure gradient dH/dL; change in water level happens over a length L; K is the saturated hydraulic conductivity which depends on grain size for saturated soils and on grain size as well as water content of pores for unsaturated soils.

Fick's First Law describes the leakage through a synthetic liner:

$$J = -D\left[\frac{dC}{dx}\right]$$

Where J is the flux (mol/cm^2s), D the diffusion coefficient (cm^2/s), C the concentration (mol/cm^3) and x the length in the direction of movement (cm). The diffusion process is similar to the rate of flow governed by Darcy's Law, except that the latter is driven by hydraulic gradient as opposed to concentration gradient.

Bernoulli's Equation can be used to estimate the flow rates through pores in geo-membranes, assuming that shape and size of pores are known.

$$Q = C_b a[2gh]^{0.5}$$

Where Q is the flow rate through a geo-membrane (cm^3/s), C_b the flow coefficient with a value of about 0.6 for a circular hole, *a* the area of circular hole (cm^2), g the acceleration due to gravity (cm/s^2), and h the liquid head acting on the liner (cm).

Generation of landfill gases

The Landfill Gas Emission Model (LandGEM) developed by USEPA describes gas production from a landfill using the following equation:

$$Q_T = \sum_{j=1}^{n} 2kL_o M_i e^{-kt_i}$$

Where $Q_T = Total\ gas\ emission\ rate\ \left(\frac{volume}{time}\right)$

$$L_o = Methane\ generation\ capacity\ of\ waste\ \left(\frac{volume}{mass}\right)$$

$$n = Total\ time\ period\ of\ waste\ placement$$

$$k = Landfill\ gas\ emission\ constant\ \left(\frac{1}{time}\right)$$

$$t_i = Age\ of\ i^{th} section\ of\ waste\ (time)$$

$$M_i = Mass\ of\ wet\ waste\ placed\ at\ time\ 'i'$$

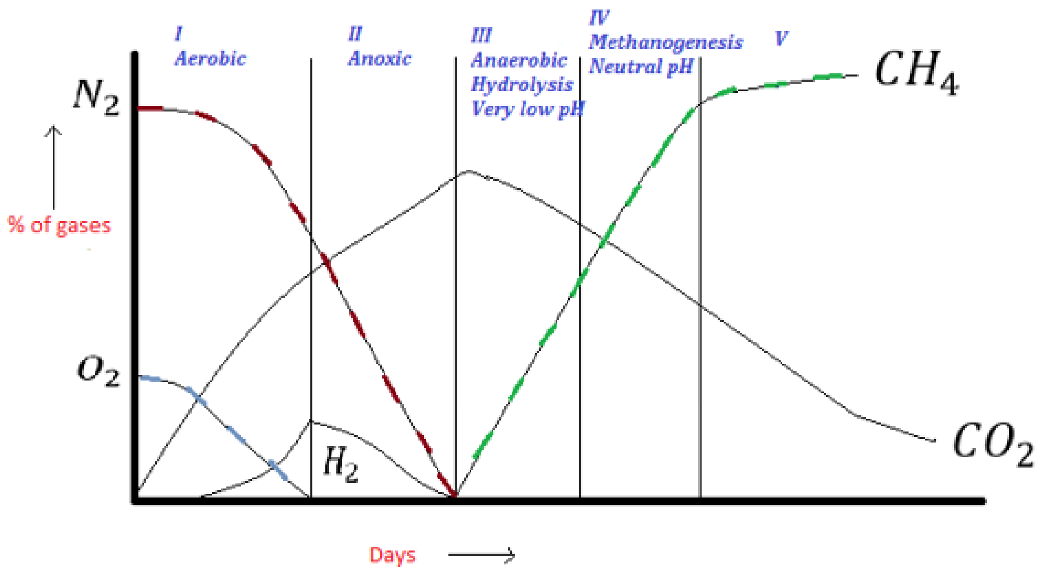


Fig. 5: Landfill gas production in different phases

It has been observed that production of gases from landfill occurs in five phases. CH_4 and CO_2 are the most common gases produced; with other gases being CO, H_2, H_2S, NH_3, N_2 and O_2 in smaller quantities.

$$C_aH_bO_cN_d + \frac{4a-b-2c+3d}{4} H_2O \rightarrow \frac{4a+b-2c-3d}{8} CH_4 + \frac{4a-b+2c+3d}{8} CO_2 + dNH_3$$

The organic component of MSW is of two types: rapidly decomposing (3 months – 5 years) and slowly decomposing (more than 50 years).

Phase I

This is an aerobic phase. Biodegradable components of MSW undergo microbial decomposition immediately after placement in landfill cell. Initially, O_2 is present in sufficient amounts. Organic matter present in waste and the soil material used as daily cover are degraded by aerobic bacteria. Once the volume of oxygen available drops to less than 15%, anaerobic organisms are cultivated.

Phase II

Phase I and Phase II together take up to a few weeks. Phase II is an anaerobic (or anoxic) phase. Organic matter acts as the electron donor, while nitrate and sulphate ions act as electron acceptors.

$$\frac{1}{5}NO_3^- + \frac{1}{4}\{CH_2O\} + \frac{1}{5}H^+ \rightarrow \frac{1}{10}N_2 + \frac{1}{4}CO_2 + \frac{7}{20}H_2O$$

$$SO_4^{2-} + 2\{CH_2O\} + 2H^+ \rightarrow H_2S + 2CO_2 + 2H_2O$$

CH_2O is the representation of organic content in a generic form.

During this phase, the pH of landfill cells drops down. This is due to the formation of organic acids and elevated levels of SO_2 within voids.

$$H_2O + CO_2 \rightarrow H_2CO_3$$

Phase III

This is the second anaerobic phase (acid phase). Anaerobic microbial activity is much higher, resulting in higher amount of organic acids and production of some hydrogen gas (due to enzyme mediated hydrolysis). The pH of landfill liquids drops to around -5 due to presence of these organic acids and there is an increased amount of CO_2 within voids. However, there is no production of methane gas as methanogenic bacteria cannot tolerate acidic conditions. As a result of the low pH values, metals and other inorganic constituents are solubilized. BOD_5, COD, and conductivity of leachate show a sudden increase due to dissolution of organic acids in leachate.

Phase IV

This is the methane fermentation phase.

$$Organic\ acids + H_2 \rightarrow CH_4 + CO_2$$

CH_4 and organic acids formation proceed simultaneously. pH increases and stabilizes around 6.8-8. BOD_5, COD and leachate conductivity reduce. Metals which were soluble previously begin to precipitate.

Phase V

This is the maturation phase. Rate of gas generation decreases as most of the available nutrients have been removed with the leachate, and substrates that remain are highly stable. Principal gases evolved are methane and carbon dioxide.

The occurrence of these phases depend on distribution of organic components in landfill cell, availability of nutrients, moisture content of waste, and degree of initial compaction. Higher moisture content results in lower production of gases.

In theory, biological decomposition of MSW produces 442 m^3 of landfill gas containing 55% CH_4 and a heat value of 19730 kJ/m^3. Actual average yield of CH_4 is closer to 100 m^3/MT of waste. Gas yields based on waste generation have been predicted using the following assumptions:

- 50% of organic material placed in landfill will actually decompose
- 50% of landfill gas generated in recoverable
- 50% of landfills operate within favourable pH range

The Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) must be continuously monitored, keeping in mind the safety of workers and residents in and around the landfill area. The range for explosive gases in air on a volume basis should be contained within 5-15%.

Closure and post-closure care

The closure standards for a landfill require that a final cover be installed to minimize infiltration of liquids and soil erosion. The permeability of the final cover must be less than that of the underlying liner system. The final cover must consist of an infiltration layer of at least 18 inches of earthen material covered by an erosion layer of at least 6 inches of earthen material that is capable of sustaining plant growth.

Post-closure care deals with monitoring the effectiveness of the:

- Final cover system
- Leachate collection system
- Groundwater monitoring system
- Methane gas monitoring system

Treatment, Storage and Disposal Facilities (TSDF)

TSDF is a facility that is permitted to treat, store and dispose hazardous wastes in special hazardous waste management units. TSDFs can be commercial or private – i.e., they may accept hazardous waste from outside generators for a fee, or they may be set up for a manufacturing facility (in which case they do not accept waste from other generators).

Definitions:

- Treatment – Incineration or oxidation are commonly used to alter the chemical properties of the incoming hazardous waste. Other chemical processes seen in Module 6 may be applied here too. Incineration is detailed in the sections below.
- Storage – Storage units are used for temporary storage of hazardous wastes until they are completely treated or disposed of.
- Disposal – Hazardous waste landfills or deep underground injection wells are used for this purpose.

In Tamil Nadu, three commercial TSDFs are located across the state – in Gummidipoondi, Karur and Tiruppur. The Gummidipoondi TSDF has a capacity of 3,00,000 tons and is designed to incinerate 1 ton per hour.

I. Waste Analysis

The incoming waste is first analyzed in order to verify the composition – the hazardous components are characterized. This is done by thorough physical and chemical analysis in a laboratory. The waste analysis must have rules for the following:

- Parameters to be analyzed
- Safe sampling methods
- Labelling
- Repeatability of tests
- Standardized tests for physical and chemical properties
- Trained personnel to handle equipment and hazardous substances

II. Hazardous Waste Landfills

A hazardous waste landfill must fulfill the following design requirements:

- Double liner
- Double leachate collection removal systems
- Leak detection system
- Monitoring storm water run-on and run-off
- Monitoring wind dispersal
- Absence of liquid wastes
- Cover system in place

Post-closure care includes: frequent groundwater monitoring, continuous operation of leachate collection and removal systems until leaks are no longer detected, maintaining final cover.

In some instances, underground repositories are used for storage and disposal of hazardous waste. These must be chosen keeping in mind the potential damage that can be caused to human health and environment.

III. Incineration of hazardous wastes

The definition of an incinerator is "any enclosed device that uses controlled flame combustion and does not meet the criteria for classification as a boiler, sludge dryer, carbon regeneration unit, or industrial furnace". Typical incinerators include rotary kilns, liquid injectors, controlled air incinerators, and fluidized-bed incinerators. There are three factors which ensure the completeness of combustion in an incinerator:

1. Temperature of combustion chamber
2. Length of time wastes are maintained at high temperatures
3. Turbulence (degree of mixing)

During a controlled burn, wastes are fed continuously or in batches into the combustion chamber. As the wastes are heated, they are converted into liquids and gases (CO_2, water, SO_x, NO_x depending on composition of waste). If combustion is incomplete, elemental carbon (C), PCBs, benzopyrenes may be emitted – known as Products of Incomplete Combustion (PICs). Ash is collected at the base of the combustion chamber; lightweight ash may be entrapped in the flue gases as particulate matter (referred to as fly-ash).

The main indicator of incinerator performance is given by Destruction Removal Efficiency (DRE). An incinerator burning hazardous waste must achieve a DRE of 99.99% for each Principal Organic Hazardous Constituent (POHC) designated in the waste stream.

$$DRE = \frac{(W_{in} - W_{out})}{W_{in}} * 100\%$$

HCl is formed when chlorinated organic compounds in wastes are burned. An incinerator burning hazardous waste cannot emit more than 1.8 kg of HCl per hour or more than 1% of the total HCl in the stack gas prior to entering any pollution control equipment.

Particulate matter consists of minute particles (solid or liquid, organic or inorganic), which are part of flue gas. They are inhaled easily. An incinerator burning hazardous waste must not emit particulate matter in excess of 180 mg/dscm (milligrams per dry standard cubic metre).

$$P_c = P_m * \frac{14}{21 - Y}$$

Where P_c is the corrected concentration of particulate matter, P_m the measured concentration of particulate.

Some reactions which take place during the incineration process:

$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$ [Combustion of alkane]

$C_6H_4(CH_3)_2 + 11.5O_2 \rightarrow 8CO_2 + 5H_2O$ [Combustion of aromatic hydrocarbon]

$2C_2H_4Cl_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O + 4HCl$ [Combustion of chlorinated hydrocarbon]

Air requirement (kg air/kg solid waste) for the incineration of hazardous is calculated as follows:

$$Weight\ of\ air\ required = 0.043[2.66C + 8H + S - O]$$

Types of incinerators

Liquid injector

Liquid wastes are combusted using this incinerator. It is a stationary system consisting of one or more combustion chambers operating under high temperatures and equipped with atomizing nozzles. The major units are horizontally or vertically fired. The advantages in using a liquid injector are: (1) Fewer moving parts resulting in less downtime and maintenance (2) Capability to incinerate a wide variety of wastes (3) Low maintenance costs due to few moving parts in the system. The disadvantages are: (1) Only capable of combusting liquids and slurries (2) Feed nozzles tend to clog.

Rotary kiln

The rotary kiln consists of a refractory-lined rotating cylinder mounted at a slight incline from ground level. Wastes in the form of liquids, slurries, or solids are fed into the entry ports and agitated under elevated temperatures for a pre-determined length of time depending on waste and kiln characteristics. Waste liquids may be pumped in through a nozzle, thereby atomizing the input. The waste is expected to burn to ash by the time it reaches the kiln exit. A long residence time is preferred because the solids bed in the kiln is not thermally uniform. The solids retention time, θ (min) is given by:

$\theta = 0.19\frac{L}{NDS}$ Where L is the kiln length (m), N the kiln rotational velocity (r/min), D the kiln diameter (m), and S the kiln slope (m/m).

The gas retention time for 99.99% destruction of a compound is given by (Kiely, 1996):

$\ln t_g = \ln\left(\frac{9.21}{A}\right) + \frac{E}{RT}$ Where A is the Arrhenius constant (s^{-1}), E the energy of activation (J/kg mol), R the universal gas constant, and T the temperature (K). A and E are usually known for a compound.

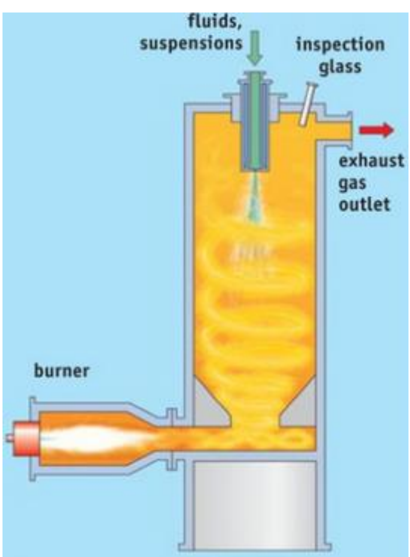


Fig. 6: Liquid injection incinerator
Source: www.eisenmann.com *Products and Services*

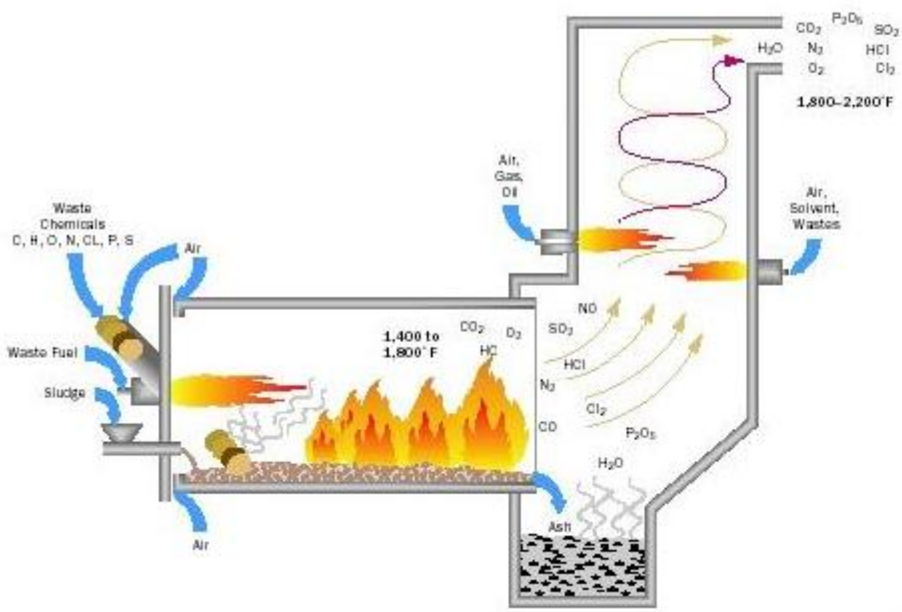


Fig. 7: Rotary kiln
Source: www.pollutionissues.com Incineration

Moving grate incinerator

This is also referred to as the MSW incinerator. The moving grate enables the movement of waste through the combustion chamber to allow for a more efficient and complete combustion. A single moving grate incinerator can handle up to 35 metric tons of waste per hour, and can operate for ~8000 hours per year.

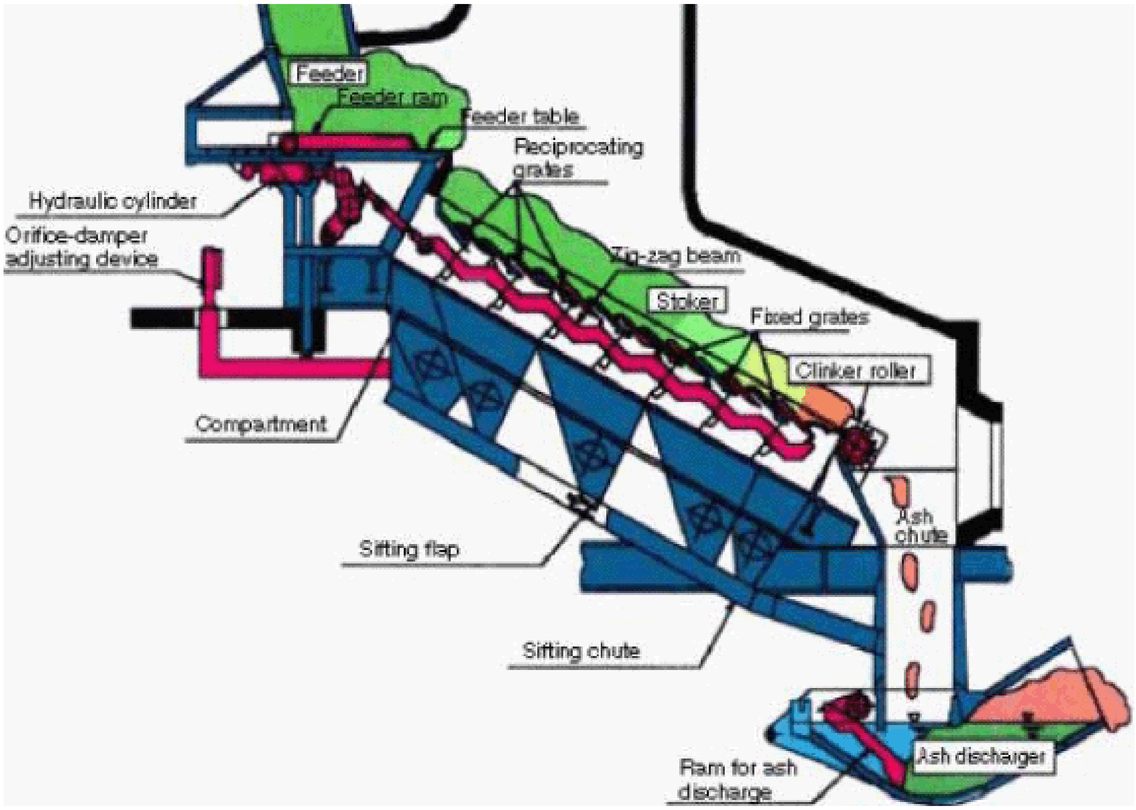


Fig. 8: Moving grate incinerator

Source: www.nett21.gec.jp/waste/data/waste_K-1.html *Mitsubishi-Martin Refuse Incineration System*

Fixed hearth incinerator

These are extensively used for combustion of bulk solid and liquid wastes from medical or municipal facilities. A controlled flow of "under-fire" combustion air (70-80% of required air) is introduced up through the hearth; and the bottom ash is removed by dumping the parts into a water bath.

