

CHAPTER 1

SOLID WASTE MANAGEMENT : GENERAL ASPECTS

What is refuse or solid waste ?

How to handle these waste ?

How to recover, reuse and recycle the valuable components of refuse ?

How can we do with hazardous waste?

How to dispose these wastes without side effects?

What is plastic waste?

Which is filthiest city in India?

These are the questions which usually crop up in our mind when we think of the refuse management. With the advancement in science and technology, exploitation of natural resources also envisaged. Consequently the life standards are also increased with production of more and more solid wastes especially in urban centers. Solid wastes are the direct consequences of what we do in our modern society.

INTRODUCTION

Any useless, unwanted discarded material that is not a liquid or gas is referred as solid waste or refuse. For e.g. it may be yesterday's news paper, junk mail, today's meal scraps, pieces of bread, roti, waste rice, raked leaves, dust, grass clippings, broken furniture, abandoned materials, animal manure, sewage sludge, industrial refuse or street sweepings etc. For the first time in India the municipal corporations have worked overtime to remove the filth produced due to the threat caused by the outbreak of plague disease in Surat city of Gujarat state, India, in the year 1994.

The refuse materials such as newspaper, cotton pieces, foodstuff, skin, clothes, leather, old dress, fish etc., anything of solids produced by the humans is going to become a waste some time somewhere and somehow. It means waste material is produced as a result of human activity. The quantity of this material is increasing readily due to increase in human population and increase in the standards of living. For example, in Bombay 7000 tons of municipal solid wastes are being produced every day. All this is contributed by the kitchen refuse, markets and slaughter house. These wastes have to be disposed off so that environment

remains clean and healthy for inhabitation. Solid waste management includes the process of generation, collection, storage, transport and disposal or reuse and re-circulation or incineration or any relevant method of disposal (WHO, 1971).

Until 1950 the solid waste disposal had not posed any problem. However during the period between 1953-55 the spread of viral disease to hogs attracted the attention of several sanitary engineers and farmers. Since that time onwards feeding garbage to hogs was banned in the USA however in India feeding to cattle is still continued unabatedly. It is probably for the first time that scientific studies on refuse management were started and published in Chicago by the Public Administration Department (APHA, 1980). The EPA of the US also published its fourth report on the resource recovery from solid waste in 1977. After 1970, several people started working on this topic. Those include, Winkler and Wilson, 1973; Alter, 1981; Bruce, 1984; Howard, *et al.*, 1985; Jeevan Rao, 1992 ; Hosetti, *et al.*, 1998 and Priya, 2001.

CLASSIFICATION

Typical classification of solid waste was suggested by Hosetti and Kumar (1998) and it is as follows.

1. *Garbage*: Putrecible wastes from food, slaughterhouses, canning and freezing industries.
2. *Rubbish*: non-putrecible wastes either combustible or non-combustible. These include wood, paper, rubber, leather and garden wastes as combustible wastes whereas the non-combustible wastes include glass, metal, ceramics, stones and soil.
3. *Ashes*: Residues of combustion, solid products after heating and cooking or incineration by the municipal, industrial, hospital and apartments areas.
4. *Large wastes*: Demolition and construction wastes, automobiles, furniture's, refrigerators and other home appliances, trees, fires etc.
5. *Dead animals*: House holds pets, birds, rodents, zoo animals, and anatomical and pathological tissues from hospitals.
6. *Sewage sludges*: These include screening wastes, settled solids and sludges.
7. *Industrial wastes*: Chemicals, paints, sand and explosives.
8. *Mining wastes*: Tailings, slug ropes, culm piles at mine areas
9. *Agricultural wastes*: Farm animal manure, crop residues and others.

Traditionally these wastes are categorized into the following five types.

1. *Residential*: It refers to wastes generated mainly from dwelling, apartments, and consisted of left over food scrapes, vegetables, peeled material, plastics, wood pieces, clothes and ashes.
2. *Commercial*: This mainly consists of grocery materials, leftover food, glasses, and metals, ashes generated from stores, hotels, markets, shops and medical facilities.
3. *Institutional*: The wastes generated from schools, colleges and offices include, paper, plastics, and glasses.
4. *Municipal*: This includes dust, leaf litter, building debris, and treatment plant sediments. These arise from various activities like demolition, construction, street cleaning, land scraping etc.
5. *Agricultural*: This mainly includes spoiled food grains, vegetables, grass, litter etc., generated from fields and farms.

Classification of Solid Wastes Based on Types

These wastes may have reuse values in some other places, but these are of no value to the possessor who wishes to dispose them. The knowledge about sources of solid wastes along with the information of the composition and rate of generation, will help in the process of design and operation of the functional elements associated with the disposal and management of solid wastes. Therefore it is important to define various types of solid waste that are generated from various sources (Pheleps *et al.*, 1995).

Refuse: This is all putrecible and nonputrecible waste except body wastes. It includes all types of rubbish and garbage.

Rubbish: This refers to that portion of the refuse, which is non-putrecible solid waste such as packaging materials.

Garbage: This refers to that portion of the refuse, which is putrecible component of solid waste. These are produced during cooking and storage of meat, fruits and vegetables.

Bulky wastes: These include household wastes, which cannot be accommodated in the normal storage containers and need a special collection mechanism. These include, household appliances such as refrigerators, washing machine, furniture, vehicle parts, tyres, trees, wood branches etc.

Street wastes: This includes wastes collected from streets, walkways, parks, playgrounds, which include paper, cardboard, plastics, leaves and other vegetable matter in large quantities.

Dead animals: These include dead animals those die naturally or accidentally killed on the road. This category does not include carcasses and animal parts from slaughterhouses, which may be regarded as commercial or industrial components. Many times as in India the large animals if died and are not lifted on right time then they may pose a threat to public health through attracting flies and produce bad odour and create an unhygienic scene.

