Waste Management: BETCK 105F/205F

M-3 Waste Collection, Storage, Transport and Disposal of Wastes

Waste Collection:
Collection Components,
Storage Containers/Collection Vehicles, and
Collection Operation.
Transfer Station,
Waste Collection System Design,
Record Keeping, Control, Inventory and monitoring,.
Waste Disposal:
key issues in Waste Disposal,
Disposal options and Selection Criteria.
Sanitary Landfill:
Landfill Gas Emission,
Leachate formation,
Environmental Effects of Landfill,
Implementing Collection and Transfer System-a Case Study
Landfill Operation Issues- a Case Study.

t. v. manju prasad, Assistant Professor, CED, HMSIT, Tumakuru- 572 104
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Waste Collection

Waste collection does not mean merely the gathering of wastes, and the process includes, as well, the transporting of wastes to transfer stations and/or disposal sites.

Collection Components:

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.

Collection frequency:

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

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

1. Cost, e.g., optimal collection frequency reduces the cost as it involves fewer trucks, employees and reduction in total route distance;
2. Storage Space, e.g., less frequent collection may require more storagespace in the locality;
3. Sanitation, e.g., frequent collection reduces concerns about health, safety and nuisance associated with stored refuse.

1. 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, standardized metal or plastic containers are typically required for waste storage. When mechanized collection systems are used, containers are specifically designed to fit the truck-mounted loading mechanisms.

While evaluating residential waste containers, consider the following;

1. Efficiency, i.e., the containers should help maximise the overall collection efficiency.
2. Convenience, i.e., the containers must be easily manageable both forresidents and collection crew.
3. Compatibility, i.e., the containers must be compatible with collectionequipment.
4. Public Health and Safety, i.e., the containers should be securely coveredand stored.
5. Ownership, i.e., the municipal ownership must guarantee compatibility with collection equipment.

2. 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. However, with increase in collection costs, the trend in recent years is towards;

1. Decrease in the frequency of collection;
2. Increase in the dependence on residents to sort waste materials;
3. Increase in the degree of automation used in collection.

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

1. Collection Route:

The collection programmemust consider the route that is efficient for collection. An efficient routing of collection vehicles helps decrease costs by reducing the labour expended for collection. Proper planning of collection route also helps conserve energy and minimise working hours and vehicle fuel consumption. It is necessary therefore to develop detailed route configurations and collection schedules for the selected collection system. The size of each route, however, depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions.

Barriers, such as railroad, embankments, rivers and roads with heavy traffic, can be considered to divide route territories.

Routing (network) analyses and planning can;

1. Increase the likelihood of all streets being serviced equally andconsistently,
2. Help supervisors locate or track crews quickly, and
3. Provide optimal routes that can be tested against driver judgment and experience.

2. 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 centralized sorting and recovery of recyclable materials are also carried out at transfer stations. The unit cost of hauling solid wastes from a collection area to a transfer station and then to disposal site decreases, as the size of the collection vehicle increases, this is due to various reasons such as the following:

1. Labour costs remain constant,
2. The ratio of payload to vehicle load increases with vehicle size,
3. The waiting time, unloading time, idle time at traffic lights and driver restperiod are constant, regardless of the collection vehicle size.

Note that waste collection often proves to be the most costly component of any waste management system. However, with a proper collection system design and management, we can significantly reduce the costs.

Consider the following criteria to evaluate, and make decisions about, collection systems;

1. **Efficiency:** Do the services help minimise the cost per household?
2. **Effectiveness:** Do the services satisfy the community needs?
3. **Equity:** Do the services address equally the concerns of all social anddemographic groups?
4. **Reliability:** Do the services ensure consistency?
5. **Safety and environmental impact:** Do the services ensure safety ofworkers, public health and protection of the environment?

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

Storage: Containers/CollectionVehicles

Containers/Storage Bins:

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

1. **Stationary containers:** These are used for contents to be transferred to collection vehicles at the site of storage.
2. **Hauled containers:** These are used for contents to be directly transferred to a processing plant, transfer station or disposal site for emptying before being returned to the storage site.

The desirable characteristics of a well-designed container are low cost, size, weight, shape, resistance to corrosion, water tightness, strength and durability.

For example, a container for manual handling by one person should not weigh more than 20 kg, lest it may lead to occupational health hazards such as muscular strain, etc. Containers that weigh more than 20 kg, when full, require two or more crew members to manually load and unload the wastes, and which result in low collection efficiency. Containers should not have rough or sharp edges, and preferably have a handle and a wheel to facilitate mobility. They should be covered to prevent rainwater from entering into the solid wastes.

The container body must be strong enough to resist and discourage stray animals and scavengers from ripping it as well as withstand rough handling by the collection crew and mechanical loading equipment. Containers should be provided with a lifting bar, compatible with the hoisting mechanism of the vehicle. The material used should be light, recyclable, easily moulded and the surface must be smooth and resistant to corrosion. On the one hand, steel and ferrous containers are heavy and subject to corrosion; the rust peels off exposing sharp edges, which could be hazardous to the collection crew. On the other, wooden containers (e.g., bamboo, rattan and wooden baskets) readily absorb and retain moisture and their surfaces are generally rough, irregular and difficult to clean.