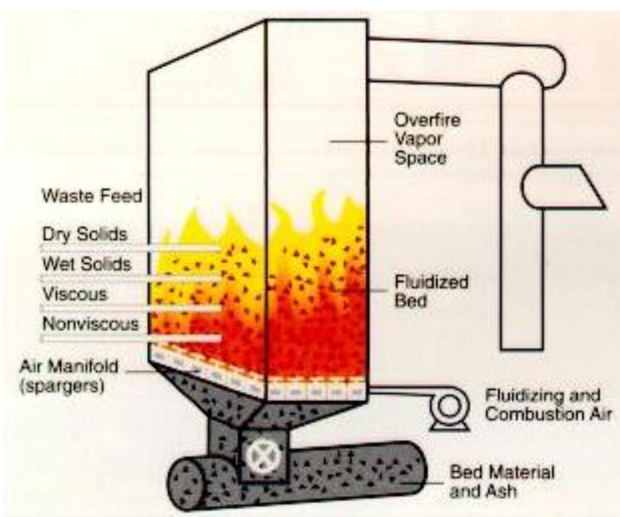


Fig. 9: Fixed hearth incinerator

Source: www.news.newclear.server279.com *Incineration Policy in Australia*

Fluidized bed incinerator

In an internal circulation type fluidized bed incinerator, the bed part is separated into combustion and heat absorption cells. Using sensible heat from the media (sand), the temperature of the boiler tubes in the heat absorption cell is increased, generating high temperature and high pressure steam. This type of incineration offers nearly isothermal combustion, with the temperature of operation being in the range of 750-1000^{o}C.

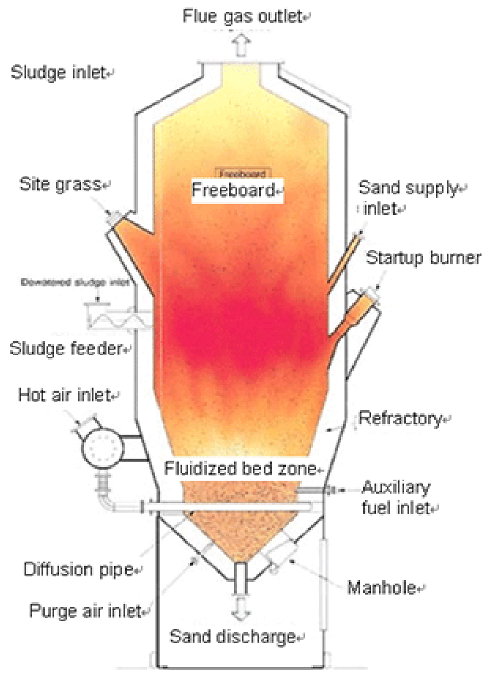


Fig. 10: Fluidized bed incinerator

Source: www.tsk-g.co.jp/en/tech/industry/tsk_fbi.html *TSK Fluidized Bed Incineration System*

Bioreactor Landfills

Problems identified in the operation and maintenance of a traditional municipal solid waste landfill led to the development of a bioreactor landfill. Some of these problems include: build-up of methane gas inside the landfill leading to risk of explosion, leachate draining into groundwater resulting in damage to humans and the environment. A bioreactor landfill is one which accelerates the decomposition of waste through the addition of liquid and air, thus enhancing microbial processes. The success of the bioreactor landfill depends on maintaining optimal conditions: the temperature maintained between 60 and 72°C, 60-80% moisture, and a high pH to alkalinity ratio (>0.25). Once a methane content of >40% is observed (on a volume basis), it indicates that methanogens are well established in the landfill cell.

Types of bioreactor landfills

1. Aerobic

- Leachate drained from bottom layer and re-circulated to the landfill cell
- Air circulated into waste
- Microbial activity improved

2. Anaerobic

- Moisture added to waste mass (in the form of re-circulated leachate or other sources)
- Biodegradation of organic fraction of waste to methane occurs in absence of oxygen

3. Hybrid

- Sequential aerobic-anaerobic process
- Organic content degraded in upper sections of landfill
- Methane gas collected from lower sections of landfill

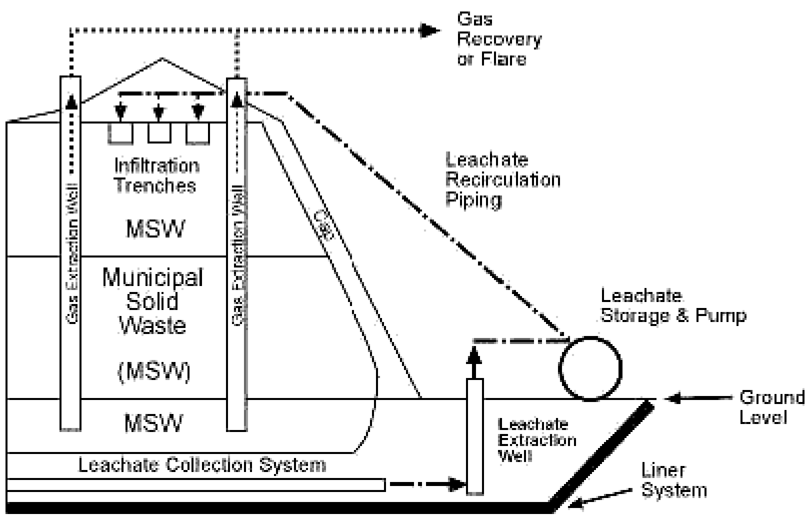


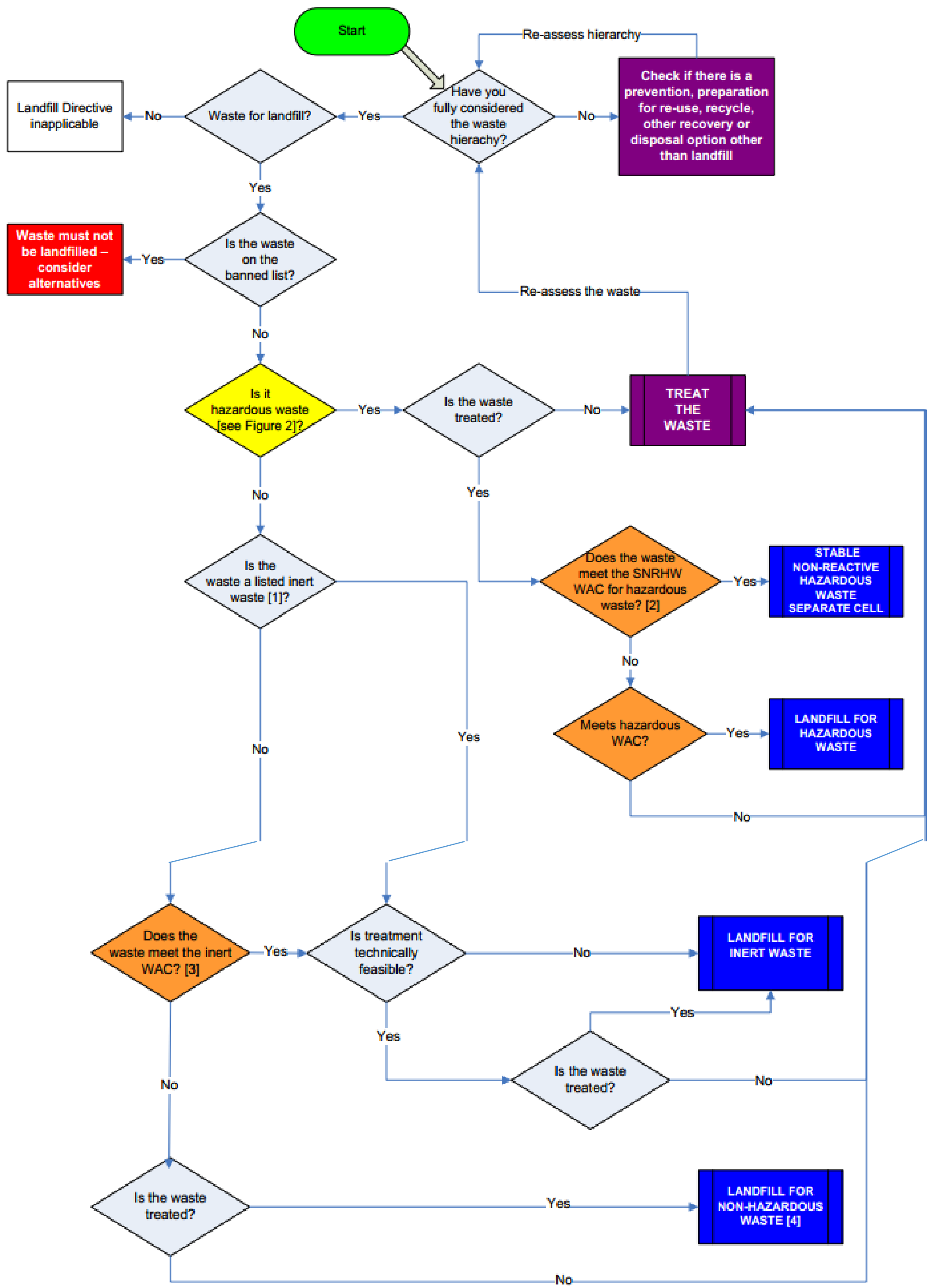
Fig. 11: Bioreactor landfill with leachate recirculation
Source: www.ohioline.osu.edu Bioreactor Landfills: Factsheet Extension

Appendix

Waste acceptance in landfills

Source: UK Environment Agency. *Waste Acceptance at Landfills*. 2010.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296422/geho1110btew-e-e.pdf
(Accessed April 10, 2015).

Figure 1



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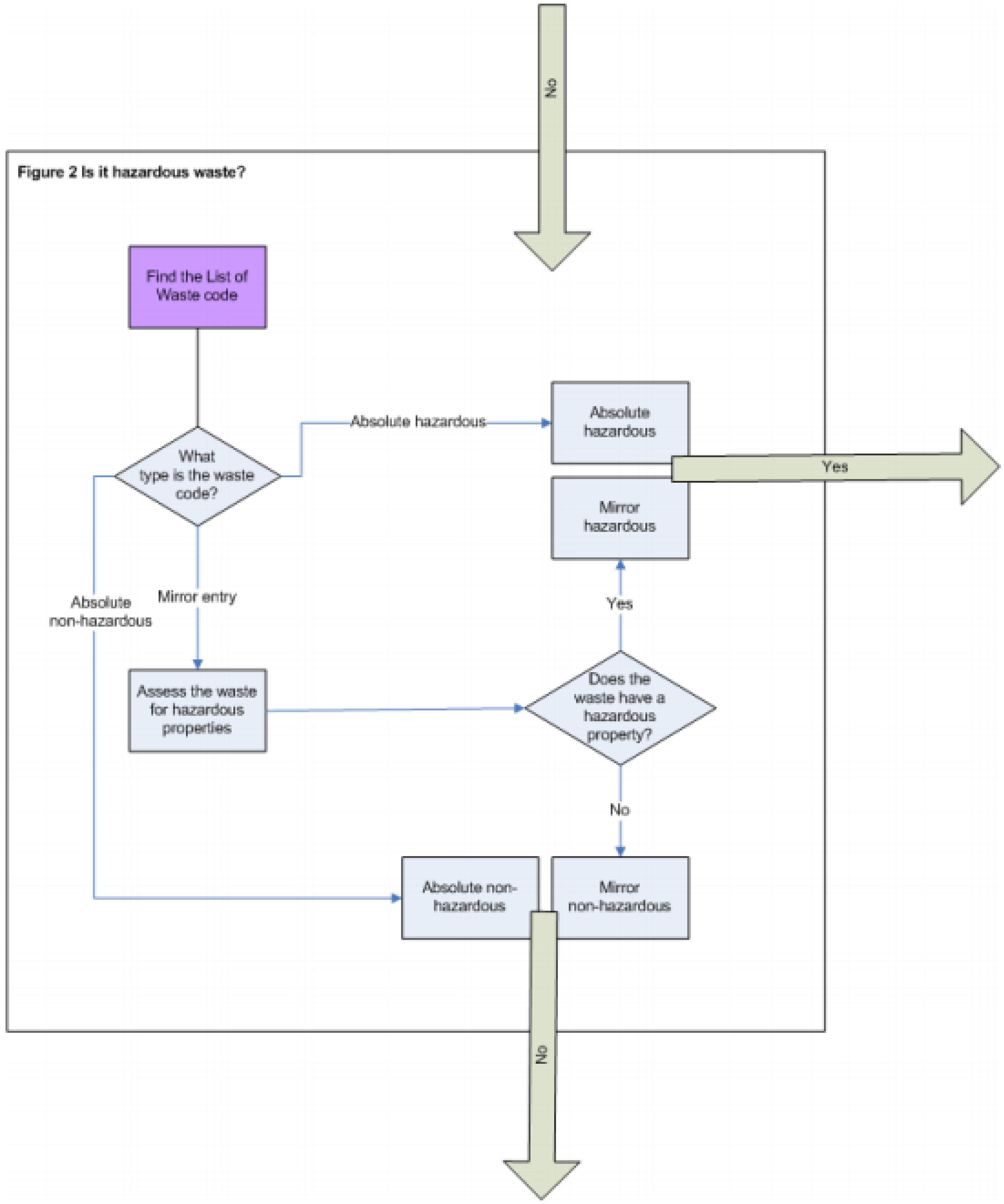

The figures above show how a decision is made regarding disposal of waste to a landfill by the UK Environment Agency.

Sources

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Lecture 9

Hazardous Waste: Management and Treatment

STRUCTURE

OVERVIEW

In Units 1 to 8, we discussed the management of solid waste and its functional elements, which include storage, collection, transport, waste disposal, processing, recycling, biological conversion of waste and incineration with energy recovery in the context of non-hazardous wastes. In view of the substantial threat – present and potential – hazardous wastes pose to human health, or living organisms in general, they ought to be handled, treated and managed differently, and this issue is discussed in the present Unit. In this Unit, we will first identify and classify hazardous wastes, and then discuss their functional elements namely generation, storage and collection, transfer and transport, processing and disposal. Subsequently, we will discuss the various physical, chemical, thermal and biological treatments to reduce the impact of hazardous wastes on public health and the environment. We will close the Unit by explaining some of the techniques for hazardous waste minimisation and pollution prevention and touching upon the prevailing hazardous waste management practices in India.

LEARNING OBJECTIVES

After completing this Unit, you should be able to:

- identify and classify hazardous wastes;
- explain the techniques of hazardous waste management, treatment and minimisation;
- describe the physical, chemical, thermal and biological methods of treating hazardous waste;
- adopt waste minimisation and pollution prevention techniques.

9.1 HAZARDOUS WASTE: IDENTIFICATION AND CLASSIFICATION

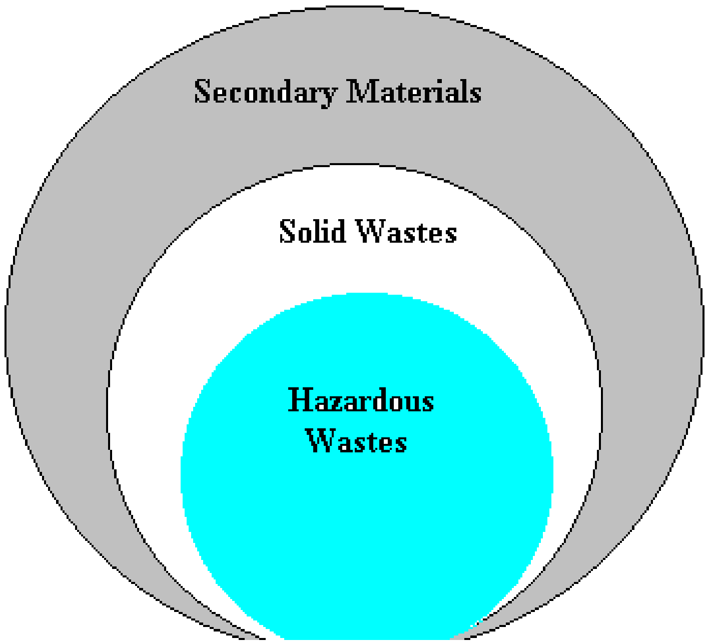
Hazardous wastes refer to wastes that may, or tend to, cause adverse health effects on the ecosystem and human beings. These wastes pose present or potential risks to human health or living organisms, due to the fact that they:

- are non-degradable or persistent in nature;
- can be biologically magnified;
- are highly toxic and even lethal at very low concentrations.

The above list relates only to the intrinsic hazard of the waste, under uncontrolled release, to the environment, regardless of quantity or pathways to humans or other critical organisms (i.e., plants and animals). The criteria used to determine the nature of hazard include toxicity, phytotoxicity, genetic activity and bio-concentration. The threat to public health and the environment of a given hazardous waste is dependent on the quantity and characteristics of the waste involved. Wastes are secondary materials, which are generally classified into six categories as inherently waste: like materials, spent materials, sludges, by-products, commercial chemical products and scrap metals. Solid wastes form a subset of all secondary materials and hazardous wastes form a subset of solid waste. However, note that certain secondary materials are not regulated as wastes, as they are recycled and reused.

Figure 9.1 illustrates the relationship among secondary materials, solid wastes and hazardous wastes (http://www.dep.state.pa.us/dep/deputate/airwaste/):

Figure 9.1
Secondary Materials, Solid and Hazardous Wastes: Relationship



Note that for a material to be classified as a hazardous waste, it must also meet the criteria specified in the regulatory definition of solid waste, which we will study next.

9.1.1 Identification

By using either or both of the following criteria, we can identify as to whether or not a waste is hazardous:

(i) The list provided by government agencies declaring that substance as hazardous.

(ii) Characteristics such as ignitibility, corrosivity, reactivity and toxicity of the substance.

Let us now explain these two criteria.

Listed hazardous wastes (priority chemicals)

A specific list showing certain materials as hazardous wastes minimises the need to test wastes as well as simplifies waste determination. In other words, any waste that fits the definition of a listed waste is considered a hazardous waste. Four separate lists cover wastes from generic industrial processes, specific industrial sectors, unused pure chemical products and formulations that are either acutely toxic or toxic, and all hazardous waste regulations apply to these lists of wastes. We will describe these wastes, classified in the F, K, P, and U industrial waste codes, respectively, below (http://www2.kumc.edu/safety/kdhehw/hwg1_10.html#SectionIV):

- **F-list:** The F-list contains hazardous wastes from non-specific sources, that is, various industrial processes that may have generated the waste. The list consists of solvents commonly used in degreasing, metal treatment baths and sludges, wastewaters from metal plating operations and dioxin containing chemicals or their precursors. Examples of solvents that are F-listed hazardous wastes, along with their code numbers, include benzene (F005), carbon tetrachloride (F001), cresylic acid (F004), methyl ethyl ketone (F005), methylene chloride (F001), 1,1,1, trichloroethane (F001), toluene (F005) and trichloroethylene (F001). Solvent mixtures or blends, which contain greater than 10% of one or more of the solvents listed in F001, F002, F003, F004 and F005 are also considered F-listed wastes.
- **K-list:** The K-list contains hazardous wastes generated by specific industrial processes. Examples of industries, which generate K-listed wastes include wood preservation, pigment production, chemical production, petroleum refining, iron and steel production, explosive manufacturing and pesticide production.
- **P and U lists:** The P and U lists contain discarded commercial chemical products, off-specification chemicals, container residues and residues from the spillage of materials. These two lists include commercial pure grades of the chemical, any technical grades of the chemical that are produced or marketed, and all formulations in which the chemical is the sole active ingredient. An example of a P or U listed hazardous waste is a pesticide,

which is not used during its shelf-life and requires to be disposed in bulk. The primary distinction between the two lists is the quantity at which the chemical is regulated. The P-list consists of acutely toxic wastes that are regulated when the quantity generated per month, or accumulated at any time, exceeds one kilogram (2.2 pounds), while U-listed hazardous wastes are regulated when the quantity generated per month exceeds 25 kilograms (55 pounds). Examples of businesses that typically generate P or U listed wastes include pesticide applicators, laboratories and chemical formulators.

Characteristics of hazardous wastes

The regulations define characteristic hazardous wastes as wastes that exhibit measurable properties posing sufficient threats to warrant regulation. For a waste to be deemed a characteristic hazardous waste, it must cause, or significantly contribute to, an increased mortality or an increase in serious irreversible or incapacitating reversible illness, or pose a substantial hazard or threat of a hazard to human health or the environment, when it is improperly treated, stored, transported, disposed of, or otherwise mismanaged.

In other words, if the wastes generated at a facility are not listed in the F, K, P, or U lists, the final step to determine whether a waste is hazardous is to evaluate it against the following 4 hazardous characteristics:

(i) **Ignitability** (EPA Waste Identification Number D001): A waste is an ignitable hazardous waste, if it has a flash point of less than 60°C; readily catches fire and burns so vigorously as to create a hazard; or is an ignitable compressed gas or an oxidiser. A simple method of determining the flash point of a waste is to review the material safety data sheet, which can be obtained from the manufacturer or distributor of the material. Naphtha, lacquer thinner, epoxy resins, adhesives and oil based paints are all examples of ignitable hazardous wastes.