Hazardous Wastes: Hazardous wastes are those produced in the industries, institutes, hospitals and laboratories. These are dangerous to the living organisms immediately or in the long run to the environment in which they are disposed. The hazard may be due to their physical, chemical, biological and radioactive characteristics like, ignitibility, corrosivity, reactivity and toxicity. In some cases various chemicals and their mixtures act as hazardous wastes. Those may be pesticides, solvents, acids and bases. Certain hazardous wastes may cause explosions in the incinerators and fires at the landfill sites. Other hazardous waste includes pathological wastes from hospitals and radioactive wastes, which require special handling. A good management practice should ensure that hazardous wastes are stored, collected, transported and disposed separately after suitable treatment.

Sewage Sludge: The sewage treatment plants produce huge amounts of sludge during primary and secondary phase of treatment, these are sticky and rich in pathogens require proper treatment. These are both inorganic and organic. The bulk of dewatered and digested sludge can be used as organic fertilizer or it may be burnt to produce energy.

MISMANAGEMENT AND SIDE EFFECTS

Solid waste management is an important facet of environmental hygiene and it needs to be integrated with total environmental planning (WHO Expert Committee, 1971). Its storage, collection, transport, treatment and disposal can lead to short term risks. In the long run there may be dangers arising particularly from the chemical pollution of water supplies.

Javeen Rao (1994) said that the problems connected with refuse storage in buildings were, insects, rats, fire, and odor. These problems are also associated with other problems of human health and aquatic systems.

Insects

A common transmission route of bacillary dysentery, amoebic dysentery and other diarrhoeal diseases are from human fecal matter spread through flies to food or water, thence to man. Flies thrive on food wastes and are plenty in USA. 90% of house flies in the cities of USA breed on open garbage. If night soil and unprotected latrines are close to refuse dumps, the disease routes are widespread, as the flies can fly upto 10 kms. Refuse dumped on ground resulted in the infestation with fly eggs and larvae upto 50 mm below the surface. The breeding of mosquitoes in discarded tyres, tins, and jam bottles are reported.

Rats and other vertebrate vectors

The main source of food for rats and other smaller rodents is refuse and rubbish dumps where they can quickly proliferate and spread to neighboring houses. The rats become vectors to histoplasmosis, rat bite fever, salmonellosis, tularemia and trichinosis etc. Most of the birds of prey always hover over these dumps and spread the waste to neighboring areas. In addition to this the other birds like pigeons, crows seagulls also serve as vectors.

Fire

Ashes added to combustible refuse pose a great danger at the source and fire in uncontrolled tips has been known to burn for months or even years. Usually the fire starts with unsustainable practice of open dumping of refuse and it can spread accidentally. Occasional fires began spontaneously from the heat given off by decomposition or by glass on open dump acting as a lens for sunlight. Flammable industrial wastes increase the danger of fire and can convert old tyres into toxic gases (dioxins and furans).

Odor

While passing through a crowded city in tropical areas a traveller may experience bad smell. It is due to the combination of rotting vegetation and fecal matter and other solid wastes indiscriminately discarded. When this stink persists all the day and night it causes a major environmental nuisance. This bad smell is also due to the release of hydrogen sulfide during decomposition.

OTHER EFFECTS ON THE ENVIRONMENT

Apart from the disease for which insects and rats are the carriers, the handling of it causes illness to workers. A survey in India conducted by CEPHERI, 1971 (Central Public Health Engineering Institute) showed that in Bhopal city up to half of the sample of refuse in the slum areas contained roundworm ova. The accident rate among workers is also high as a result of lifting heavy load of waste and dealing with mechanical equipments.

Atmospheric Pollution

When refuse is burnt in an open area, a dense smoke often covers the site and neighboring land. Old-fashioned incinerators without air pollution control equipment are little better than open burning. Apart from particulate matter that constitutes smoke, the gaseous discharges from the incomplete combustion may include SO₂, NO_x and various gases. If PVC is a constituent of the refuse, the gases may include hydrogen chloride. In addition to pest nuisance and health hazards, the solid wastes also cause air pollution. Burning of solid wastes

in open dumps or use of improperly designed incinerators produce excessive pollution. Studies revealed that emission from the uncontrolled burning leads to the production of particulate matter, sulfur oxides, nitrogen oxides, carbon monoxides, lead and mercury. Discharge of arsenic and cadmium are to be controlled. Polychlorinated dibenzofurans are called as dioxins and furans. These are of more concern about their toxicity as carcinogens and mutagens.

Visual Pollution

The aesthetic feeling is offended by the unsightfulness of piles of wastes on the roadsides. This situation was being made worst by the presence of scavenging animals, especially in the third world countries. The scavenging animals search their food in the waste and spread it around places. Similarly the rag pickers in India also create such unhygienic scene while collecting recyclables. This creates an ugly situation and under such conditions apart from cleaning the waste, there is a need to educate the public about environmental health. Undesirable noise and traffic sound is also produced while operating the landfills and incinerators. This is due to the movement of vehicles and large machines.

Tourism/Ethics/Recreation

Uncontrolled refuse and sanitary tips in full public view are eye corers. If tourism is important in such cases esthetic nuisance may reduce the number of visitors with the resultant economic loss. There can be depreciation of the value of property nearer to a garbage area or incinerator spillage from vehicle. In addition to this, bad smell, increase of flies, rats, windblown dust, paper and plastics all of which are harmful to the locality. On the other hand, refuse can be used in a well-planned controlled way to improve low lying and derelict or arid lands and property values may then increase in the vicinity.

Water Pollution

When the rain run-off joins the surface water sources there is an inevitably pollution due to suspended solid particles. Organic matters exert high oxygen demand and pathogen load can create a health risk to downstream users. Unless the water table is not high or underlying rock is not fissured, the ground water will be hardly affected. Dumps should not be close to shallow wells. A distance of 12 kms is suggested. On the other hand avoidance of ground water pollution is of paramount importance in the dumping of refuse.