Communal containers:

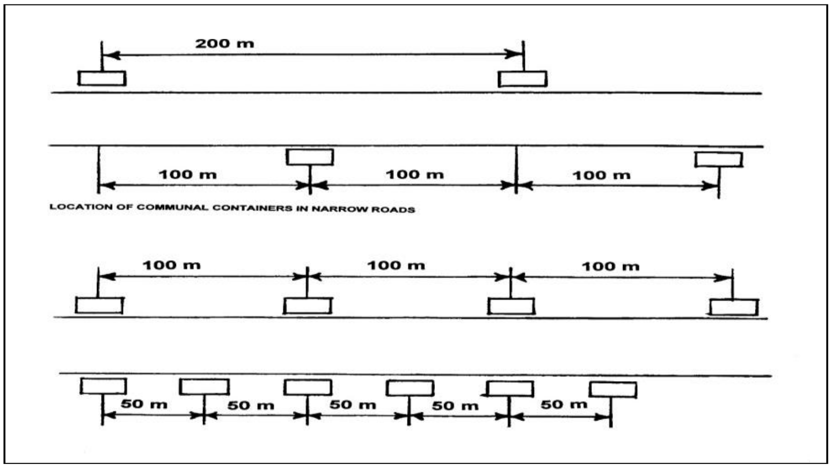
Generally, the containers used for waste storage are communal/public containers. Figure below shows a typical communal container, which a compactor collection vehicle can lift and empty mechanically:

Typical Communal Container

The use of communal containers is largely dependent on local culture, tradition and attitudes towards waste. Communal containers may be fixed on the ground (stationary) or movable (hauled). Movable containers are provided with hoists and tails compatible with lifting mechanism of collection vehicles and such containers have capacities of 1 – 4 m^3.

The waste management authority must monitor, maintain and upgrade the communal containers. Note that in residential and commercial areas in India, the communal containers are often made of concrete. In areas with very high waste generation rates, i.e., rates exceeding two truckloads daily, such as wet markets, large commercial centres and large business establishments, roll-on-roll or hoisted communal containers with capacities of 12 – 20 m^3 and a strong superstructure with wheels are used. Normally, the collection vehicle keeps an empty container as a replacement before it hauls the filled container. When a truck is used as a collection vehicle, the use of communal containers may be appropriate. It is advisable to place the containers 100 – 200 m apart for economic reasons. The communal containers are usually staggered such that the effective distance of 100 m is maintained as shown in Figure

Location of Communal Container



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

Disadvantages:

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

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

Collection Vehicles:

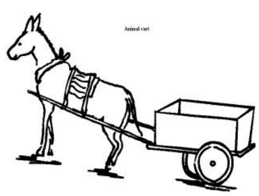
Almost all collections are based on collector and collection crew, which move through the collection service area with a vehicle for collecting the waste material. The collection vehicle selected must be appropriate to the terrain, type and density of waste generation points, the way it travels and type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

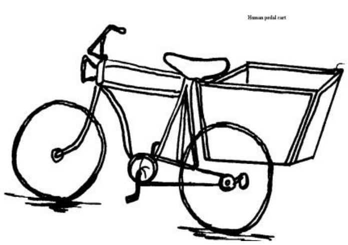
A description of some vehicle types follows:

- **Small-scale collection and muscle-powered vehicles:**

These are common vehicles used for waste collection in many countries and are generally used in rural hilly areas. These can be small rickshaws, carts or wagons pulled by people or animals, and are less expensive, easier to build and maintain compared to other vehicles.

Small-scale Collection Vehicles: An Illustration





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

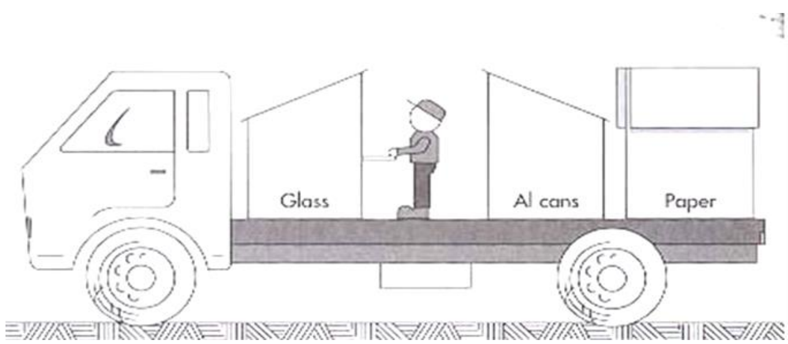
Non-compactor trucks:

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

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

Compactor truck:

Compaction vehicles are more common these days, generally having capacities of 12 – 15 m^3 due to limitations imposed by narrow roads. Although the capacity of a compaction vehicle,



illustrated in Figure is similar to that of a dump truck, the weight of solid wastes collected per trip is 2 to 2.5 times larger

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

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

The advantages of the compactor collection vehicle include the following;

1. Containers are uniform, large, covered and relatively visually inoffensive;
2. Waste is set out in containers so that the crew can pick them up quickly;
3. Health risk to the collectors and odor on the streets are minimised;
4. Waste is relatively inaccessible to the waste pickers.