(ii) **Corrosivity** (EPA Waste Identification Number D002): A liquid waste which has a pH of less than or equal to 2 or greater than or equal to 12.5 is considered to be a corrosive hazardous waste. Sodium hydroxide, a caustic solution with a high pH, is often used by many industries to clean or degrease metal parts. Hydrochloric acid, a solution with a low pH, is used by many industries to clean metal parts prior to painting. When these caustic or acid solutions are disposed of, the waste is a corrosive hazardous waste.

(iii) **Reactivity** (EPA Waste Identification Number D003): A material is considered a reactive hazardous waste, if it is unstable, reacts violently with water, generates toxic gases when exposed to water or corrosive materials, or if it is capable of detonation or explosion when exposed to heat or a flame. Examples of reactive wastes would be waste gunpowder, sodium metal or wastes containing cyanides or sulphides.

(iv) **Toxicity** (EPA Waste Identification Number D004): To determine if a waste is a toxic hazardous waste, a representative sample of the material must be subjected to a test conducted in a certified laboratory. The toxic characteristic identifies wastes that are likely to leach dangerous concentrations of toxic chemicals into ground water.

9.1.2 Classification

From a practical standpoint, there are far too many compounds, products and product combinations that fit within the broad definition of hazardous waste. For this reason, groups of waste are considered in the following five general categories:

(i) **Radioactive substance:** Substances that emit ionising radiation are radioactive. Such substances are hazardous because prolonged exposure to radiation often results in damage to living organisms. Radioactive substances are of special concern because they persist for a long period. The period in which radiation occurs is commonly measured and expressed as *half-life*, i.e., the time required for the radioactivity of a given amount of the substance to decay to half its initial value. For example, uranium compounds have half-lives that range from 72 years for U_{232} to 23,420,000 years for U_{236}. The management of radioactive wastes is highly controlled by national and state regulatory agencies. Disposal sites that are used for the long-term storage of radioactive wastes are not used for the disposal of any other solid waste.

(ii) **Chemicals:** Most hazardous chemical wastes can be classified into four groups: synthetic organics, inorganic metals, salts, acids and bases, and flammables and explosives. Some of the chemicals are hazardous because they are highly toxic to most life forms. When such hazardous compounds are present in a waste stream at levels equal to, or greater than, their threshold levels, the entire waste stream is identified as hazardous.

(iii) **Biomedical wastes:** The principal sources of hazardous biological wastes are hospitals and biological research facilities. The ability to infect other living organisms and the ability to produce toxins are the most significant characteristics of hazardous biological wastes. This group mainly includes malignant tissues discarded during surgical procedures and contaminated materials, such as hypodermic needles, bandages and outdated drugs. This waste can also be generated as a by-product of industrial biological conversion processes.

(iv) **Flammable wastes:** Most flammable wastes are also identified as hazardous chemical wastes. This dual grouping is necessary because of the high potential hazard in storing, collecting and disposing of flammable wastes. These wastes may be liquid, gaseous or solid, but most often they are liquids. Typical examples include organic solvents, oils, plasticisers and organic sludges.

(v) **Explosives:** Explosive hazardous wastes are mainly ordnance (artillery) materials, i.e., the wastes resulting from ordnance manufacturing and some industrial gases. Similar to flammables, these wastes also have a high potential for hazard in storage, collection and disposal, and therefore, they should be considered separately in addition to being listed as hazardous chemicals. These wastes may exist in solid, liquid or gaseous form.

vi) Household hazardous wastes: Household wastes such as cleaning chemicals, batteries, nail polish etc in MSW constitute hazardous waste. Especially batteries contain mercury which are alkaline which is dangerous enough to kill people. Generic household hazardous material include non chlorinated organic, chlorinated organic, pesticides, latex paint, oil based paints, waste oil, automobile battery and household battery.

LEARNING ACTIVITY 9.1

Identify the characteristics of a major hazardous 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.

We will discuss the management of hazardous waste, which is different from the management of other solid wastes due to hazardous nature of wastes, next.

9.2 HAZARDOUS WASTE MANAGEMENT

Hazardous waste management, as is the case with non-hazardous solid waste management, which we studied earlier, consists of several functional elements. We will discuss these elements in Subsections 9.2.1 to 9.2.5.

9.2.1 Generation

Hazardous wastes are generated in limited amounts in a community and very little information is available on the quantities of hazardous waste generated within a community and in various industries. Hazardous waste generation outside the industry is irregular and very less in amount, rendering the waste generation parameter meaningless. The only practical means to overcome these limitations is to conduct a detailed inventory and measurement studies at each potential source in a community. As a first step in developing a community inventory, potential sources of hazardous waste are to be identified. The total annual quantity of hazardous waste at any given source in a community must be established through data inventory completed during onsite visits.

Table 9.1 below presents a list of hazardous waste generation sources:

Table 9.1
Common Hazardous Wastes: Community Source

Waste Category	Sources
Radioactive substances	Biomedical research facilities, colleges and university laboratories, offices, hospitals, nuclear power plants, etc.
Toxic chemicals	Agricultural chemical companies, battery shops, car washes, chemical shops, college and university laboratories, construction companies, electric utilities, hospitals and clinics, industrial cooling towers, newspaper and photographic solutions, nuclear power plants, pest control agencies, photographic processing facilities, plating shops, service stations, etc.
Biological wastes	Biomedical research facilities, drug companies, hospitals, medical clinics, etc.
Flammable wastes	Dry cleaners, petroleum reclamation plants, petroleum refining and processing facilities, service stations, tanker truck cleaning stations, etc.
Explosives	Construction companies, dry cleaners, ammunition production facilities, etc.

Source: Tchobanoglous, et al., (1977 and 1993)

In addition to the sources listed, the spillage of containerised hazardous waste must also be considered an important source. The quantities of hazardous wastes that are involved in spillage are usually not known. The effects of spillage are often spectacular and visible to the community. Because the occurrence of spillage cannot be predicted, the potential threat to human health and environment is greater than that from routinely generated hazardous wastes.

9.2.2 Storage and collection

Onsite storage practices are a function of the types and amounts of hazardous wastes generated and the period over which generation occurs. Usually, when large quantities are generated, special facilities are used that have sufficient capacity to hold wastes accumulated over a period of several days. When only a small amount is generated, the waste can be containerised, and limited quantity may be stored. Containers and facilities used in hazardous waste storage and handling are selected on the basis of waste characteristics. For example, corrosive acids or caustic solutions are stored in fibreglass or glass-lined containers to prevent deterioration of metals in the container. Great care must also be exercised to avoid storing incompatible wastes in the same container or locations. Figures 9.2 and 9.3 show typical drum containers used for the storage of hazardous waste:

Figure 9.2
Light-Gauge Closed Head Drum

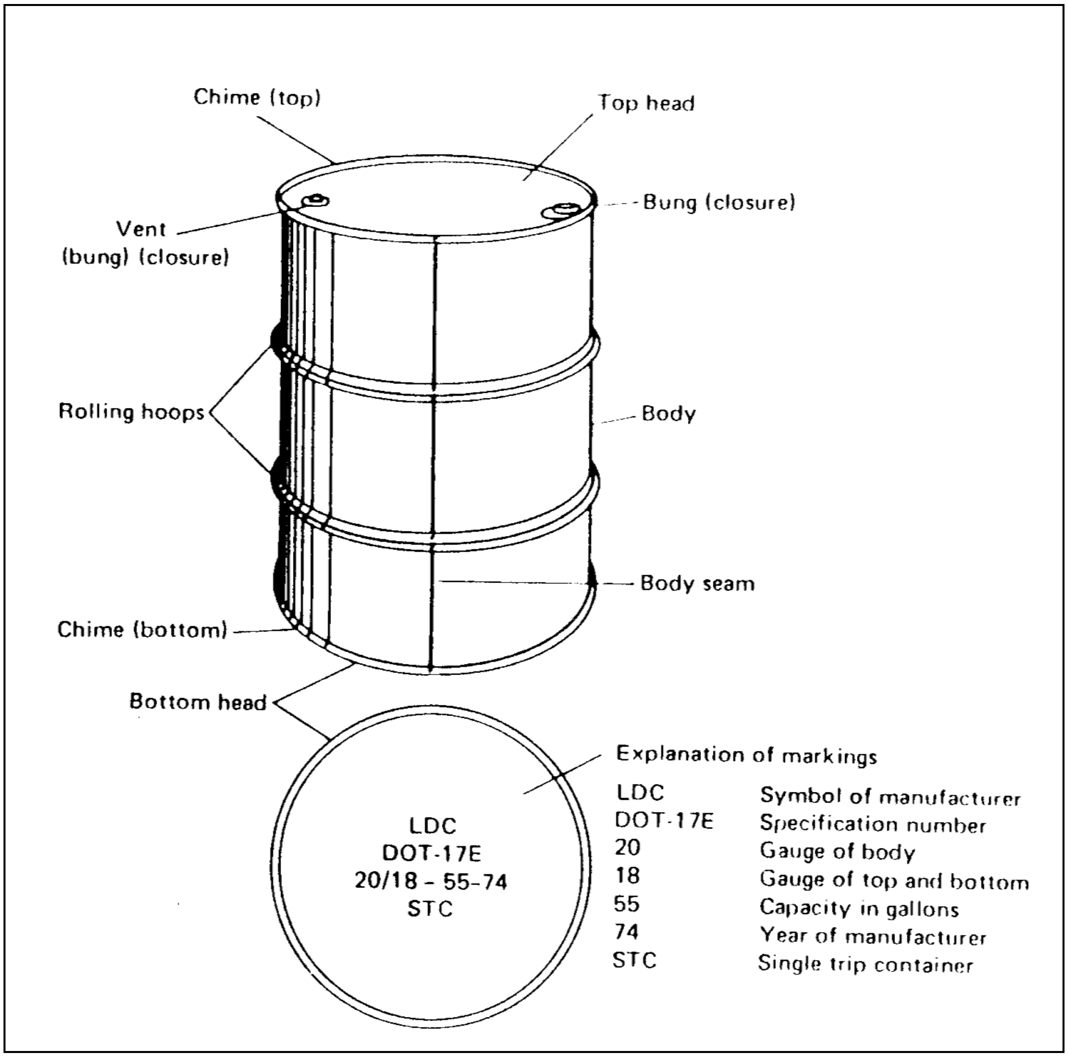
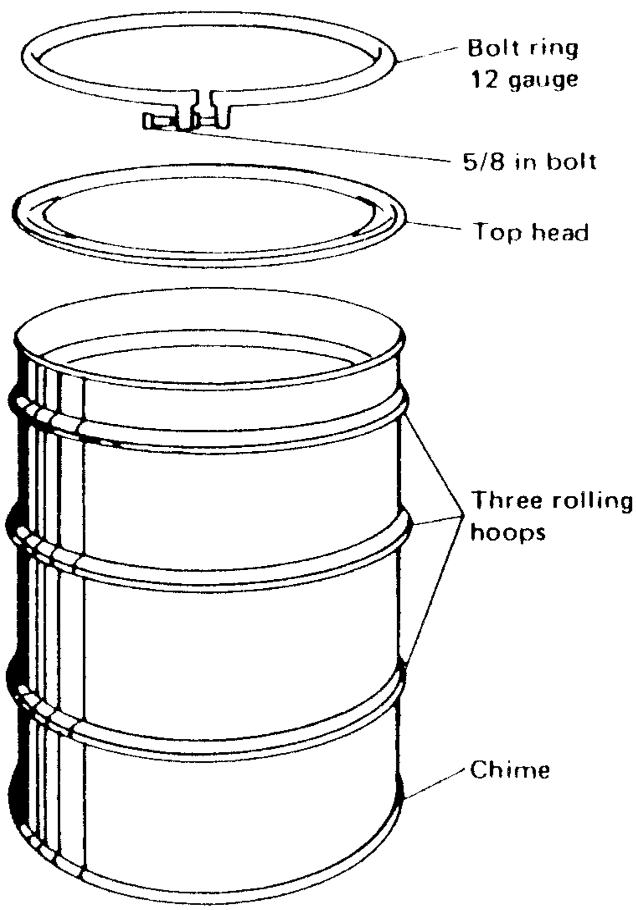


Figure 9.3
Light-Gauge Open Head Drum



The waste generator, or a specialised hauler, generally collects the hazardous waste for delivery to a treatment or disposal site. The loading of collection vehicles is completed in either of the following ways:

(i) Wastes stored in large-capacity tanks are either drained or pumped into collection vehicles;

(ii) Wastes stored in sealed drums or sealed containers are loaded by hand or by mechanical equipment onto flatbed trucks.

The stored containers are transported unopened to the treatment and disposal facility. To avoid accidents and the possible loss of life, two collectors should be assigned when hazardous wastes are to be collected. The equipment used for collection vary with the waste characteristics, and the typical collection equipment are listed in Table 9.2 below:

Table 9.2
Equipment for Collection of Hazardous Waste

Waste Category	**Collection equipment and accessories**
Radioactive substances	Various types of trucks and railroad equipment depending on characteristics of wastes; special marking to show safety hazard; heavy loading equipment to handle concrete-encased lead containers.
Toxic chemicals	Flatbed trucks for wastes stored in drums; tractor-trailer tank truck combination for large volumes of wastes; railroad tank cars; special interior linings such as glass, fibreglass or rubber.
Biological wastes	Standard packers' collection truck with some special precautions to prevent contact between wastes and the collector; flatbed trucks for wastes stored in drums.
Flammable wastes	Same as those for toxic chemicals, with special colourings and safety warning printed on vehicles.
Explosives	Same as those for toxic chemicals with some restriction on transport routes, especially through residential areas.

Source: Tchobanoglous, et al., (1977 and 1993)

Note that for short-haul distances, drum storage and collection with a flatbed truck is often used. As hauling distances increase, the larger tank trucks, trailers and railroad tank cars are used.

9.2.3 Transfer and transport

The economic benefits derived by transferring smaller vehicle loads to larger vehicles, as discussed for non-hazardous solid waste in Unit 3, are equally applicable to hazardous wastes. However, the facilities of a hazardous waste transfer station are quite different from solid waste transfer station. Typically, hazardous wastes are not compacted (i.e., mechanical volume reduction) or delivered by numerous community residents. Instead, liquid hazardous wastes are generally pumped from collection vehicles and sludge or solids are reloaded without removal from the collection containers for transport to processing and disposal facilities.

It is unusual to find a hazardous waste transfer facility, where wastes are simply transferred to larger transport vehicles. Some processing and storage facilities are often part of the material handling sequence at a transfer station. For example, neutralisation of corrosive wastes might result in the use of a lower-cost holding tank on transport vehicles. As in the case of storage (see Subsection 9.2.3 above), great care must be exercised to avoid the danger of mixing incompatible wastes.

9.2.4 Processing

Processing of hazardous waste is done for purposes of recovering useful materials and preparing the wastes for disposal.

Processing can be accomplished on-site or off-site. The variables affecting the selection of processing site include the characteristics of wastes, the quantity of wastes, the technical, economical and environmental aspects of available on-site treatment processes and the availability of the nearest off-site treatment facility (e.g., haul distance, fees, and exclusions). The treatment of hazardous waste can be accomplished by physical, chemical, thermal or biological means. Table 9.3 below gives the various individual processes in each category:

Table 9.3
Hazardous Waste Treatment Operations and Processes

Operation/Processes	Functions performed[$]	Types of wastes[*]	Forms of waste[#]
Physical Treatment			
Aeration	Se	1, 2, 3, 4	L
Ammonia stripping	VR, Se	1, 2, 3, 4	L
Carbon sorption	VR, Se	1, 3, 4, 5	L,G
Centrifugation	VR, Se	1, 2, 3, 4, 5	L
Dialysis	VR, Se	1, 2, 3, 4	L
Distillation	VR, Se	1, 2, 3, 4, 5	L
Electro dialysis	VR, Se	1, 2, 3, 4, 6	L
Encapsulation	St	1, 2, 3, 4, 6	L,S
Evaporation	VR, Se	1, 2, 5	L
Filtration	VR, Se	1, 2, 3, 4, 5	L,G
Flocculation/Settling	VR, Se	1, 2, 3, 4, 5	L
Flotation	Se	1, 2, 3, 4	L
Reverse osmosis	VR, Se	1, 2, 4, 6	L
Sedimentation	VR, Se	1, 2, 3, 4, 5	L
Thickening	Se	1, 2, 3, 4	L
Vapour scrubbing	VR, Se	1, 2, 3, 4	L
Chemical Treatment			
Calcination	VR	1, 2, 5	L
Ion exchange	VR, Se, De	1, 2, 3, 4, 5	L
Neutralisation	De	1, 2, 3, 4	L
Oxidation	De	1, 2, 3, 4	L
Precipitation	VR, Se	1, 2, 3, 4, 5	L
Reduction	De	1, 2	L
Solvent extraction	Se	1, 2, 3, 4, 5	L
Sorption	De	1, 2, 3, 4	L
Thermal treatment			
Incineration	VR, De	3, 5, 6, 7, 8	S, L, G
Pyrolysis	VR, De	3, 4, 6	S, L, G
Biological Treatment			
Activated sludges	De	3	L
Aerated lagoons	De	3	L
Anaerobic digestion	De	3	L
Anaerobic filters	De	3	L
Trickling filters	De	3	L
Waste stabilisation pond	De	3	L

Source: Tchobanoglous, et al., (1977, 1993)

[$] Functions: VR= volume reduction; Se = separation; De = detoxification; St = storage; [*] Waste types: 1= inorganic chemical without heavy metals; 2 = inorganic chemical with heavy metal; 3 = organic chemical without heavy metal; 4 = organic chemical with heavy metal; 5= radiological; 6 = biological; 7= flammable and 8= explosive; [#] Waste forms: S=solid; L= liquid and G= gas

Note that in practice, the physical, chemical and thermal treatment operations are the most commonly used. (Biological treatment processes are used less often because of their sensitivity.) Depending on the type of wastes being treated, one or more of these methods may be used. We will explain some of these methods later in Section 9.3.

9.2.5 Disposal

Regardless of their form (i.e., solid, liquid, or gas), most hazardous waste is disposed off either near the surface or by deep burial. Table 9.4 shows the various hazardous waste disposal methods:

Table 9.4
Hazardous Wastes Disposal and Storage Methods

Operation/Process	Functions performed$	Types of wastes*	Forms of waste#
Deep well injection	Di	1, 2, 3, 4,5,6,7	L
Detonation	Di	6, 8	S, L, G
Engineered storage	St	1, 2, 3, 4, 5,6,7,8	S, L, G
Land burial	Di	1, 2, 3, 4, 5,6,7,8	S, L
Ocean dumping	Di	1, 2, 3, 4, 7, 8	S, L, G

Source: Tchobanoglous, et al., (1977 and 1993)

*$ Functions: Di= disposal; St = storage; * Waste types: 1= inorganic chemical without heavy metals; 2 = inorganic chemical with heavy metal; 3 = organic chemical without heavy metal; 4 = organic chemical with heavy metal; 5= radiological; 6 = biological; 7= flammable and 8= explosive.*
 # Waste form: S=solid; L= liquid and G= gas

Although, controlled landfill methods have been proved adequate for disposing of municipal solid waste and limited amounts of hazardous waste, they are not suitable enough for the disposal of a large quantity of hazardous waste, due to the following reasons:

- possible percolation of toxic liquid waste to the ground water;
- dissolution of solids followed by leaching and percolation to the ground water;
- dissolution of solid hazardous wastes by acid leachate from solid waste, followed by leaching and percolation to the ground water;
- potential for undesirable reactions in the landfill that may lead to the development of explosive or toxic gases;

- volatilisation of hazardous waste leading to the release of toxic or explosive vapours to the atmosphere;
- corrosion of containers with hazardous wastes.

We must, therefore, take care both in the selection of a hazardous waste disposal site and its design. In general, disposal sites for hazardous wastes should be separate from those for municipal solid wastes. As hazardous wastes can exist in the form of liquids, sludges, solids and dusts, a correct approach for co-disposal for each of the hazardous wastes should be determined. To avoid the co-disposal of incompatible wastes, separate storage areas within the total landfill site should be designated for various classes of compatible wastes (Phelps, et al., 1995).

Liquid wastes are usually stored in a tank near the site and can be introduced into the landfill by means of trenches or lagoons, injection or irrigation. Sludges are also placed in trenches. During disposal of lightweight wastes, the disposal area must be kept wet to prevent dust emissions. Hazardous solid waste characterised by a high degree of impermeability as such must not be disposed of over large areas. When containerised wastes are to be disposed of, precautions must be taken to avoid the rupturing of containers during the unloading operation and the placement of incompatible waste in the same location. To avoid rupturing, the containers are unloaded and placed in position individually. The covering of the containers with earth should be monitored and controlled carefully to ensure that a soil layer exists between each container and the equipment placing the soil does not crush or deform the container.

