CHAPTER ONE

EVALUATION OF SOLID WASTE MANAGEMENT

Solid waste comprises all the waste arising from human and animal activities that are normally solid and that are discarded as useless or unwanted.

Materials Flow and Waste Generation

An indication of how and where solid waste are generated in our technological society is presented in Fig. 1.1.

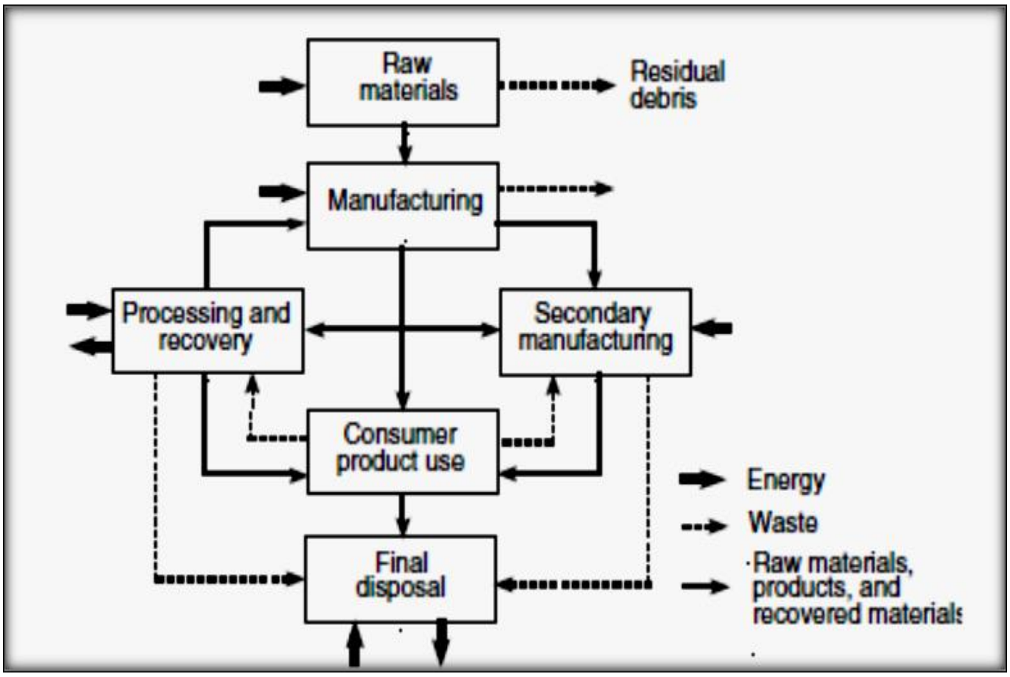


Figure 1.1 Materials Flow and Waste Generation in a technological society

One of the best ways to reduce the amount of solid waste that must be disposed of is to limit the consumption of raw materials and to increase the rate of recovery and reuse of waste materials.

Unlike water-borne and air-dispersed wastes, solid wastes, solid waste will not go away. Where it is thrown …….is where it will be found in the future.

Solid Waste Management

Q1. Define solid waste management

: may be defined as the activities associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations.

Functional Elements/ Definitions

Q2: State solid waste management functional elements and define each.

Six functional elements: (1) waste generation; (2) waste handling and separation, storage, and processing at the source; (3) collection; (4) separation and processing and transformation of solid wastes; (5) transfer and transport; and (6) disposal (Fig. 1.2)

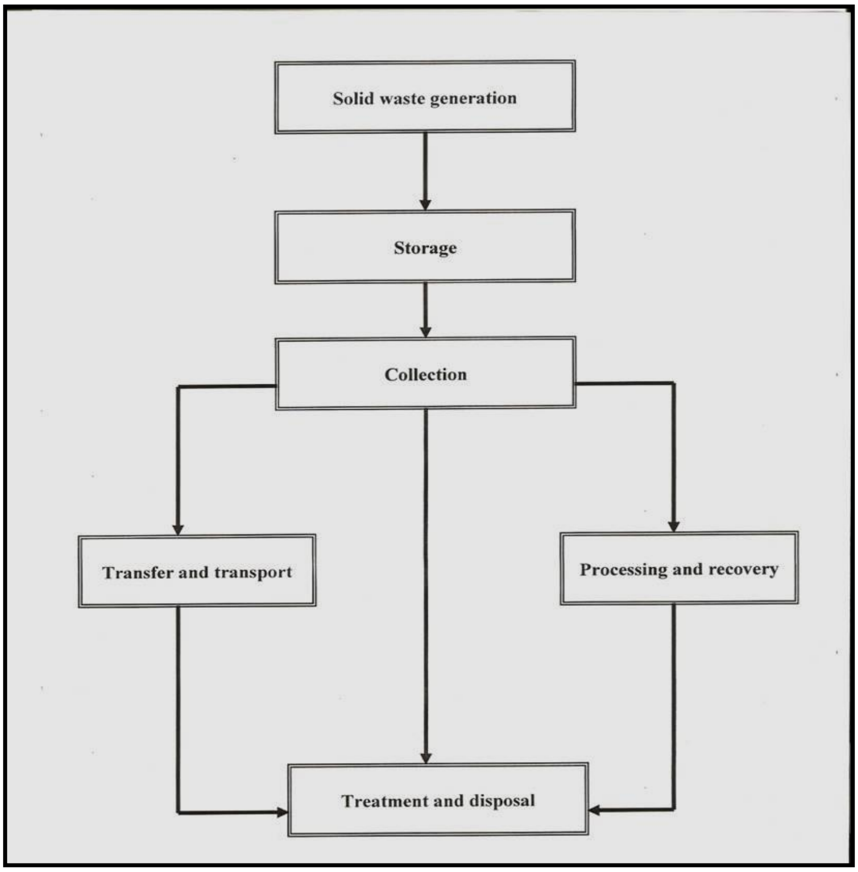


Figure 1.2 Functional elements of Solid waste

Waste Generation

Encompasses activities in which materials are identified as no longer being of value and are either thrown away or gathered together for disposal. For example the wrapping of candy bar is usually considered to be of little value to the owner once the candy is consumed.

Waste Handling and Separation, Storage, and Processing at the Source.

Waste handling and separation involves the activities associated with management of wastes until they are placed in storage containers for collection. Handling also encompasses the movement of loaded containers to the point of collection.

On site storage is of primary importance because of public health concerns and aesthetics consideration

Collection

The functional element of collection includes not only the gathering of solid wastes and recyclable materials, but also the transport of these materials, after collection, to the location where the collection vehicle is emptied. This location may be a materials processing facility, a transfer station, or a landfill disposal site. In small cities where the final disposal sites are nearby, the hauling of wastes is not a serious problem. In large cities, however where the haul distance to the point of disposal is often more than 15 miles (about 25. km) the haul may have significant economic implications. Where long distances are involved, transfer and transport facilities are normally used.

Separation, Processing, and Transformation of Solid Waste. The fourth of the functional elements is recovery of separated materials that occurs primarily in locations away from the source of waste generation.

Transfer and Transport. The functional element of transfer and transport in-volves two steps: (1) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and (2) the subsequent transport of the wastes, usually over long distances, to a processing or disposal site.

Disposal. (Ultimate destination) The final functional element in the solid waste management system is disposal. Today the disposal of wastes by land filling or land spreading is the ultimate fate of all solid wastes. A modern sanitary land fill is not a dump it is an engineered facility used for disposing of solid waste on land or within the earth s mantle without creating nuisance or hazards to public health or to the surrounding environment, such as the breeding of rats and insects and the contamination of ground water.

NIMBY: Not in My Back Yard

Q3. Define ISWM.

Integrated Solid Waste Management (ISWM) can be defined as the selection and application of suitable technique, technologies, and management programs to achieve specific waste management objectives and goals.

Q4. Define the word hierarchy and what are its components as adopted by the EPA, explain each

A Hierarchy (arrangement in order of rank) in waste management can be used to rank actions to implement programs within the community (Fig. 1.3). The ISWM hierarchy adopted by the U.S. Environmental Protection Agency (EPA) is composed of the following elements: source reduction (waste minimization or Prevention), Reuse, Recycling, Resource Recovery (waste combustion), and landfilling.

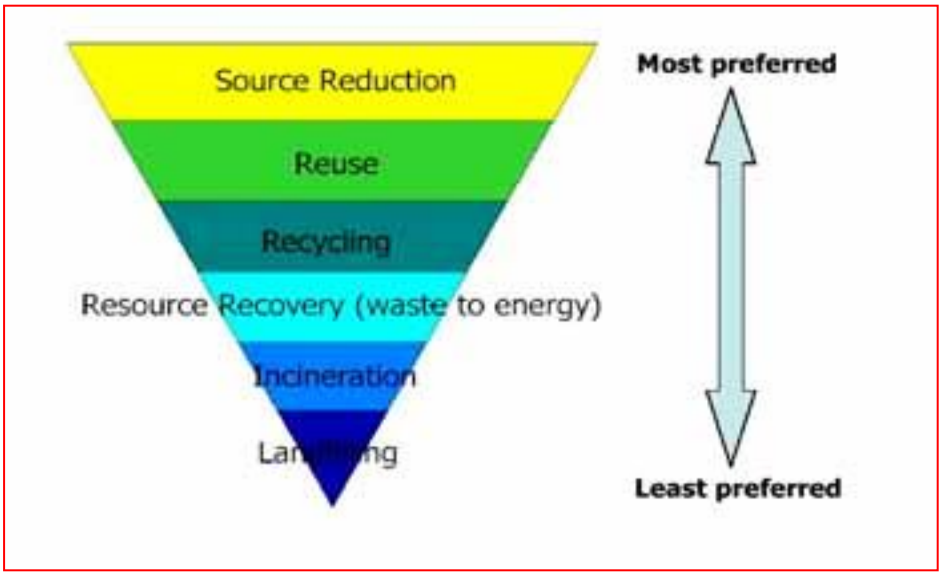


Figure 1.3 Hierarchy of Processing Techniques of Solid Waste.

This hierarchy directs society to develop their solid waste management plans by first seeking to prevent the production of solid waste, for example, by encouraging the use of ***fabric bags*** in grocery stores (thus eliminating the use of one-time plastic bags). When further elimination is not feasible, the states should consider actions that promote reuse, such as the use of ***heavy-duty plastic*** grocery bags that can be reused. Next, the recycling option should be considered, such as the collection and remanufacturing of onetime plastic bags. The fourth option would be to burn the collected bags for energy production. Finally**, when all else fails, the bags will be disposed in landfills.**

Source Reduction (waste minimization)

The highest rank of the ISWM hierarchy, is source reduction, involves reducing the amount and/or toxicity of the wastes that arc now generated. Source reduction is first in the hierarchy because it is the most effective way to reduce the quantity of waste, to reduce the cost associated with its handling, and its environmental impacts.

Waste reduction can be achieved in three basic ways:

1. Reducing the amount of material used per product without sacrificing the utility of that product.

2. Increasing the lifetime of a product.

3. Eliminating the need for the product.

Waste reduction in industry is called ***pollution prevention***—an attractive concept to industry because in many cases the cost of treating waste is greater than the cost of changing the process so that the waste is not produced in the first place.

For example, automobile manufacturers for years painted new cars using spray enamel المينا paint. The cars were then dried in special ovens that gave them a glossy لامعه finish. Unfortunately, such operations produced large amounts of volatile organic compounds (VOCs) that had to be controlled, and control measures were increasingly expensive. The manufacturers then developed a new method of painting, using dry powders applied under great pressure. Not only did this result in better finishes, but it all but eliminated the problem with the VOCs.

Pollution prevention is the process of changing the operation in such a manner that pollutants are not even generated.

Reduction of waste on the household level is called waste reduction (sometimes referred to as source reduction by the EPA). Typical alternative actions that result in a reduction of the amount of municipal solid waste being produced include: using laundry detergent refills instead of purchasing new containers, bringing one's own bags to grocery stores, stopping junk mail deliveries, and using cloth diapers. Unfortunately, the level of participation in source reduction is low compared to recycling activities. Even though source reduction is the first solid waste alternative for the EPA,

Reuse

Many of our products are reused without much thought given to ethical الاخلاقيه considerations. These products simply have utility and value for more than one purpose. For example, paper bags obtained in the supermarket are often used to pack refuse for transport from the house to the trash can or to haul recyclables to the curb for pickup. Newspapers are rolled up to make fireplace logs, and coffee cans are used to hold bolts and screws. Plastic bottles may be used for storage purposes and plastic sheets as rough covering materials. All of these are examples of reuse. Textile wastes and spongy materials may be sold to local pillow markets. Cans can be used to store charcoal stoves dust and other utility items. Clean paper waste is used as wrapping materials.

Recycling

Recycling of wastes is an environmentally friendly technology since it reduces waste transport costs, prolongs the life span of sanitary landfill and reduces pollution to the environment through leachates. Recycling is an important factor in helping to reduce the demand on resources and the amount of waste requiring disposal by landfilling. For example paper waste is shredded, repulped and processed in paper mills for the production of boxes, eggs trays and cheap boards. Metal wastes are melted and refined to other forms. Glass are melted and put in other shapes. Sheet metals, tins and cans are reshaped into charcoal stoves, dust bins and other utility items.

Waste Transformation

The third rank in the ISWM hierarchy, waste transformation, involves the physical, chemical, or biological alteration of wastes. The transformation of waste materials usually results in the reduced use of landfill capacity and offering useful byproducts. The reduction in waste volume through combustion is a well-known example.

Landfilling

Ultimately, something must be done with the solid wastes that cannot be recycled or reused and are of no further use. There are only two alternatives options for storing solid waste:

1. Disposal on or in the earth's mantle,
2. and disposal at the bottom of the ocean.

The former is forbidden by federal law and is similarly illegal in most other developed nations.

The placement of solid waste on land is called a ***dump*** *(EPA)* or a *tip* or tipping (Britain**)**. The open dump is by far the least expensive means of solid waste disposal, and thus, it was the original method of choice for almost all inland communities. The operation of a dump is simple and involves nothing more than making sure that the trucks empty at the proper spot. Volume was often reduced by setting the dumps on fire, thus prolonging the dump lifespan.

Sanitary landfills are engineered operations, designed and operated according to acceptable standards. The basic principle of a landfill operation is to prepare a site with liners to prevent pollution of groundwater. Landfilling, is the lowest rank in the ISWM hierarchy because it represents the least desirable means of dealing with society's wastes.

REVIEW

Q1. Give reason to the following:

1. **Source reduction is first in the hierarchy**

2. **On site storage is of primary importance**

3. Transfer and transport facilities are normally used.

4. The second highest rank in the hierarchy is recycling.

5. **Solid waste is unlike water-borne and air-dispersed wastes**.

6. Landfilling, is the lowest rank in the ISWM hierarchy.

7. Physical, chemical, and biological transformations can be applied to MSW

Q2. Suggest the best ways to reduce the amount of solid waste that must be disposed of

Q3. Give Differences between

a. Transport and transfer

b. Sanitary landfill and dumping site

CHAPTER THREE
SOURCE, TYPES AND COMPOSITION OF MUNICIPAL SOLID WASTE

3.1 SOURCES AND TYPES OF SOLID WASTES

Although any number of source classification can be developed, the following four common categories of solid waste are:

1. Municipal waste.
2. Industrial waste.
3. Agriculture and Animal waste.
4. Hazardous waste.

3.1.1 Municipal Waste

Municipal solid waste (MSW) mainly consists of:

(a) ***Food wastes***, commonly called garbage, are prone معرضه to decompose. They include food products of animal and vegetable origin, arising out of preparation, processing, handling, and eating. Wastes that will decompose rapidly especially in warm weather are also known as **putrescible waste** قابلة للتعفن. The main source of putrescible waste is handling, preparing cooking and eating of foods. Often decomposition will lead to the development of offensive odors and breeding of flies.

(b) ***Waste Paper*** are found in MSW as well, waste paper are typically composed of newspaper, books and magazines, commercial printing, office paper, other paperboard, paper packaging, other non- packaging paper, tissue paper and towels, and corrugated cardboard.