WASTE RESOURCES

During the past 20 years there has been an increasing awareness in industrialized nations that the vast growing quantities of refuse are an indication of wasteful use of resources. Conservationists support separation of valuable materials from refuse. In developing countries everything of value are already separated for recycling. The refuse contain both putrecible and non-putrecible components. The putrecible components include, food, wood, paper, leather, flower, vegetable and ash. That non-putrecible is metal, glass, plastics, foils, hair and bones.

The management strategy includes the following steps.

1. Material flow in a society
2. Reduction in raw material usage
3. Reduction in solid waste quantity
4. Reuse of materials
5. Energy recovery
6. Day to day solid waste management.

Characterization of solid waste is important in evaluating alternative equipment needs, systems and management program and plans, especially with respect to the implementation of disposal and energy and resource recovery options. It depends on a number of factors such as food habits, cultural conditions, and socio-economic and climatic conditions. Refuse characteristics vary not only vary from city to city, but within the city itself and also seasonally. Quality of refuse should be assessed taking into account seasonal variations and zonal characteristics etc. NEERI (1983) reports that per capita production in metro cities like Bombay, Calcutta, Madras, and Delhi range from 0.45 to 0.6 kg/day, however, it is minimum in quantity when compared to American cities.

The management of solid waste should include the following general steps:

1. Waste generation
2. Onsite handling, storage and processing
3. Collection, transport, sorting and recycling
4. Treatment and reuse
5. Disposal options.

WASTE GENERATION

It includes all solid or semisolid materials that are no longer having sufficient value to retain by the possessor. Success of solid waste management depends on the appropriate assessment of quantity of waste generated. Tchobanoglous et al. (1977) have showed a simplified flow diagram for the solid wastes (Fig. 1.1). Wastes are generated at the start of the process, beginning with the process of raw materials. Then onwards at each and every step of processing wastes may be released.

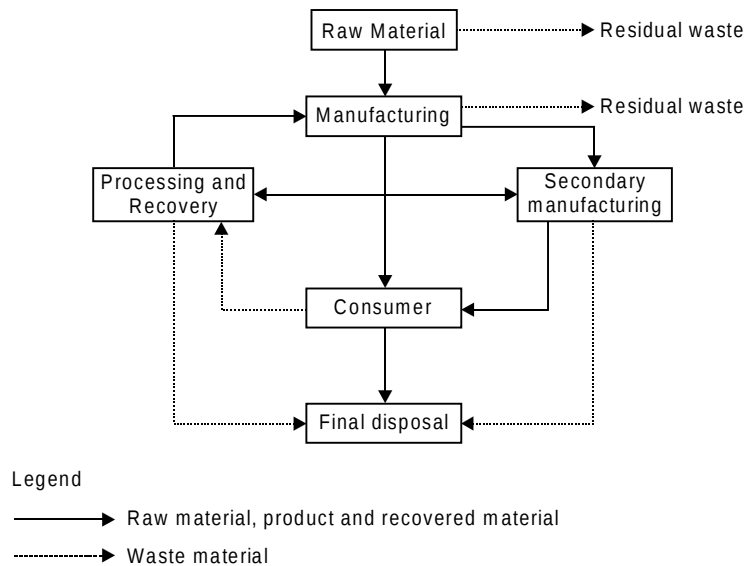


Fig. 1

We can reduce the amount of solid wastes by minimising the consumption of raw materials and increasing the rate of recovery and reuse. Although this concept is simple, implementing such changes in the society is difficult unless appropriate management solutions

are provided. Forecasting waste quantities are also difficult and are similar to waste composition. Another point to mention is waste density. As the waste moves from the source of generation to the point of ultimate disposal, it is also influenced by the storage methods, salvaging activities, exposure to weather, handling methods and decomposition.

WASTE COMPOSITION

The typical composition of solid waste is showed in Table 1.1.

1. Important constituents are paper and decomposable organic matter.
2. Metal, glass, ceramics, textile, dust, dirt, and wood are generally present and their relative proportion depends on the local factor.
3. Average proportion of constituents reaching the disposal sites is consistent. Urban wastes are fairly constant in their composition although subject to long-term changes such as seasonal variations.

Table 1.1 Typical composition municipal solid wastes in India

<i>Components</i>	<i>Mass% Range</i>	<i>Moisture % Typical</i>	<i>Density Range</i>	<i>Kg / m Typical</i>	<i>Range</i>	<i>Typical</i>
Food wastes	6-26	14	50-80	70	120-480	290
Paper	15-45	34	4-10	6	30-130	86
Cardboard	3-15	7	4-8	5	30-80	50
Plastics	2-8	5	1-4	2	30-130	65
Textiles	0-4	2	6-15	10	30-100	65
Rubber	0-1	0.5	1-4	2	90-200	130
Leather	0-2	0.5	8-12	10	90-260	160
Garden						
Trimmmings	0-20	12	30-80	60	60-225	105
Wood	1-4	2	15-40	20	120-320	240
Misc.Org Sub.	0-5	2	10-60	25	90-360	240
Glass	4-16	8	1-4	2	160-480	195
Tin cans	2-8	6	2-4	3	45-160	90
Non ferrous						
Metals	0-1	1	2-4	3	60-240	160
Ferrous metals	1-4	2	2-6	3	120-1200	320
Dirt ash bricks	0-10	4	6-12	8	320-960	480

Source: Ramachandra, 2003

Waste composition also varies with the socio-economic status within a particular community since the income determines the life style, composition pattern and cultural behaviors (<[http:// ces.iiseernet.in /energy/ SWMTR/ TR85.html](http://ces.iiseernet.in/energy/SWMTR/TR85.html)>). To evidence this difference in the income group's Table 1.2 is presented.

Various factors influence the composition of the wastes. Those include geographic location, seasons, collection frequency, population diversity, salvaging and recycling, public attitude and legislation etc.