While designing a landfill site for hazardous waste, provision should be made to prevent any leachate escaping from landfill site. This requires a clay liner, and in some cases, both clay and impermeable membrane liners are used. A layer of limestone is placed at the bottom of the landfill to neutralise the pH of leachate. A final soil cover of 25 cm or more should be placed over the liner. The completed site should be monitored continuously, both visually and with sample wells.

LEARNING ACTIVITY 9.2

Suggest the ways and means of properly managing hazardous 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.

Hazardous waste options

A three stage hierarchy of options for handling hazardous wastes are:

1) The top tier includes in plant options such as process manipulation, recycle and reuse options that reduce the production of hazardous waste in the first place. It also contains most desirable options.
2) Middle stage highlights processes that convert hazardous waste to less hazardous or non hazardous substances that include
   a) Incineration
   b) Land treatment
   c) Ocean and atmospheric assimilation

d) Chemical, physical and biological treatments
e) Thermal treatments

3) Last stage which is least preferred or desirable tier that is perpetual storage cheapest alternative. Few process include landfill, underground injection, arid region unsaturated zone, surface impoundments, salt formations and waste piles.

9.3 HAZARDOUS WASTE TREATMENT

In Section 9.2, we discussed the various elements of hazardous waste management such as generation, storage and transport, transfer and transport, processing and disposal. Processing is mainly done to recover useful products and to prepare waste for disposal. But prior to disposal, hazardous wastes need appropriate treatment, depending on the type of waste. The various options for hazardous waste treatment can be categorised under physical, chemical, thermal and biological treatments. We will discuss these options, in Subsections 9.3.1 to 9.3.3.

9.3.1 Physical and chemical treatment

Physical and chemical treatments are an essential part of most hazardous waste treatment operations, and the treatments include the following (Freeman, 1988):

(i) **Filtration and separation:** Filtration is a method for separating solid particles from a liquid using a porous medium. The driving force in filtration is a pressure gradient, caused by gravity, centrifugal force, vacuum, or pressure greater than atmospheric pressure. The application of filtration for treatment of hazardous waste fall into the following categories:

- **Clarification,** in which suspended solid particles less than 100 ppm (parts per million) concentration are removed from an aqueous stream. This is usually accomplished by depth filtration and cross-flow filtration and the primary aim is to produce a clear aqueous effluent, which can either be discharged directly, or further processed. The suspended solids are concentrated in a reject stream.

- **Dewatering** of slurries of typically 1% to 30 % solids by weight. Here, the aim is to concentrate the solids into a phase or solid form for disposal or further treatment. This is usually accomplished by cake filtration. The filtration treatment, for example, can be used for neutralisation of strong acid with lime or limestone, or precipitation of dissolved heavy metals as carbonates or sulphides followed by settling and thickening of the resulting precipitated solids as slurry. The slurry can be dewatered by cake filtration and the effluent from the settling step can be filtered by depth filtration prior to discharge.

(ii) **Chemical precipitation:** This is a process by which the soluble substance is converted to an insoluble form either by a chemical reaction or by change in the composition of the solvent to diminish the solubility of the substance in it. Settling and/or filtration can then remove the precipitated solids. In the treatment of hazardous waste, the process has a wide applicability in the removal of toxic metal from aqueous wastes by converting them to an insoluble form. This includes wastes containing arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium and zinc. The sources of wastes containing metals are metal plating and polishing, inorganic pigment, mining and the electronic industries. Hazardous wastes containing metals are also generated from cleanup of uncontrolled hazardous waste sites, e.g., leachate or contaminated ground water.

(iii) **Chemical oxidation and reduction (redox):** In these reactions, the oxidation state of one reactant is raised, while that of the other reactant is lowered. When electrons are removed from an ion, atom, or molecule, the substance is oxidised and when electrons are added to a substance, it is reduced. Such reactions are used in treatment of metal-bearing wastes, sulphides, cyanides and chromium and in the treatment of many organic wastes such as phenols, pesticides and sulphur containing compounds. Since these treatment processes involve chemical reactions, both reactants are generally in solution. However, in some cases, a solution reacts with a slightly soluble solid or gas.

There are many chemicals, which are oxidising agents; but relatively few of them are used for waste treatment. Some of the commonly used oxidising agents are sodium hypochlorite, hydrogen peroxide, calcium hypochlorite, potassium permanganate and ozone. Reducing agents are used to treat wastes containing hexavalent chromium, mercury, organometallic compounds and chelated metals. Some of the compounds used as reducing agents are sulphur dioxide, sodium borohydride, etc. In general, chemical treatment costs are highly influenced by the chemical cost. This oxidation and reduction treatment tends to be more suitable for low concentration (i.e., less than 1%) in wastes.

(iv) **Solidification and stabilisation:** In hazardous waste management, solidification and stabilisation (S/S) is a term normally used to designate a technology employing activities to reduce the mobility of pollutants, thereby making the waste acceptable under current land disposal requirements. Solidification and stabilisation are treatment processes designed to improve waste handling and physical characteristics, decrease surface area across which pollutants can transfer or leach, limit the solubility or detoxify the hazardous constituent. To understand this technology, it is important for us to understand the following terms:

- **Solidification:** This refers to a process in which materials are added to the waste to produce a solid. It may or may not involve a chemical bonding between the toxic contaminant and the additive.
- **Stabilisation:** This refers to a process by which a waste is converted to a more chemically stable form. Subsuming solidification, stabilisation represents the use of a chemical reaction to transform the toxic component to a new, non-toxic compound or substance.
- **Chemical fixation:** This implies the transformation of toxic contaminants to a new non-toxic compound. The term has been

misused to describe processes, which do not involve chemical bonding of the contaminant to the binder.

- **Encapsulation:** This is a process involving the complete coating or enclosure of a toxic particle or waste agglomerate with a new substance (e.g., S/S additive or binder). The encapsulation of the individual particles is known as micro-encapsulation, while that of an agglomeration of waste particles or micro-encapsulated materials is known as macro-encapsulation.

In S/S method, some wastes can be mixed with filling and binding agents to obtain a dischargeable product. This rather simple treatment can only be used for waste with chemical properties suitable for landfilling. With regard to wastes with physical properties, it changes only the physical properties, but is unsuitable for landfilling. The most important application of this technology, however, is the solidification of metal-containing waste. S/S technology could potentially be an important alternative technology with a major use being to treat wastes in order to make them acceptable for land disposal. Lower permeability, lower contaminant leaching rate and such similar characteristics may make hazardous wastes acceptable for land disposal after stabilisation.

(v) **Evaporation:** Evaporation is defined as the conversion of a liquid from a solution or slurry into vapour. All evaporation systems require the transfer of sufficient heat from a heating medium to the process fluid to vaporise the volatile solvent. Evaporation is used in the treatment of hazardous waste and the process equipment is quite flexible and can handle waste in various forms – aqueous, slurries, sludges and tars. Evaporation is commonly used as a pre-treatment method to decrease quantities of material for final treatment. It is also used in cases where no other treatment method was found to be practical, such as in the concentration of trinitrotoluene (TNT) for subsequent incineration.

(vi) **Ozonation:** Ozone is a relatively unstable gas consisting of three oxygen atoms per molecule (O_3) and is one of the strongest oxidising agents known. It can be substituted for conventional oxidants such as chlorine, hydrogen peroxide and potassium permanganate. Ozone and UV radiations have been used to detoxify industrial organic wastes, containing aromatic and aliphatic polychlorinated compounds, ketones and alcohols.

9.3.2 Thermal treatment

The two main thermal treatments used with regard to hazardous wastes are:

(i) **Incineration:** Incineration can be regarded as either a pre-treatment of hazardous waste, prior to final disposal or as a means of valorising waste by recovering energy. It includes both the burning of mixed solid waste or burning of selected parts of the waste stream as a fuel. The concept of treating hazardous waste is similar to that of municipal solid waste (see Unit 8).

(ii) **Pyrolysis:** This is defined as the chemical decomposition or change brought about by heating in the absence of oxygen. This is a thermal process for transformation of solid and liquid carbonaceous materials into gaseous components and the solid residue containing fixed carbon and ash. The application of pyrolysis to hazardous waste treatment leads to a two-step process for disposal. In the first step, wastes are heated separating the volatile contents (e.g., combustible gases, water vapour, etc.) from non-volatile char and ash. In the second step volatile components are burned under proper conditions to assure incineration of all hazardous components (Freeman, M. H. et al., 1988).

To elaborate, pyrolysis is applicable to hazardous waste treatment, as it provides a precise control of the combustion process. The first step of pyrolysis treatment is endothermic and generally done at 425 to 760°C. The heating chamber is called the pyrolyser. Hazardous organic compounds can be volatilised at this low temperature, leaving a clean residue. In the second step, the volatiles are burned in a fume incinerator to achieve destruction efficiency of more than 99%. Separating the process into two very controllable steps allows precise temperature control and makes it possible to build simpler equipment. The pyrolysis process can be applied to solids, sludges and liquid wastes. Wastes with the following characteristics are especially amenable to pyrolysis:

- Sludge material that is either too viscous, too abrasive or varies too much in consistency to be atomised in an incinerator.
- Wastes such as plastic, which undergo partial or complete phase changes during thermal processing.
- High-residue materials such as high-ash liquid and sludges, with light, easily entrained solids that will generally require substantial stack gas clean up.
- Materials containing salts and metals, which melt and volatilise at normal incineration temperatures. Materials like sodium chloride (NaCl), zinc (Zn) and lead (Pb), when incinerated may cause refractory spalling and fouling of the heat-exchanger surface.

9.3.3 Biological treatment

On the basis of the fact that hazardous materials are toxic to living beings, it is not uncommon for some to assume that biological treatment is not possible for hazardous wastes. This assumption is untenable, and, in fact, we must aggressively seek biological treatment in order to exploit the full potential of hazardous wastes in terms of removal efficiency and cost (Freeman, et al., 1988). Against this background, let us now list some of the techniques used for biological treatment of hazardous waste:

(i) **Land treatment:** This is a waste treatment and disposal process, where a waste is mixed with or incorporated into the surface soil and is degraded, transformed or immobilised through proper management. The other terminologies used commonly include land cultivation, land farming, land application and sludge spreading. Compared to other land disposal options (e.g., landfill and surface impoundments), land treatment has lower long-term monitoring, maintenance and potential clean up liabilities and because of this, it has received considerable attention as an ultimate disposal method. It is a dynamic, management-intensive process involving waste, site, soil, climate and biological activity as a system to degrade and immobilise waste constituents.

In land treatment, the organic fraction must be biodegradable at reasonable rates to minimise environmental problems associated with migration of hazardous waste constituents. The various factors involved in the operation of the system are as follows:

- **Waste characteristics:** Biodegradable wastes are suitable for land treatment. Radioactive wastes, highly volatile, reactive, flammable liquids and inorganic wastes such as heavy metals, acids and bases, cyanides and ammonia are not considered for land treatment. Land treatability of organic compound often follows a predictable pattern for similar type of compounds. Chemical structure, molecular weight, water solubility and vapour pressure are few of the characteristics that determine the ease of biodegradation.
- **Soil characteristics:** The rate of biodegradation and leaching of waste applied, the availability of nutrients and toxicants to microorganisms and the fate of hazardous waste constituents are determined largely by application rate as well as the soil's chemical and physical characteristics or reaction. Principal soil characteristics affecting land treatment processes are pH, salinity, aeration, moisture holding capacity, soil temperature, etc. Some of the characteristics can be improved through soil amendments (e.g., nutrients, lime, etc.), tillage or through adjustments of loading rate, frequency, etc., at the time of waste application.
- **Microorganisms:** Soil normally contains a large number of diverse microorganisms, consisting of several groups that are predominantly aerobic in well-drained soil. The types and population of microorganisms present in the waste-amended soil depend on the soil moisture content, available oxygen, nutrient composition and other

characteristics. The key groups of the microorganisms present in the surface soil are bacteria, actinomycetes, fungi, algae and protozoa. In addition to these groups, other micro and macro fauna, such as nematodes and insects are often present.

- **Waste degradation:** Conditions favourable for plant growth are also favourable for the activity of soil microorganisms. The factors affecting waste degradation that (may be adjusted in the design and operation of a land treatment facility) are soil pH (near 7), soil moisture content (usually between 30 to 90 %), soil temperature (activity decreases below 10°C) and nutrients.

(ii) **Enzymatic systems:** Enzymes are complex proteins ubiquitous in nature. These proteins, composed of amino acids, are linked together via peptide bonds. Enzymes capable of transforming hazardous waste chemicals to non-toxic products can be harvested from microorganisms grown in mass culture. Such crude enzyme extracts derived from microorganisms have been shown to convert pesticides into less toxic and persistent products. The reaction of detoxifying enzymes are not limited to intracellular conditions but have been demonstrated through the use of immobilised enzyme extracts on several liquid waste streams. The factors of moisture, temperature, aeration, soil structure, organic matter content, seasonal variation and the availability of soil nutrients influence the presence and abundance of enzymes.

(iii) **Composting:** The principles involved in composting organic hazardous wastes are the same as those in the composting of all organic materials (See Unit 8), though with moderate modifications. The microbiology of hazardous wastes differs from that of composting in the use of inoculums. The reaction is that certain types of hazardous waste molecules can be degraded by only one or a very few microbial species, which may not be widely distributed or abundant in nature. The factors important in composting of hazardous wastes are those that govern all biological reactions. The principal physical parameters are the shape and dimensions of the particles of the material to be composted and the environmental factors of interest in an operation are temperature, pH, available oxygen, moisture, and nutrient availability.

As we studied in Unit 7, the compost technology can be divided into two broad classes – windrow (open pile) and in-vessel (enclosed), and the former may be further subdivided into turned and forced aeration (static pile). Composting, by no means, is a panacea for the hazardous waste problem. When considering the future of hazardous waste composting needs, attention must be paid to the advantages and disadvantages inherent in composting as compared to those inherent in physical, chemical and thermal method of waste treatment.

(iv) **Aerobic and anaerobic treatment:** Hazardous materials are present in low to high concentration in wastewaters, leachate and soil. These wastes are characterised by high organic content (e.g., up to 40,000 mg/l total organic carbon), low and high pH (2 to 12), elevated salt levels (sometimes, over 5%), and presence of heavy metals and hazardous organics. Hazardous wastes can be treated using either aerobic or anaerobic treatment methods.

In aerobic treatment, under proper conditions, microorganisms grow. They need a carbon and energy source, which many hazardous wastes satisfy, nutrients such as nitrogen, phosphorus and trace metals and a source of oxygen. Some organisms can use oxidised inorganic compounds (e.g. nitrate) as a substitute for oxygen. Care is to be taken such that all the required nutrients and substances are supplied in sufficient quantities. Temperature and pH must be controlled as needed and the substances that are toxic to the organisms (e.g., heavy metals) must be removed.

Anaerobic treatment is a sequential biologically destructive process in which hydrocarbons are converted, in the absence of free oxygen, from complex to simpler molecules, and ultimately to carbon dioxide and methane. The process is mediated through enzyme catalysis and depends on maintaining a balance of population within a specific set of environmental conditions. Hazardous waste streams often consist of hydrocarbons leading to higher concentrations of chemical oxygen demand (COD). Depending upon the nature of waste, the organic constituents may be derived from a single process stream or from a mixture of streams.

The treatability of the waste depends upon the susceptibility of the hydrocarbon content to anaerobic biological degradation, and on the ability of the organisms to resist detrimental effect of biologically recalcitrant and toxic organic and inorganic chemicals. The metabolic interactions among the various groups of organisms are essential for the successful and complete mineralisation of the organic molecules. Various parameters such as the influent quality, the biological activity of the reactor and the quality of the reactor environment are monitored to maintain efficient operating conditions within the reactor.

LEARNING ACTIVITY 9.3

Explain the factors required for land treatment operation of hazardous 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.

9.4 POLLUTION PREVENTION AND WASTE MINIMISATION

Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the generation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous and non-hazardous materials, energy, water or other resources as well as those that protect natural resources through conservation or more efficient use. Pollution prevention is the maximum feasible reduction of all wastes generated at production sites. It involves the judicious use of resources through source reduction, energy efficiency, reuse of input materials and reduces water consumption.

Waste minimisation means the feasible reduction of hazardous waste that is generated prior to treatment, storage and disposal. It is defined as any source reduction or recycling activity that results in the reduction of the total volume of hazardous waste, or toxicity of hazardous waste, or both. Practices that are considered in waste minimisation include recycling, source separation, product substitution, manufacturing process changes and the use of less toxic raw materials.

Pollution prevention and waste minimisation provides us with an opportunity to be environmentally responsible (http://www.ehs.umaryland.edu/waste/pollutio.htm). While pollution prevention reduces waste at its source, waste minimisation, including recycling and other methods, reduces the amount of waste. In what follows, we will look at some of the factors that can contribute to pollution prevention and waste minimisation.

(i) **Management support and employee participation:** A clear commitment by management (through policy, communications and resources) for waste minimisation and pollution prevention is essential to earn the dedication of all employees. For this to happen, a formal policy statement must be drafted and adopted. The purpose of this statement is to reflect commitment and attitude towards protecting the environment, minimising or eliminating waste and reusing or recycling materials by the laboratories, departments and industries. Creative, progressive and responsible leadership will serve to develop an environmental policy. However, the total employee workforce will need to be involved to realise the fruits of the planning.

(ii) **Training:** As with any activity, it is important for management to train employees so that they will have an understanding of what is expected of them and why they are being asked to change the way things are done.

Employees must be provided with formal and on-the-job training to increase awareness of operating practices that reduce both solid and hazardous waste generation. The training programme should include the industries' compliance requirements, which may be found in the waste management policies, occupational health and safety requirements. Additionally, training on waste minimisation and pollution prevention is necessary.

(iii) **Waste audits:** A programme of waste audits at the departmental level will provide a systematic and periodic survey of the industries designed to identify areas of potential waste reduction. The audit programme includes the identification of hazardous wastes and their sources, prioritisation of various waste reduction actions to be undertaken, evaluation of some technically, economically and ecologically feasible approaches to waste minimisation and pollution prevention, development of an economic comparison of waste minimisation and pollution prevention options and evaluation of their results.

(iv) **Good operating practices:** These practices involve the procedural or organisational aspects of industry, research or teaching activities and, in some areas, changes in operating practices, in order to reduce the amount of waste generated. These practices would include, at a minimum, material handling improvements, scheduling improvements, spill and leak prevention, preventive maintenance, corrective maintenance, material/waste tracking or inventory control and waste stream segregation, according to the toxicity, type of contaminant and physical state.

(v) **Material substitution practices:** The purpose of these practices is to find substitute materials, which are less hazardous than those currently utilised and which result in the generation of waste in smaller quantities and/or of less toxicity.

(vi) **Technological modification practices:** These practices should be oriented towards process and equipment modifications to reduce waste generation. These can range from changes that can be implemented in a matter of days at low cost to the replacement of process equipment involving large capital expenditures.

(vii) **Recycling options:** These options are characterised as use/reuse and resource recovery techniques. Use and reuse practices involve the return of a waste material either to the originating process or to another process as a substitute for an input material. Reclamation practices tender a waste to another company.

(viii) **Surplus chemical waste exchange options:** Inter- and intra-department chemical exchange is to be implemented and encouraged by employers/employees. Material exchanges not only reduce wastes but also save money – both are important considerations, during times of fiscal crisis.

In addition, by auditing each department or section, a knowledge base of chemical purchase and usage can be developed, allowing each department to develop and implement controls on the purchase of chemicals, institute intra-departmental chemical sharing/swapping programmes and eliminate excessive purchase and usage.

Research protocols should also be examined and modified in a manner similar to the above. Facility operations need to be examined to determine whether changes in practices and procedures will result in the generation of non-hazardous or less hazardous waste, or waste reduced in toxicity or volume. The specifics to be considered in this context include the substitution of non-toxic materials for toxic ones, distillation or evaporation of water-based chemical end-products, reclamation and reuse of common solvents, use of non-chromate cleaners as a standard part of doing business to generate non-hazardous end products. By implementing and adhering to the guidelines for handling and storing wastes at the point of generation, the costs associated with hazardous waste disposal will also be minimised.

LEARNING ACTIVITY 9.4

Explain the advantages of waste minimisation and pollution prevention.