Collection Operation

Movement of Collection Crew:

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

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

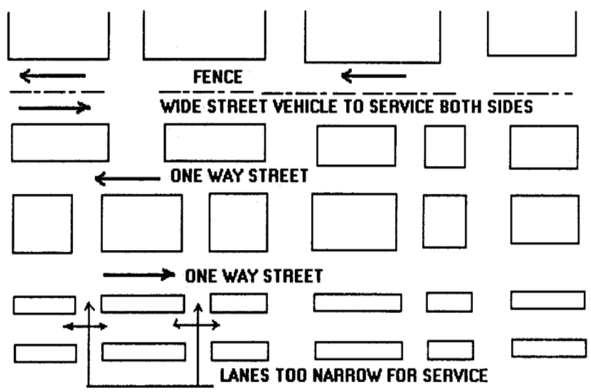
The movement of collection crew, container location and vehicle stopping point affect collection system costs. Figure highlights the distance the collection crew will have to walk, if it were to serve the farthest point first or serve the point closest to the vehicle.

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

Generally, familiarity of the crew with the collection area improves efficiency. For example, the driver becomes familiar with the traffic jams, potholes and other obstructions that he or she must avoid. The crew is aware of the location of the containers and the vehicle stops. It is, therefore, important to assign each crew specific areas of responsibility. Working together also establishes an understanding of the strong and weak points of the team members and efficient work sequences.

The collection operation must also observe a strict time schedule. Testing of new routes, new gadgets and vehicles is best carried out first in the laboratory and later in a pilot area. Testing of a new sequence using the whole service area could result in disorder and breakdown of the solid waste collection system. Studies show that it takes two hours to recover for every hour of a failed system.

Effect of Container Location and Vehicle Stopping



Motion Time Measurement (MTM) Technique:

Motion time measurement (MTM) studies are now an integral part of the standard procedure in the development of solid waste collection systems. MTM is a technique to observe and estimate the movement of the collection crew with the help of stopwatches. The results thus gathered are tabulated as shown;

MTM Study: Determination of Time, Distance and Number on Containers inCollection Route

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

MTM also helps in deciding the best combination of equipment to maintain a desired level of output, reduce health problems related to the repetitive work sequence and predict the effects of changes in materials handled. Sophisticated MTM studies involve hidden or open video cameras at different collection stops to record, replay and study the operation sequence of the collection crew. If the crew is conscious of being observed, they tend to work faster and reduce time wastage in unauthorized salvaging and other non- scheduled activities. Once the crew is familiar with the person(s) observing them, it begins to perform more credibly. In studies involving video cameras, therefore,the first two or three hours of observation are often neglected.

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:

1. **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.

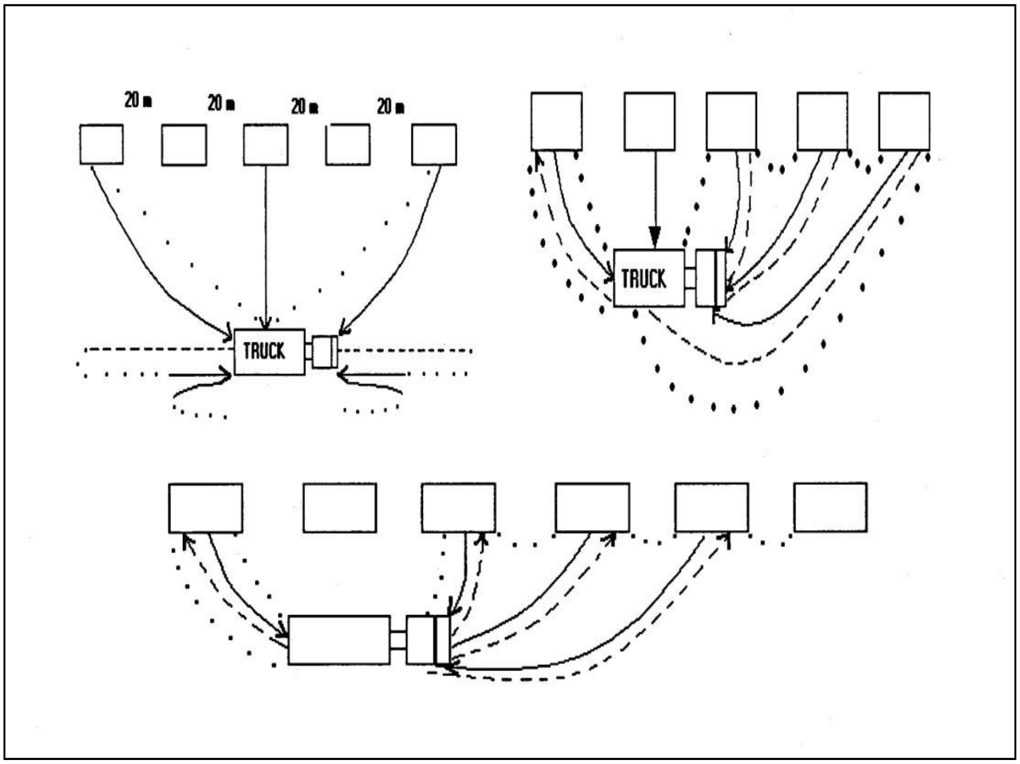
2. **Micro-routing:** Using the results of the macro-routing analysis, micro- routing can define the specific path that each crew and collection vehicle will take each collection day. Results of micro-routing analyses can then be used to readjust macro-routing decisions. Micro-routing analyses should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