Table 1.2 Comparison on composition of solid wastes from low and high income groups from India

<i>Characteristics</i>	<i>Low Income</i>	<i>High Income</i>	<i>Remarks</i>
Paper	1-4%	20-50%	Low calorific values due to less paper contents
Plastics	1-6%	5-10%	Plastic use is less in high income groups
Ash etc	17-62%	3-10%	Ash do not contribute to combustion
Moisture	30-40%	15-30%	It depends on the nature of contents
Bulk density	300-400kg/m ³	150kg/m ³	Heavier waste cost more to handle

Source: Ramachandra, 2003

The influence of geographical location is related primarily to different climates that influence both the amounts of solid wastes generated and the collection operation. The amount of garden and yard wastes collected in any country is related to the climate. The season of the year is also important. For example in rainy and summer seasons food and vegetables will decay faster, than during rest of the seasons. Based on the frequency of the collection, the composition also varies. The attitude of the population also influence the waste composition. The amount of waste generated in terms of paper, plastics and other recyclables is always more in the high-income groups than in the low-income groups. The attitude of the public is another aspect, which influence the waste composition. Significant reduction in the solid waste is possible when the people are willing to change their own choice, their habits and life styles to conserve the natural resources and reduce the economic burden associated with the management of solid wastes. Legislation of the land or state regulation will also affect the waste composition. Legislation with packing and beverage container materials in the developed nations is an example.

PHYSICAL CHARACTERISTICS

Density: It is expressed as mass per unit volume (kg/m³). This parameter is required for designing a solid waste management program. A reduction in volume by 75% is achieved through normal compaction equipment, so that an initial density of 100kg/m³ may readily be increased to 400 kg/m³. Significant changes in the density occur as waste moves from sources to disposal site, as a result of scavenging, handling, wetting, and drying by the weather and vibration during transport. Density is critical in the design of sanitary landfill as well as for storage, collection and transport of wastes. Efficient operation of landfill requires compaction of wastes to optimum density.

Moisture Content

It is defined as the ratio of weight of water content in the waste to the total weight of the wet waste.

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

A typical range of moisture content is 20-40% and it varies with the season of the year. Values greater than 40% are also not common. Moisture increases the weight of the solid wastes and therefore the cost of collection and transport increases. Consequently waste should be insulated from rain or other extraneous water source. Moisture content is critical determinant in the economic feasibility of waste treatment by incineration. During incineration energy must be supplied for evaporation of water and raising the temperature of vapour.

CHEMICAL CHARACTERISTICS

Information of chemical characteristics is important in evaluating alternative processing and recovery options. Typically waste is considered as combination of combustible and noncombustible components. If solid waste is to be used as a fuel or for any other use we should know its chemical components.

Lipids

These are included in the class of fats, oils and grease. The principal sources of lipids in the garbage are cooking oil and fats. Lipids have high heating values about 38,000 Kj/Kg (kilojoules/kilograms), which makes the waste with high lipid content suitable for energy recovery. Since lipids become liquids at temperature slightly above ambient they add to the liquid content during waste decomposition. They are biodegradable, but they have low solubility in water and hence the rate of biodegradation is slow.

Carbohydrates

These are primarily originated from the food sources rich in starch and celluloses. These readily biodegrade into carbon dioxide, water and methane. Decomposition of carbohydrates attracts the flies and rats and hence should not be left exposed for long duration

Proteins

These are the compounds containing carbon, hydrogen, nitrogen and oxygen and organic acid with amino groups. They are primarily found in food and garden wastes, but their partial decomposition result in the production of amines, which impart unpleasant odors.

Natural Fibers

These are the natural products contain cellulose and lignins that are relatively resistant to biodegradation. These are found in paper products, food and yard wastes. Paper is almost 100% cellulose, cotton over 95% and wood products over 40-50%. These are highly combustible products most suitable for incineration. The calorific value of oven dried paper products are in the range 12000-18000 kj/kg.

Synthetic Organic Materials

In the recent years plastics have become a significant components of solid waste, accounting for 1-10%. They are highly resistant to the biodegradation; hence their presence in the waste is objectionable. Currently much attention is given to reduce this component at disposal sites. Plastics have a high heating value, about 32000 kj/kg, which makes them very suitable for incineration. However, among the plastics Polyvinyl chloride (PVC) when burnt produces dioxin and acid gas. The trace gases produced during the burning of plastic are proved to be carcinogenic.

HEATING VALUES

An evaluation of the potential of the waste material for use as a fuel in the incinerator requires the determination of its heating value, expressed as kilo joules/ kilo grams (kj/kg). The heating value is determined experimentally using bomb calorimeter test in which the heat is generated at a constant temperature of 25°C from the combustion of dry sample. The heating values for various components is showed in Table 1.3. The heating values are important in the evaluation of incineration process as a means of energy recovery or disposal.

Ultimate Analysis

During the mass balance calculations for a thermal process an analysis of waste must be carried out to determine the proportion of carbon, hydrogen, oxygen, nitrogen and sulfur,

which is referred as ultimate analysis. The ash fraction is also analyzed as it contains toxic metal residues such as cadmium, mercury, chromium, nickel, lead and zinc. The ultimate analysis of typical municipal solid waste is given Table 1.4.

Proximate Analysis

This is an important step in the evaluation of combustion properties of waste ash, volatile substances and fixed carbon substances. Moisture will add to the weight of the waste without heating during combustion. Volatile matter is that portion of the wastes which is converted into the gas before and during combustion. Fixed carbon is the carbon remaining on surface as charcoal. A waste with high fixed carbon requires a longer detention time on the surface of the furnace to achieve complete combustion than the waste with a low fixed carbon load.