(c) Plastic materials

Recovery and reuse of plastics are growing, but still quite limited. Only the two most common beverage container plastics, PET (water bottles) and HDPE (milk bottles), are recycled in large quantities.

In the context of solid waste, plastic coding refers to a system to identify recyclable materials. The coding system for plastics utilizes a three-sided arrow with a number in the center and letters underneath. The number and letters indicate the resin from which each container is made:

1 = polyethylene terephthalate (PETE),

2 = high-density polyethylene (HDPB),

3 = vinyl (V),

4 = low-density polyethylene (LDPE),

5 = polypropylene (PP),

6 = polystyrene (PS), and

7 = other/mixed plastics.

Non-coded containers are recycled through mixed-plastics processes. To help recycling sorters, the code is molded into the bottom of a material.

Note coding system is designed to facilitate recycling, the presence of a code on a product does NOT mean it is recyclable

This guide is intended to help you make safer choices when using plastics. There are several types of plastics – some being safer than others. Plastic products are commonly marked with a number enclosed by the recycling symbol, which is typically found on the bottom of the product. This symbol is used to identify the plastic and recyclability of the product. In general plastic products marked with the numbers 2, 4 and 5 are the safer choices.

The following graphic is a quick summary of the plastics labels and their "threat" level.

The following sections provide information on each type of plastic.

Polyethylene Terephthalate

Where is PETE found?

PETE is commonly used to package:

- Cosmetics
- Household cleaners
- Water
- Juice
- Soft drinks
- Salad dressings
- Oil
- Peanut butter

Health-Concerns

Studies have found levels of **antimony** (a toxic chemical) leaching from water bottles that have been placed in heat for prolonged times. It's always best to make sure that your water bottles are not temperature abused. <u>PETE plastic should not be reused because cleaning detergents and high temperatures can cause chemicals to leach out of the plastic.</u> **Plastic #1 is only intended for one time use**.

High-Density Polyethylene is a polyethylene thermoplastic made from petroleum. HDPE is hard, opaque غير شفافه and can withstand somewhat high temperatures.

Where is HDPE found?

HDPE is used in the manufacturing of toys, and the packaging of:

Laundry detergent

Milk jugs

Folding chairs & tables

Health Concerns

No known health concerns.

Polyvinyl Chloride (PVC) is a thermoplastic polymer. It can be made softer and more flexible.

Where is PVC found?

- **Shower curtains**
- **Water beds**
- **Pool toys**
- **Inflatable structures هياكل نفخ**
- **Clothing**

- **Vinyl IV bags used in neo-natal intensive care تستخدم في العناية المركزة للولادة الجديدة**

  PVC can also be found in car interiors and vinyl flooring, resulting in the release of toxic chemicals into the air.

Health Concerns
PVC is one of the toxic plastics that should be avoided.

- Purchase a shower curtain made from organic or (polyethylene vinyl acetate) is a non-vinyl (PVC-free), chlorine-free, biodegradable plastic.
- Air out the car before getting in.
- Avoid using cling wrap made with PVC.
- Avoid inflatable structures, air mattresses, and toys made with PVC.
- Choose all baby toys, pool toys, and bath toys that are labeled to be PVC, Phthalate and BPA free.

Inflatable Structure.

Low-density polyethylene: (LDPE) is a thermoplastic made from petroleum. It can be found opaque. It is flexible and tough but breakable.

Where is LDPE found?

- Juice and milk containers (as the water-proof inner and outer layer)
- Most plastic grocery bags

- Some packaging material

Health-Concerns
No known health concerns.

Polypropylene: (PP) is a thermoplastic polymer. It is strong, tough, has a high resistance to heat and acts as a barrier to moisture.

Where is Polypropylene found?

- Yogurt & margarine tubs
- Plastic cups & baby bottles
- Kitchenware, microwavable plastic containers and lids

Health-Concerns
Most PP are microwavable safe and dishwasher safe.

NOTE: microwavable/dishwasher safe only means that the plastic will not warp تتشوه when heated. It does not imply that it is a healthy practice. A better alternative is using glass containers to heat foods and to hand wash plastic instead of using the dishwasher.

Polystyrene: (PS) is a petroleum-based plastic. It can either be hard or used in the form of Styrofoam.

Where is Polystyrene found?
Polystyrene is widely used in packaging materials and insulation. Some common items include:

- Disposable cutlery السكاكين
- CD and DVD cases
- Egg cartons
- Foam cups & to-go foam packaging from restaurants.

Health-Concerns
Long term exposure to small quantities of styrene can cause neurotoxic (fatigue, nervousness, difficulty sleeping), hematological امراض الدم (low platelet and hemoglobin

values), cytogenetic (chromosomal and lymphatic abnormalities), and carcinogenic effects. Styrene is classified as a possible human carcinogen by the EPA and by the International Agency for Research on Cancer (IARC).

Ways to avoid Polystyrene:

- Package left over foods from a restaurant in your own glass or any safe container.
- Avoid Styrofoam cups or plates and instead use stainless steel, glass, or bamboo products.

OTHER (Varies): can be a little tricky as it stands for “Other” which may or may not contain unsafe plastics.

Where is Polycarbonate found?

- Electrical wiring
- CD/DVD cases
- Baby bottles
- 3 and 5 gallon reusable bottles

Health-Concerns

BPA has been found to be an endocrine disruptor اختلال الغدد الصماء.

Choose bottles made with the #1, #2, #4, or #5 recycling codes.

Safest Choices

In conclusion, plastic products marked with the numbers 2, 4 and 5 are the safer choices. Regardless of what plastic you use, avoid exposing your plastics to high temperatures (microwave, dishwasher) and use mild detergents for cleaning. Since there is no guarantee that plastics will not leach out harmful chemicals, I suggest playing it safe by trying to avoid plastic when possible.

Degradable plastics Plastics specifically developed for special products that are formulated to break down after exposure to sunlight or microbes, however, they degrade only gradually, causing litter and posing a hazard to birds and marine animals.

Note: Rubbish is combustible and non-combustible rejected materials. The combustible portion (trash) consists of paper, cardboard, textiles, plastics, rubber, etc. The non-combustible portion consists of glass, ceramics, metals, etc.(In general common waste other than food waste).

(d) Ashes الرماد originate mainly from coal, firewood, and burnt residues of other combustible materials.

(f) Construction and demolition wastes include wide varieties of materials, mostly non-combustible in nature. Civil works of construction, remodeling, repair works and demolition of building structures and others that include broken pieces of bricks, stones, plasters, dirt, sand, wooden articles, metal pieces, electrical parts, etc.

(g) Water treatment plant wastes are obtained from the water treatment plants in solid or semisolid form, such as resins, organic waste, inorganic waste, etc.

(h) Special wastes are uncommon materials accumulated from unpredictable and infrequent sources, include bulky items, consumer electronics, abandoned vehicles, dead animals, limbs اجزاء اشحار ضخمة, and that found from street sweepings.

Bulky Items: are large worn –out or broken house hold items such as furniture

White goods : such as stoves, refrigerators, dishwasher, clothes washer……etc.

3.1.2 Industrial Wastes

They include the wastes produced during various industrial operations. Even though our discussion has more emphasized on typical MSW and not the major industrial wastes, one cannot afford to overlook the contribution of some minor or small scale operations which are located within the municipal territories to meet the daily requirements of the residents.

These are candle making, plywood manufacturing, bakeries, leather goods, rubber industries, pharmaceutical products, canned goods, laundry trades, dairy products and photographic products, etc. The spent solution and solid waste of these industries contains major organic constituents.

Every company should have their own solid waste handling and treatment systems as otherwise they produce bad odour and cause problems to public health authorities.

3.1.3 Agriculture and Animal Wastes

The agriculture wastes are usually of plant origin. Plants that remain after harvesting are in huge quantities. Animal wastes include the remains after slaughter.

3.1.4 Hazardous Wastes

Hazardous substances, depending on their quantity, concentration (physical or chemical), infectious characteristics, is of potential hazard to human health. They may cause or significantly contribute to an increase in mortalityالوفيات and to serious, irreversible or reversible but incapacitating illnesses. It will also affect the animal and plant lives on a short or long-term basis. Hazardous waste may include (a) radioactive substance (b) fuming, odorous, corrosive and toxic chemicals, and (c) biological wastes, combustibles, flammable and explosive wastes.

Examples of hazardous solid waste:

Example 1. Household batteries come in a variety of types, including alkaline, mercury, silver, zinc, nickel, and cadmium. The metals found in household batteries can cause groundwater contamination by their presence in leachate; they can also contaminate air emissions and ash from waste combustion facilities. Many states now prohibit the land filling of household batteries. Automobiles use lead-acid batteries, each of which contains approximately 8 g of lead and a 3.7 L of sulfuric acid, both are hazardous materials.

Example 2. The principal source of used oil is from the servicing of automobiles and other moving vehicles by their owners. Waste oil, not collected for recycling, is often poured onto the ground; down sanitary, combined, and storm water sewers; or into trash containers.

Waste oil discharged onto the ground or into municipal sewers

1. Often contaminates surface water and groundwater as well as the soil.
2. Waste oil placed in the same container as other solid waste components tends to contaminate the waste components and thus reduces their value as recycled materials.

Example 3 Because tires do not compact well, their disposal in landfills is expensive and wasteful of space. Stockpiling of tires also poses serious aesthetic, as, well as environmental problems. Large, difficult-to-extinguish fires من الصعب إطفاء Fires have occurred in a number of stockpiles.

Q. Tiers disposal in landfills is expensive

1. They do not compact well

2. wasteful of space

3. Stocking of tires poses serious aesthetic as well as environmental problems.

4. Large

5. Difficult to extinguish. Fires have occurred in a number of stockpiles.

3.2 COMPOSITION OF SOLID WASTES

Composition is the term used to describe the individual components that make up a solid waste stream and their relative distribution, usually based on percent by weight. For example, if the solid wastes generated at a commercial facility consist of only paper products, the use of special processing equipment, such as shredders and balers, may be appropriate.

Note that the values given in later years for food waste, plastics, and yard wastes are considerably different from the values given in the text, published in 1970s or in later 2020s.

The differences are due largely to

(1) Improved food processing techniques and the increased use of kitchen food waste grinders,

(2) The increased use of plastics for food packaging and other packaging, and

(3) The fact that burning of yard wastes is no longer allowed in most communities.

3.2.1 Determination of the Composition of MSW in the Field

Because of the heterogeneous nature of solid wastes, determination of the-composition of solid waste is not an easy task. Strict statistical procedures are difficult, if not impossible to implement. For this reason, more generalized field procedures, based on common sense and random sampling techniques, have evolved for determining composition.

a. Residential MSW

The procedure for residential MSW involves:

1. Unloading and analyzing a quantity of residential waste in a controlled area of a disposal site that is isolated from winds and separated from other operations.
2. A representative residential sample might be a truckload resulting from a typical weekday collection route in a residential area.
3. Common sense is important in selecting the load to be sampled. To ensure that the results obtained are representative, a large enough sample must be examined.
4. To obtain a sample for analysis, the load is first quartered. One part is then selected for additional quartering until a sample size of about 200 Ib (90.7 kg) is obtained.

5. It is important to maintain the integrity of each selected quarter, regardless of the odor or physical decay, and to make sure that all the components are measured. Only in this way can some degree of randomness and unbiased selection be maintained.

Industrial MSW

The field procedure for component identification for industrial solid wastes involves the analysis of representative waste samples taken directly from the source not from a mixed waste load in a collection vehicle.

3.3 MATERIALS COMMONLY SEPARATED FROM MSW

The most common materials that are separated from MSW are:

1. **Aluminum.**

Aluminum recycling is made up of two sectors: aluminum cans and secondary aluminum. Secondary aluminum includes window frames, storm doors, siding, and gutter مزاريب. Because secondary materials are of different grades, specifi-cations for recycled aluminum should be checked to recover the maximum value when selling separated materials to brokers. The demand for recycled aluminum cans is high as it takes 95 percent less energy to produce an aluminum can from existing can than from ore.

2. **Paper.**

The principal types of waste paper that are recycled are old newspaper cardboard, high-grade paper and mixed paper

3. **Plastics.**

Plastics can be classified into two general categories: clean commercial grade scrap and post-consumer scrap. The two types of post-consumer plastics that are now most commonly recycled are polyethylene terephthalate (PBTE/l), which is used for the manufacture of soft-drink bottles, and high-density polyethylene (HDPE/2),used for milk and water containers and detergent bottles.

4. Glass.

Glass is also a commonly recycled material. Container glass (for food and beverage), flat glass (e.g., window glass), and pressed or amber and green glass are the three principal types of glass found in MSW. Glass to be reprocessed is often separated by color into categories of clear, green, and amber.

5. Ferrous Metals (Iron and Steel)

The largest amount of recycled steel has traditionally come from large items such as cars and-.appliances.

6. Nonferrous Metals

Recyclable nonferrous metals are recovered from common household items (outdoor furniture, kitchen cookware and appliances, ladders, tools, hardware); from construction and demolition projects (copper wire, pipe and plumbing supplies, light fixtures, aluminum siding, gutters and downspouts. doors, windows); and from large consumer, commercial, and industrial products (appliances, automobiles, boats, trucks, aircraft, machinery). Virtually all nonfer-rous metals can be recycled if they are sorted and free of foreign materials such as plastics, fabrics, and rubber.

7. Yard Wastes Collected Separately

In most communities yard wastes are collected separately. The composting of yard wastes has become of great interest in cities and towns. Leaves, grass, and bush clipping are the most commonly composted yard wastes stumps and wood are also compostable, but only after they have been chipped to produce a smaller more uniform size. Composting of the organic fraction of MSW is also becoming more popular.

3.4 FUTURE CHANGES IN WASTE

In planning for future waste management systems, it will be important to consider the changes that may occur in the composition of solid waste with time.

Four waste components that have an important influence on the composition of the wastes collected are food waste, paper and cardboard, yard waste and plastics.

a. **Food Wastes**, the quantity of residential food wastes collected has changed significantly over the years as a result of technical advances and changes in public attitude. Two technological advances that have had a significant effect are the development of the food processing and packaging industry and the use of kitchen food waste grinders. The percentage of food waste, by weight, has decreased over the years.

b. **Paper and Cardboard**. The percentage of paper and cardboard (also known as paperboard and corrugated paper) found in solid wastes has increased greatly over the past half century, rising from about 20 percent in the early 1940s to about 40 % in 1992. While lately waste paper had decreased from 32% to 15%. This change was likely due to two factors:

    1. Less newspaper were sold.

    2. Most of paper were recycled since 2012.

While packaging papers were dramatically increased.

c. **Yard Wastes**. (The percentage of yard wastes in MSW has also increased significantly during the past quarter century, due primarily to passage of laws that prohibit burning of yard wastes. By weight, yard waste currently accounts for about 16 to 24 percent of the waste stream. Environmental conditions such as droughts have also affected the quantities of yard wastes collected in certain locations.

CHAPTER FOUR

PHYSICAL, CHEMICAL, AND BIOLOGICAL PROPERTIES OF MUNICIPAL SOLID WASTE

The purpose of this chapter is to introduce the reader to the physical, chemical, and biological properties of MSW and to the transformations that can affect the form and composition of MSW.

4.1 PHYSICAL PROPERTIES OF MSW

Important physical characteristics of MSW include specific weight, moisture content, particle size and size distribution, field capacity, and compacted waste porosity. The discussion is limited to an analysis of residential, commercial, and some industrial solid wastes.

4.1.1 Specific Weight

Specific weight is defined as the weight of a material per unit volume (e.g., Ib/ft^3. Ib/yd^{3,} kg/M^3). It should be noted that -specific weight expressed as Ib/yd^3 is commonly referred to in the solid waste literature incorrectly as density.