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

9.5 HAZARDOUS WASTES MANAGEMENT IN INDIA

In the USA, more than 70% of the hazardous waste generated was produced from chemical and petrochemical industries. Of the remaining waste produced, 22% was generated by metal related industries. As industrialisation proceeds, the management of hazardous wastes is increasingly becoming a serious problem in India as well. The Indian chemical industry, which accounts for about 13% of the total industrial production and about 10% of the GNP valued at US $ 2.64 X 1011 (NNP is US $ 2.345 X 1011) per annum, employs about 6% of the nation's industrial workforce and is one of the major generators of toxic and hazardous wastes. There are 13,011 industrial units located in 340 districts, out of which 11,038 units have been granted authorization for multiple disposal practices encompassing incineration, storage land disposal and other disposal options. However, small and medium sized enterprises (SMEs) are the major sources of hazardous wastes. And, the States of Andhra Pradesh, Assam, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan and Tamil Nadu generate the majority of all hazardous wastes. The total estimate of hazardous waste generated in India is 4,434,257 tonnes per annum.

India is the first country that has made provisions for the protection and improvement of environment in its Constitution. The Directive Principles of State Policy of the Constitution, Article 48-A of Chapter IV enjoins the State to make endeavor for protection and improvement of the environment and for safeguarding the forest and wild life of the country. In Article 51 A (g) of the Constitution, one of the Fundamental Duties of every citizen of India is to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures. India has enacted the following laws, regulations and standards governing the country's environmental protection:

(i) The Water (Prevention and Control of Pollution) Act, 1974 as amended in 1988.
(ii) Water (Prevention and Control of Pollution) Rules, 1975.
(iii) The Water (Prevention and Control of Pollution) Cess Act, 1977, as amended by Amendment Act, 1991.
(iv) The Water (Prevention and Control of Pollution) Cess Rules, 1978.
(v) The Air (Prevention and Control of Pollution) Act, 1984, as amended by Amendment Act, 1987.
(vi) The Air (Prevention and Control of Pollution) Rules 1982 and 1983.
(vii) The Environment (Protection) Act, 1986.

(viii) Hazardous Waste (Management and Handling) Rules, 1989 as amended in 2000.

(ix) Management, Storage and Import of Hazardous Chemical Rules, 1989.

(x) Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms, Genetically Engineered Microorganisms or Cells Rules, 1989.

(xi) The Public Liability Insurance Act, 1991.

(xii) The Public Liability Insurance Rules, 1991.

(xiii) The Biomedical Wastes (Management and Handling) Rules, 1995.

(xiv) Municipal Wastes (Management and Handling) Draft Rules, 1999.

(xv) Hazardous Waste (Management and Handling) Amendment Rules 2000.

Because of these amendments, the legal management of hazardous substances in India will now apply to 44 industrial processes, as specified in Schedule I of the Rules. The penal provisions for non-compliance under Hazardous Waste (Management and Handling) Amended Rules 2000 and Environment (Protection) Act, 1986 are:

- The State Pollution Control Board may cancel an authorisation issued under these rules or suspend it for such period as it thinks fit, if, in its opinion, the authorised person has failed to comply with any of the conditions of the authorisation or with any provisions of the Act of these rules, after giving the authorised person an opportunity to show cause and after recording reasons therefore.
- The occupier, transporter and operator of a facility shall be liable for damages caused to the environment resulting due to improper disposal of hazardous waste listed in Schedule 1, 2 and 3 of The Hazardous Waste (Management and Handling) Amendment Rules, 2000. The occupier and operator of a facility shall also be liable to reinstate or restore damaged or destroyed elements of the environment. The occupier and operator of a facility shall be liable to pay a fine as levied by the SPCB with the approval of the Central Pollution Control Board (CPCB) for any violation of the provisions under these rules. An appeal shall lie against any order of grantor refusal of an authorisation by the Member Secretary, SPCB, etc., to the Secretary, Department of Environment of the State.

Besides the aforementioned provisions for non-compliance(s), the Penalty Provisions, delineated under Sections 15 (1,2) and 16 of the Environmental (Protection) Act, 1986 are also applicable.

Furthermore, the Union Ministry of Environment and Forests, through the Gazette Notification of March 24, 1992, introduced Public Liability Insurance Act Policy, which is specially designed to protect any person, firm, association, or company who owns or has control over handling any hazardous substance at the time of accident. These include 179 hazardous substances along with three categories of inflammable substances. The term *handling* means manufacturing, processing, treatment, packaging, storing, transportation by vehicle, use, collection, destruction, conversion, offering for sale, transfer or any other similar form of dealing with hazardous substances.

Hazardous waste (Management, Handling and transboundary movement) rules 2007.

Hazardous Changes to the Hazardous waste Rules

Existing Regulation

The Ministry had notified the Hazardous Wastes (Management and Handling) Rules,1989 as amended in 2000 and 2003 for regulating management and handling of hazardous waste. Based on the experience gained in the implementation of these Rules, the Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2008 have been notified repealing the earlier Rules with a view to ensuring effective implementation. The Ministry has also provided financial assistance for strengthening the State Pollution Control Boards (SPCBs) for facilitating implementation of the Rules. Financial assistance has also been provided for setting up Common Treatment, Storage and Disposal Facilities for hazardous waste management. In addition, the Ministry and the Central Pollution Control Board (CPCB) from time to time sponsor training programmes for creation of awareness about the provisions laid down in the Rules. The CPCB has also published guidelines on various aspects of the hazardous waste management for ensuring compliance of the Rules.(source: http://www.pib.nic.in/release/release.asp?relid=44081)

In new rules, categories of wastes banned for export and import had also been defined, fulfilling the Basel Convention, ratified by India in 1992. The basic objectives of the Basel Convention are for the control and reduction of transboundary movements of hazardous and other wastes subject to the Convention, prevention and minimization of their generation, environmentally sound management of such wastes and for active promotion of the transfer and use of cleaner technologies.

Current Scenario

The hazardous waste generated in the country per annum currently is estimated to be around 8 million tonnes out of which 70% is being generated by five states, namely Gujarat, Maharashtra, Tamil Nadu, Karnataka and Andhra Pradesh. Only three States have developed common TSDF (Treatment, Storage, Disposal Facility), which are essential component of proper hazardous waste management activity for ultimate disposal of the hazardous wastes in an environmentally sound manner. These 10 facilities are currently operational only in Gujarat, Andhra Pradesh and Maharashtra. (Source: Central Pollution Control Board).

Ground Reality

Though the Hazardous Wastes (Management & Handling) Rules were notified in 1989, the implementation on the ground has left a lot to be desired. Lack of proper infrastructure and strict enforcement mechanism has led to hazardous waste still remaining a grave problem. New emerging wastes and loopholes in the current legislation have also contributed to this. There are still problems of hazardous waste not being managed in sound environmental conditions, improper dumping and lack of proper treatment and disposal facilities.

However, the new draft claims to address sustainable development concerns and also enable the recovery and/or reuse of useful materials from hazardous materials generated from a process, thereby, reducing the hazardous wastes destined for final disposal and to ensure the environmentally sound management of all hazardous materials.Drawbacks for these new rules were mentioned in the Annexure I source: http://www.toxicslink.org/art-view.php?id=130

SUMMARY

In this Unit, our focus was on the management of hazardous wastes. We began the Unit with a discussion on the identification and classification of hazardous wastes, and in that context, explained the major identification lists (i.e., F, K, P and U), the characteristics (i.e., corrosivity, ignitability, toxicity and reactivity) and classifications (i.e., radioactive substances, chemicals, biological wastes, flammable wastes and explosives.) We then discussed the functional elements involved in hazardous waste management (i.e., generation, storage and collection, transfer and transport, processing and disposal.) Subsequently, we explained how hazardous wastes could be treated through the physical, chemical, thermal and biological means to reduce their impact on public health and the environment. We then discussed some of the techniques for hazardous waste minimisation and pollution prevention. We closed the Unit by touching upon some aspects of hazardous waste management in India.

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Lecture 9

Model Answers to Learning Activities

LEARNING ACTIVITY 9.1

The major hazardous waste generated, though in small amounts, is that generated from garages and residences. There are 4 garages in operation in our locality and the major waste constituents that are considered hazardous include gas, fuel, antifreeze, brake fluid, motor oil, batteries, etc. Of these, the major one is motor oil. The 2 characteristics of motor oil are ignitability and toxicity. Motor oil readily causes fire and burns vigorously so as to create a hazard. The flash point varies in motor oil. The lower the flash point the greater the tendency for the oil to suffer vaporization loss at high temperatures and to burn off on hot cylinder walls and pistons. Toxicity of motor oil has a deleterious effect on aquatic animals and plants.

LEARNING ACTIVITY 9.2

Management of hazardous waste follows the functional elements of solid waste, viz., generation, storage and collection, transfer and transport, processing and disposal. Special facilities are used that have sufficient capacity to hold wastes accumulated over a period of several days. Small amounts are containerised, and limited quantities may be stored for periods covering months or years. The waste generator or a specialised hauler normally does the collection of hazardous wastes for delivery to a treatment or disposal facility. All storage containers remain unopened till they reach the treatment and disposal facility. Processing of waste can be done to recover useful materials and to prepare the wastes for disposal. Processing can be accomplished either on-site or off-site. Regardless of their forms, most hazardous wastes are disposed of either near the surface or by deep burial. When landfills are used for such wastes, precautions must be taken to avoid the rupturing of containers during the unloading operation and the placement of incompatible wastes in the same location. Also provisions should be made to prevent any leachate from escaping from landfills, which can be done both visually and by monitoring wells.

LEARNING ACTIVITY 9.3

The factors required for land treatment operation involve the consideration of waste and soil characteristics, microorganisms and waste degradation.

LEARNING ACTIVITY 9.4

Waste minimisation means reduction, to the extent feasible, of hazardous waste that is generated prior to treatment storage and disposal. The advantages include reduction of the total volume and toxicity of hazardous waste or reduction in both. By using materials carefully so as to reduce the generation of waste, pollution is reduced, resources are conserved and costs of waste disposal are minimised. Pollution prevention is the use of materials, processes or practices that reduce or eliminate the creation of pollutants or wastes at the source. The advantages include reduction of the use of hazardous and non-hazardous materials, energy, water or other resources as well as those that protect natural resources through conservation or that is more efficient.

Annexure I

This new revision is a major departure from the earlier amendments, as it talks about 'Hazardous Materials' instead of 'Hazardous Waste'. It categories recyclable hazardous waste as non-waste, instead of giving it a term "Hazardous Material'. This change is bound to create uncertainty among the generators regarding whether they are handling hazardous waste or hazardous materials and leaves scope for different interpretation. In fact this will take out most hazardous waste out of 'waste' category and will eventually lead to improper handling causing environmental degradation. This ill-defined categorisation will also put all the raw materials with the mentioned characteristics (like flammability, corrosiveness etc) under this Rule. This can snowball into a major monitoring and implementation drawback. The Rule also has overlapped with the existing Manufacture, Storage and Import of Hazardous Chemical Rules, 1989. Moreover, it is an unnecessary change as terming recyclables as waste is not in anyway anti recycling.

This move is also in complete violation of the Basel Convention. The new categorization will open the floodgates for import of recyclable hazardous waste to India, making it a global waste destination. In times when India is finding it difficult to manage its own waste, this shift is certainly not warranted.

The revision also does not take into account the observation made in the Supreme Court judgments on the issue, which clearly stresses on the need to have better implementation of the existing Rule.

The Draft Rule also reduces the control over the generators and handlers of hazardous waste. It removes the stipulation, which required them to seek authorisation from State Pollution Control Boards. This is bound to worsen the situation, as it will be impossible for the Central Bodies to monitor the units, leading to no control situation.

Some of the other major drawbacks in this new draft rules are:

-- The Draft Rule describes certain characteristics by which the waste can be termed hazardous. Characteristics like leachibility have not been included

-- The definition of Disposal covers only land disposal- missing out on disposal in other mediums

-- The Rule does not mandate permission from Transit countries in case of export-import- this is in complete violation of the Basel Convention

-- It does not propose streamlined collection mechanism for hazardous waste- specially new wastes like E-Waste

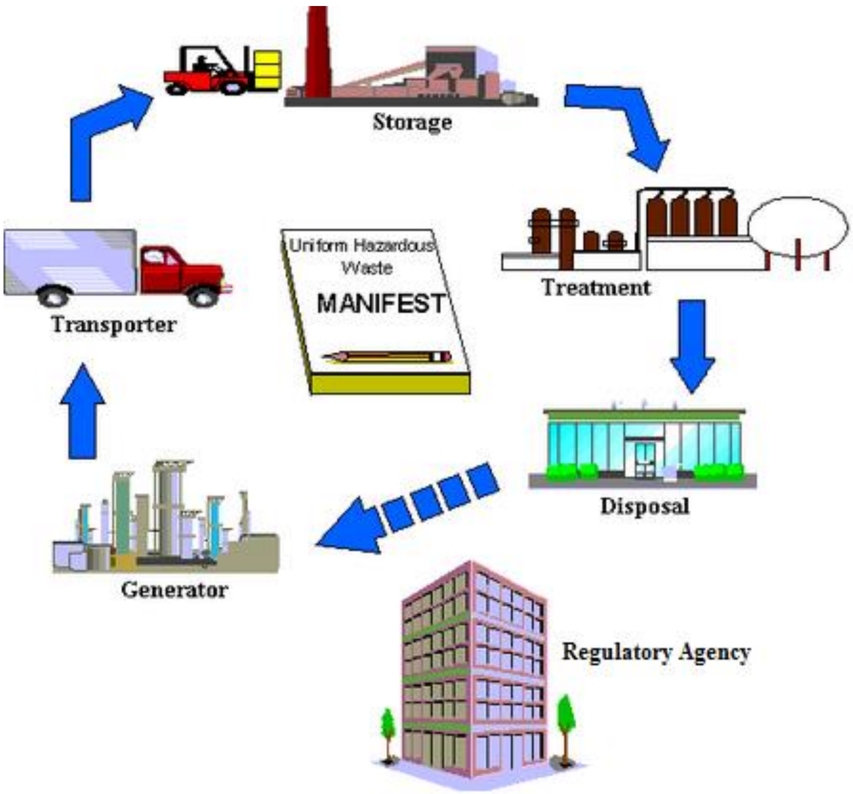
-- The rule also does not address the inadequacy of disposal sites

-- Occupational health safety measures in the units handling hazardous waste have also not been dealt with.

-- No incentive or move to phase out toxic products in the production stage

These new modifications are bound to worsen the situation, which currently needs a strict and effective monitoring and implementation strategy. The problem, at present, is that the enforcement mechanism lacks teeth and has failed in curbing the improper handling of Hazardous waste.

The need of the hour is to have stringent implementation of the Existing Rules, which will lead to proper collection mechanism, sound recycling technologies, adequate and scientifically designed disposal sites. Sustainable Development concerns or enabling recovery and reuse of useful material from hazardous waste and thereby reducing the waste for final disposal is certainly a welcome thought. But the steps taken to achieve these in the draft Rule do seem ineffectual. The steps, in fact, seem to be more favourable towards making India a 'Dumping Destination' in garb of 'Recycling Destination'.



TOPIC 1: RELEVANT REGULATIONS IN HAZARDOUS WASTE MANAGEMENT

Content: Municipal solid waste and hazardous waste (management and handling), biomedical waste handling rules, batteries (management and handling), fly ash rules

ABSTRACT

This module gives an introduction to the rules and regulations governing management of different types of waste.

IITM-EWRE

Solid and Hazardous Waste Management

TOPIC 1: RELEVANT REGULATIONS IN HAZARDOUS WASTE MANAGEMENT

USEPA defines **Hazardous Waste** as waste that is dangerous or potentially harmful to our health or environment. Hazardous wastes can be liquid, solid, gaseous or sludge. They can be discarded commercial products, by-products from industries, or from households.

This module gives a brief introduction to the different kinds of waste and guidelines for waste management practices.

Hazardous Waste includes many different toxic chemicals (organic compounds as well as metals). They require complex treatment processes. Some of the commonly known priority chemicals are polychlorinated biphenyls (PCBs), furans, polyaromatic hydrocarbons (PAHs); and toxic metals include lead, cadmium, chromium, mercury. These pose serious health hazards and their migration must be contained.

- Further reading on Priority Chemicals (PCs):
  - http://www.epa.gov/osw/hazard/wastemin/priority.htm

Municipal Solid Waste Landfills (MSWLFs) receive household waste. MSWLFs can also receive non-hazardous sludge, industrial solid waste, construction debris. Some of the governing regulations are:

- Location: MSWLFs to be built away from faults, wetlands, plains, farmlands
- Composite liner: A geomembrane liner to protect groundwater and underlying soil
- Leachate removal and collection systems: Removes leachate from landfill
- Operation and management: Covering waste frequently with few inches of soil – to protect human and animal health
- Groundwater monitoring: To ensure materials have not escaped from landfill
- Closure and post-closure: Covering landfills and constant monitoring
- Corrective action: Control and clean-up discharges from landfill – to protect groundwater
- Financial assistance: Funding to maintain the landfill and the surrounding environment

Municipal Solid Waste Generation Quantity in Indian Cities:

It has been estimated that urban India generates about 188,500 tons of municipal solid waste per day, at a per capita generation of 500 grams per day.

Suggested Reading: *Sustainable Solid Waste Management in India.* Earth Engineering Center (EEC), Waste-To-Energy Research & Technology Council (WTERT), Columbia University. 2011.

Hospital Waste is produced by hospitals, clinics, veterinary hospitals, dental practices and so on. Medical waste is mostly incinerated. However, burning of waste leads to air pollution; it must be seen if the resulting air emissions are well within the standards for that area. Open dumping of medical waste is not advised, as it will contribute to spread of diseases. There are some alternatives to incineration of medical waste:

- Thermal treatment (such as microwave)
- Steam sterilization
- Electropyrolysis
- Chemical treatment

Batteries contain heavy metals (mercury, zinc, nickel, cadmium) and improper disposal of batteries will contaminate the environment. It is important to recycle batteries:

- Lead-acid (wet) batteries can be recycled. The battery is crushed into pieces, following which the plastic is reclaimed and processed into new plastic products; while the purified lead is used in battery manufacturing and other industries.
- Dry cell batteries (used in household items such as flashlight) contain zinc, mercuric oxide, silver oxide and lithium. The heavy metals can be reclaimed in this case as well.

Fly ash is the residue from combustion of coal is usually captured by the use of pollution control technology such as scrubbers. Fly ash constitutes the majority of particulate matter; and poses a significant problem when it mixes with groundwater (as leachate from landfills). USEPA has recently approved the use of fly ash in concrete, and this can be seen in a favourable light (sustainable materials management).

- The article can be found at:
    - http://www.worldcement.com/news/environmental/articles/EPA_approves_use_of_flyash_in_concrete_868.aspx#.U7TlFPmSwu8

Plastic Waste must be recycled – the repercussions of indiscriminate dumping of plastic waste has been made very clear. Plastic is recycled according to the resin type – it is shredded, the impurities eliminated, the remaining material is extruded into pellets and then used to manufacture other products. The most common one is PET (polyethylene terephthalathe) bottle recycling – the mineral water bottle for instance.

Hazardous Waste Management Guidelines

Guidelines for Generator of Hazardous Waste

1. To keep a complete record of the types, quantities and characteristics of waste.
2. To segregate hazardous waste from non-hazardous waste at source.
3. To transport hazardous waste only through the specified and registered transporters.
4. To fulfill the pre-transport requirements before transporting hazardous waste.
5. To dispose of hazardous waste only at the notified disposable facilities.
6. The regulatory authorities shall ask the occupier or generator to submit quarterly reports.
7. The authorities should ensure that the occupier/generator sends a copy of the manifest to them as soon as the hazardous wastes is shipped for ultimate disposal.
8. The regulatory authorities may allow the occupier/generator to store his hazardous waste on-site provided that:
    - The waste is stored in the specified containers and occupier/generator follows the requirements for storing in the containers.
    - The date upon which each period of storage begins is clearly marked and visible on each container.
    - While being stored on-site, each container is labelled or marked with the words **"HAZARDOUS WASTE"**, both in English and respective local language.
9. The regulatory authorities may allow the occupier/generator to store his hazardous waste on-site a maximum quantity of 10,000 kg or a truckload – whichever is less for a maximum period of 90 days.
10. If an occupier/generator generates less than 1,000 kg of hazardous waste in a month, he may be considered as a small quantity generator. Such type of generators may be allowed to store their waste on-site for a maximum period of 180 days. In any case, the quantity of waste should not exceed 6,000 kg at any given point of time.