Table 1.3 Typical heating values of inert residue of municipal solid wastes

<i>Component</i>	<i>Inert Residue Range</i>	<i>Heating value Typical</i>	<i>Range</i>	<i>Typical</i>
Food wastes	2-8	5	3500-7000	4500
Paper	4-8	6	11500-18500	16500
Cardboard	3-6	5	14000-17500	16000
Plastics	2-20	10	28000-37000	32500
Textiles	2-4	2.5	15000-20000	17500
Rubber	8-20	10	21000-28000	18500
Leather	8-20	10	15000-20000	17500
Garden Trimmings	2-6	4.5	2300-18500	17500
Wood	0.6-2	1.5	17500-20000	18500
Glass	96-99	98	120-240	140
Tin cans	96-99	96	—	—
Non ferrous Metals	90-99	96	240-1200	700
Ferrous metals	94-99	98	240-1200	700
Dirt/ash/brick	60-80	70	2300-11500	7000
Municipal waste	—	—	9500-13000	10500

Source: Ramachandra, 2003

Table: 1.4 Ultimate analysis of municipal waste components

<i>Elements</i>	<i>Range (% dry weight)</i>
Carbon	23.0-30.0
Hydrogen	2.5-6.0
Oxygen	15.0-39.0
Nitrogen	0.25-1.2
Sulfur	0.02-0.12
Ash	12.0-13.0

Source: Ramachandra, 2003

WASTE COLLECTION, STORAGE AND TRANSPORT

Collection of Wastes

Collection of solid wastes is the most costly part of waste management and a proper collection system design can reduce the cost significantly. Collection system will be operated either by the public or by municipalities and corporations. This aspect is left with the local decision makers of the respective areas (EPA, 1989). Collection frequency is based on the cost as well as requirements of the locality. The residential wastes usually contain food and other putrecible materials frequent collection of these wastes is desirable for health and aesthetic reasons. Local climatic conditions often have a strong influence in determining the collection frequency. In hot and humid climates, solid wastes must be collected at least twice per week, as the decomposing of solid waste may produce bad odor and the leachate may create unhygienic scene. The quality of solid waste containers on site also affects the collection frequency. Closed containers allow collection frequency up to three days, where as open and unsealed containers may require daily collection. Collection efficiency mainly depends on the demographic factors (such as income groups and community type etc.) of the area where collection takes place. Based on the intensity of waste production the points or collection stations designed. The optimum collection frequency reduces the cost as it involves few trucks and reduction in total route distance. The less frequent collection may require more storage place in the localities whereas the frequent collection reduces the concern about health, safety, and storage space and also nuisance associated with the stored refuse.

Storage Containers

Appropriate storage containers are required to save the energy and labor and increase the speed of collection and reduce the crew size. It is important that the containers should be functional to the type of materials and the collection vehicles used. Containers should also be durable, easy to handle, economical as well as resistant to corrosion, weather conditions, and metals, glass tips etc. Usually these are made up of thick plastics. When mechanized collection system is used the containers are specially designed to fit the truck mounted loading mechanisms.

Collection Crew

The size of the crew for a particular community depends on the labor force and equipment cost, collection methods and route characteristics. The crew size has a great impact on the overall collection systems. With the increase in collection costs there may be decreasing frequency of collection, increased dependency on the residents to sort out the materials and increased automation used in collection. These aspects have resulted in smaller crews in municipalities in recent years. Solid waste collection vehicle could be a motorized vehicle or a trailer towed by suitable prime mover/tractor. The size of the collection crew depends on the type and size of collection vehicle used, space between the houses, waste generation rate, collection frequency and labor cost. Increase in waste collection rate and quantity of waste collected per stop due to less frequent collection results in bigger crew size. It is possible to adjust the ratio of collectors to collection vehicles such that the crew idle time may be minimized. An effective crew collection size and proper workforce management can influence the efficiency of the collection system.

The collection program must consider the route that is suitable. By proper planning energy can be conserved and working hours and vehicle fuel consumption can be minimized. Detailed route configuration and collection schedules need to be developed for the selected

collection system. Proper routing of collection vehicles can decrease the costs by reducing the labor spent on collection. The size of each route depends on the amount of waste collected per stop, distance between the stops, loading time and traffic conditions. If the disposal site is far from the collection area, a transfer station may be justified where smaller collection vehicles transfer their loads to larger vehicles, which further carry the wastes to longer distances. In some instances, the transfer station may serve as a pre processing point where wastes are dewatered, scooped and compressed (EPA, 1989).

Containers and Collection Vehicles

Proper attention is required to be incorporated in the plan, design and operation of waste management. It is necessary to provide facilities at the point of generation of waste for storage of wastes until they are collected. The design of an efficient collection system needs careful selection of type and size and location for containers. Small containers are used for single-family households while large containers are required for residential, industrial and institutional units. Smaller containers are usually handled manually whereas larger and heavier containers require mechanized handling. The containers may be stationary or hauled to the disposal stations for emptying before returned to the storage site.

A container designed for manual handling should not weigh more than 20 kg when full in order to avoid occupational health hazards. Containers weighing more than 20 kg require more crewmembers to load the wastes into the collection vehicle, resulting in lowering of collection efficiency. The container should not have rough surface or sharp edges and preferable have a handle and wheels to facilitate the mobility. It should be covered to prevent the entry of rainwater, which increases the moisture, weight and rate of decomposition. The container body must be strong enough to resist the weight and chemical action and to deter the scavengers. The materials used for preparing the containers should be light, recyclable, easily molded, smooth and resistant to corrosion. The use of communal containers is highly dependent on the local practice and culture and attitude of the people towards the wastes. These communal containers may fix or movable provided with wheels. For areas with very high waste generation capacity such as vegetable markets, large commercial centers and business establishments, communal containers are used. The containers have usual capacity of 12-20m³ and provided with strong wheels. Normally the transport vehicle keeps an empty container as a replacement before it loads the filled container. In residential and commercial areas the communal containers may be made of concrete or plastic. The containers are placed at 100-200 m apart. Longer distances are used in narrow streets with low traffic where the house owner can easily cross the street.