Because the specific weight of MSW is often reported as loose, as found in containers, uncompacted, compacted, and the like, the basis used for the reported values should always be noted. Specific weight data are often needed to assess the total mass and volume of waste that must be managed. Typical specific weights for various wastes as found in containers, compacted, or uncompacted are reported in Table 4-1.

Municipal solid waste has a highly variable bulk density, depending on the pressure exerted. Loose, as it might be placed into a garbage can by the homeowner, the bulk density of MSW might be between 150 and 250 lb/yd^3 (90 and 150 kg/m^3); pushed into the can, it might be at 300 lb/yd^3 (180 kg/m^3). In a collection truck that compacts the refuse, the bulk density is normally between 600 and 700 lb/yd^3 (350 and 420 kg/m^3). Once deposited in a landfill and compacted with machinery, it can achieve bulk densities of about 1200 lb/yd^3 (700 kg/m^3). If the covering soil in landfills is included, the total landfilled density can range from about 700 lb/yd^3 for a poorly compacted landfill to as high as 1700 lb/yd^3 (1000 kg/m^3), for a landfill where thin layers of refuse are compacted. Such landfills are quite dense.

TABLE 4-1 Typical specific weight and moisture content data for residential, commercial, industrial, and agricultural wastes

Type of waste	Specific weight lb/yd^3		Moisture content % by weight	
	Range	Typical	Range	Typical
Residential uncompacted				
Food wastes (mixed)	220-810	490	50-80	70
Paper	70-220	150	4-10	6
Cardboard	70-135	85	4-8	5
Plastics	70-220	110	1-4	2
Textiles	70-170	110	6-15	10
Rubber	170-340	220	1-4	- 2
Leather	170-440	270	8-12	10
Yard wastes	100-380	170	30-80	60
Wood	220-540	400	15-40	20
Glass	270-810	330	1-4	2
Tin cans	85-270	150	2-4	3
Aluminum	110-405	270	2-4	2
Other metals	220-1940	540	2-4	3
. Dirt, ashes, etc.	540-1685	810	6-12	8
Ashes	1095-1400	1255	6-12	6
Rubbish	150-305	220	. 5-20	15
Residential yard wastes				
Leaves (loose and dry)	50-250	100	20-40	30
Green grass loose and moist	350-500	400	40-80	60
Green grass wet and compacted	1000-1400	1000	50-90	80
Yard waste (shredded)	450-600	500	20-70	50
Yard waste (composted)	450-650	550	40-60	50
Municipal				
In compactor truck	300-760	500	15-40	20
In landfill				
Normally compacted	610-640	760	15-40	25
Well compacted	995-1250	1010	15-40	25

Because the specific weights of solid wastes vary markedly with geographic location, season of the year, and length of time in storage, great care should be used in selecting typical values. For comparison, the density of water is 1000 kg/m^3. The bulk densities of refuse in various stages of compaction are listed in Table 4-2.

Condition	Density (lb/yd^3
Loose refuse, no processing or compaction	150–250
In compaction truck	600–900
Baled refuse	1200–1400
Refuse in a compacted landfill (without cover)	750–1250

This is different from *materials* densities, or densities of materials without any void spaces. Because of the highly variable density, MSW quantities are seldom expressed in volumes and are almost always expressed in mass terms as either pounds or tons in the American standard system or kilograms or tonnes in the SI system. Note that in this text, ton = 2000 lb and tonne = 1000 kg.

Example: Estimate the moisture content on a wet base and density of a solid waste sample with the following composition

Component	Percent by mass	Typical density kg/m3	Moisture content %
Food waste	45	290	70
Paper	15	85	6
Cardboard	5	50	5
Plastics	5	65	2
Garden trimming	10	105	60
Wood	5	240	20
Tin cans	15	90	3

Based on 1000 kg sample of waste.

4.1.2 Moisture Content

A transfer of moisture takes place in the garbage can and truck, and thus, the moisture content of various components changes with time. Newsprint has about 7% moisture by weight as it is deposited into waste containers, but the average moisture content of newsprint coming from a refuse truck often exceeds 20%. The moisture content becomes important when the refuse is processed into fuel or when it is fired directly. The usual expression for calculating moisture content is

$$M= \frac{A-B}{A}\ x\ 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

Where M= moisture content, %

A= initial weight of sample as delivered, Ib (kg)

B= weight of sample after drying Ib (kg)

Typical data on the moisture content for the solid waste components given in Table. Some engineers define moisture content on a dry weight basis as

M on dry basis (Md)= $\frac{A-B}{B}\ x\ 100$ **……………………………………(4.2)**

where Md ; moisture content on a dry basis, %

Drying is usually done in an oven at 77ºC (170ºF) for 24 h to ensure complete dehydration and yet avoid undue vaporization of volatile material. Temperatures above this will melt some plastics and cause problems.

The moisture content of any waste can be estimated by knowing the fraction of various components and using either measured values of moisture content or typical values from a list (such as Table 4-1). This calculation is illustrated in Example 4-1.

EXAMPLE 4-2: A residential waste has the following components:

Components	weight percentages
Paper	50%
Glass	20%
Food	20%
Yard waste	10%

Estimate its moisture content using the typical values in Table 2-1

Solution

Assume a wet basis of 100 lb. Set up the tabulation:

Component	Percent	Moisture	Dry weight (based on 100 lb)
Paper	50	6	47
Glass	20	2	19.6
Food	20	70	6
Yard waste	10	60	4
Total:			76.6 lb dry

The moisture content (wet basis) would then be

24%

EXAMPLE 4-3: Estimation of moisture content of typical residential MSW.

Estimate the overall moisture content of a sample of as collected residential MSW with the typical composition given below

Solution

1. Set up the computation table to determine dry weights of the solid waste components

Component	weight%	Moisture content, %	Dry weight,* kg
Organic Food	**9.0**	**70**	**2.7**
Paper	**34.0**	**6.0**	**32.0**
Cardboard	**6.0**	**5**	**5.7**
Plastics	**7.0**	**2**	**6.9**
Textiles	**2.0**	**10**	**1.8**
Rubber	**0-5**	**2**	**0.5**
Leather	**0.5**	**10**	**0.4**
Yard wastes	**18.5**	**60**	**7.4**
Wood	**2.0**	**20**	**1.6**
Inorganic :glass	**8.0**	**2**	**7.8**
Tin cans	**6.0**	**3**	**5.8**

Aluminum	**0.5**	**2**	**0.5**
Other metal	**3.0**	**3**	**2.9**
Dirt, ash, etc.	**3.0**	**8**	**2.8**
Total	**100**		**78.8**

Based on an as delivered sample weight of 100 kg.

Moisture content on wet weight= $\frac{100-78.8}{100}$ x 100 = 21.2%

Typically, the moisture content of loose refuse is about 20% if there have not been rainstorms before collection. During rainy weather, the moisture content can go as high as 40%. In a refuse truck, moisture transfer takes place, and the moisture of various components of refuse changes. Paper sops up much of the liquid waste, and its moisture increases substantially. The moisture content of refuse that has been compacted by a collection truck is therefore quite different from the moisture of various components as they are in the can ready for collection, therefore moisture contents varies depending on the composition of the wastes, degree of compaction, the season of the year, and the humidity and weather conditions, particularly rain

Analysis Procedure:

1. Weigh the aluminum dish
2. Fill the dish with SW sample and re-weigh
3. Dry SW + dish in an oven for at least 24 hrs at 77°C.
4. Remove the dish from the oven, allow to cool in a desiccator, and weigh.
5. Record the weight of the dry SW + dish.
6. Calculate the moisture content (M) of the SW sample using the equation given above.

4.1.3 Particle Size and Distribution

Any mixture of particles of various sizes is difficult to describe analytically. If these particles are irregularly shaped, the problem is compounded. Municipal refuse is possibly the worst imaginable material for particle size analysis, and yet much of the MSW processing technology depends on an accurate description of particle size. The size and size distribution of the component materials in solid wastes are an important consideration the recovery of materials, especially with mechanical means such as trommel screens and magnetic separators.

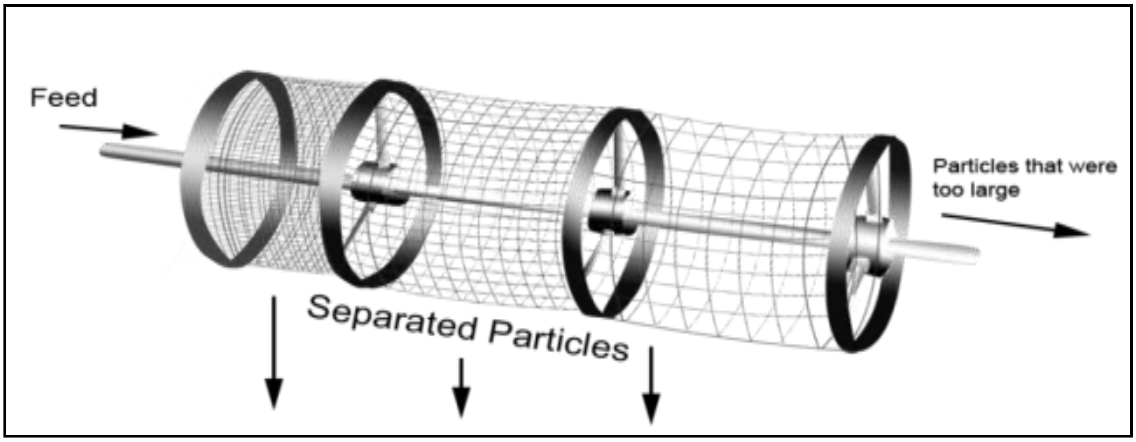


Fig. 4.1 Trommel Screen or Rotary Screen

4.1.4 Field Capacity

The field capacity of solid waste is the total amount of moisture that can be retained in a waste sample subject to the downward pull of gravity. The field capacity of waste materials is of critical importance in determining the formation of leachate in landfills. Water in excess of the field capacity will be released as leachate.

4.2 CHEMICAL PROPERTIES OF MSW

Information on the chemical composition of the components that constitute MSW is important in evaluating alternative processing and recovery options. For example, the feasibility of combustion depends on the chemical composition of the solid wastes. If solid wastes are to be used as fuel, the four most important properties to be known are:

1. Proximate analysis
2. Fusing point of ash
3. Ultimate analysis (major elements)

4. Energy content

4.2.1 Proximate Analysis

The proximate analysis is an attempt to define the fraction of volatile organics and fixed carbon in the fuel.Proximate analysis for the combustible components of MSW includes the following tests:

1. Moisture (loss of moisture when heated to 105°C for 1 h)
2. Volatile combustible matter (additional loss of weight on ignition at 950°C in a covered crucible)
3. Fixed carbon (combustible residue left after volatile matter is removed)
4. Ash (weight of residue after combustion in an open crucible)

4.2.2 Fusing Point of Ash

The fusing point of ash is defined as that temperature at which the ash resulting from the burning of waste will form a solid (clinker) خبث المعادن by fusion الانصهار and agglomeration التكتل. Typical fusing temperatures for the formation of clinker from solid waste range from (1100 to 1200)°C.

4.2.3 Ultimate Analysis of Solid Waste Components

The ultimate analysis of a waste component typically involves the determination of the percent C (carbon), H (hydrogen), O (oxygen), N (nitrogen), S (sulfur), and ash. Because of the concern over the emission of chlorinated compounds during combustion, the determination of halogens is often included in an ultimate analysis. The results of the ultimate analysis are used to characterize the chemical composition of the organic matter in MSW. They are also used to define the proper mix of waste materials to achieve suitable C/N ratios for biological conversion processes.

EXAMPLE 4.2: Estimation of the chemical composition of a solid waste sample. Determine the chemical composition of the organic fraction, without and with sulfur and without and with water, of a residential MSW with the typical composition shown in Table below

Typical data on the ultimate analysis of the combustible components in residential MSW Percent by weight (dry basis)

Organic	Carbon	Hydrogen	Oxyge	Nitrog	sulfur	Ash
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5-9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	—	—	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	—	2.0	—	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard wastes	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Inorganic						
Glass	0.5	0.1	0.4	<0.1	—	98.9
Metals	4.5	0.6	4.3	<0-1	—	90.5
Dirt, ash, etc.	26.3	3.0	2.0	0.5	0.2	68.0

Solution:

1. Set up a computation table to determine the percentage distribution of the major elements composing the waste:

Component	Wet weight, lb	Dry weight, lb	Composition, lb C	H	O	N	S	Ash
Food wastes	9.0	2.7	1.30	0.17	1.02	0.07	0.01	0.14
Paper	34.0	32.0	13.92	1.92	14.08	0.10	0.06	1.92
Cardboard	6.0	5.7	2.51	0.34	2.54	0.02	0.01	0.28
Plastics	7.0	6.9	4.14	0.50	1.57	—	—	0.69
Textiles	2.0	1.8	0.99	0.12	0.56	0.08	—	0.05
Rubber	0.5	0.5	0.39	0.05	—	0.01	—	0.05
Leather	0.5	0.4	0.24	0.03	0.05	0.04	—	0.04
Yard wastes	18.5	6.5	3.11	0.39	2.47	0.22	0.02	0.29
Wood	2.0	1.6	0.79	0.10	0.68	—	—	0.02
Total	79.5	58.1	27.39	3.62	22.97	0.54	0.10	3.48

2. Prepare a summary table of the percentages distribution of the elements

	Weight 1b or kg	
Components	Without water	With water
Carbon	27.39	27.39

Hydrogen	3.62	6.00
Oxygen	22.97	41.99
Nitrogen	0.54	0.54
Sulfur	0.10	0.10
Ash	3.48	3.48

79.5-58.1=21.4 1b

H_2O H_2+ 1/2 O_2

$\frac{21.4\ 1b}{18\ 1b/mole}$= 1.188 mole

H_2O= 1.188 mole, H_2=1.188 mole , O2= .5(1.188) mole

H2= 2.377 1b+ 3.62 1b=6.00 1b

O2= 0.594 mole x 321b/mole=19.008 1b+ 22.971b= 41.978 1b

3. Compute the molar composition of the elements neglecting the ash.

		Moles	
Components	Atomic Weight	Without water	With water
Carbon	12.01	2.280	2.280
Hydrogen	1.01	3.584	5.940
Oxygen	16.00	1.436	2.624
Nitrogen	14.01	0.038	0.038
Sulfur	32.07	0.003	0.003

4. Determine an approximate chemical formula without and with sulfur and without and with water.

	Mole ratio (Nitrogen= 1)		Mole ratio (Sulfur=1)	
Components	Without water	With water	Without water	With water
Carbon	60.0	60.0	760.0	760.0
Hydrogen	94.3	156.3	1194.7	1980.0
Oxygen	37.8	69.1	478.7	874.7
Nitrogen	1.0	1.0	12.7	12.7
Sulfur	0.1	0.1	1.0	1.0

(a) The chemical formulas without sulfur are

1. **Without water: $C_{60.0}H_{94.3}O_{37.8}N$**
2. **With water: $C_{60.0}H_{156.3}O_{69.1}N$**

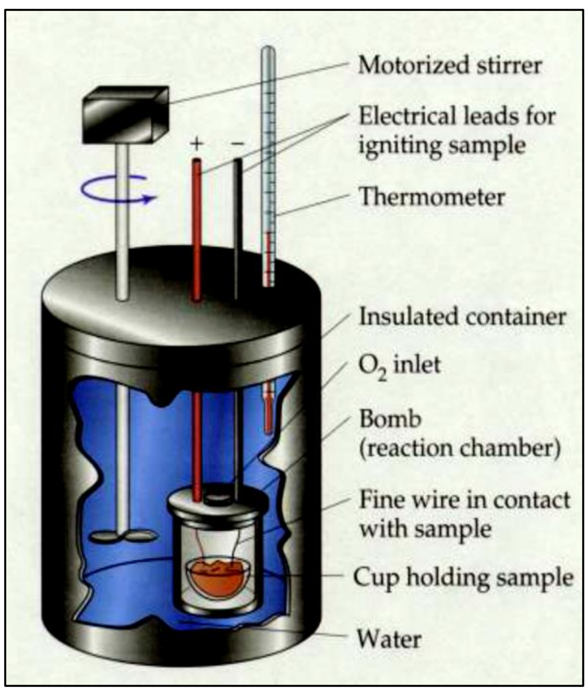
(b) The chemical formulas with sulfur are

1. **Without water: $C_{760.0}H_{1194.7}O_{478.7}N_{12.7}S$**
2. **With water: $C_{760.0}H_{1980.0}O_{874.7}N_{12.7}S$**

4.3 ENERGY CONTENT OF SOLID WASTE COMPONENTS

The energy content of the organic components in MSW can be determined (1) by using a full scale boiler as a calorimeter. Commonly, the heat values of refuse and other heterogeneous materials are measured with a *calorimeter*, a device in which a sample is combusted and the temperature rise is recorded. Knowing the mass of the sample and the heat generated by the combustion, the Btu/lb is calculated (recognizing, of course, that 1 Btu is the heat necessary to raise the temperature of 1 lb of water 1°F).