Districting is the other method for collection route design. For larger areas it is not possible for one institution to handle it then the best way is to sub divide the area and MSW collection districting plan can be made. This routing will be successful only when road network integrity is good and the regional proximity has been generated. The heuristic (i.e., trial and error) route development process is a relatively simple manual approach that applies specific routing patterns to block configurations. The map should show collection, service garage locations, disposal or transfer sites, one-way streets, natural barriers and areas of heavy traffic flow.

Routes should then be traced onto the tracing paper using thefollowing rules:

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

Collection Vehicle Route


20 m
20 m
20 m
20 m
TRUCK
TRUCK

Transfer Station:

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

Transfer station

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

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

1. Types of waste received.
2. Processes required in recovering material from wastes.
3. Required capacity and amount of waste storage desired.
4. Types of collection vehicles using the facility.
5. Types of transfer vehicles that can be accommodated at the disposalfacilities.
6. Site topography and access.

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

Types of Transfer Station:

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

1. Small to Medium Transfer Stations:

These are direct-discharge stations that provide no intermediate waste storage area. The capacities are generally small (<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 depends on the size and population density of the area served and the frequency of collection.

2. 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;

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

Designs for Larger Transfer Operations:

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

1. **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.
2. **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.
3. **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. Compaction stations are used when:
    1. Wastes must be baled for shipment;
    2. Open-top trailers cannot be used because of size restrictions;

3. 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-nest 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.

Capacity:

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

Factors that should be considered in determining the appropriate capacity of a transfer facility include:

1. Capacity of collection vehicles using the facility.
2. Desired number of days of storage space on tipping floor.
3. Time required unloading collection vehicles.
4. Waste sorting or processing to be accomplished at the facility,
5. transfer trailer capacity;
6. Hours of station operation.
7. Availability of transfer trailers waiting for loading.
8. Time required, if necessary, to attach and disconnect trailers from tractors or compactors.

Transfer station capacity can be determined using the following formulae:

1. **Pit stations:**

Based on the rate at which wastes can be unloaded fromcollection 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:

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

2. **Direct dump stations:**

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

3. **Hopper compaction stations:**

$$C = (N_n \times P_t \times F \times 60 \times H_w)/[(P_t/P_c \times T_c) + B]$$

4. **Push pit compaction station:**

$$C = (N_p \times P_t \times F \times 60 \times H_w)/[(P_t/P_c \times W/L_p \times T_c) + B_c + B]$$

Where;

C = Station capacity (tonnes/day)

P_c = Collection vehicle payload (tonnes)

L = Total length of dumping space (feet)

H_w = Hours per day that waste is delivered

T_c = Time (in minutes) to unload each collection vehicle

F = Peaking factor (ratio of the number of collection vehicles received during an average 30-minute period to the number received during a peak 30-minute period)

L_p = Length of push pit (feet)

N_p = Number of push pits

B_c = Total cycle time for clearing each push pit and compacting waste into trailer

P_t = Transfer trailer payload (tonnes)

N = Number of transfer trailers loading simultaneously

H_t = Hours per day used to load trailers (minutes)

B = Timeto remove and replace each loaded trailer (minutes)

T_t = Time to load each transfer trailer (minutes)

N_n = Number of hoppers; L_n = Length of each hopper (feet).

These formulae are useful in estimating the capacity of various types of transfer station and should be adapted, as necessary, for specific applications.