Collection Vehicle

The collection vehicles may be small and simple or large, complex and energy intensive. The most commonly used vehicle is the dump truck fitted with a hydraulic lifting mechanism. The collection vehicle selected must be suitable to the terrain type and density of waste generation points (UNEP, 1996).

Small-scale Vehicles

These are commonly used for waste collection in many developing countries, as well as in rural hilly areas of developed countries. Such vehicles are small rickshaws, carts, wagons pulled by people or animals. These are inexpensive, easy to build and maintain, compared to other mechanized vehicles. These are suitable in places where relatively less waste is produced. The drawbacks of these small vehicles are limited to travel range, small holding capacity and weather exposure that can affect humans and animals.

Large Vehicles

The non compactor trucks are more efficient and cost effective in small cities and in areas where waste tend to be very dense and have little potential for compaction. When these trucks are used for waste collection, they require a dumping system to easily discharge the waste. It is generally required to cover the trucks in order to avoid the spillage on roads or rain soaking the wastes. Trucks with capacities of 10-12m³ are suitable if distance between the disposal site and the collection area is less. Non-compactor trucks are generally used when labor cost is high. Compaction vehicles are more common in these days. These have capacity of 10-15m³ due to limitation imposed by narrow roads. Compaction vehicles are superior over non-compactor vehicles due to low risk for exposure to pathogens and wastes.

Movement of Collection Crew

Normally the collection crew and the driver of the vehicle work as a team. In most cultures especially in India and Bangladesh, solid waste collection is assigned to the lowest social group. Most often the collection crew members takes the job as a temporary position, while trying for another respectable job. It is not the case in any developed countries. The problem in developing countries is compounded by the attitude of the SWM authorities, who think solid waste collection requires no skill and do not provide any adequate training for the collection crew. Generally familiarity of the crew with the collection areas improves the work efficiency. The driver becomes familiar with the traffic jams, potholes, and other obstructions that he must avoid. The crew will be aware of location of the containers and the vehicle stops. For this reason it is important to assign each crew with specific area responsibility.

Transfer Stations

It is the centralized facility where waste is unloaded from smaller collection vehicle and reloaded into a large vehicle for transport to a disposal or processing site. This transfer of waste is frequently accompanied by removal, separation or handling of wastes. In the areas where wastes are not dense, they may be compacted at the transfer station. A transfer station is needed because of the technical, limitations of smaller collection vehicles and to lower the transport cost by using larger vehicles. The use of transfer station is a sound practice when there is a need for vehicles servicing a collection route to travel shorter distance, unload, and return quickly to their primary tasks of waste collection. However establishing of transfer station will be a financial burden to the authority. The following factors will affect the cost of waste collection.

1. Types of waste received
2. Required capacity and amount waste storage desired
3. Types of collection vehicles used
4. Types of transfer vehicles that can be accommodated at the disposal sites
5. A site topography and access.
6. It is difficult to get a suitable site for transfer station. Because it always busy with the noise of vehicles and it may create nuisance to the public who are living around. Usually transfer site will be near the city or town.

Compaction Station

In these stations mechanical equipment is used to increase the density of the wastes before they are transferred. The most common type of compaction station uses a hydraulically powered compactor to compress the 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 the wastes into the central trailer, which is usually mechanically linked to the compactor (EPA, 1995). This compactor is used during shipment of wastes or to transfer to long distances. The transfer station should have enough capacity to manage and handle the wastes at the facility throughout its operating life. While selecting the design capacity of transfer station we should consider trade offs between capital costs associated with the station and equipment and the operation costs. Designer should also make provisions for sufficient space for storage capacity and for the movement of the trucks and other vehicles.

WASTE DISPOSAL

Disposal is the final stage in the solid waste management, and all the wastes whether they are residential, commercial or from any other sources are collected and transported to a disposal site. It may be a landfill site or an incinerator or some other mode of disposal. In most of the third world countries solid wastes are disposed around cities and towns along the roads, which gave rise to several problems like pollution due to smoke, water pollution due to leachate, blockage of drains and sewers due to plastics and health hazards to workers and rag pickers and humans living nearby areas. Due to these reasons safe disposal of solid waste is important for safeguarding the public health, environment and wildlife as well. An efficient waste management system is the one that provides ecologically sound disposal option for waste that can not be reduced, recycled, composted, combusted or processed further (Ali *et al.*, 1999). Safe disposal is possible only when we understand the reasons for inefficient practices.

As the amount of waste generation is enormous, the municipalities struggle to collect the waste and give less importance to disposal. They may not be having sufficient funds to pay the salaries of the staff and most of the municipal corporations are inefficient in managing the waste due to various reasons. It may be due to corruption at all levels, or due to lack of political will to fund for the practice of solid waste management. Many government authorities give less priority to waste management and do not reserve any funds. A wide range of options are available for the safe waste disposal. They are listed as follows.

1. Open dumping
2. Sanitary dumping
3. Composting
4. Incineration
5. Gasification
6. Refuse derived fuel
7. Pyrolysis.

1. OPEN DUMPING

In this method the solid wastes collected from the town are deposited in low lying areas usually on the outskirts of the town in most of the under developed and developing countries. Since the open dumps are uncovered these attract flies, birds, insects, rodents and also emit odors. This method is unscientific and causes nuisance to the public and subjected to fire hazards. At the same time it causes health and pollution hazards and not suitable aesthetically. Yet this method is the easiest, and used in many urban places of the world, because of lack of planning and funding.

2. SANITARY LAND FILLING

It is essentially an earthen pit, where the environmental risk is controlled at an appropriate and acceptable level and where, subsequent to disposal, land can be made available

for other purposes. The purpose of landfilling 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 homogenous and are usually made up of cells in which a known volume of waste is kept isolated from adjacent waste cells by a suitable barrier. Barriers between the cells commonly consists of a layer of natural soil or clay, which checks the downward or later escape of the waste components or leachate. If properly executed, it is a safer and cheaper method than incineration. Appropriate liners for protection of the ground water from leachates, surface run offs are integral components of environmentally sound sanitary landfill (Philips, et al., 1995).