(2) by using a laboratory bomb calorimeter and



(3) by calculation, if the elemental composition is known. Typical data for energy content and inert residue for the components of residential wastes are reported in table below. In common American engineering language, heat value is expressed as Btu/lb of refuse, while the proper SI designation is kJ/kg.

Refuse can be characterized as being made up of organic materials, inorganic materials, and water. Usually, the heat value is expressed in terms of all three components (the Btu/lb), where the sample weight includes the inorganics and water. But sometimes, the heat value is expressed as moisture-free, and the water component is subtracted from the denominator. A third means of defining heat value is to also subtract the inorganics, so the Btu is *moisture- and ash-free*, the ash being defined as the inorganic upon combustion.

$$\text{Btu/lb (dry basis)} = \text{Btu/lb}\left(\frac{100}{100 - \%\ \text{moisture}}\right) \qquad (4\text{-}3)$$

The corresponding equation for the Btu per pound on a dry ash-free basis is Btu/lb (dry ash-free basis)

$$= \text{Btu/lb}\left(\frac{100}{100 - \%\ \text{moisture} - \%\text{ash free}}\right) \qquad (4\text{-}4)$$

Example

A sample of refuse is analyzed and found to contain 10% water (measured as weight loss on evaporation). The Btu of the entire mixture is measured in a calorimeter and is found to be 4000 Btu/lb. A 1.0 g sample is placed in the calorimeter, and 0.2 g ash remains in the sample cup after combustion. What is the comparable, moisture free Btu and the moisture- and ash-free heat value?

Solution

Basis =1.0g

The one pound of refuse would have 10% moisture, so the moisture-free heat value would be calculated as

$4000\ \text{Btu/lb X}\ \frac{1}{1-0.1} = 4444.444\ \text{Btu/1b}$ moisture free (on dry basis)

Similarly, the moisture- and ash-free heat value would be

$4000 \text{ Btu/lb} \times \frac{1}{1-0.1-0.2} = 5{,}714.285 \text{ Btu/1b}$

The heat value of various components of refuse is quite different, as shown in Table 4.6. As is the case with moisture content, the heat value of a refuse where the fraction of components is known can be estimated by using such estimated heat values for the various components. An important aspect of calorimetric heat values is the distinction between *higher heat value* and *lower heat value*. The higher heat value (HHV) is also called the *gross calorific energy*, while the lower heat value (LHV) is also known as the *net calorific energy*. The distinction is important in design of combustion units.

Table 4-6 typical values for inert residue after complete combustion and energy content of residential MSW

Components	Residue% After combustion	Energy
Organic		Kjoule/kg
Food wastes	5.0	4,652
Paper Cardboard	6.0 5.0	16,747 16,282
Plastics	10.0	32,564
Textiles	2.5	17,445
Rubber	10.0	23,260
Leather	10.0	17,445
Yard wastes Wood	4.5 1.5	6513 18608
Inorganic		
Glass	98.0	140
Tin cans	98.0	698
Aluminum	96.0	—
Other metal	98.0	698
Dirt, ashes, etc.	70.0	6978
Total solid waste		11630

EXAMPLE 4-3 Estimation of energy content of typical residential MSW. Determine the energy value of a typical residential MSW with the average composition shown **in Table** below

Solution

components	Solid wastes kg	Energy J/kg	Total energy J
Organic			
Food wastes	9.0	4,652	
Paper	34.0	16,747	
Cardboard	6.0	16,282	
Plastics	-7.0	32,564	
Textiles	2.0	17,445	
Rubber	0-5	23,260	
Leather	0.5	17,445	
Yard wastes	18.5	6,513	
Wood	2.0	18,608	
Glass	8.0	140	
Tin cans	6.0	698	
Aluminum	0.5	—	
Other metal	3.0	698	
Dirt, ashes, etc.	3.0	6978	
Total	100.0	11630	

Determine the as discarded energy content per kg of waste

Energy content = 11,78200 kJ

1178200kJ/100 kg = 11782 kJ/kg =5065 Btu/1b

The computed value compares well with the typical value given in Table 4-5. If Btu values are not available, approximate Btu values for the individual waste materials can be determined by using Eq. (4-9), known as the modified Dulong equation: $\text{Btu/lb} = 145C + 610\left(H_2 - \frac{1}{8}O_2\right) + 40S + 10N$ (4-9)

where C = carbon, percent by weight
H2 = hydrogen, percent by weight , O2 = oxygen, percent by weight
S = sulfur, percent by weight, N = nitrogen, percent by weight.

EXAMPLE 4-4 Estimation of energy content of typical residential MSW based on chemical composition. Determine the energy value of typical residential MSW with the average composition determined in Example 3-2 including sulfur and water.

Solution

1. The chemical composition of the waste including sulfur and water is:

$$C_{760.0}H_{1980.0}O_{874.7}N_{12.7}S$$

2. Determine the total energy content using Eq. (4.9).

(a) Determine the percentage distribution by weight of the elements composing the waste, using coefficients that have been rounded off.

Component	Number of atoms / mole	Atomic weight	Weight contribution of each element	%
Carbon	760	12	9120	36.03
Hydrogen Oxygen	1980 875	1 1	1980 14.000	7.82 55.30
Nitrogen	13	14	182	0.72
Sulfur	1	32	32	0.13
Total			25314	100.00

$$\text{Btu/lb} = 145(36.0) + 610\left(7.8 - \frac{55.3}{8}\right) + 40(0.1) + 10(0.7)$$

Btu/Ib= 5772

Comment. The computed energy content of the waste is higher than the value computed in Example 4-3 because only the organic fraction of the residential MSW was considered in Example 4-4

4-4 BIODEGRADABILITY OF ORGANIC WASTE COMPONENTS

Almost all of the organic components in MSW can be converted biologically to gases (CH_4& CO_2), inert organic and inorganic solids. Volatile solids (VS), determined by ignition at 550 ^{o}C, is often used as a measure of the biodegradability. Components such as Newsprint are highly volatile but low in biodegradability due to their high lignin content. Practically, organic waste components in MSW are often classified as rapidly and slowly decomposable. the lignin content of a waste can be used to estimate the biodegradable fraction, using the following relationship :

BF = 0.83-0.028 LC (4-10)

where BF = biodegradable fraction expressed on a volatile solids (VS) basis

0.83 = empirical constant 0.028 = empirical constant

LC = lignin content of the VS expressed as a percent of dry weight

The biodegradability of several of the organic compounds found in MSW, based on lignin content, is reported in Table 4.3.

Table 4.3 Data on the biodegradable fraction of selected organic waste components based on lignin content

Component	Volatile solids (VS). percent of total solids (TS)	Lignin content (LC), percent of VS	Biodegradable fraction (BF)
Food wastes	**7-15**	**0.4**	**0.82**
Paper			
Newsprint	**94.0**	**21.9**	**0.22**
Office paper	**96.4**	**0.4**	**0.82**
Cardboard	**94.0**	**12.9**	**0.47**
Yard wastes	**50-90**	**4.1**	**0.72**

As shown in Table 4.3, wastes with high lignin contents, such as newsprint, are significantly less biodegradable than the other organic wastes found in MSW.

4-4-1 Production of Odors

Odors can develop when solid wastes are stored for long periods of time on-site between collections, in transfer stations, and in landfills. The development of odors in on-site storage facilities is more significant in warm climates. Typically, the formation of odors results from the anaerobic decomposition of the readily decomposable organic components found in MSW. For example, under anaerobic (reducing) conditions, sulfate can be reduced to sulfide (S^{-2}), which subsequently combines with hydrogen to form H_2S The formation of H_2S can be illustrated by the following two series of reactions.

$$4H_2 + SO_4^{2-} \rightarrow S^{2-} + 4H_2O \qquad (4\text{-}11)$$

$$S^{2-} + 2H^+ \rightarrow H_2S \qquad (4\text{-}12)$$

The sulfide ion can also combine with metal salts that may be present, such as iron, to form metal sulfides.

$$S^{-2} + Fe^{+2} \text{ -----------> } FeS \qquad (4\text{-}13)$$

The black color of solid wastes that have undergone anaerobic decomposition in a landfill is primarily due to the formation of metal sulfides.

The biochemical reduction of an organic compound containing a sulfur radical can lead to the formation of malodorous compounds such as methyl mercaptan and aminobutyric acid. The methyl mercaptan can be hydrolyzed biochemically to methyl alcohol and hydrogen sulfide:

$CH_3SH + H_2O$ ------------------ $CH_4OH + H_2S$ ……………….. (4-14)

4-5 PHYSICAL, CHEMICAL, AND BIOLOGICAL TRANSFORMATIONS OF SOLID WASTE

4-5-1 Physical Transformations

The principal physical transformations that may occur in the operation of solid waste management systems include (1) component separation, (2) mechanical volume reduction, and (3) mechanical size reduction. Physical transformations do not involve a change in phase (e.g., solid to gas), unlike chemical and biological transformation processes.

a) Component Separation.

Component separation is the term used to describe the process of separating, by manual and/or mechanical means. Component separation is used to transform a heterogeneous waste into a number of more-or-less homogeneous components. Component separation is a necessary operation in the recovery of reusable and recyclable materials from MSW, in the removal of contaminants from separated materials to improve specifications of the separated material, in the removal of hazardous wastes from MSW, and where energy and conversion products are to be recovered from processed wastes.

b) Mechanical Volume Reduction.

Volume reduction (sometimes known as densification) is the term used to describe the process whereby the initial volume occupied by waste is reduced, usually by the application of force or pressure.

In most cities, the vehicles used for the collection of solid wastes arc equipped with compaction mechanisms to increase the amount of waste collected per trip. Paper, cardboard, plastics, and aluminum and tin cans removed from MSW for recycling arc baled to reduce storage volume, handling costs and shipping costs to processing centers as shown in figure 4-2. At disposal sites solid wastes are compacted to use the available land effectively.

c) Mechanical Size Reduction.

Size reduction is the term applied to the transformation processes used to reduce the size of the waste materials. The objective of size reduction is to obtain a final product that is reasonably uniform and considerably reduced in size in comparison with its original form. Note that size reduction does not necessarily imply volume reduction. In some situations, the total volume of the material after size reduction may be greater than that of the original volume (e.g., the shredding of office paper as shown in figure (4-3). In practice, the terms shredding, grinding, and milling are used to describe mechanical size-reduction operations.

Fig. 4-2 Baler to Bale Plastics Paper, Cardboard and Aluminum Cans.

Fig. 4-3 Paper and Cardboard Shredding.

4-5-2 Chemical Transformations

Chemical transformations of solid waste typically involve a change of phase (e.g., solid to liquid, solid to gas, etc.). To reduce the volume and/or to recover conversion products, the principal chemical processes used to transform MSW include (1) combustion (chemical oxidation), (2) pyrolysis. and (3) gasification. All three of these processes are often classified as thermal processes.

a)Combustion (Chemical Oxidation). Combustion is defined as the chemical reaction of oxygen with organic materials, to produce oxidized compounds accompanied by the emission of light and rapid generation of heat. In the presence of excess air and under ideal conditions, the combustion of the organic fraction of MSW can be represented by the following equation:

Organic matter + excess air —> N2 + CO2 + H2O + O2 + ash + heat (4-15)

Excess air is used to ensure complete combustion. The end products derived from the combustion of MSW, Eq. (4-15), include hot combustion gases—composed primarily of nitrogen (N_2), carbon dioxide (CO_2), water (H_2O. flue gas), and oxygen (O_2)—and noncombustible residue. In practice, small amounts of ammonia (NH_3). sulfur dioxide (SO_2), nitrogen oxides (NOx), and other trace gases will also be present, depending on the nature of the waste materials.

Pyrolysis. Because most organic substances are thermally unstable, they can be split, through a combination of thermal cracking and condensation reactions in an oxygen-free atmosphere, into gaseous, liquid, and solid fractions. In contrast with the combustion process, which is highly exothermic, the pyrolytic process is highly endothermic. For this reason, destructive distillation is often used as an alternative term for pyrolysis.

The characteristics of the three major component fractions resulting from the pyrolysis of the organic portion of MSW are (1) a gas stream containing primarily hydrogen (H2). methane (CH4), carbon monoxide (CO), carbon dioxide (CO2), and various other gases, depending on the organic characteristics of the waste material being pyrolyzed; (2) a tar and/or oil stream that is liquid at room temperature and contains chemicals such as acetic acid, acetone, and methane and (3) a char consisting of almost pure carbon plus any inert material that may have entered the process.

Gasification. The gasification process involves partial combustion of a carbonaceous fuel so as to generate a combustible fuel gas rich in carbon monoxide, hydrogen, and some saturated hydrocarbons, principally methane. The combustible fuel gas can then be combusted in an internal combustion engine or boiler. When a gasifier is operated at atmospheric pressure with air as the oxidant, the end products of the gasification process are (1) a low-Btu gas typically containing carbon dioxide (CO2), carbon monoxide (CO), hydrogen (H2), methane (CH4). and nitrogen (N2); (2) a char containing carbon and the inerts originally in the fuel, and (3) condensable liquids resembling pyrolytic oil as shown in figure 4-4.

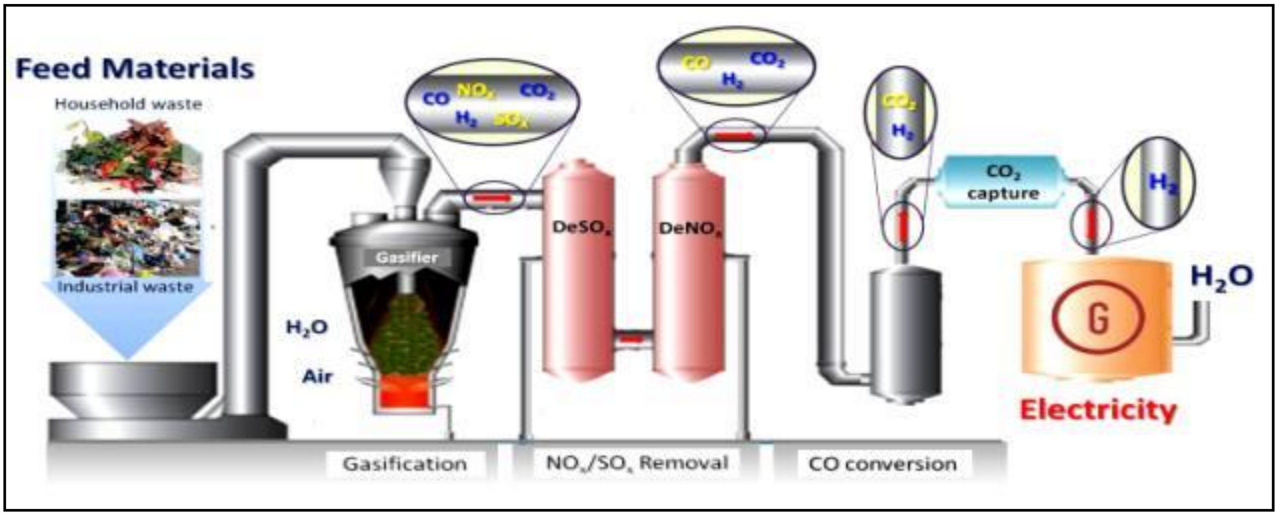


Fig.4- 4 Gasification Process

Other Chemical Transformation Processes. The hydrolytic conversion of cellulose to glucose, followed by the fermentation of glucose to ethyl alcohol, is an example of such a process.