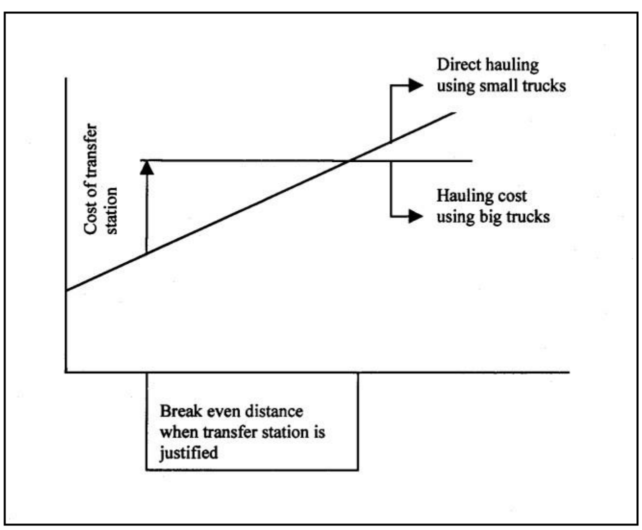
Viability:

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

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

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

Cost Analysis to Determine Viability of Transfer Station



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

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

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

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

The transfer station is justified,

When: $$T < T_1$$

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

$$2AX + B + 2CY < 2AX + 2AY \qquad \text{or} \qquad Y > B/(2A - 2C)$$

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

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

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

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

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

$$\text{or} \qquad Y > (B + 2CZ + 2AZ)/(2A - 2C)$$

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

Waste Collection System Design

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

1. **Number of services/vehicle load (N):**

$$\mathbf{N = \frac{(C \times D)}{W}}$$

Where,

C = Vehicle capacity (m^3)

D = Waste density (kg/m^3)

W =Waste generation/residence (kg/service)

2. **Time required collecting one load (E):**

$$E = N \times L$$

Where,

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

3. **Number of loads/crew/day (n):**

The number of loads, 'n', that each crew can collect in a day can be estimated based on the workday length 't', and the time spent on administration and breaks 't_1',, time for hauling and other travel,'t_2', and collection route time,'t_3'.

1. **Administrative and break time (t_1):**

$$\mathbf{t_1 = A + B}$$

Where,

A = Administrative time (i.e., for meetings, paperwork,unspecified slack time) and

B = Time for breaks and lunch

2. **Hauling and other travel time (t_2):**

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

Where,

n = Number of loads/crew/day;

H = Time to travelto disposal site, empty truck, and return to route;

f = Timeto return from site to route;

G = Time to travel from staging garage to route and

J = Time to return from disposal site to garage.

3. **Time spent on collection route (t_3):**

$$t_3 = n \times E$$

Where, variables have been previously defined.

4. **Length of workday (t):**

$$t = t_1 + t_2 + t_3$$

Where,

t is defined by work rules and equations A through D are solvedto find n.

4. **Calculation of number of vehicles and crews (K):**

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

Where,

S = Total number of services in the collection area;

F = Frequency of collection (numbers/week) and

M = Number of workdays/week

5. **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**

Record Keeping, Control, Inventory and Monitoring:

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

Checklist of Variables Affecting Collection System

Components	Factors to Consider
Crew size	• labour cost • distance between container • size and types of containers • loading accessories available in thetruck • collection vehicle used
Container type	• solid wastes generation ratedensity of waste • generation street width • traffic volume • collection crew configuration • standard of living
Collection accessory	• labour cost • protection of worker's health
Vehicle size/type	• Street width, traffic volume solid waste generation ratescrew size • viability of a transfer station
Collection route	• street width, traffic volumedirection of traffic flow • solid waste generation ratesspatial distribution of wastes • local topography
Transfer station	• Distance between disposal site andcollection area • hauling cost for small and large trucks • cost of transferring the solid wastesfrom small to large trucks

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

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

All these decisions should be based on reliable data, without which the waste collection system will inevitably be ineffective. Proper interpretation of monitoring data allows the authority to adapt the proposed system to actual conditions. In some instances, it also allows management to identify areas, where the design isnot realistic.

Implementing Collection andTransfer System

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

1. **Finalizing and implementing the system management plan:**

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

2. **Purchasing and managing equipment:**

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

1. Preventive maintenance schedule
2. Current list of specific engine
3. A description of repairs and a list containing information on the repair date, mechanic, cost, type and manufacturer of repair parts and the length of time the truck was out of service, for each maintenance event.

3. Hiring and training personnel:

As in all organizations, good personnel management is essential to an efficient, high-quality waste collection system. Authorities responsible for SWM should, therefore, strive to hire and keep well-qualified personnel. The recruitment programme should assess applicants' abilities to perform the types of physical labour required for the collection, equipment and methods used. To retain employees, management should provide a safe working environment that emphasises career advancement, participatory problem solving and worker incentives. Worker incentives should be developed to recognize and reward outstanding performance by employees. Ways to accomplish motivation include merit-based compensation, awards programme and a work structure. Feedback on employee performance should be regular and frequent. Safety is especially important because waste collection employees encounter many hazards during each workday. As a result of poor safety records, insurance costs for many collection services are high. To minimise injuries, haulers should have an ongoing safety programme. This programme should outline safety procedures and ensure that all personnel are properly trained on safety issues. Haulers should develop an employee-training programme that helps employees improve and broaden the range of their job-related skills. Education should address such subjects as driving skills, first aid, safe lifting methods, identification of household hazardous wastes, avoidance of substance abuse and stress management.