The feasibility of the land disposal of solid waste depends on the factors such as type, quality, quantity and characteristics of wastes, legal aspects, soil and site characteristics. The microbial degradation process is the most important biological activity occurring in sanitary landfills. These activities also influence the physical and chemical changes in the waste mass, which determine the quality of leachate and the quantity of landfill gas. Assumed that landfills mostly receive organic wastes, microbial process will dominate the stabilization of waste. Soon after disposal, the predominant part of waste becomes anaerobic and the anaerobic bacteria will start degrading the solid organic carbon, eventually to produce carbon dioxide and methane. The solid and dissolved organic compounds are hydrolyzed 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. The methanogenic bacteria convert acetic acid to methane and carbon dioxide. Hydrogenophilic bacteria transform hydrogen and carbon dioxide to methane.

Types of Land Filling

Three types of land filling have been practiced :

1. **Trench method:** This method involves excavation of trench into which waste is deposited and covered with a layer of soil
2. **Area method:** In this method waste may be deposited in layers and so form terraces over the available area. In this type of operation excessive leachate generation may occur and is difficult to control.
3. **Cell method:** This method involves the deposition of waste within pre constructed bonded area. It is the preferred method in industries, 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 since the cell serve to both conceal the tipping and trap much of the litter, which may be generated.

In all the above at the end of each working day all the exposed surfaces including the flanks and working space should be covered with a suitable inert material to a depth of 15 cm. This daily covering is essential, as it minimizes the windblown litter and also reduces the odors.

Resource Reduction

Reducing the waste before it is generated is a logical way to save cost as well as natural resources. It reduces the municipal and commercial costs involved in waste collection and disposal and helps in protecting the local environment. However a successful implementation of source reduction program requires the cooperation of stakeholders: businessmen, industrialists, consumers and state and local governments. The source reduction should be a part of community waste management plan. Source reduction activities vary widely and

many factors have to be considered while evaluating them. Source reduction will promote the product reuse, and its lifetime and also reduce the probable toxicity of the material to the environment. For example Plastics.

Recycling

It is the process of separating, collecting, processing, marketing and ultimately using a material that would have been discarded. It also helps in the source reduction. It has benefits similar to other forms of source reduction. It reduces reliance on landfills and incinerators. It protects human health and the environment by removing the harmful substances from the waste stream. It also conserves natural resources by reducing the demand for raw materials. Recycling reduces the volume of the waste that has to be finally dumped, which means a reduction in pollution at the waste sites.

The re-cyclables may be separated by various agencies at various stages.

The drop-off program requires residents to separate the cyclabable materials and bring them to a specified drop-off or collection center. Local conditions should be taken into account while designing a collection station. A recycling center can be established at the same location where residents deliver wastes. Mobile recycling drop-off vehicles may also be used. Buy-back is another recycling program that provides monitory incentives to participate. In this type of program the resident are paid back for their recyclable material directly or indirectly through the reduction in collection and disposal fees. Establishing a buy-back center may help to induce citizens to recycle. Some buyback centers purchase some materials and donot accept some others depending on current market conditions. Private or public buyback mobile operations can serve better in some countries.

Recyclable materials

The non-biodegradable materials like paper, plastics, metals, glass and wood are commonly recycled in many parts of the world.

Paper

Paper and cardboard form the second largest component of domestic solid waste and contribute more than 13% of the total (UNCHS, 1994). Paper recycling is one of the most profitable activities and is practiced extensively. It reduces the demand for wood and energy and helps to solve littering problem in the city and around dumping sites. It has acceptable working conditions and has limited health risks. Recycled paper and paper products are sold through a well-established network of local processors and vendors. Now a days paper mills are buying the waste paper materials directly from the collectors. The paper industry is making a significant investment in manufacturing capacity for making paper and paper products with recycled components. Recovered paper is classified as newsprint, corrugated cardboard, junk mail, journals, magazines, high-grade paper and pulp substitutes. Paper mills are the most common end users of recovered papers. They use recovered paper for the manufacture of newsprint, chipboard, and craft linerboard, package material and for roofing materials etc.

Glass

It is also one of the most commonly recycled materials and the market for post consumer glass has historically been remained steady. Glass generally accounts for 2.5% by weight of the total solid waste generated (UNCHS, 1994). Glass doesn't contribute to the environmental problem directly but causes serious harm to littering and those who handle it. Recycling of broken glass reduces the risk of injuries caused by cuts and wounds. Glass recycling is labour intensive process and provides employment opportunity. Glass manufactures purchase glass

for reprocessing into new clear green and brown glass jars and bottles. Glass is typically broken for size reduction or crushed and ultimately sold to the glass manufacturer as furnace ready cullet after metal caps, rings and labels etc. are removed. Alternative market for glass includes art glass, sandblasting, and industrial windowpane glass and fiberglass insulation. Market for recovered glass has been strong and stable for green and brown containers.

Metals

On the average the components of metals in the solid waste stream is around 2% (UNCHS, 1994). Ferrous metals like iron, steel and nonferrous metal like, aluminium, copper, zinc, lead and silver etc. exist in the waste stream. Using recycling metal reduces considerable amount of operating cost for the industries. Metal scrap is cheap and the energy consumption is lower when products are manufactured from scrap. Extraction of metals from natural ores depletes the mineral resources. Metals when dumped at landfill sites produce hazardous leachates, which are toxic to organisms in the environment. The ferrous and nonferrous metals scrap are bought and sold through processors and vendors. The long lasting track record makes ferrous and nonferrous metal market among the most stable of all recyclables. Ferrous scrap includes, household appliances, equipments, cans, iron and steel products. The nonferrous scrap includes aluminium, copper, lead, tin etc. Several foundries and steel mills have begun recycling efforts.