4-5-3 Biological Transformations

The biological transformations of the organic fraction of MSW may be used to reduce the volume and weight of the material; to produce compost, a humus-like مثل الدبال material that can be used as a soil conditioner; and to produce methane. The principal organisms involved in the biological transformations of organic wastes are bacteria, fungi, yeasts, and actinomycetes. These transformations may be accomplished either aerobically or anaerobically depending on the availability of oxygen. The principal differences between the aerobic and anaerobic conversion reactions are the nature of the end products and the fact oxygen must be provided to accomplish the aerobic conversion. Biological processes that have been used for the conversion of the organic fraction of MSW include aerobic composting, anaerobic digestion, and high-solids anaerobic digestion.

a) Aerobic Composting. the organic fraction of MSW will undergo biological decomposition. The extent and the period of time over which the decomposition occurs will depend on the nature of the waste, the moisture content, the available nutrients, and other environmental factors. Yard wastes and the organic fraction of MSW can he converted to a stable organic residue known as compost in a reasonably short period of time (four to six weeks).

Composting the organic fraction of MSW under aerobic conditions can be represented by the following equation:

$$\text{Organic matter} + O_2 + \text{nutrients} \dashrightarrow \text{new cells} + \begin{matrix}\text{Resistant}\\ \text{organic}\\ \text{matter}\end{matrix} + CO_2 + H_2O + NH_3 + SO_2 + \text{heat} \quad (4\text{-}14)$$

In Eq. (4-14), the principal end products are new cells, resistant organic matter, carbon dioxide, water, ammonia, and sulfate. Compost is the resistant organic matter that remains. The resistant organic matter usually contains a high percentage of lignin, which is difficult to convert biologically in a relatively short time. Lignin, found most commonly in newsprint, is the organic polymer that holds together the cellulose fibers in trees and certain plants.

Fig. 4-6 Aerobic Composting

b) Anaerobic Digestion. The biodegradable portion of the organic fraction of MSW can be converted biologically under anaerobic conditions to a gas containing carbon dioxide and methane (CH4). This conversion can be represented by the following equation:

$$\text{Organic matter} + H_2O + \text{nutrients} \longrightarrow \text{new cells} + \begin{matrix}\text{Resistant}\\ \text{organic}\\ \text{matter}\end{matrix} + CO_2 + CH_4$$

$$+NH_3 + H_2S + \text{heat} \ldots\ldots \qquad (4\text{-}15)$$

Thus, the principal end products are carbon dioxide, methane, ammonia, hydrogen sulfide and resistant organic matter. In most anaerobic conversion processes carbon dioxide and methane constitute over 99 percent of the total gas produced.

Fig. 4-7 In vessel composting

Fig. 3-8 Windrow composting

4-5-4 Why is composting important?

Composting is important because it puts organic materials back into the ground which is necessary for a naturally healthy lawn and garden. In addition, composting is important because it's a better alternative than sending these natural organic materials to the landfill.

4-5-5 What can be done to stop the foul smell sometimes emitted by a compost pile?

Smelly compost piles can be avoided by not placing meats, oils, dairy products, and pet waste in the compost pile. Also, too many grass clippings (source of nitrogen) can cause the compost pile to smell.

4-5-6 Recovery of Materials for Reuse and Recycling, As a practical matter, components that arc most amenable to recovery arc those for which markets exist and which are present in the wastes in sufficient quantity to justify their separation. Materials most often recovered from MSW include paper, cardboard, plastic, garden trimmings, glass, ferrous metal, aluminum, and other nonferrous metal.

Transformation Processes used for MSW Management (Textbook, p.91, Table 4-8)

	Process	Method	Principal Conversion Products
Physical Transformation	• separation	manual and/or mechanical	individual components found in comingled MSW
	• volume reduction	Force or pressure	original waste reduced in volume
	• size reduction	Shredding, grinding, or milling	altered in form and reduced in size
Chemical Transformation	• combustion	thermal oxidation	CO_2, SO_2, oxidation products, ash
	• pyrolysis	destructive distillation	a variety of gases, tar and/or oil
	• gasification	starved air combustion	gases and inerts
Biological Transformation	• aerobic compost	aerobic biological conversion	compost
	• anaerobic digestion	anaerobic biological conversion	methane, CO_2, trace gases, humus
	• anaerobic digestion in landfills	anaerobic biological conversion	methane, CO_2, digested waste

CHAPTER SIX

SOLID WASTE GENERATION RATES

Measures Used to Quantify Solid Waste Quantities

The principal reason for measuring the quantities of solid waste generated, separated for recycling and collected for further processing or disposal is to obtain data that can be used to develop and implement effective solid waste management programs. Therefore, in any solid waste management study, extreme care must be exercised in deciding what actually needs to be known and in allocating funds for data collection. The measures and units used to quantify solid waste quantities are discussed below.

Volume and Weight Measurements. Both volume and weight are used for the measurement of solid waste quantities. Unfortunately, the use of volume as a measure of quantity can be misleading. For example, a cubic yard of loose wastes is a different quantity from a cubic yard of wastes that has been compacted in a collection vehicle, and each of these is different from a cubic yard of wastes that has been compacted further in a landfill. Accordingly, if volume measurements are to be used, the measured volumes must be related to either the degree of compaction of the wastes or the specific weight of the waste under the conditions of storage.

To avoid confusion, solid waste quantities should be expressed in terms of weight. Weight is the only accurate basis for records because tonnages can be measured directly, regardless of the degree of compaction. Weight records are also necessary in the transport of solid wastes because the quantity that can be hauled usually is restricted by highway weight limits rather than by volume. On the other hand, volume and weight are equally important with respect to the capacity of landfills.

Suggested units of expression for different generation sources are considered in Table 6-1. In predicting residential solid waste generation rates, the measured rate seldom reflects the true rate because there are confounding factors (onsite storage and the use of alternative disposal locations) that make the true rate difficult to assess. Most solid waste generation rates reported in the literature prior to about 1990 are actually based on measurement of the amount of waste collected, not the actual amount generated, excluding the amount of waste material that was: (1) recycled (directly and indirectly), (2) ground up in kitchen food waste grinders, (3) burned in fireplaces, (4) composted, and (5) stored temporarily.

TABLE 6-1 Suggested units of expression for solid waste quantities

Type of waste	Discussion
Residential	Because of the relative stability of residential wastes in a given location, the most common unit of expression used for their generation rates is Ib/capita • d. or (kg/capita. d).
Commercial	Commercial waste generation rates have also been expressed in b/capita • d. or kg/c.d
Industrial	Ideally, wastes generated from industrial activities should be expressed on the basis of some repeatable measure of production, such as pounds per automobile for an automobile assembly plant or pounds per case for a packing plant. When such data are developed, it will be possible to make meaningful comparisons between similar industrial activities throughout the country.
Agricultural	Where adequate records have been kept, solid wastes from agricultural activities are now most often expressed in terms of some repeatable measure of production, such as Ib of manure/1400-lb cow • d and Ib of waste/ton of raw product.

METHODS USED TO ESTIMATE WASTE QUANTITIES

Load-Count Analysis. In this method, the number of individual loads and the corresponding waste characteristics (types of waste, estimated volume) are noted over a specified time period.

Example 6-1 Estimation of unit solid waste generation rates for a residential area. From the following data estimate the unit waste generation rate per week for a residential area consisting of 1200 homes. The observation location is a local transfer station that receives all of the wastes collected, for disposal. The observation period was one week.

1. Number of compactor truck loads = 9.0
2. Average size of compactor truck = 20.0 yd3
3. Number of flatbed loads = 7.0
4. Average flatbed volume = 2.0 yd3
5. Number of loads from individual residents' private cars and trucks = 20
6. Estimated volume per domestic vehicle = 8.0 ft3

Solution

Table 4-1 to convert the measured waste volumes to weight.

Item	No.of loads	Ave.No. of volume, yd3	Specific Wt 1b/yd3	Total 1b
Compactor truck	**9**	**20**	**500**	**90,000**
Flatbed truck	**7**	**2**	**225**	**3,150**
Individual private cars	**20**	**0.3**	**150**	**900**
Total 1b/wk				**94,050**

Determine the unit waste collection rate based on the assumption that each household is comprised of 3.5 people.

Unit rate =

$$\frac{94{,}050\ 1b/wk}{1200\ x 3.5\ x\ 7d/wk}$$

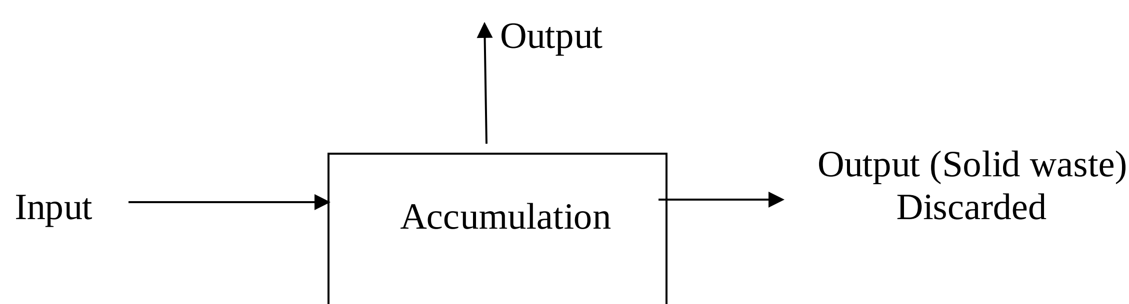
3.2 1b /capita. d = 1.45 kg/capita • d

Weight-Volume Analysis. The use of detailed weight-volume data obtained by weighing and measuring each load will certainly provide better information on the specific weight of the various forms of solid wastes at a given location.

Materials Mass Balance Analysis The only way to determine the generation and movement of solid wastes with any degree of reliability is to perform a detailed materials balance analysis for each generation source, such as an individual home or a commercial or industrial activity. In some cases, the materials balance method of analysis will be required to obtain the data needed to verify compliance with state-mandated recycling programs.

Example 6-2 Materials-balance analysis.

Example 6-2 :In an average week a family purchase and bring to their house about 50 kg of consumer goods (food , magazine, newspaper, appliances, furniture, and associated packaging). Of this amount 50% is consumed as food. Half of the food is used for biological maintenance and ultimately released as CO2 and the remainder is discharged to the sewer system. Approximately 1 kg accumulates in the house. The family recycles approximately 25% of the solid that is generated. Estimate the amount of solid waste they place at the curb each week.



Output (recycled)

Output (sewer)

Rate in = Rate Out

Rate in = Rate Out +accumulated

Accumulated = Rate in – Rate out

One half of input is food = 0.5(50 kg)= 25 kg

One half of the food is used for biological maintenance =(0.5) (25 kg)=12.5 kg

One half of the food is lost to the sewer system =(0.5) (25 kg)=12.5 kg

The recycled amount is 25% of what remains of input = .25 (50 kg -12.5 kg -12.5 kg -1 kg)= 6 kg

i.e discarded solid waste = 50 kg -12.5 kg -12.5 kg -1 kg- 6 kg =18 kg

SOLID WASTE COLLECTION RATES

The difference between the amount of residential and commercial MSW generated and the amount of waste collected for processing or disposal will typically vary from 4 to 15 % . The difference can be accounted for by the amount of material (1) composted (2) burned in fire places(3) discharged to sewers,(4) given to charitable agencies,(5) sold at garage sales, (6) delivered to recycling centers, (7) recycled directly.

FACTORS THAT AFFECT WASTE GENERATION RATES

The effect of (1) source reduction and recycling activities, (2) public attitudes and legislation, and (3) geographic and physical factors on the generation of solid waste are considered in the following discussion.

Effect of Source Reduction and Recycling Activities on Waste Generation

Waste reduction may occur through the design, manufacture, and packaging of products with minimum toxic content, minimum volume of material, and/or a longer useful life. Waste reduction may also occur at the household, commercial or industrial facility through selective buying patterns and the reuse of products and materials.

Effect of Public Attitudes and Legislation on Waste generation

Along with source reduction and recycling programs, public attitudes and legislation also significantly affect the quantities generated.

Significant reductions in the quantities of solid wastes generated occur when and if people are willing to change—of their own volition—their habits and lifestyles to conserve natural resources and to reduce the economic burdens associated with the management of solid wastes. A program of continuing education is essential in bringing about a change in public attitudes.

Effect of Geographic and Physical Factors on Waste Generation

Geographic and physical factors that affect the quantities of waste generated and collected include location, season of the year, the **use** of kitchen waste food grinders, waste collection frequency, and the characteristics of the service area.

Geographic Location. The influence of geographic location include the different climates that can influence both the amount of certain types of solid wastes generated and the time period over which the wastes are generated. For example, substantial variations in the amount of yard and garden wastes generated in various parts of the country are related to climates. That is, in the warmer southern areas, where the growing season is considerably longer than in the northern areas, yard wastes are collected not only in considerably greater amounts but also over a longer time.

Season of the Year. The quantities of certain types of solid wastes are also affected by the season of the year. For example, the quantities of food wastes related to the growing season for vegetables and fruits.

Use of Kitchen Food Waste Grinders. While the use of kitchen food waste grinders definitely reduces the quantity of kitchen wastes collected, but do they affect quantities of wastes generated is not clear.

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

Characteristics of Service Area. Peculiarities of the service area can influence the quantity of solid wastes generated. For example, the quantities of yard wastes generated on a per capita basis are considerably greater in many of the wealthier neighborhoods than in other parts of town. Other factors that will affect the amount of yard waste include the size of the lot, the size of landscaping, and the frequency of yard maintenance.

Practice

Q1. The student population of a high school is 881. The school has 30 standard classrooms. Assuming a 5-day school week with solid waste pickups on Wednesday and Friday before school starts in the morning, determine the size of storage containers required. Assume waste generation rate = 0.11 kg/capita/day and 3.6 kg/room, density of waste = 120 kg/m^3, standard containers are 1.5, 2.3, 3.0, and 4.6 m^3

Solution:

a. Determine total waste production

waste = 881 persons(0.11 kg/capita/d) + 30 rooms(3.6 kg/room/d) = 204.91 kg/d

b. Total volume of waste

$$\forall waste = \frac{204.91 \text{ kg/d}}{120 \text{ kg/m}^3} = 1.708 \text{ m}^3\text{/d}$$

Since the maximum storage period is 3 days (Friday, Monday & Tuesday),

Volume = 3d * 1.708 m3/d = 5.12 m^3

One solution to this would be: 1 container of **2.3** m^3 and 1 container of **3.0** m^3

CHAPTER 7

WASTE HANDLING AND SEPARATION, STORAGE AND PROCESSING AT THE SOURCE

In general, handling refers to the activities associated with managing solid wastes until they are placed in the containers used for their storage before collection. Handling may also be required to move the loaded containers to the collection point and to return the empty containers to the point where they are stored between collections as shown in (Fig. 7-1) and (Fig.7-2)

Figure 7-1: Typical storage containers for curb collection service.

Figure 7-2 Solid waste scavengers

In some residence, waste compactors are being used to reduce the volume of waste to be collected. Compacted wastes are usually placed in waste containers or in sealed plastic bags.

As there are number of different collection systems, Example 7-1 compares two residential waste separation systems

Example 7-1 Comparison of residential waste separation programs

The effectiveness of residential waste separation programs depends on the type of system used for the collection of separated wastes. A number of communities use a collection system in which three containers are used for recycled materials in addition to one or more containers for non-recyclable materials. In the three-container system (system 1), newspaper is placed in one container. Aluminum cans, glass, and plastics arc placed in the second container. The remaining wastes arc placed in the third container. The separated materials, placed in special containers, are collected at the curb.