4. Providing public information:

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

5. **Monitoring system cost and performance:**

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

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

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

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

1. Analyse the quantum of waste generated with composition
2. Capacity building of town municipalities with appropriate infrastructure and the knowledge of existing laws or regulations on waste collection, transport and safe disposal.
3. Designate a para-state agency to oversee waste collection, transport and disposal to avoid confusion among para-stategovernment agencies.
4. Determine geographic scope of collection and transport services.
5. Determine funding, equipment and labour needs.
6. Determine the type and amount of waste to be processed
7. Implement decentralised waste treatment through proven localtechniques
8. Deploy GPS (Global Positioning System) based trucks for wastecollection and transport to minimise pilferages.
9. Adopt spatial information system for the management
10. Consider a transfer station that serves as a central location foractivities to sort and recover waste.
11. Implement decentralised waste management including all stakeholders with active participation of the public.

Waste Disposal

Key Issues in Waste Disposal:

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.

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

1. 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 withwastes, etc.);
2. Pollution due to smoke;
3. Pollution from waste leachate and gas;
4. 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 theconstraints:

1. **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.
2. **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.
3. **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.

4. **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.
5. **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.
6. **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.

Disposal Options and Selection Criteria:

The most common disposal option practiced 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.

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:

1. **Uncontrolled dumping or non-engineered disposal:** As mentioned, this is the most common method being practiced 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 adversehealth and environmental impact associated with it, the non-engineered disposal is not considered a viable and safe option.
2. **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.

3. **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 centralized 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.

4. **Incineration:** This refers to the controlled burning of wastes, at a high temperature (roughly 1200 – 1500 °C), which sterilizes and stabilizes 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.

5. **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.

6. **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.

7. **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 solidburned residue.

Relative merits of some 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	√	√	×	√

Selection criteria

With the help of proper frameworks and sub-frameworks, we can assess the effectiveness of each of the waste disposal options. 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. 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;

1. Technical:

This feature, involving efficient and effective operation of the technology being used, evaluates the following components of a SWM system;

1. Composition of wastes, e.g., type, characteristics and quantity.
2. Existing practices, e.g., collection, transport, and recycling process.
3. Siting, e.g., location of disposal site, engineering material, etc.
4. Technology, e.g., operation, maintenance, technical support, etc.
5. Impact, e.g., anticipated by-product, requirement for their treatment and disposal, etc.

2. Institutional:

This involves the ability and willingness of responsibleagencies to operate and manage the system by evaluating the following:

1. Structures, roles, and responsibilities, e.g., current institutional frame works
2. Operational capacity, e.g., municipal capacities, local experience and staff

training
3. Incentives, e.g., management improvement and waste disposal practices
4. Innovation and Partnership

3. **Financial:**

This assesses the ability to finance the implementation,operation and maintenance of the system by evaluating the following:

1. Financing and cost recovery, e.g., willingness to raise finance for waste management.
2. Current revenue and expenditure on waste management.
3. Potential need for external finance for capital cost.

4. **Social:**

This helps in avoiding adverse social impact by evaluating thefollowing;

1. Waste picking, which has an impact on livelihood and access to wastepickers.
2. Health and income implication.
3. Public opinions on the existing and proposed system.

5. **Environmental:**

This means setting up an environment friendly disposal system by evaluating the following;

1. Initial environmental risks, i.e., impact of existing and proposed disposaloption.
2. Long-term environmental risks, i.e., long-term implication (futureimpacts).

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:

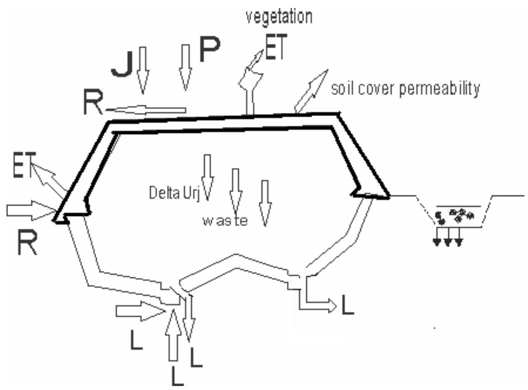
1. Full or partial hydrological isolation;
2. Formal engineering preparation;
3. Permanent control;
4. Planned waste emplacement and covering.