Plastics

It constitutes an average of 8% of the total solid wastes generated. It is one of the major objectionable components of solid wastes. Unrecycled plastic when burned it contributes to green house and carcinogenic gases. Direct benefits of recycling of plastic is reduction in the cost of the raw material and energy saving. These days plastic is posing serious littering problem in all the rural and urban areas. Plastic recycling helps in employment generation along with the reduction in the volume of transport and space requirement for dumping. Most plastics are densified locally by flattening, baling or granulating and sold either to converters where the resins are turned into pellets or it may be directly sold to end users who manufacture them into products like bottles, carpets, flower pots and insulation materials. Only five to ten years ago, post consumer high-density polyethylene (HDPE) and polyethylene terephthalate (PET) plastics were vaguely considered as recyclables, these two resins now hold a stronger position in the market.

Batteries and Tyres

Battery recycling is more important as it contains heavy metals like lead, cadmium and mercury. Like other materials battery recycling depends largely on market conditions and requires consistent collection and processing. Household batteries come in variety of types including alkaline, carbon, zinc, cadmium, etc. Only those containing mercury and silver are marketed to end-users. Automobiles use lead acid battery, which contain lead and sulfuric acid, both are hazardous to environment. Battery reprocessing includes breaking the batteries, neutralizing the acids and chipping the containers for recycling. Tyres represent a challenge to solid waste recycling and management. Use of chipped or shredded tyres as a fuel source to electricity generation facilities; pulp and paper mills and cement kiln are most common processes using these scraps heating source (EPA, 1995).

3. COMPOSTING

Composting is a biochemical degradation of the organic fraction of the solid wastes having humus like final products that could be primarily used as soil conditioner. The first

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

Biodegradation is natural ongoing biological process that is a common occurrence in both manmade and natural environments. Grass clippings left in the lawn to decompose or food scraps rotten in the dustbins are the two examples of uncontrolled decomposition. To derive maximum benefit from this natural but slow process of decomposition it is needed to control the environmental conditions during the decomposition process. During this process in addition to compost it also produces carbon dioxide and water as by-products. Air is introduced into the waste pile through manual or mechanical turning or through blowers.

The overall composting process can be explained as follows:

Organic matter + O_2 + aerobic bacteria = CO_2 + NH_3 + H_2O + other end products + energy

Humus is a dark substance looks peat like has a crumbly texture and earthy odor and it resembles rich topsoil. The final product has no resemblance in the physical form to the original wastes from which the compost was made. Good quality compost is devoid of weed seeds, pathogens and other organisms. Cured compost is relatively stable and resistant to further decomposition. It is important to view the combustible materials as usable and not as a waste-requiring disposal. The composting process is environmentally sound and beneficial means of recycling organic materials and not a means of waste disposal. In fact humans have used this naturally occurring process for centuries to stabilize and recycle agricultural and human wastes. Now composting is a diverse process that includes a variety approaches depending on the type of organic material being composted and desired properties of the final product (Luis et al., 1993).

Composting of organic materials can significantly reduce waste stream volume; it reduced the space in landfills. When compost is mixed with soil, it promotes a proper balance between air and water in the resulting mixture, helps to reduce the soil erosion and serves as a slow release fertilizer. Different techniques and stages are adopted for the composting process in various parts of the world.

4. INCINERATION

It is a chemical reaction in which carbon, hydrogen and other elements in the waste combine with oxygen in the combustion zone and generate heat. Usually excess air is supplied to the incinerator to ensure the complete mixing and combustion. The principal gas products of combustion are carbon dioxide, carbon monoxide, water, oxygen and oxides of nitrogen. Excess air also added to the incinerator to regulate operating temperature and control emissions. Excess air requirements will differ with moisture content of waste, heating values and the type of combustion technology employed. Many incinerators are designed to operate in the combustion zone of 900-1100°C. This temperature zone is selected to ensure a good combustion, complete elimination of odors and protection of the wall of the incinerator. These systems are

designed to maximize the waste burnt out and heat output while minimizing the emissions by balancing the oxygen (air). The incineration process while combustion process emits air pollutants (fine particulate matter and gases) to the environment and their control is needed. The emission of combustible, carbon pollutants can be controlled by optimizing the combustion process (EPA, 1989).

Oxides of nitrogen and sulfur and other gases have not been a problem because of their relatively small concentrations. Other concern related to incineration includes the disposal of the liquid wastes from the floor drainage; quench water and the scrubber effluents. The ash produced is disposed into the landfills. The objective of incineration is to reduce their volume to one tenth without producing offensive gases and ashes (Phelps *et al.*, 1995). Depending on the components the incineration process of solid waste reduces the volume of the waste by an average of 90%. The weight of the solid waste will be reduced to 70-75%. This has both ecological and economic advantages because there is less demand for final disposal to landfill, as well as reduced costs and environmental problems due to transport. Incineration of solid waste is becoming an increasingly important aspect of solid waste management, as the communities are looking for quick method of disposal. Modern incineration facilities are no longer simple garbage burners. Instead they are designed to produce energy during controlled burning of the wastes as well as attempts to solve the environmental problems.

5. BIOGASIFICATION

Biogas is originated from bacterial activities in the process of biodegradation of organic matter under anaerobic conditions. The natural generation of biogas is an important part of the biogeochemical cycle. Methane producing bacteria are the last link in the chain of microorganisms, which degrade organic matter and transfer the materials to the environment. In this process the biogas is generated which is a source of renewable energy. Biogas is a mixture of methane (40-70%), carbon dioxide 30-60%, and other gases 1-5%. Biogas may be used for producing heat, electricity and light. The biogas technology can substantially contribute to energy conservation and development, if the conditions are favorable. However the economic viability and social acceptance of biogas technology should be considered.