In another system (system 2), four containers arc used. All paper and cardboard materials are placed in one container. All plastic, glass, tin cans, aluminum, and any other metals arc placed in a second container. Garden wastes arc placed in the third container, and all remaining waste materials arc placed in the fourth container. Compare these two systems. Assume newspaper represents 25 percent of the total amount of paper.

Solution

Determine how much of the waste stream can be separated for recycling using the two systems described above. Assume:

1. 80% of the available material is separated
2. The participation rate is 100%

Component	Percent by weight			
	Recycling system 1		Recycling system 2	
	As generated[a,b]	Separated for recycle[c]	As generated[a,b]	Separated for recycle[d]
Organic				
Food wastes	9.0 (3)[e]		9.0 (4)[e]	
Paper	**34.0** (1)	6.8[f]	**34.0** (1)	27.2
Cardboard	6.0 (3)		**6.0** (1)	4.8
Plastics	**7.0** (2)	5.6	**7.0** (2)	5.6
Textiles	2.0 (3)		2.0 (4)	
Rubber	0.5 (3)		0.5 (4)	
Leather	0.5 (3)		0.5 (4)	
Yard wastes	18.5 (3)		**18.5** (3)	14.8
Wood	2.0 (3)		2.0 (4)	
Misc. organics	—	—	—	
Inorganic				
Glass	**8.0** (2)	6.4	**8.0** (2)	6.4
Tin cans	6.0 (3)		**6.0** (2)	4.8
Aluminum	**0.5** (2)	0.4	**0.5** (2)	0.4
Other metal	3.0 (3)		**3.0** (2)	2.4
Dirt, ash, etc.	3.0 (3)		3.0 (4)	
Total	100.0	19.2	100.0	66.4

Comment. As shown in above computation table, the amount of material separated for recycling with system 1 is 19.2 percent versus 66.4 percent for system 2. If the participation rate were to drop to 50 percent, the corresponding amounts are 9.6 versus 33.2 percent. Using system 1, it will be difficult to achieve the 25 percent recycling goal without a high degree of homeowner participation. Additional separation, possibly at a MRF, will be required to reach the 50 percent goal by the year 2000. Using system 2, both the 25 and 50 percent diversion goals are achievable with a reasonable amount of homeowner participation.

At Low –and Medium –Rise Apartments

Handling methods in most low- and medium-rise apartment buildings resemble those used for low-rise dwellings, but methods may vary somewhat depending on the waste storage location and collection method. Typical solid waste storage locations include basement storage, outdoor storage, and, occasionally, compactor storage.

At High-Rise Apartments

In high-rise apartment buildings the most common methods of handling solid wastes involve one or more of the following: (1) wastes are picked up by building maintenance personnel or porters حمالين from the various floors and taken to the basement or service area; (2) wastes are taken to the basement or service area by tenantsالمستأجرين ; or (3) wastes, usually bagged, are placed by the tenants in specially designed vertical chutes المزالق (usually circular) with openings located on each floor (see Fig. 7-3). Wastes discharged in chutes are collected in large containers, compacted into large containers, or baled directly- Recyclable materials may be put outside in the hall or entry way for pickup, or they may be taken by the tenants to the service area located on each floor for pickup. The entrance to the waste chute is usually located in the service area. Bulky items are usually taken to the service area by the tenants or the building maintenance crew.

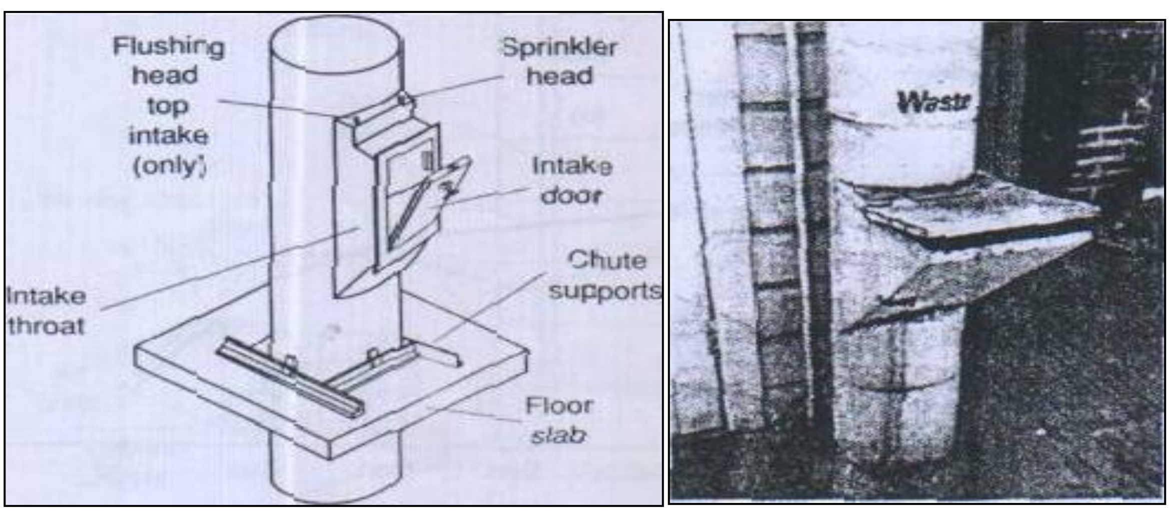


FIGURE 7-3 typical chute openings for the discharge of waste materials in high-rise apartment buildings: (a) isometric view of waste chute opening on individual floor and (b) outdoor type used in some older high-rise apartment building

Chutes for use in apartment buildings are available in, diameters from 12 to 36 in. The most common size is 24 in in diameter. All the available chutes can be furnished with suitable intake doors.

In some of the more recent apartment building developments underground pneumatic transport systems have been used in conjunction with the individual apartment chutes. The underground pneumatics systems are used to transport the wastes from the chute discharge points in each building to a central location for storage in large containers or onsite processing. Both air pressure and Vacuum transport systems have been used in this application.

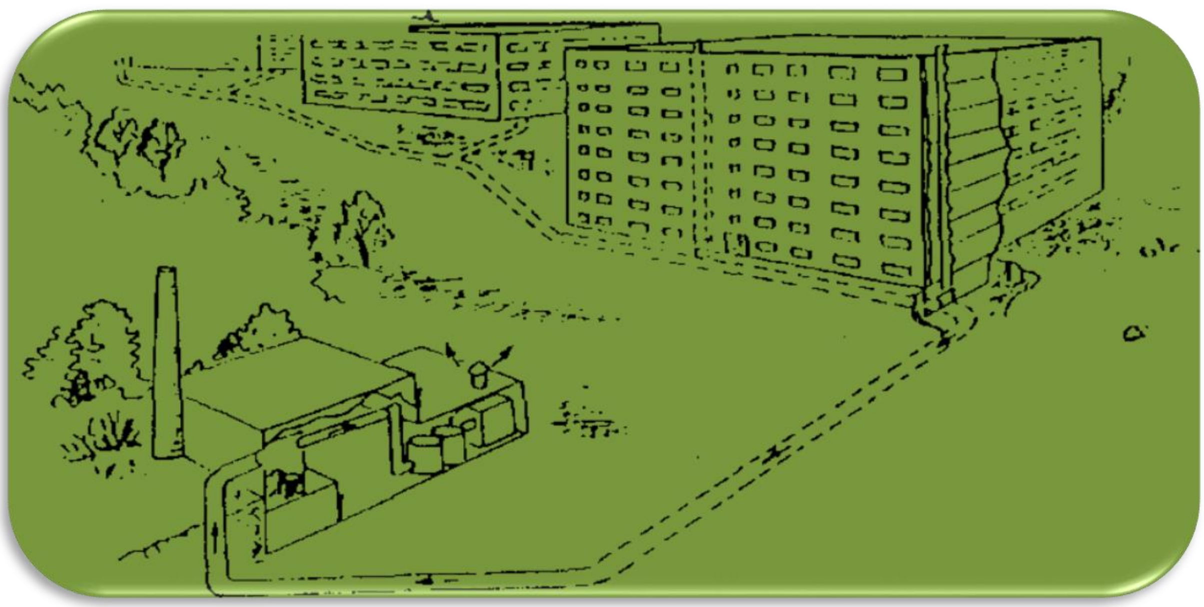


Figure 7-4 Pneumatic transport systems for solid wastes

STORAGE OF SOLID WASTES AT THE SOURCE

Factors that must be considered in the onsite storage of solid wastes include (1) the effects of storage on the waste components (2) the type of container to be used (3) the container location, and (4) public health and aesthetics.

(1) Effects of Storage on Waste Components

An important consideration in the onsite storage of wastes arc the effects of storage itself on the characteristics of the wastes being stored. These effects of storing wastes include (a) biological decomposition, (b) the absorption of fluids and (c) the contamination of waste components.

a. **Biological decomposition or Microbiological Decomposition**

Food and other wastes placed in onsite storage containers will almost immediately start to undergo microbiological decomposition (often called putrefaction) as a result of the growth of bacteria and fungi. If wastes are allowed to remain in storage containers for extended periods of time, flies can start to breed and odorous compounds can develop.

b. **Absorption of Fluids**

Because the components that comprise solid wastes have differing initial moisture contents re-equilibration takes place as wastes are stored onsite in containers. Where mixed wastes are stored together, paper will absorb moisture from food wastes and fresh garden trimmings. The degree of adsorption that takes place depends on the length of time the waste are stored until collection.

c. **Contamination of Waste Components**

Perhaps the most serious effect of onsite storage of wastes is the contamination that occurs. The major waste components may be contaminated by small amounts of wastes such as motor oils, household cleaners, and paints. The effect of this contamination is to reduce the value of the individual components for recycling.

(2)Types of Containers

To a large extent, the types and capacities of the containers used depend **on a. the characteristics and types of solid wastes to be collected**, b, **the type of collection system in use**, c. **the collection frequency, and d. the space available for the placement of containers**.

Because solid waste is collected manually from most residential low –rise detached dwellings, the container should be light enough to be handled easily by one collector when full. Injuries to collectors have resulted from handling containers that were loaded too heavy Table 7-1 gives data on the types of containers and advantages and disadvantages of each.

Table 7-1 Data on the Types of Containers and Disadvantages of Each.

Container type	Limitations
Galvanized	a. Containers are damaged over time and degraded in appearance and capacity; b. containers add extra weight that must be lifted during collection operations, c. tend to be noisy when being emptied and, d. in time can be damaged so that a proper lid seal cannot be achieved.
Plastic	a. Containers are damaged over time and degraded in appearance, b. some containers constructed of plastic materials tend to crack under exposure to the ultraviolet rays of the sun and to freezing temperatures, but the more expensive plastic containers apparently do not present these problems.
Disposal paper bags	a. Bag storage is more costly: b. if bags are set out on streets or curbside, dogs or other animals tear them and spread their contents: c. paper bags themselves add to the waste load. d. Paper and cardboard containers tend to disintegrate because of the leakage of liquids.
Disposal plastic bags	a. Bag storage is more costly; b. bags tear easily, causing litter and unsightly conditions: c. bags become brittle in very cold weather, causing breakage; d. plastic lightness and durability causes later disposal problems. e. In extremely warm areas where disposable plastic bags are used for lawn trimmings, plastic containers frequently stretch or break at the seams when the collector lifts the loaded bag. Such breakage is potentially hazardous and may lead to injuries to the collector because of the presence of glass and sharp or otherwise dangerous items in the wastes.

Example 7-2 Selection of container size for use at a commercial facility

A commercial facility produced the following quantities of solid waste each week for a calendar quarter of operation. Using these waste production data, determine the size of container at which it becomes more cost effective to make extra pickup trips, on call instead of using a larger-sized container. Assume the data given below arc applicable.

1. **Waste production data**

Week no.	Waste yd3/wk	Week no.	Waste yd3/wk
1	41	8	27
2	30	9	37
3	35	10	36
4	34	11	33
5	39	12	28
6	25	13	31
7	32		

2. **Collection system data**

Capacity yd3	Capital cost $	Annual O&M cost &/yr
30	3000	150
35	3500	175
40	4000	225
45	4900	300
50	6100	400

- **Cost per trip= 50$.00/trip**
- **Useful life of the containers= 10 yr**
- **Discount rate=10%**
- **Capital recovery factor= (i=10%, n=10yr)= 0.16275**

CHAPTER 7 WASTE HANDLING AND SEPARATION, STORAGE AND PROCESSING AT THE SOURCE

3) Container Storage Locations

Container storage locations depends on the type of the dwelling or commercial and industrial facilities, the available space, and access to collection services

(4) Public Health and Aesthetics

Although residential solid wastes account for a relatively small proportion of the total wastes generated in the United States (10 to 15 percent), they are perhaps the most important because they are generated in areas with limited storage space. As a result, they can have significant public health and aesthetic impacts.

Public health concerns are related primarily to the infestation of areas used for the storage of solid wastes with vermin and insects that often serve as potential disease vectors. By far the most effective control measure for both rats and flies is proper sanitation. Typically, ***proper sanitation involves***:

- The use of containers with tight lids,
- the periodic washing of the containers as well as of the storage areas, and
- The periodic removal of biodegradable materials (usually within less than 8 days), which is especially important in areas with warm climates.

Aesthetic considerations are related to the production of odors and the unsightly conditions that can develop when adequate attention is not given to the maintenance of sanitary conditions.

- Most odors can be controlled through the use of containers with tight lids
- Maintenance of a reasonable collection frequency.
- If odors persist, the contents of the container can be sprayed with a masking deodorant as a temporary expedient.
- To maintain aesthetic conditions, the container should be scrubbed and washed periodically.

PROCESSING OF SOLID WASTES AT RESIDENTIAL DWELLINGS

Waste processing is used to (1) reduce the volume, (2) recover usable materials, or (3) alter the physical form of the solid wastes. The most common onsite processing operations used at low-rise detached residential dwellings include food waste grinding, component separation, compaction, incineration (in fireplaces), and composting.

Grinding of Food Wastes

Food waste grinders are used primarily for wastes from the preparation, cooking, and serving of foods. Most grinders sold for home use cannot be used for large bones or other bulky items.

Functionally, grinders render the material that passes through them suitable for transport through the sewer system. Because the organic material added, the wastewater has resulted in overloading many treatment facilities; it has been necessary in some communities to forbid the installation of waste food grinder in new developments until additional treatment capacity becomes available.

Where food waste grinders are used extensively, the weight of waste collected per person will tend to be lower. In terms of the collection operation, the use of home grinders does not have a significant impact on the volume of solid wastes collected. In some cases where grinders are used, it has been possible to increase the time period between collections pickups because wastes that might readily decay are not stored, see figure 7-5.

Fig. 7-5 kitchen home grinders.