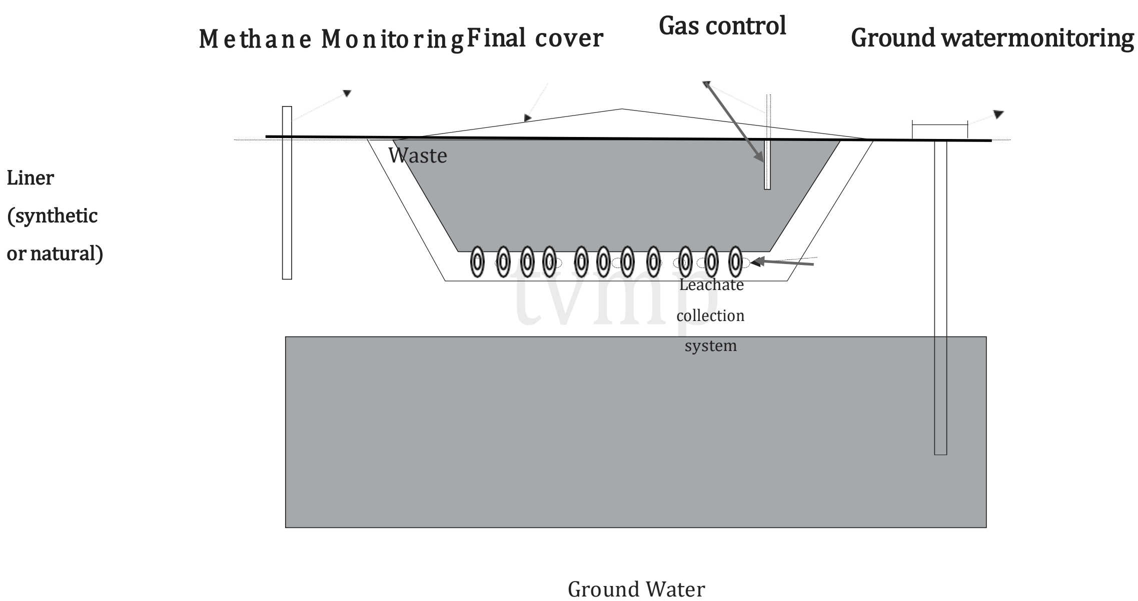
Principle:

The purpose of land filling is to bury or alter the chemical compos ition 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. 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 below gives a schematic layout of sanitary landfill along with its various components:





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; Pi = P+J+R*- R-ET+/ Us;

Us : water contents in soil;

Uw : water content in waste; S: water added in sludge disposal;

B : water production (if>0) or Consumption (if <0) caused by biological degradation of organic matter;

Is/Ig : water from natural aquifers;

L=Pi+S+Ig+b +/- Uw; L: total leachate production;

Li : infiltration into aquifers;

Lr : leachate collected by drains.

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.

1. **Construction phase**: This involves earthworks, road and facility construction and preparation (liners and drains) of the fill area.
2. **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.
3. **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.
4. **Final storage phase:** In this phase, the landfill is integrated into the surroundings for other purposes, and no longer needs special attention.

Landfill Processes:

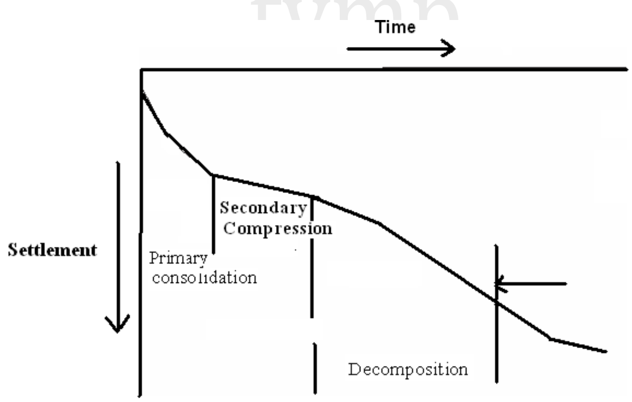
The feasibility of land disposal of solid wastes depends on factors such as the type, quantity and characteristics of wastes, the prevailing laws and regulations, and soil and site characteristics. Let us now explain some of these processes.

1. **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.

2. **Settling process:**

The waste body of a landfill undergoes different stages of settling or deformation. Figure below illustrates these stages:



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. Themovement 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 an increase 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.

3. **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 stabilization 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 fomenters 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.
- **Reticulating 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.

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:

1. **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.
2. **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.
3. **pH:** The methanogenic bacteria within a landfill produce methane gas, which will grow only at low pH range around neutrality.
4. **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.
5. **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.
6.

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.

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.

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:

1. **Methane:** This is a colorless, odorless and flammable gas with a density lighter than air, typically making up 50 – 60% of the landfill gas.
2. **Carbon dioxide:** This is a colorless, odorless and non-inflammable gas that is denser than air, typically accounting for 30 – 40%.
3. **Oxygen:** The flammability of methane depends on the percentage of oxygen. It is, therefore, important to control oxygen levels, where gas abstraction is undertaken.
4. **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.

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:

1. **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.

2. **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.

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.

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.

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.

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:

1. Water availability;
2. Landfill surface condition;
3. Refuse state;
4. 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:

$$Lo = I - E - aW$$

$$\text{i.e. } I - E < aW$$

Where,

Lo = free leachate retained at 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-chemicalpath for its removal (Ali, et al., 1995). Leachate composition varies with time and location. Table shows a typical leachate properties and composition at various stages of waste decomposition:

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	-

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.

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.

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 includ***e:***

- **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.