11. The regulatory authorities may provide an extension in the storage period to the occupier, on case-by-case basis, provided that:
    - An occupier/generator who generates less than 1000 kg of hazardous waste in a month and who transports his waste more than a distance of 500 km for off-site storage, treatment and/ or disposal may be allowed to store hazardous waste on-site for a maximum period of 270 days at the discretion of regulatory authorities. In any case the quantity of waste should not exceed 10,000 kg at any given point of time.
12. To ensure that the occupier/generator disposes their waste only in the notified disposal facilities.
13. In case of any unforeseen, temporary, and uncontrollable circumstances, the regulatory authorities may grant an extension to 90-day or 180-day or 270-day in the on-site period up to a maximum period of 30 days, after receiving written application from the occupier/generator.
14. An occupier/generator who generates less than 1000 kg of hazardous waste or more than 10,000 kg; or store hazardous waste more than 90 days or 180 days or 270 days, as the case may be; should be considered as an operator of a storage facility, unless an extension has been provided by the regulatory authorities.
15. An occupier may be allowed to store not more than one day's quantity of semi-solid hazardous waste at a time in containers near the source/point of generation, which is under the control of the operator generating the waste. In any case, the container should have marking of the words **"HAZARDOUS WASTE"** both in English and respective local language.
16. At all times there must be at least one employee either on the premises or on call with the responsibilities for coordinating all emergency response measures.
17. To inspect the on-site storage areas for proper storage.
18. In order to track the hazardous waste from the source of generation to the final disposal points, the regulatory authorities should introduce the manifest system. This system should not only help the regulatory authorities in tracking the hazardous waste but also ensure the safe disposal of the waste. The manifest system would serve as a "chain of custody" document. Every time the shipment changes hands, those responsible sign the manifest.

Guidelines for Transportation of Hazardous Waste

1. Transportation of hazardous waste being the important link in hazardous waste management system, it requires precise control to ensure safe disposal of such wastes. Therefore, it would be prudent to consider registering the transporters of hazardous waste with the Department of Environment & Forests, in addition to the Department of Transport. This would enable the Ministry of Environment and Forests/ respective State Pollution Control Boards to ensure safe and secured transport of hazardous wastes.
2. To ensure that the occupier/generator transport their hazardous waste only in the specified transport vehicles.
3. The transporters should be asked to train the drivers and helpers of hazardous waste transport vehicles to handle the wastes under emergency situations.

Guidelines for Owner/ Operator of Hazardous Waste Storage, Treatment and Disposal Facility

1. Licensing system: The regulatory authorities may issue a consent to an owner/operator of a facility who can demonstrate his technical, financial and managerial competence; and that his staff is properly

trained. The authorities shall specify in the consent, the weights which a facility can receive, the operational conditions which must be met, the monitoring and control procedures to be carried out and the records which must be kept. Along with the application for consent, the following information should be furnished by the owner/operator of a facility:

- Area required for the facility
- Types of wastes to be handled, stored, treated and/or disposed
- Facilities available for managing these wastes
- Environment Impact Assessment of the area where the activity has been proposed
- Contingency plan of the facility

2. The regulatory authorities should ensure that the owner/ operator of a facility has the necessary equipment for fire control, decontamination, water spray and internal communication or alarm systems capable of meeting any emergency situation at the facility.
3. Establishment of standards: The regulatory authorities should identify the Principal Organic Hazardous Constituents (POHCs) in the waste and fix standards for stack emission of POHC from the incinerator. The effluent and ground water quality should be monitored regularly. The records of the facility should be checked regularly.
4. Post-closure care and use of property: The post closure-care for each hazardous waste storage, treatment, and/ or disposal facility should begin after closure of the facility and the regulatory authorities must ensure that post-closure monitoring continues for 30 days from date of closure. The local or state administrative body should be held responsible for post-closure care.
5. To ensure that the copy of the manifest reaches the authorities after receiving the hazardous waste from the occupier/ generator. The owner/ operator should indicate the proposed treatment and disposal scheme to be followed for the hazardous waste. This copy of the manifest should be linked with the copy of the manifest sent by the occupier/generator.

Source: Ministry of Environment & Forests, India *http://www.envfor.nic.in/citizen/specinfo/hsmg.html*

BIOMEDICAL WASTE MANAGEMENT

Facilitator:

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Specific Learning Objectives

- At the end of session, the learner shall be able to know about:

INTRODUCTION

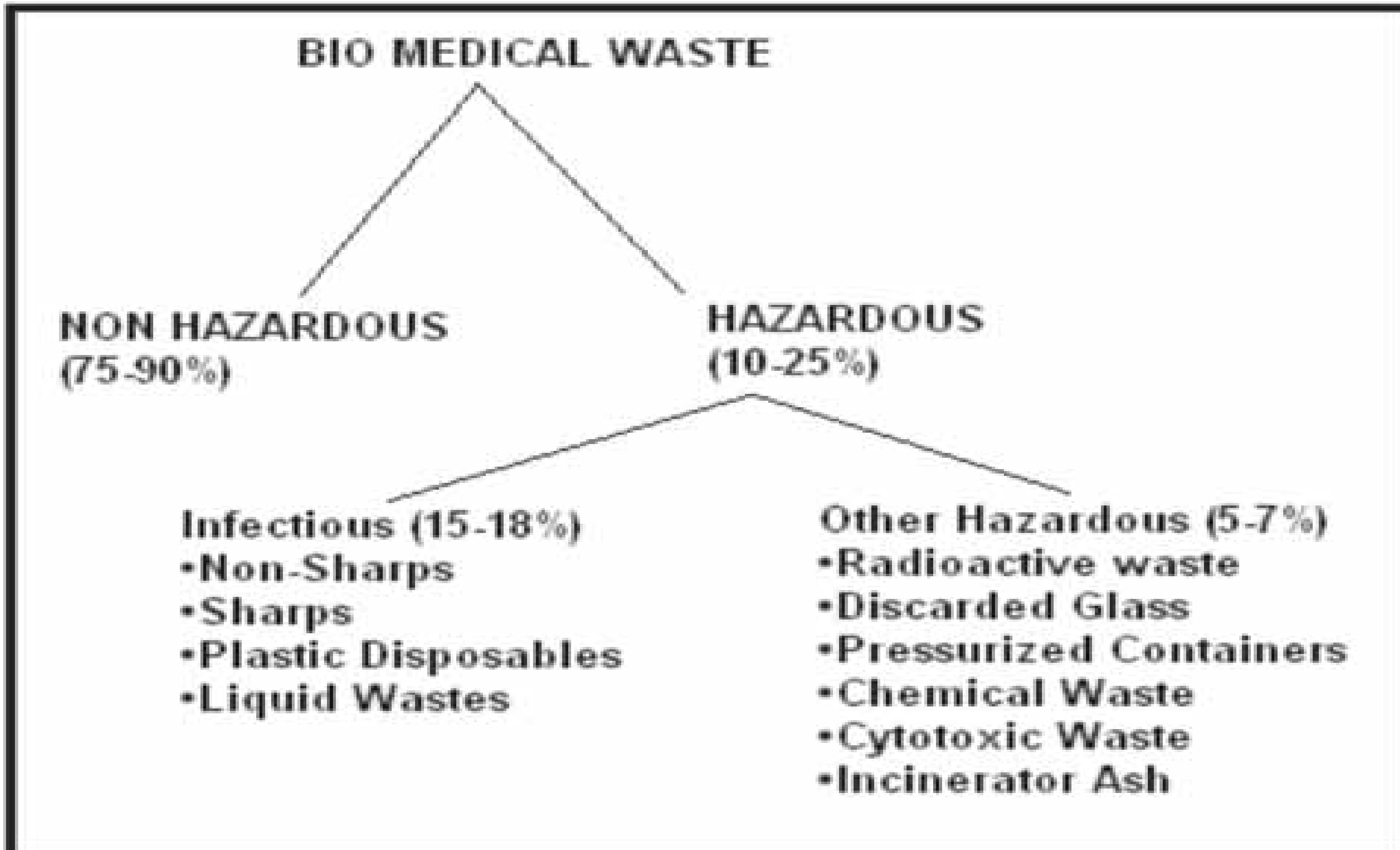
- Since beginning, the hospitals are known for the treatment of sick persons but we are unaware about the adverse effects of the garbage and filth generated by them on human body and environment. Now it is a well established fact that hospital waste is a potential health hazard to the health care workers, public and flora and fauna of the area.

The act was passed by the Ministry of Environment and Forests in 1986 & notified **the Bio Medical Waste (Management and Handling) Rules** in July 1998. In accordance with these rules, it is the duty of every "occupier" i.e. a person who has the control over the institution or its premises, to take all steps to ensure that waste generated is handled without any adverse effect to human health and environment.

DEFINITIONS

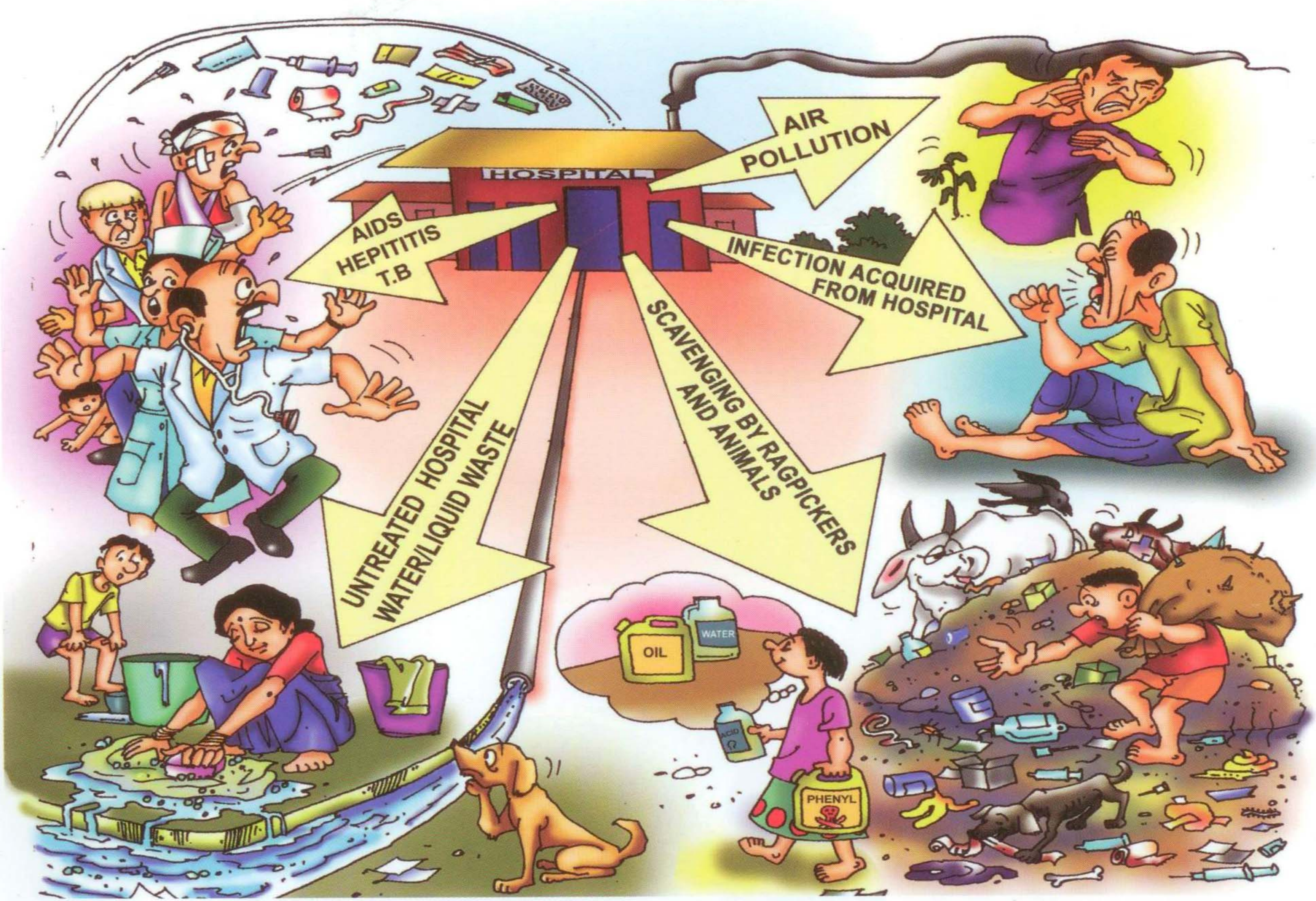
- **Hospital waste** refers to all waste, biological or non-biological that is discarded and not intended for further use.
- **Bio-medical waste** means any waste, which is generated during the diagnosis, treatment or immunization of human beings or animals or in research activities pertaining thereto or in the production or testing of biologicals, and including categories mentioned in Schedule I.
- **Infectious waste:** The wastes which contain pathogens in sufficient concentration or quantity that could cause diseases. It is hazardous e.g. culture and stocks of infectious agents from laboratories, waste from surgery, waste originating from infectious patients.

Classification of Bio-Medical Waste



SOURCES OF BIO MEDICAL WASTE

- Hospitals
- Nursing homes
- Clinics
- Medical laboratories
- Blood banks
- Mortuaries
- Medical research & training centers
- Biotechnology institution/production units
- Animal houses etc.
- Such a waste can also be generated at home if health care is being provided there to a patient (e.g. injection, dressing material etc.)



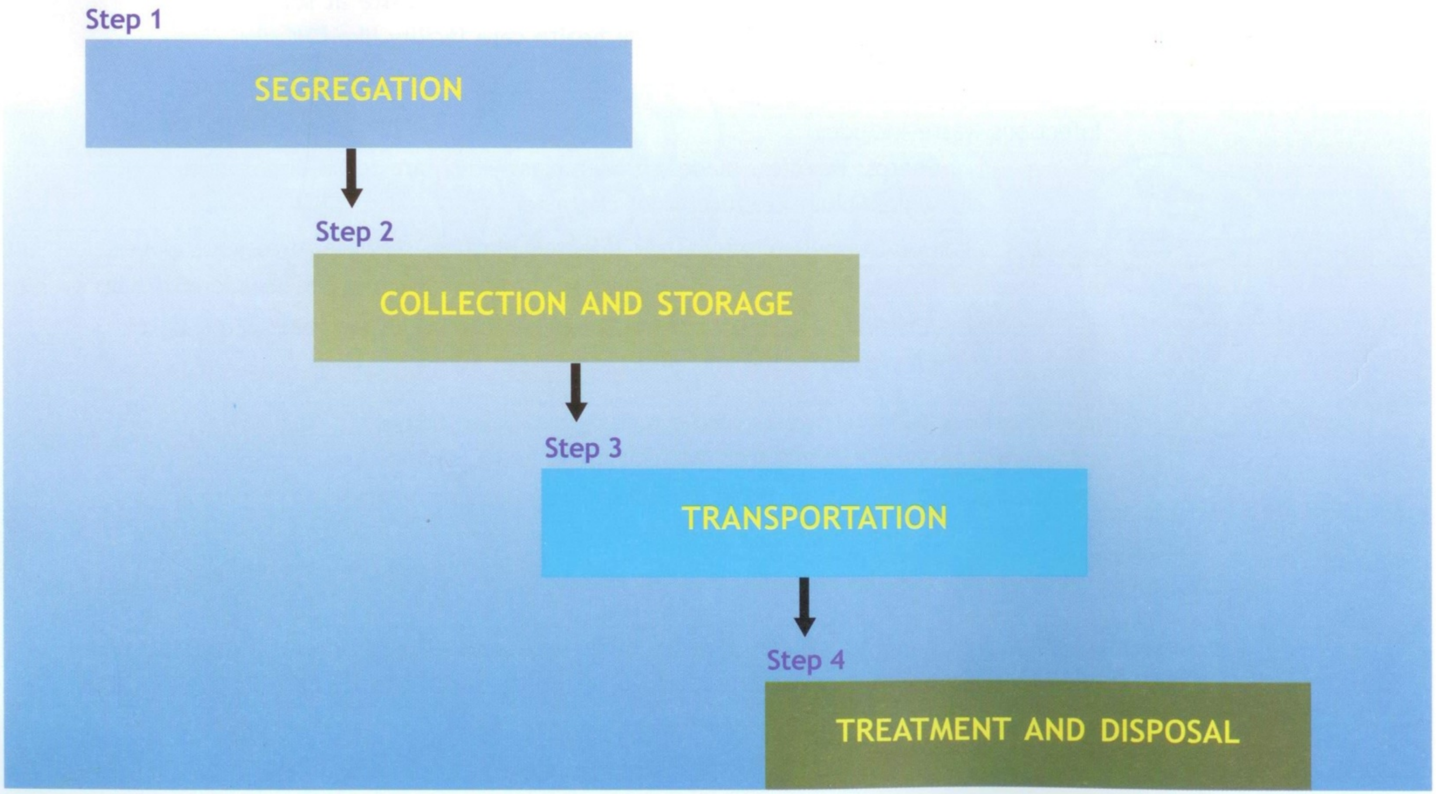
Health care waste is a risk to all, it affects us in different ways

CATEGORIES OF BIO-MEDICAL WASTE

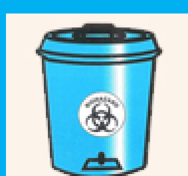
Option	Waste Category	Treatment & Disposal
Category No. I	Human Anatomical Waste (human tissues, organs, body parts)	incineration/deep burial
Category No. 2	Animal Waste (animal tissues, organs, body parts carcasses, bleeding parts, fluid, blood and experimental animals used in research, waste generated by veterinary hospitals colleges, discharge from hospitals, animal houses)	incineration/deep burial
Category No 3	Microbiology & Biotechnology Waste (wastes from laboratory cultures, stocks or specimens of micro-organisms live or attenuated vaccines, human and animal cell culture used in research and infectious agents from research and industrial laboratories, wastes from production of biologicals, toxins, dishes and devices used for transfer of cultures)	local autoclaving/micro-waving/incineration
Category No 4	Waste sharps (needles, syringes, scalpels, blades, glass, etc. that may cause puncture and cuts. This includes both used and unused sharps)	disinfection (chemical treatment/autoclavin g/microwaving and mutilation/shredding

Category No 5	Discarded Medicines and Cytotoxic drugs (wastes comprising of outdated, contaminated and discarded medicines)	incineration@/destruction and drugs disposal in secured landfills
Category No 6	Soiled Waste (Items contaminated with blood, and body fluids including cotton, dressings, soiled plaster casts, lines, beddings, other material contaminated with blood)	Incineration/ autoclaving/microwaving
Category No. 7	Solid Waste (wastes generated from disposable items other than the waste sharps such as tubings, catheters, intravenous sets etc).	disinfection by chemical treatment/autoclaving/ microwaving and mutilation/ shredding
Category No. 8	Liquid Waste (waste generated from laboratory and washing, cleaning, house-keeping and disinfecting activities).	disinfection by chemical treatment and discharge into drains
Category No. 9	Incineration Ash (ash from incineration of any bio-medical waste)	disposal in municipal landfill
Category No. 10	Chemical Waste (chemicals used in production of biologicals, chemicals used in disinfection, as insecticides, etc.)	Chemical discharge into drains for liquids and secured landfill for solids