Separation of Wastes

The question that must be answered is what is the energy content of residual solid waste? The effect of home separation on the energy content of the residential MSW is considered in **Example 7-3.**

Example 7-3 Using the typical percentage distribution data in the given table below, estimate the number of Kj/Kg of the remaining solid wastes if 90 percent of the cardboard and 60 percent of the paper were recovered by homeowner

Component	Percent by weight	Energy kJ/kg	Total energy Kj
Organic			
food wastes	9.0	4720	42480
Paper	34.0	16747.2	570000
Cardboard	6.0	16282	97692
Plastics	7.0	32564	227948
Textiles	2.0	17445	34890
Rubber	0,5	23260	11630
Leather	0.5	17445	8722.5
Yard wastes	18.5	6512.8	120486.8
Wood	2.0	18608	37216
Inorganic			
Glass	8.0	139.5	1116
Tin cans	6.0	697.5	4185
Aluminum	0.5	----	----
Other metal	3.0	697.5	2092.5
Dirt, ash, etc.	3.0	6975	20925
Total	100		

Solution

2. Determine the energy content and weight of 60 percent of the paper in the original sample.
   (*a*) Energy content, 60% paper

$$0.60 \times 244{,}800 \text{ Btu} = 146{,}880 \text{ Btu}$$

   (*b*) Weight, 60% paper

$$0.60 \times 34 \text{ lb} = 20.4 \text{ lb}$$

3. Determine the energy content and weight of 90 percent of the cardboard in the original sample.
   (*a*) Energy content, 90% cardboard

$$0.90 \times 42{,}000 \text{ Btu} = 37{,}800 \text{ Btu}$$

   (*b*) Weight, 90% cardboard

$$0.90 \times 6 \text{ lb} = 5.4 \text{ lb}$$

4. Determine the total energy content, weight, and energy content per pound of the original sample after paper and cardboard have been separated.
   (*a*) Total energy after recovery

$$(506{,}530 - 146{,}880 - 37{,}800) = 321{,}850 \text{ Btu}$$

   (*b*) Total weight after recovery

$$(100 - 20.4 - 5.4) \text{ lb} = 74.2 \text{ lb}$$

   (*c*) Energy content of waste per lb after separation

$$\frac{321{,}850 \text{ Btu}}{74.2 \text{ lb}} = 4338 \text{ Btu/lb } (10{,}090 \text{ kJ/kg}) \text{ versus } 5065 \text{ Btu/lb } (11{,}781 \text{ kJ/kg})$$

in original sample

Comment. In this example, the removal by weight of approximately 26 percent of the wastes reduced the per-pound energy content of the original sample by approximately 14 percent.

Refuse and Diversion

Refuse can be defined in terms of as generated and as collected solid waste. The refuse generated includes all of the wastes produced by a household whatever is no longer wanted and is to be gotten rid of. Often some part of the refuse, especially organic matter and yard waste, is composted on premises المباني. The fraction of refuse that is generated but not collected is called diverted refuse. The as generated refuse is always larger than the as collected refuse, and the difference is the diverted refuse.

In summary:

(As generated refuse) = (as collected refuse) + (diverted refuse)

Refuse does not include

- Construction and demolition debris
- Water and wastewater treatment plant sludges
- Leaves and other green waste collected from community streets and parks
- Bulky items such as large appliances, hulks of old cars, tree limbs, and other large-objects that often require special handling

C & D wastes, for example, are commonly landfilled in a separate section of a landfill, and these wastes do not require daily cover. Leaves, in some parts of the United States, represent a serious problem to communities during the autumn, and composting facilities are often developed to handle this seasonal load. In summary:

(MSW) = (refuse) + (C & D waste) + (sludge) + (leaves) + (bulky items)

Sometimes diversion is defined on basis of MSW instead of refuse. When defined in this way, diverted MSW is that fraction of MSW that is generated but does not find its way to the landfill. The objective is to increase the life of a landfill or to reduce the cost of disposal. One major diversion is the collection of recyclables (aluminum cans, newspaper, etc.} that can be sold on the secondary materials market. The EPA has challenged communities to increase their diversion to 35%, up from the

25% originally established in 1988. California has set an even higher goal of 50% diversion.

The calculation of diversion in terms of either refuse or MSW is important and controversial. MSW includes refuse plus C & D debris, sludges, leaves, and bulky items. When communities are under state mandates to increase the recycling of consumer products, the calculation often is made using MSW as the denominator instead of the refuse, thereby achieving large diversion rates. This is demonstrated by the example below.

EXAMPLE; A community produces the following on an annual basis:

Fraction	ton
Mixed household waste	210
Recyclables	23
Commercial waste	45
Construction and demolition debris (**C & D**)	120
Treatment plant sludges	32
Leaves and miscellaneous	4

The **recyclables** are collected separately and processed at a materials recovery facility. **The mixed household waste** and **the commercial waste** go to the landfill, as do the **leaves and miscellaneous solid wastes**. The **sludges** are dried and applied on land (not into the landfill), and the C & D wastes are used to fill a large ravine. Calculate the diversion.

If the calculation is on the basis of MSW, the total waste generated is 434 tons per year. If everything not going to the landfill is counted as having been diverted, the diversion is calculated as

40%

This is an impressive diversion. However, if the diversion is calculated as that fraction of the refuse (mixed household and commercial waste.) that has been kept out of the landfill by the recycling program, the diversion is

8%

This is not nearly as impressive, but a great deal more honest.

Compaction: To reduce the volume of solid wastes that must be handled, compaction units commonly are installed in larger apartment buildings. Typically, a compactor is installed at the bottom of a solid, waste chute. Wastes falling through the chute activate the compactor by means of photoelectric cells or limit switches. The compressed wastes may be formed into bales or extruded and loaded automatically into metal containers or paper bags

Component	Weight,[a] lb	Specific weight,[b] lb/yd³	Volume, yd³ × 10⁻²
Organic			
Food wastes	9.0	490	1.84
Paper	34.0	150	22.67
Cardboard	6.0	167[c]	3.59
Plastics	7.0	110	6.36
Textiles	2.0	110	1.82
Rubber	0.5	220	0.23
Leather	0.5	270	0.19
Yard wastes	18.5[d]	170	10.88[d]
Wood	2.0[d]	400	0.50[d]
Inorganic			
Glass	8.0	330	2.42
Tin cans	6.0	150	4.00
Aluminum	0.5	270	0.19
Other metal	3.0[d]	540	0.56[d]
Dirt, ash, etc.	3.0[d]	810	0.37[d]
Total	100.0		55.62
			43.31[e]

[a] Data from Table 3-4.
[b] Data from Table 4-1.
[c] Cardboard partially compressed by hand before being placed in waste compactor.
[d] Components not usually placed in home waste compactors.
[e] Total excluding components not usually placed in home waste compactors.

2. Determine the volume of compacted wastes, excluding yard wastes; wood; metals than aluminum and tin cans; and dirt, ashes, etc.

$$\text{Compacted volume} = \frac{(100 - 18.5 - 2 - 3 - 3)\text{ lb}}{540 \text{ lb/yd}^3}$$

$$= \frac{73.5 \text{ lb}}{540 \text{ lb/yd}^3} = 0.136 \text{ yd}^3$$

3. Determine the volume reduction for the compressible material.

$$\text{Volume reduction} = \left(\frac{(0.433 - 0.136)\ \text{yd}^3}{0.433\ \text{yd}^3}\right) \times 100$$

$$= 69\%$$

4. Determine the overall volume reduction achieved with a home compactor, taking into account garden trimmings; wood; metals other than aluminum and tin cans; dirt, ashes, etc.

Overall volume reduction

$$= \left(\frac{0.556\ \text{yd}^3 - (0.136 + 0.109 + 0.005 + 0.006 + 0.004)\ \text{yd}^3}{0.556\ \text{yd}^3}\right) \times 100$$

$$= \left(\frac{0.556 - 0.260}{0.556}\right) \times 100$$

$$= 53\%$$

Comment. When the overall volume reduction is assessed, the significance of a home compactor is reduced. This finding is especially true as the percentages of the components not compacted, such as garden trimmings, increase.

Composting

It is an effective way of reducing the volume and altering physical composition of solid wastes while at the same time producing a useful by-product. A variety of methods are used, depending on the amount of space available and the wastes to be composted. Composting can be a significant factor in the computation to determine the quantity of waste diverted from landfills.

Backyard Composting.

The simplest backyard composting method involves placement of material to be composted in a pile and occasionally watering and turning it to provide moisture and oxygen to the microorganisms within the pile. During composting period, which can take up to year, the material placed in the pile undergo bacterial and fungal decomposition until only a humus material known as compost remains. The composted material, which is biologically stabilized, can be used as a soil amendment or as a mulching material. See figures below.

Fig 7.7 (a) Rotary and horizontal composter, (b) composted materials

Combustion

In the past, the burning of combustible materials in fireplaces and the burn of rubbish in backyard incinerators was common practice. Backyard incinerator is now banned in most parts of the country.

EXAMPLE : Determine the quantity and composition of the residue from an incinerator used for municipal solid wastes with the average composition given in Table 4-9. Estimate the reduction in volume if it is assumed that the density weight of the residue is 10001b/yd^3. Assume the average density of the solid waste in the incinerator storage pit is about 375 1b/yd3.

PROCESSING OF SOLID WASTES AT COMMERCIAL AND INDUSTRIAL FACILITIES

Onsite processing operations carried out at commercial-industrial facilities generally similar to those described for residential sources.

Compaction

The baling of waste cardboard at markets and other commercial establishments is quit common. The bales vary in size, baled cardboard is reprocessed for the production of packing materials or shipping overseas for remanufacture into a variety of products.

Shredding and Hydro pulping

Shredding is used most common in commercial establishments and by governmental agencies to destroy sensitive documents that are no longer of value. In some cases, the volume of wastes has been observed to increase after shredding.

Although hydro pulping systems work well, they are expensive and typically involve discharge to the local wastewater collection system. Because the discharged of pulped material increases the organic loading on local treatment facilities, use of pulverizers may be restricted if treatment capacity is limited.

Fig. 7.8 Hydro pulping

Fig. 7.9 Paper and cardboard shredding

QUESTIONS:

1. **What is chute?**

2. **Give reasons to the followings.**

1. **Food and other wastes placed in onsite storage containers will almost immediately start to undergo putrefaction**.

2. Where mixed wastes are stored together, paper will absorb moisture from food wastes and fresh garden trimmings

3. Perhaps the most serious effect of onsite storage of wastes is the contamination of waste.

4. **In some residence waste compactors are being used.**

5. **Containers from residential low –rise detached dwellings handled by one collector should be light enough when they are full**.

6. **Although residential solid wastes account for a relatively small proportion of the total wastes generated they can have significant public health and aesthetic impacts.**

7. **It has been necessary in some communities to forbid the installation of waste food grinder**

8. **In some cases where grinders are used, it has been possible to increase the time period between collections pickups.**

9. **Describe backyard composting method. State the simplest backyard composting main steps:**

10. **Composting may be considered as an effective solid waste management**

11. **Occasionally watering and turning should be provided to compost piles**

12. **Backyard incinerator is now banned in most parts of the country.**
13. **Although hydro pulping systems work well they are not widely used**

14. **Use of** pulverizers **may be restricted**

15. **Use of** pulverizers **may be restricted if treatment capacity is limited.**

Q3.What is the advantages and disadvantages of each

a. ***Galvanized metal containers :***
b. ***Plastic materials container***
c. ***Bag storage***
d. ***Paper bag storage***

Q4 Estimate the energy content of a solid waste sample with the composition below and what is the content on a dry basis and on ash free dry basis?

Component	Percent by mass	Moisture content %	Energy kJ/kg
Food waste	15	70	4,650
Paper	45	6	16,750
Cardboard	10	5	16,300
Plastics	10	2	32,600
Garden trimming	10	60	6,500
Wood	5	20	18,600
Tin cans	5	3	700
Total	100		

Based on 100 kg sample of waste

CHAPTER 8
COLLECTION OF SOLID WASTE

8-1 WASTE COLLECTION

The term *collection,* includes not only the gathering or picking up of solid wastes from the various sources, but also the hauling of these wastes to the location where the contents of the collection vehicles are emptied. The unloading of the collection vehicle is also considered part of the collection operation.

From Low-Rise Detached Dwellings. The most common types of residential collection services for low-rise detached dwellings include

(1) Curb
(2) Alley
(3) Setout-setback, and
(4) Setout

Where **curb** service is used, the homeowner is responsible for placing the containers to be emptied at the curb on collection day and for returning the empty containers to their storage location until the next collection Figures (8.1, 8.2)

Where **alleys** are part of the basic layout of a city or a given residential area, alley storage of containers used for solid waste is common.

In **setout-setback** service, containers are set out from the homeowner's property and set back after being emptied by additional crews that work in conjunction with the collection crew responsible for loading the collection vehicle. **Setout service** is essentially the same as setout-setback service, except that the homeowner is responsible for returning the containers to their storage location.

From Low- and Medium-Rise Apartments. Curbside collection service is common for most low- and medium-rise apartments. Where large containers are used the containers are emptied mechanically using collection vehicles equipped with unloading mechanisms.

From High-Rise Apartments. Typically, large containers are used to collect wastes from large apartment buildings.

Fig. 8.1 Typical example of mechanically loaded collection vehicle used for the collection of residential wastes

From Commercial-Industrial Facilities. Both manual and mechanical means are used to collect wastes from commercial facilities- To avoid traffic congestion during the day, solid wastes from commercial establishments in many large cities are collected in the late evening and early in early morning hours.

Fig.8.2 Collection vehicle

Example 8-1 Home separation and curbside collection of recyclables. A community is purchasing specialized vehicles for the curbside collection of source-separated wastes. Three recycling containers are to be provided to each residence and residents will be asked to separate newspaper and cardboard, plastics and glass, and aluminum and tin cans. The homeowner is to place the separated materials in the appropriate containers and then move the recycling containers to curbside once per week for collection by special recycling vehicles. Estimate the relative volumetric capacity required for each material in recycling collection vehicles. Assume 80 percent of the recyclable material will be separated and that newsprint represents 20 percent of the total paper waste. The number of homes that will participate in the separation program is estimated to be 60 percent. If the separated wastes are to be collected from a subdivision of 1200 homes, determine the number of trips that will be required if the size of the collection vehicle **is** 15 yd^3 (11.5 M^3). Assume 3.5 residents per residence and solid waste generation is 3.82 1b/capita. d.

Component	Total solid waste (1b)	Waste material Separated 1b	Specific weight $1b/ft^3$	Volume ft^3
Food wastes	8.0	--	18.0	--
Paper	35.8	5.7	5.6	1.02
Cardboard	6.4	5.1	3.1	1.65
Plastics	6.9	5.5	4.1	1.34
Textiles	1.8	--	4.1	--
Rubber	0.4	--	8.1	--
Leather	0.4	--	10.0	--
Yard wastes	17.3	--	6.3	--
Wood	1.8	--	14.8	--
Glass	9.1	7.3	12.2	0.6
Tin cans	5.8	4.6	5.6	0.82
Aluminum	0.6	0.5	10.0	0.05
Other metals	3.0	---	20.0	--
. Dirt, ashes, etc.	2.7	---	30.0	--
Total	100	28.7		5.48

Determine the relative volume of the recycled materials.

(*a*) The volume in each category is:

i. Newspaper + cardboard = 1.02 + 1.65 = 2.67 ft^3

ii. Plastics + glass = 1.34 + 0.60 = 1.94 ft^3

iii. Aluminum and tin cans = 0.82 + 0.05 = 0.87 ft^3

(*b*) The relative volumes of waste compared with aluminum plus tin cans are

i. Newspaper + cardboard = 3.1 (= 2.67 ft^3/0.87 ft^3)

ii. Plastics + glass = 2.2 (= 1.94 ft^3/0.87 ft^3)

iii. Aluminum and tin cans = 1.0

(*c*) Thus, if a 15 yd^3 collection vehicle is to be used, 7.3 yd^3 [(2.67/5.48) × 15] of the capacity would be allocated for newspaper and cardboard, 5.3 yd^3 for plastic and glass, and 2.4 yd^3 for aluminum and tin cans.

3. Determine the number of trips required to collect the separated materials.

(*a*) Estimate the total weekly solid waste production rate using the data from Table 6-3.