Environmental Effects of Landfill:

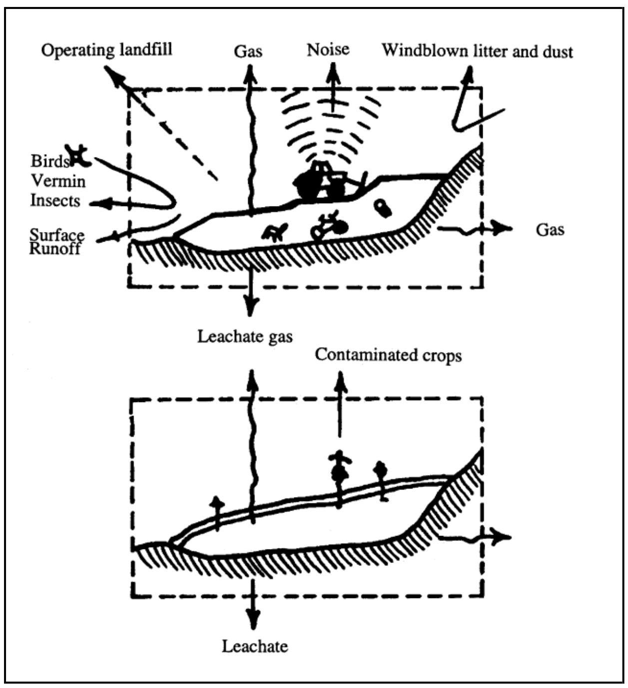
The environmental effects of a landfill include wind-blown litter and dust, noise, obnoxious odour, vermin and insects attracted by the waste, surface runoff and in aesthetic conditions. Gas and leachate problems also arise during the operation phase and require significant environmental controls. In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

1. Wind-blown litter and dust are continuous problems of the ongoing landfill operation and a nuisance to the neighborhood. 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.
2. 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.
3. 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.
4. 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.
5. An operating landfill, where equipment and waste are exposed, appears in aesthetic. This problem may be reduced by careful design of screening soil embankments, plantings, rapid covering and re-vegetation of filled sections.
6. 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.

7. 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.

Environmental Emissions from a Sanitary Landfill



Besides the emissions shown in Figure , 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.

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.

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.

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.

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:

1. Need to comply with planning, building, fire, health and safety regulations and controls;
2. Security and resistance to vandalism;
3. Durability of service and the possible need to relocate accommodation during the lifetime of the site operations; ease of cleaning and maintenance;
4. 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.

1. **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.

2. 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.

3. 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.

4. 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.

Operation

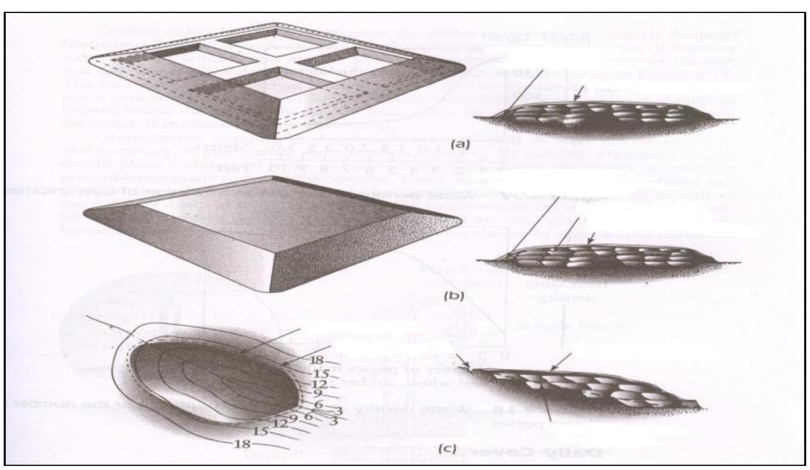
To secure public acceptability, landfill operations require careful planning and determination of the extent of environmental effects. The basic factor influencing the planning of site operations is the nature and quantity of incoming wastes. The various aspects of this include the following:

1. **Methods of filling:**

The following variations in land filling techniques are;

1. **Trench method:** This involves the excavation of a trench into which waste is deposited, and the excavated material is then used as cover.
2. **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.
3. **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 ofthe litter that has been generated.
4. **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 illustrates the land filling methods touched upon above:



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

2. **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.
3. **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.
4. **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.

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:

1. **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.

2. **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.

Module: 3

Question no. 5

1. Explain the various collection components that influences the waste collection systems. **(10M, Jan./Feb. 2023)**
2. What is the transfer station? Explain the types based on its use. **(10M, Jan./Feb. 2023)**
3. Briefly explain the methods of control and treat the leachate. **(10M, June/July 2023)**
4. Discuss the landfill operation issued in waste disposal. **(10M, June/July 2023)**

Question no. 6

1. Describe the various options of disposal of solid wastes. **(10M, Jan./Feb. 2023)**
2. Explain the various stages involved in sanitary Lanfilling. **(10M, Jan./Feb. 2023)**
3. Explain the different factors that affect the selection of transfer station. **(10M, June/July 2023)**
4. Briefly explain collection components in solid waste management. **(10M, June/July 2023)**