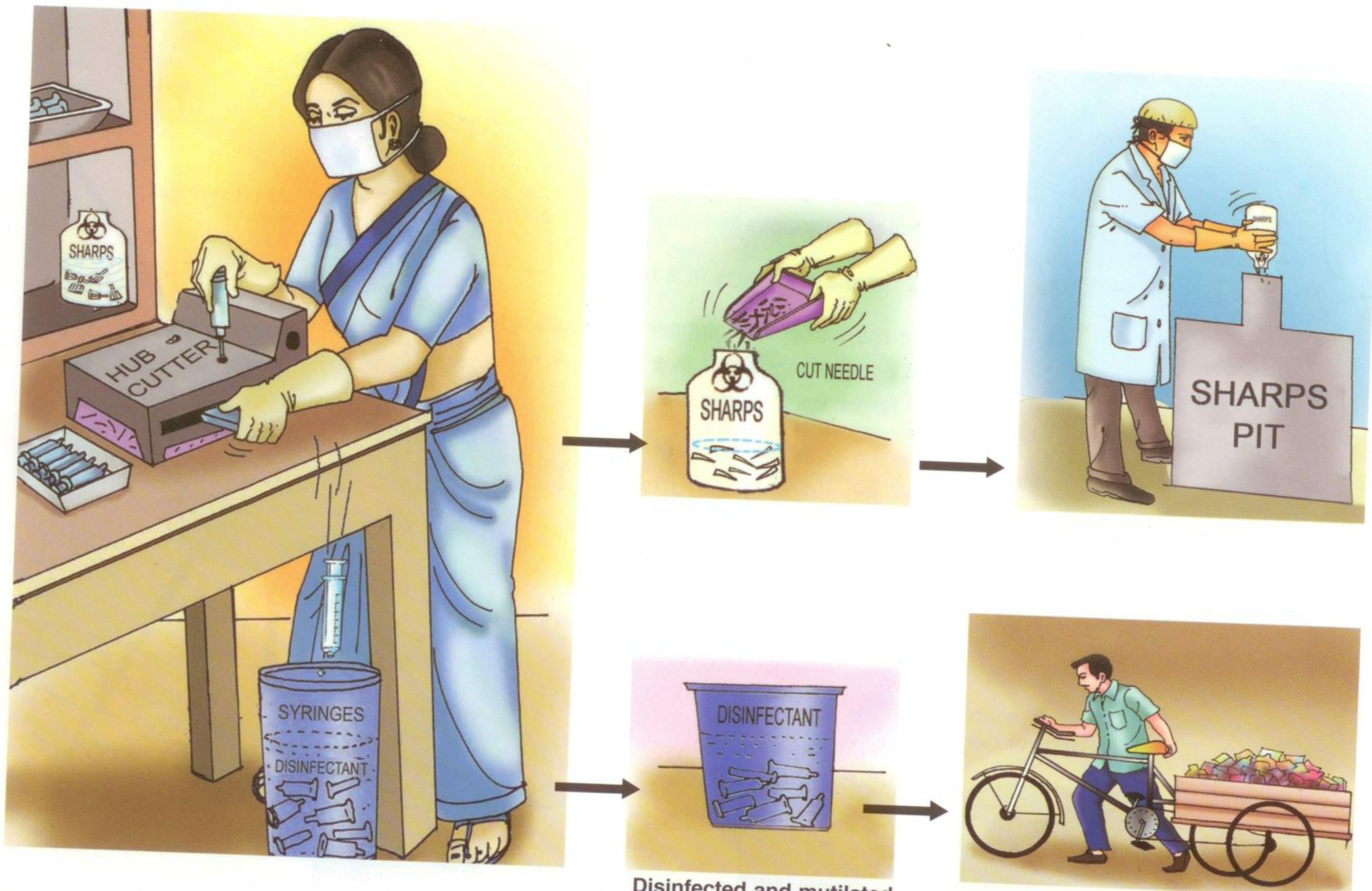
1. Steps For Waste Management



Rule 1998 schedule II

Color coding	Type of container	Waste categories
Yellow 	Plastic bags	Cat 1 human anatomical waste Cat 2 Animal Waste Cal 3 Microbiological Waste Cat 6 Solid Waste
Red 	Disinfected container plastic bags	Cat 3 Microbiological Cat. 6 Soiled Dressing
Blue/white 	Plastic bags, puncture proof containers	Cat. 4 Waste sharp Cat.7 Plastic disposable
Black 	Do	Cat. 5 Discarded medicine Cat. 9 Incineration ash Cat 10 Chemical Waste

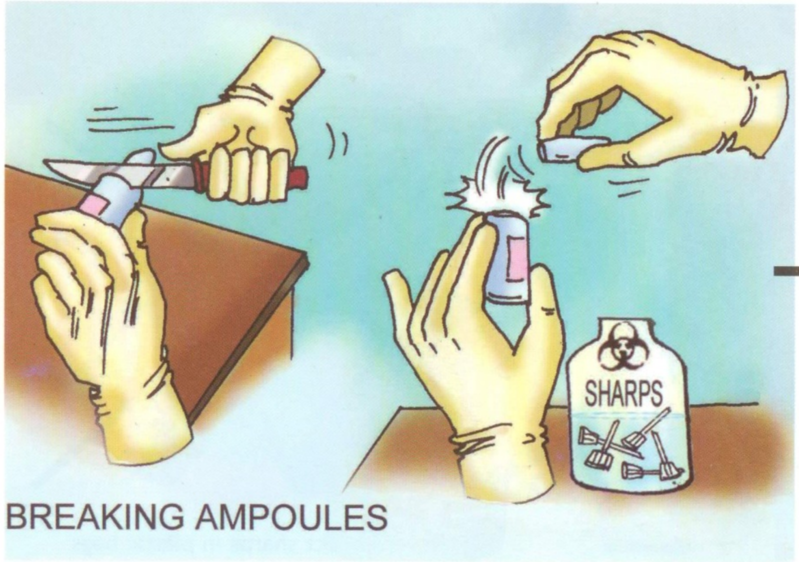
Auto-Disable Syringes

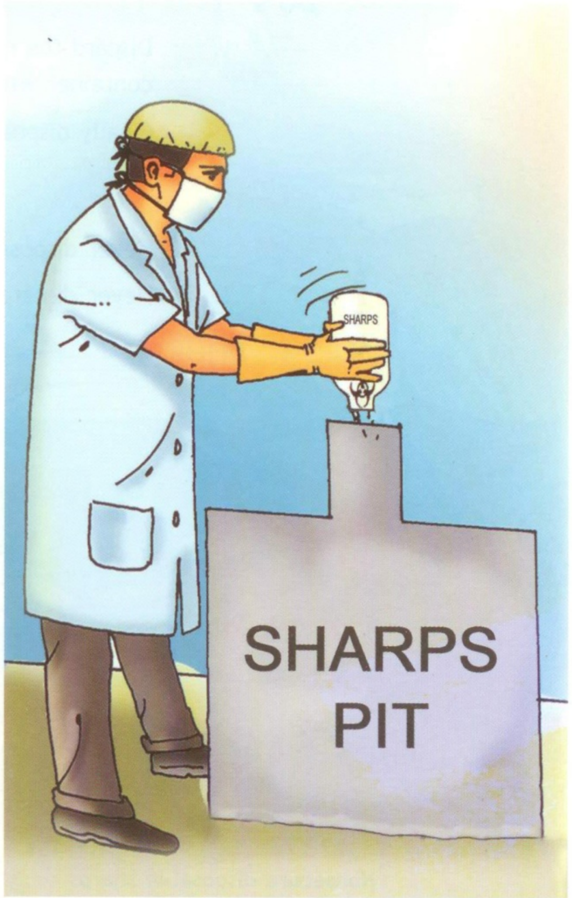


Disinfected and mutilated auto-disable syringes

General waste stream

Broken Glasses





TRANSPORTATION AND STORAGE

- The waste may be temporarily stored at the central storage area of the hospital and from there it may be sent in bulk to the site of final disposal once or twice a day depending upon the quantum of waste. During transportation following points should be taken care of:
- Ensure that waste bags/containers are properly sealed and labeled.
- Bags should not be filled completely, so that bags can be picked up by the neck again for further handling. Hand should not be put under the bag. At a time only one bag should be lifted.
- Manual handling of waste bags should be minimized to reduce the risk of needle prick injury and infection.
- BMW should be kept only in a specified storage area.
- After removal of the bag, clean the container including the lid with an appropriate disinfectant.
- Waste bags and containers should be removed daily from wards / OPDs or even more frequently if needed (as in Operation Theatres, ICUs, labour rooms). Waste bags should be transported in a **covered wheeled containers or large bins in covered trolleys.**
- **No untreated bio-medical waste shall be kept stored beyond a period of 48 hours**

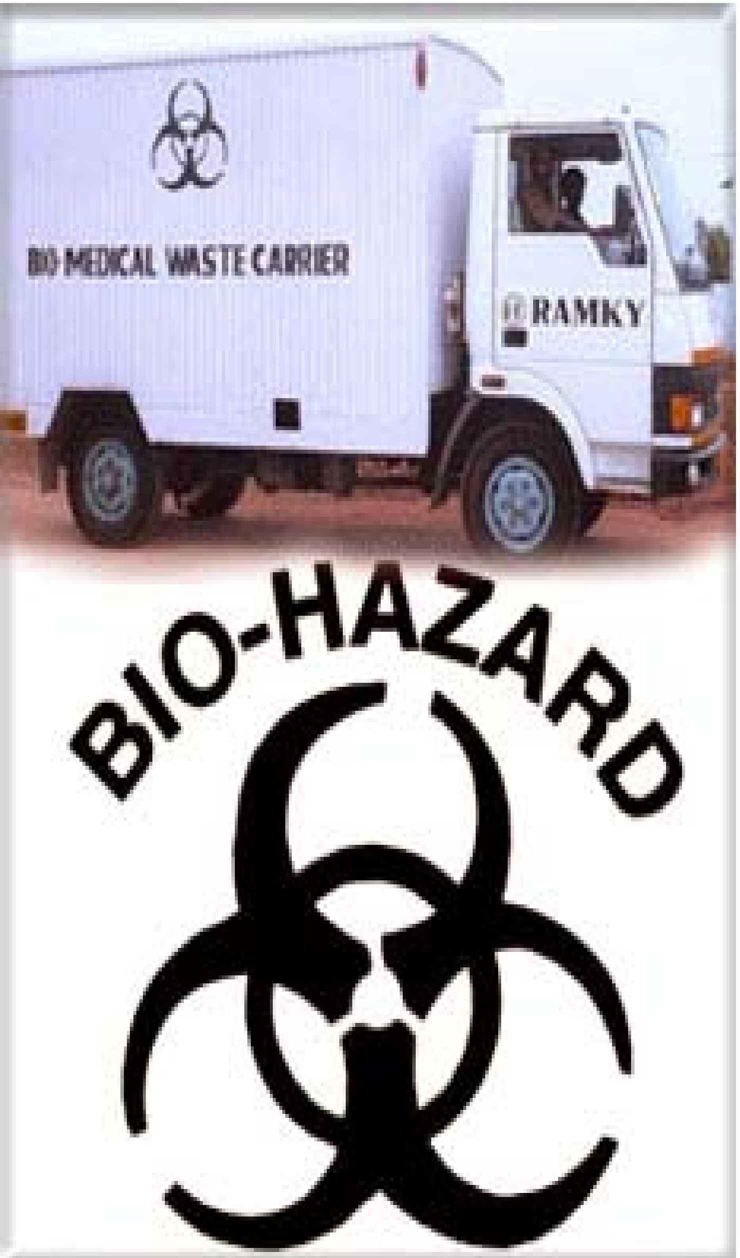
TRANSPORT TO FINAL DISPOSAL SITE

- Transportation from health care establishment to the site of final disposal in a closed motor vehicle (truck, tractor-trolley etc.) is desirable as it prevents spillage of waste on the way.
- Vehicles used for transport of BMW must have the **"Bio-Hazard" symbol** and these vehicles should not be used for any other purpose.
- 

CYTOTOXIC HAZARD SYMBOL

HANDLE WITH CARE

Note: Label shall be non-washable & prominently visible.


BIO-MEDICAL WASTE CARRIER
RAMKY
BIO-HAZARD


BIO HAZARDS
BIO-MEDICAL WASTE
COLLECTION VEHICLE
STOP

DISPOSAL OF BIOMEDICAL WASTE

- ***Deep burial:***
  - Category 1 and 2 only
  - In cities having less than 5 lakh population & rural area.

- ***Autoclave and microwave treatment***
  - Standards for the autoclaving and microwaving are also mentioned in the Biomedical waste (Management and Handling) Rules 1998.
  - All equipment installed/shared should meet these specifications.
  - Category 3, 4, 6 and 7 can be treated by these techniques.

- ***Shredding:***
  - The plastic (I.V. bottles, I.V. sets, syringes, catheters etc.), sharps (needles, blades, glass etc) should be shredded but only after chemical treatment/microwaving/autoclaving.
  - Needle destroyers can be used for disposal of needles directly without chemical treatment.

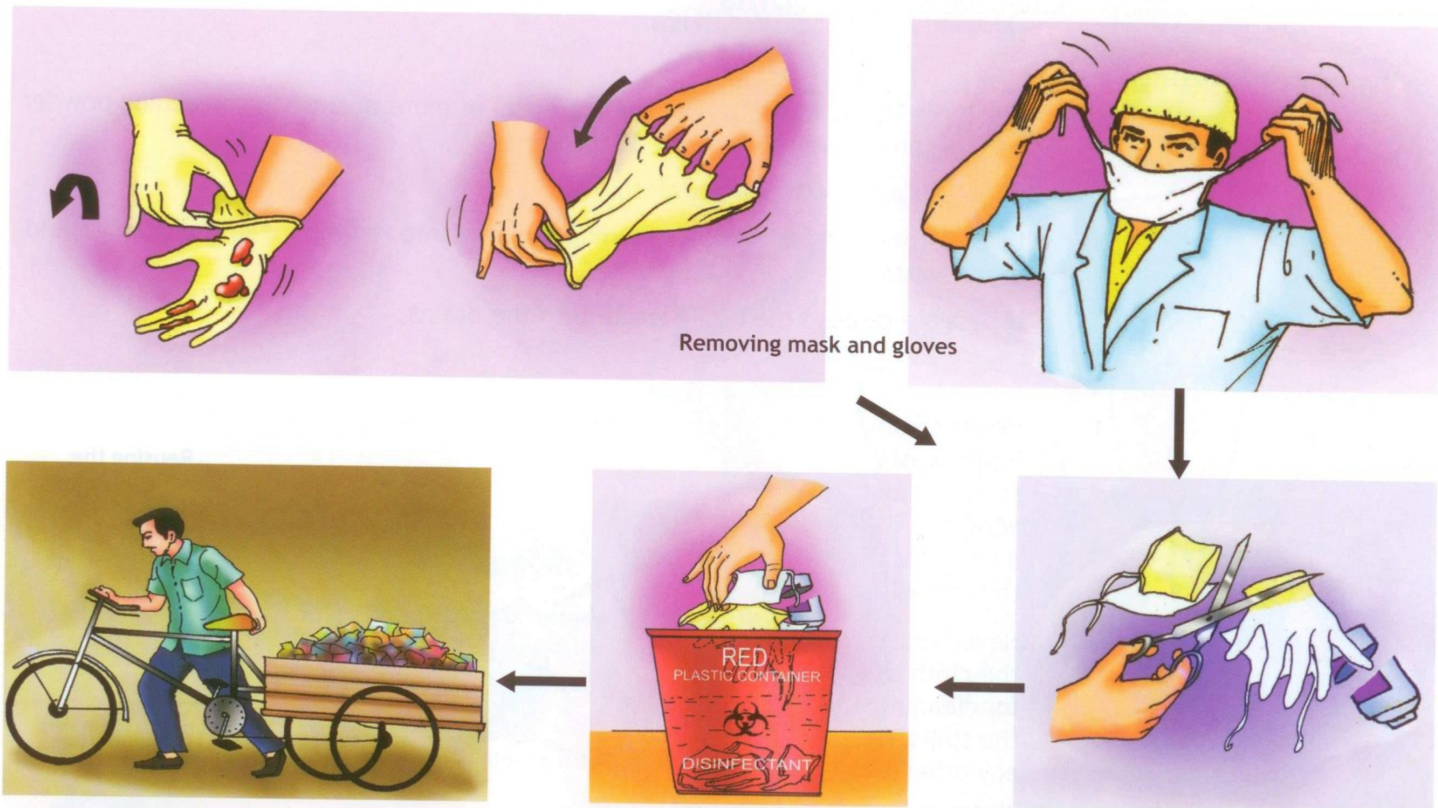
- ***Land disposal:***
  - ***Open dumps***
  - ***Secured/Sanitary landfill:*** **advantages.**

  - The incinerator ash, discarded medicines, cytotoxic substances and solid chemical waste should be treated by this option.

Incinerator

Autoclaves

Plastic Waste

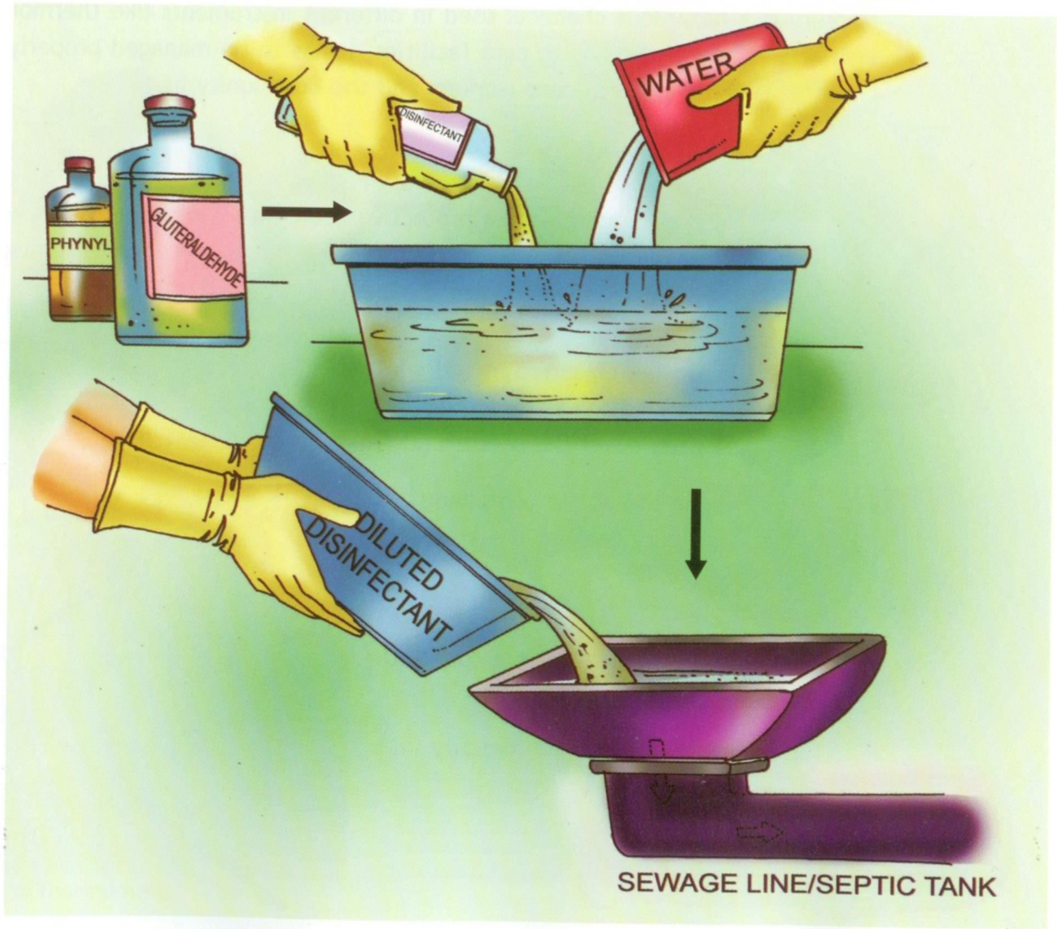


Removing mask and gloves

Mutilation

General waste stream

Disposal of Disinfectants



Incineration

- A high temperature dry oxidation process, which reduces organic and combustible waste to inorganic incombustible matter.
- Usually used for the waste that can not be reused, recycled or disposed of in landfill site.
- The incinerator should be installed and made operational as per specification under the BMW rules 1998
- Certificate may be taken from CPCB/State Pollution Control Board
- Category 1, 2, 3, 5, and 6 can be incinerated.

- Characteristics of **waste suitable for incineration** are:

- Low heating volume
  - above 2000 Kcal/Kg for single chamber incinerators and
  - above 3500 Kcal/Kg for pyrolytic double chamber incinerators.
- Content of combustible matter above 60%.
- Content of non combustible matter below 50%.
- Content of non combustible fines below 20%.
- Moisture content below 30%.

- **Waste types not to be incinerated** are:

- ➢ Pressurized gas containers.
- ➢ Large amount of reactive chemical wastes.
- ➢ Silver salts and photographic or radiographic wastes.
- ➢ Halogenated plastics such as PVC.
- ➢ Waste with high mercury or cadmium content such as broken thermometers, used batteries.
- ➢ Sealed ampoules or ampoules containing heavy metals.

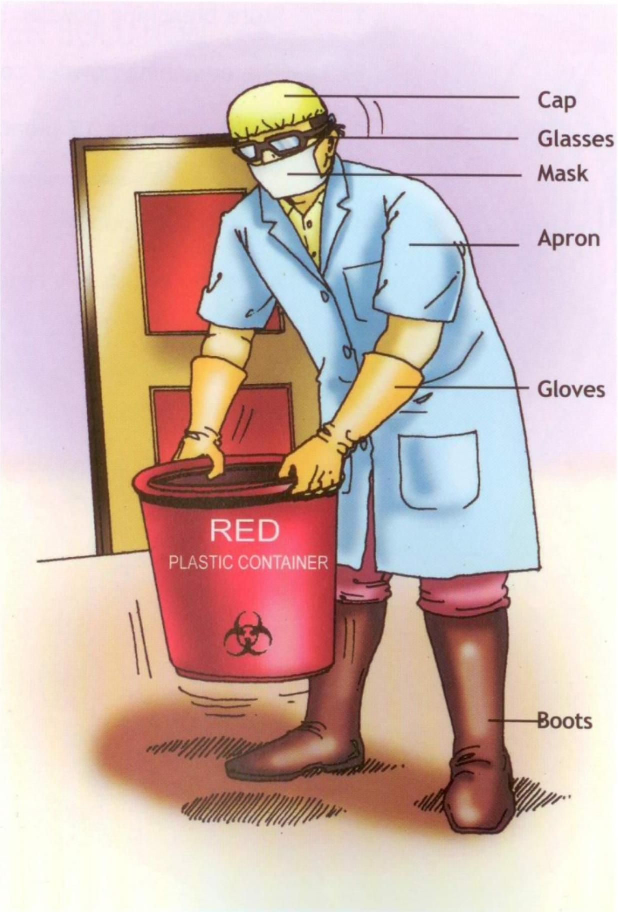
1. Double chamber pyrolytic incinerators
2. Single-chamber furnaces
3. Rotary kilns

Safety measures

- All the generators of biomedical waste should adopt universal precautions and appropriate safety measures while handling the bio-medical waste.
- It should be ensured that:
  - drivers, collectors and other handlers are aware of the nature and risk of the waste.
  - written instructions provided regarding the procedures to be adopted in the event of spillage/ accidents.
  - protective gears provided and instructions regarding their uses are given.
  - workers are protected by vaccination against tetanus and hepatitis B.

2. Personal Protective Equipments

1. Always wear personal protective gears while handling waste
2. Wearing head gears, eye covers (glasses), mask, apron, gloves and boots these constitute the barrier for transmission of infections
3. Taking immunization against Hepatitis B and Tetanus are important universal precautions



Training

- Every hospital must have well planned awareness and training programme for all category of personnel.
- Training should be conducted in appropriate language/medium and in an acceptable manner.
- All the medical professionals must be made aware of Bio-medical Waste (Management and Handling) Rules 1998.

Management and Administration

- Each hospital should constitute a **hospital waste management committee**
  - chaired by the head of the Institute and having wide representation from all major departments.
- This committee should be responsible for making Hospital specific action plan
  - for hospital waste management and its supervision, monitoring and implementation.
- The annual reports, accident reports, as required under BMW rules should be submitted to the concerned authorities as per BMW rules format.

Measures for waste minimization

- As far as possible, purchase of reusable items made of glass and metal should be encouraged.
- Select non PVC plastic items.
- Adopt procedures and policies for proper management of waste generated, the mainstay of which is segregation to reduce the quantity of waste to be treated.
- Establish effective and sound recycling policy for plastic recycling and get in touch with authorized manufactures.

Coordination between hospital and outside agencies

- **Municipal authority :**
- As quite a large percentage of waste (in India up to **85%**), generated in Indian hospitals, belong to general category (**non-toxic and non-hazardous**), hospital should have constant interaction with municipal authorities so that this category of waste is regularly taken out of the hospital premises for land fill or other treatment.

- **Co-ordination with Pollution Control Boards:**
  - To search for better methods technology, provision of facilities for testing, approval of certain models for hospital use in conformity with standards 'aid down.
  - To search for cost effective and environmental friendly technology for treatment of bio-medical and hazardous waste.
  - To search for suitable materials to be used as containers for bio-medical waste requiring incineration/autoclaving/ microwaving.

V-BMW

E-WASTE MANAGEMENT IN INDIA – CURRENT SCENERIO

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Introduction

- In the 20^{th} Century, the information and communication revolution has brought enormous changes in the way we organise our lives, our economies, industries and institution.
- At the same time, these have led to manifold problems including the problem of massive amount of hazardous waste and other wastes generated from electric products.
- It constitutes a serious challenge to the modern societies and require coordinated effects to address it for achieving sustainable development.

What is E-Waste?

Rapid growth of technology, upgradation of technical innovations, and a high rate of obsolescence in the electronics industry have led to one of the fastest growing waste streams in the world which consist of end of life electrical and electronic equipment product such as :

- ✓ Refrigerator, Washing machines, Computers and Printers, Televisions, Mobiles, Ipods etc.

- ✓Many of which contain toxic materials.

Composition of E-Waste

Consists of –

Ferrous & Non-ferrous Metals Plastics, Glass, Wood etc.

Iron & Steel - 50%

Plastics - 21%

Non-ferrous metal - 13%

Mercury, Arsenic, Lead etc.

E-Waste Generation in India

Projection by International Association of Electronic Recycler (IAER).

- 3 billion electronic and electrical appliances became WEEE in 2010.

- Globally about to 20 – 50 million tonnes of E-Waste are disposed of each year.

- Which accounts for 5% of all Municipal Solid Waste.

According to Comptroller and Auditor-General's (CAG) Report, over 7.2 MT of Industrial Hazardous Waste, 4 lakh Tonnes of electronic waste, 1.5 MT of Plastic waste, 1.7 MT of medical waste and 48 MT of municipal waste are generated in the country annually.

- CPCB has estimated that E-Waste exceeded 8 lakh tonnes mark in 2012.

Contd………….

E-Waste Generation in India

- There are 10 states that contribute to 70% of the total E-Waste generated in the country.

- 65 cities generate more than 60% of the total E-Waste in India.

- Among the top ten cities generating E-Waste, Mumbai ranks first followed by Delhi, Bengaluru, Chennai, Kolkata, Ahmedabad, Hyderabad, Pune, Surat & Nagpur.

- Main source of electronic waste in India are the government, public and private (Industrial) sectors – 70%

- Contribution of individual house hold – 15%

- Rest being contributed by manufacturers.

Contd…………

E-Waste Generation in India

Out of total E-Waste volume in India –

Television	-	68%
Desktop, Server	-	27%
Imports	-	2%
Mobile	-	1%

-Despite 23 units currently registered with Govt. of India, Ministry of Environment and Forest / Central Pollution Control Board, as E-Waste recyclers / preprocessors the entire recycling process more or less still exists in the unorganised sector.

-

Electronic waste in the global context

- It is estimated that more than 50MT E-Waste is generated globally every year

- A report of the United Nations predicted that by 2020, E-Waste from old computers would jump by 400% on 2007 levels in China and by 500% in India

- Additionally E-Waste from discarded mobile phones would be about seven times higher than 2007 levels in China and in India 18 timers higher by 2020

- China already produces about 2.3 million tonnes of E-Waste domestically second only to the US with about 3 million tonnes

Contd…….

Electronic waste in the global context

- Such predictions highlight the urgent need to address the problem of E-Waste in developing countries like India where the collection and management of E-Waste and the recycling process is yet to be properly regulated
- It may cause rising environmental damage and health problems of E-Waste recycling if left to the vagaries of the informal sector

Growth of electrical and electronic industry in India

The electronic market in India jumped from US $ 11.5 billion in 2004 to US $ 32 billion in 2009 making it one of the fastest growing electronic market worldwide with US $ 150 billion in 2010

India’s low manufacturing costs, skilled labour, raw materials, availability of engineering skill and opportunity to meet demand in the populous Indian Market have contributed significantly

India’s large and growing middle class of 320 – 340 million has disposable income for consumer goods

Environmental concerns & health hazard

-Generation of E-Waste in 2012 in India – 8 lakh tonnes

- Annual growth rate of E-Waste generation – 10%

- E-Waste highly complex to handle

- Pollutants and their occurrence in waste electrical and electronic equipment

Pollutant	Occurrence
Liquid crystal	Displays
Lithium	Mobile telephones, Photographic equipments, video equipments, batteries
Mercury	Components of Copper machines and steam irons, batteries in clocks and pocket calculators, switches, LCDs
Nickel	Alloys, batteries, relays, semiconductors, pigments
PCBs (poly chlorinated biphenyls)	Transformers, capacitors, softening agents for paints, glue, plastic
Selenium	Photoelectric cells, pigments, photo copiers, fax machines
Silver	Capacitors, Switches (contacts) batteries, resistors
Zinc	Steel, brass, alloys, disposable and rechargable batteries, luminous substances

Contd…………………

Pollutant	Occurrence
Arsenic	Semiconductors, diodes, microwaves, LEDs (light emitting diodes), solar cells
Barium	Electron tubes, filler of plastic and rubber, lubricant additives
Brominated flame proofing agent	Casings, circuit boards (plastic), cables and PVC cables
Cadmium	Batteries, pigments, solders, alloys, circuit boards, computer batteries, monitor, cathode ray tubes (CRTs)
Chrome	Dyes/ Pigments, Switches, Solar
Cobalt	Insulator
Copper	Conductor Cables, copper ribbons, coils, circuitry, Pigments
Lead	Lead reachable batteries, solar, transistors, lithium batteries, PVC (polyvinyl chloride), stabilizers, lasers, LEDs, thermo electrical elements, circuit boards

Impact of Hazardous Substances on health and environment

- Many of these substances are toxic and carcinogenic

-The materials are complex and have been found to be difficult to recycle in an environmentally sustainable manner causing health hazard

- The impacts is found to be worse in developing countries like India where people engaged in recycling E-Waste are mostly in the unorganised sector, living in close proximity to dumps or landfills of untreated E-Waste and working without any protection or safe guards

Dealing with E-Waste

Currently, around the world, the volume of obsolete computers and other E-Wastes temporarily stored for recycling or disposal is growing at an alarming rate causing enormous environmental and health hazard to any community.

How much waste is in 500 million computers –

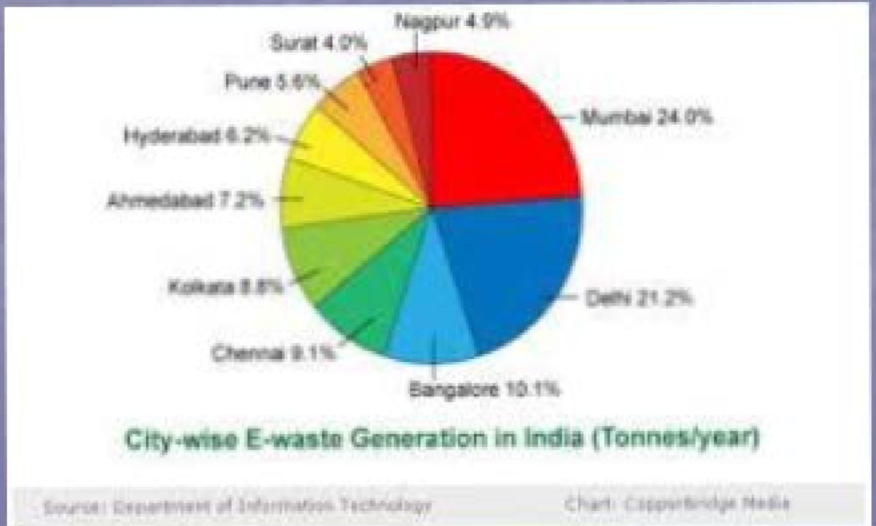
Plastic	-	6.32 Billion Pounds
Lead	-	1.58 Billion Pounds
Cadmium	-	3 Million Pounds
Chromium	-	1.9 Million Pounds
Mercury	-	0.632 Million Pounds

Contd………

Page 2

Storing of E-Waste in landfills	-	environmental & health hazard
Incineration	-	environmental & health hazard
Reusing and recycling	-	limited life span, hazardous in unorganised sector


E-waste Recycling
Don't really have any plans
As an organization hasn't given it a thought
We have already implemented
Will implement in 3 to 6 months
33.8%
27.2%
21.5%
11.2%
6.1%
22.2%
14.2%
18.4%


Nagpur 4.9%
Surat 4.0%
Pune 5.6%
Hyderabad 6.2%
Ahmedabad 7.2%
Kolkata 8.8%
Chennai 9.1%
Bangalore 10.1%
Delhi 21.2%
Mumbai 24.0%
City-wise E-waste Generation in India (Tonnes/year)
Source: Department of Information Technology
Chart: CopperBridge Media

Recycling of E-Waste – global trade in hazardous waste

-Basel convention on the control of Trans – boundary Movement of Hazardous waste and their Disposal, 1989

- Conference of Parties of the Basel Agreement, 2006 – to regulate the E-Waste movement

Major factors in global waste trade economy

- E-Waste export to the developing countries is governed by brute global economics
- low enforcement of environmental and occupational regulations
- low labour cost

Import of hazardous E-Waste in India

India is one of the largest waste importing countries in the world.

It generates about 350000 tonnes of electronic waste every year and imports another 50000 tonnes.

E-Waste economy in the unorganised sector

- More than 90% of the E-Waste generated in the country end up in the unorganised market for recycling and disposal
- The unorganised sector mainly consists of the urban slums of the metros and mini metros where recycling operations are carried out by the unskilled employees using the most rudimentary methods to reduce cost.
- Workers face dangerous working conditions as they may be without protection like gloves or masks.

Contd………..

E-Waste economy in the unorganised sector

- Very often child labour is employed to separate the parts from the circuit board utilising wire cutters pliers
- Nitric acid is used on the circuit board to remove gold and platinum
- It is estimated that about half of the circuit boards used in the appliances in India end up in Moradabad (Uttar Pradesh) also called Peetal Nagri or the brass city
- Private and Public Sector prefer auctioning their E-Waste to informal dismantlers and get good price of it
- Strict regulation is necessary to process E-Waste through organised sector

E-Waste economy in the organised sector

In July 2009, E-Waste Recyclers Association was formed

Problem facing the organised sector

- Lack of proper collection and disposal mechanism
- Stiff resistance from large informal sector
- TIC Group India Pvt. Ltd. in Noida (UP) has capacity 500 tonnes of E-Waste annually but processing only 200 tonnes per year
- Attero recycling unit in Roorkee (Uttarakhand) is a 35 crore plant can process 36000 tonnes per year although getting 600 tonnes currently
- License to import may be necessary to sustain formal business
- Collection system to improve

Contd…………….

E-Waste economy in the unorganised sector

E-Parisara in the formal sector in Bengaluru has been encouraged by the Central and State Pollution Control Board which would like it replicated in all major cities in the country

IBM, Tate Elxsi, ABB and Philips are among its clients. But many major IT firms are not responding

Capacity	-	3 tonnes / day
Utilising	-	1 tonne / day

Guidelines for Environmentally Sound Management Of E-Waste, 2008

- The concept of Extended Producer Responsibility (EPR)
- The EPR is an environment protection strategy that makes the producer responsible for the entire life cycle of the product, specially for take back, recycle and final disposal of the product
- State Pollution Control Boards were made responsible for enforcement of the guideline


"Nokia has covered around 300 offices across India, of several partner corporations from across sectors"
Poonam Kaul, director, corporate Communications, Nokia India


REDUCE
REUSE
RECYCLE


e-waste
COLLECTION
BIN
RECYCLE
REUSE

E-Waste (Management & Handling) Rules, 2011

EPR principle will apply

Collection of E Waste

- **Generated during manufacturing**
- **Generated from the end of life products**
- **Such E Wastes are channelized to a registered refurbisher or dismantler or recycler**
- **Individual identification code for product tracking**
- **Provide contact details of dealers and authorized collection centers to consumers**
- **Finance and organise the system**
- **Ensure safe transportation, storage**
- **Submit annual return**

Criticism of the new rule

- It ignores the unorganized and small and medium sector, where 90% of the E-Waste is generated
- Does not provide any plan to rehabilitate those involved in informal recycling
- Collection, and dismantling of E-Waste is not hazardous and can be carried out by informal sector
- Extraction of precious metals is the hazardous process, which should be left to the organized sector

Contd……

Criticism of the new rule

- **Business model to develop for collection of E-Waste from consumers**
- **Producers need to set up collection centers**
- **MSME sector, low turnover, not able to set up collection / processing centre**

Government Assistance for Treatment, storage and Disposal Facilities (TSDFS)

- It encourages setting up of integrated TSDF for hazardous waste management on Public Private Partnership (PPP) mode
- 28 TSDF have been set up
- Centre has provided financial assistance
- Memorandum of Understanding signed between MOEF, SPCB and entrepreneur
- Utilization certificate and progress report taken annually

Recognising the unorganised sector in India

- There are 23 formal recycling and reprocessing units having environmentally sound management facilities which are registered with CPCB
- E-Waste sector can be made into a viable business model indicated by a Bengaluru-based successful conglomeration of 70 informal recyclers
- Kabariwalas – called the Harit Recycler Union
- The Manufacturers Association for information Technology (MAIT) has embarked on a new MAIT-EU initiative which is a four year project beginning 2010 until 2014. The project create linkage between informal and formal recyclers and to set up collection centers to channelize E-waste for processing

Contd…..

- **Four cities including Delhi, Kolkata, Pune and Bengaluru have been identified for the project.**

- **Metal extraction is discouraged in the informal sector**

  It is therefore important that viable solutions are found to address the problem of the E-waste involving skilled manpower from the informal sector of the economy and the use of appropriate technology.

E-Waste (Management & handling) rules, 2011 came into effect from 1st May, 2012

- The concept of Extended Producer Responsibility (EPR)
- The EPR is an environment protection strategy that makes the producer responsible for the entire life cycle of the product, specially for take back, recycle and final disposal of the product.
- State Pollution Control Boards were made responsible for enforcement of the guideline

E-Waste (Management & handling) rules, 2011 came into effect from 1st May, 2012

CHAPTER I

APPLICATION

These rules shall apply to every producer, consumer or bulk consumer involved in the sale, purchase and processing of electrical and electronic equipment or components as specified in schedule I, collection centre, dismantler and recycler of E-Waste and shall not apply to –

a) Batteries as covered under the Batteries (Management and Handling) Rules, 2001 made under the act;

b) Micro and small enterprises as defined in the Micro, Small and Medium Enterprises Development Act, 2006 and

c) Radio active wastes as covered under the provisions of the Atomic Energy Act, 1962 and rules made there under.

E-Waste (Management & handling) rules, 2011 came into effect from 1st May, 2012

CHAPTER – II

Responsibilities of the producer –

- ❖ Extended Producer Responsibility
- ❖ Responsibilities of the collection centers
- ❖ Responsibilities of dismantler
- ❖ Responsibilities of recycler

E-Waste (Management & handling) rules, 2011 came into effect from 1st May, 2012

CHAPTER III

- Procedure for seeking Authorization and Registration for handling E-Waste.
- Procedure for grant of authorization
- Power to suspend or cancel an authorization
- Procedure for registration with State Pollution Control Board
- Procedure for grant of registration

CHAPTER IV

Procedure for storage of E-Waste

E-Waste (Management & handling) rules, 2011 came into effect from 1st May, 2012

CHAPTER V

Reduction in the use of Hazardous Substances in the Manufacture of Electrical and Electronic equipment.

CHAPTER VI

Miscellaneous

- **Duties of Authorities**
- **Annual Report**
- **Transportation of E Waste**
- **Accident reporting and follow up**
- **Schedule i) Categories of electrical and electronic equipment covered under the rule**
- **Schedule ii) Applications, Exemptions**
- **Schedule iii) List of Authorities and corresponding duties**

Contd……

- **Form I – Application for obtaining Authorization for generation/collection/storage/dismantling/recycling of E-waste**
- **Form I(a) – Form for granting Authorization for generation/collection/storage/dismantling/recycling of E-waste**
- **Terms and conditions of Authorization**
- **Form 2 – Form for maintaining records of E-waste handled/generated**
- **Form 3 – Form for filing Annual Return**
- **Form 4 – application form for registration of facilities processing environmentally sound management practice for recycling E-waste**
- **Form 5 – Form for Annual Report to be submitted by the State Pollution Control Board /Committees to the Central Pollution Control Board**

Conclusion

- The quantum of wastes generated over the past several years have posed an ever increasing threat to environment and public health.
- CPCB have identified over 88 critically polluted industrial zones
- As far as e-waste is concerned, it has emerged as one of the fastest growing waste streams worldwide today
- As long as electronic products continue to contain an assortment of toxic chemicals and are designed without recycling aspect, they would pose a threat to environment and public health at their end-of-life
- Repeated awareness programme through print and electronic media is the need of the hour

Let us keep our City Clean

Thanks