Solid waste production, lb/wk

$$= 3.5 \text{ persons } \times 7 \text{ d/wk } \times 3.82 \text{ lb/capita} \cdot \text{d } = 93.6 \text{ lb/wk}$$

(*b*) Estimate the total weekly quantity of separated newspaper and cardboard.

i. Separated newspaper, lb/wk

$$= 93.6 \text{ lb/wk} \times (5.7/100) = 5.3 \text{ lb/wk}$$

ii. Separated cardboard, lb/wk

$$= 93.6 \text{ lb/wk} \times (5.1/100) = 4.8 \text{ lb/wk}$$

(*c*) Estimate the total weekly volume of separated newspaper and cardboard.

i. Separated newspaper, ft^3/wk

$$= (5.3 \text{ lb/wk})/(5.6 \text{ lb/ft}^3) = 1.0 \text{ ft}^3\text{/wk}$$

ii. Separated cardboard, ft^3/wk

$$= (4.8 \text{ lb/wk})/(3.1 \text{ lb/ft}^3) = 1.5 \text{ ft}^3\text{/wk}$$

(*d*) Estimate the total number of weekly collection trips

Number of trips

$$= [(1.0 + 1.5) \text{ ft}^3\text{/wk} \cdot \text{ home}] \times 1200 \text{ homes}$$

$$\times 0.60 \text{ (percent participation rate)}/(27 \text{ ft}^3\text{/yd}^3)/(7.3 \text{ yd}^3\text{/trip})$$

$$= 9.1 \text{ trips/wk, say 9 trips/wk}$$

TYPES OF COLLECTION SYSTEMS, EQUIPMENT AND PERSONNEL REQUIREMENTS

Collection systems have been classified according to their mode of operation into two categories: (1) hauled container systems (HCS) and (2) stationary container systems (SCS). In the former, the containers used for the storage of wastes are hauled to the disposal site, emptied, and returned to either their original location or some other location. In the latter, the containers used for the storage of wastes remain at the point of generation, except when they are moved to the curb or other location to be emptied.

Hauled Container Systems

Hauled container systems are ideally suited for the removal of wastes from sources where the rate of generation is high, because relatively large containers are used. The use of large containers reduces handling time as well as the unsightly accumulations and unsanitary conditions associated with the use of numerous smaller containers. There are three main types of hauled container systems: (1) hoist truck, مرفاع (fig. 8.3) (2) tilt-frame الميل-الإطارloading (fig.8.4) , and (3) trash-trailer (fig.8.5).

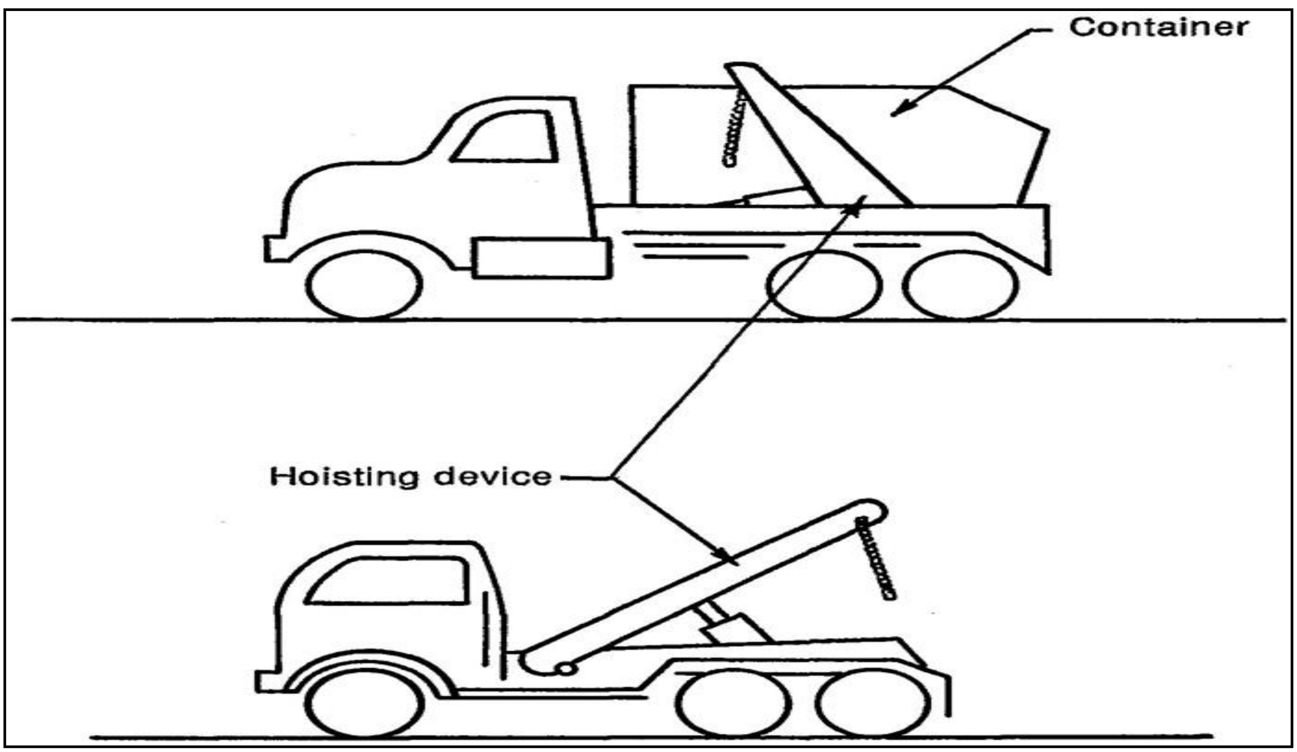


Fig. 8.3 **hoist-type equipment or hoist equipment, t**he hoist arms, chains, and frames used to elevate, support, transport, dump, and unload refuse containers.

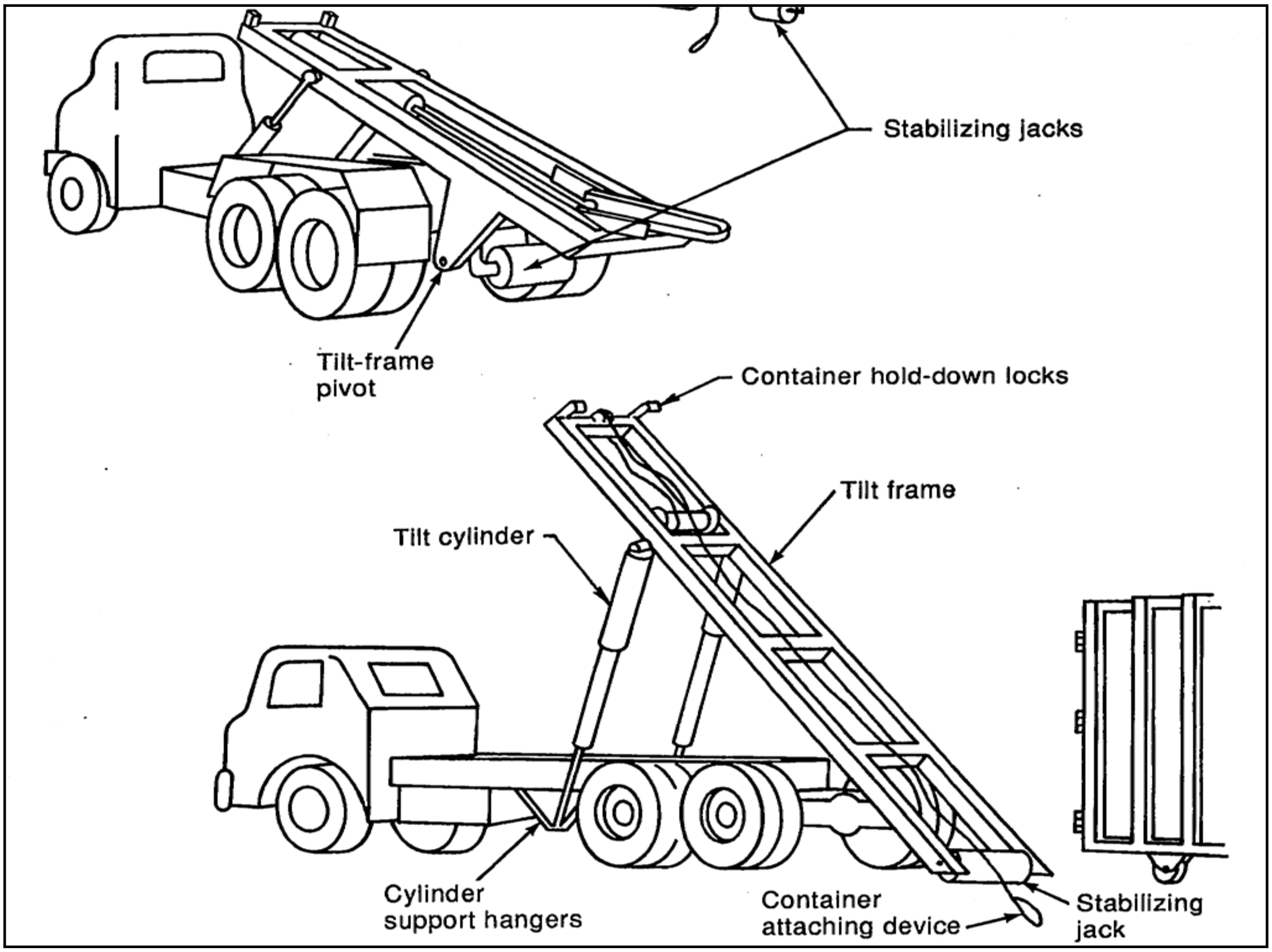


Fig. 8.4 Truck with tilt-frame loading mechanism used to haul and unload large-capacity containers.

Fig. 8.5 Trash-trailer.

Transfer Operations. Transfer operations, in which the wastes, containers, or collection vehicle bodies holding the wastes are transferred from a collection vehicle to a transfer or haul vehicle, are used primarily for economic considerations. **Transfer operations may prove economical** when (1) relatively small, manually loaded collection vehicles are used for the collection of residential wastes and long haul distances are involved, (2) extremely large quantities of wastes must be hauled over long distances, and (3) one transfer station can be used by a number of collection vehicles.

Definition of Terms

The operational tasks for the hauled container and stationary container systems are shown schematically in Figs. 8.5 and 8.6, respectively. The activities involved in the collection of solid wastes can be resolved into four unit operations: (1) pickup. (2) haul, (3) at-site, and (4) off-route .

Pickup. The definition of the term *pickup* depends on the type of collection system used.

1. For hauled container systems operated in the conventional mode (see Fig. 8-6 a), **pickup (Phcs)** refers to the time spent driving to the next container after an empty container has been deposited, the time spent picking up the loaded container, and the time required to redeposit the container after its contents have been emptied. For hauled container systems operated in the exchange-container mode (see Fig. 8-6/b), pickup includes the time required to pick up a loaded container and to redeposit the container at the next location after its contents have been emptied.

2. For stationary container systems (see Fig. 8-7), pickup (Pscs) refers to the time spent loading the collection vehicle, beginning with stopping the vehicle before loading the contents of the first container and ending when the contents of the last container to be emptied have been loaded.

Haul. The definition of the term haul (h) also depends on the type of collection system used.

1. For hauled container systems, haul represents the time required to reach the location where the contents of the container will be emptied (e.g., transfer station, disposal site), starting when a container whose contents are to be emptied

has been loaded on the truck and continuing through the time after leaving the unloading location until the truck arrives at the location where the empty container is to be rcdeposited. Haul time does not include any time spent at the location where the contents of the container are unloaded.

2. For stationary container systems, haul refers to the time required to reach the location where the contents of the collection vehicle will be emptied (e.g., transfer station, or disposal site), starting when the last container on the route has been emptied or the collection vehicle is filled and continuing through the time after leaving the unloading location until the truck arrives at the location of the first container to be emptied on the next collection route. Haul time does not include the time spent at the location where the contents of the collection vehicle are unloaded.

At-Site.

The unit operation at-site (s) refers to the time spent at the location where the contents of the container (hauled container system) or collection vehicle (stationery container system) are unloaded (e.g., transfer station, MRF, or disposal site) and includes the time spent waiting to unload as well as the time spent unloading the wastes from the container or collection vehicle.

Off-Route. The unit operation off-route (W) includes all time spent on activities that are nonproductive from the point of view of the overall collection operation.-Many of the activities associated with off-route times are sometimes necessary or inherent in the operation. Therefore, the time spent on off-route activities may be -subdivided into two categories: necessary and unnecessary. In practice, however, both necessary and unnecessary off-route times are considered together because -they must be distributed equally over the entire -operation.

1. ***Necessary off-route time includes*** (1) time spent checking in and out in the morning and at the end of the day, (2) time lost due to unavoidable congestion, and (3) time spent on equipment repairs, maintenance, and so on.

2. ***Unnecessary off-route time includes*** time spent for lunch in excess of the stated lunch period: and time spent on taking unauthorized coffee breaks, talking to friends.

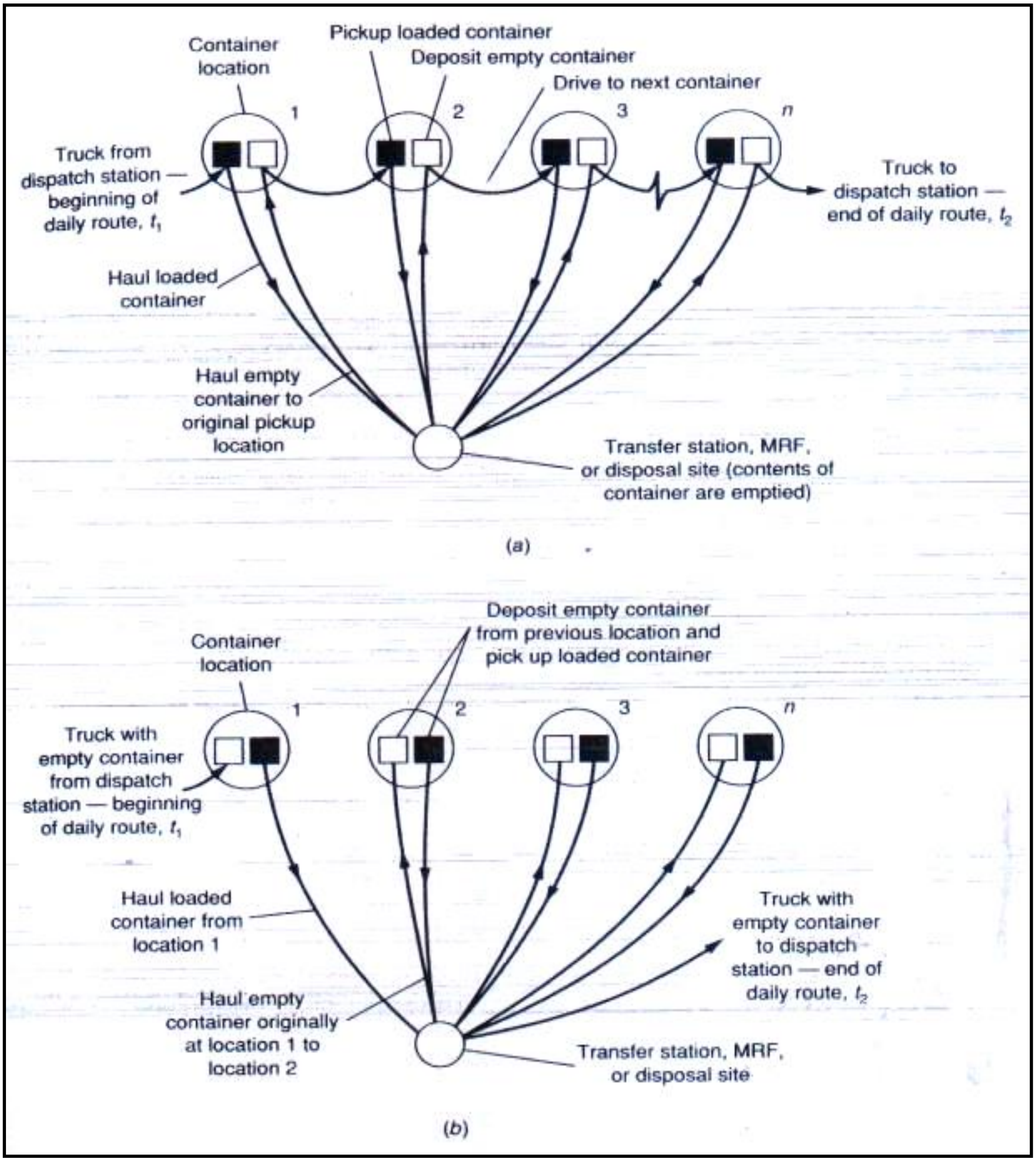


Fig. 8.6 Schematic of operational sequence for hauled container system: (a) conventional mode and (b) exchange container mode.

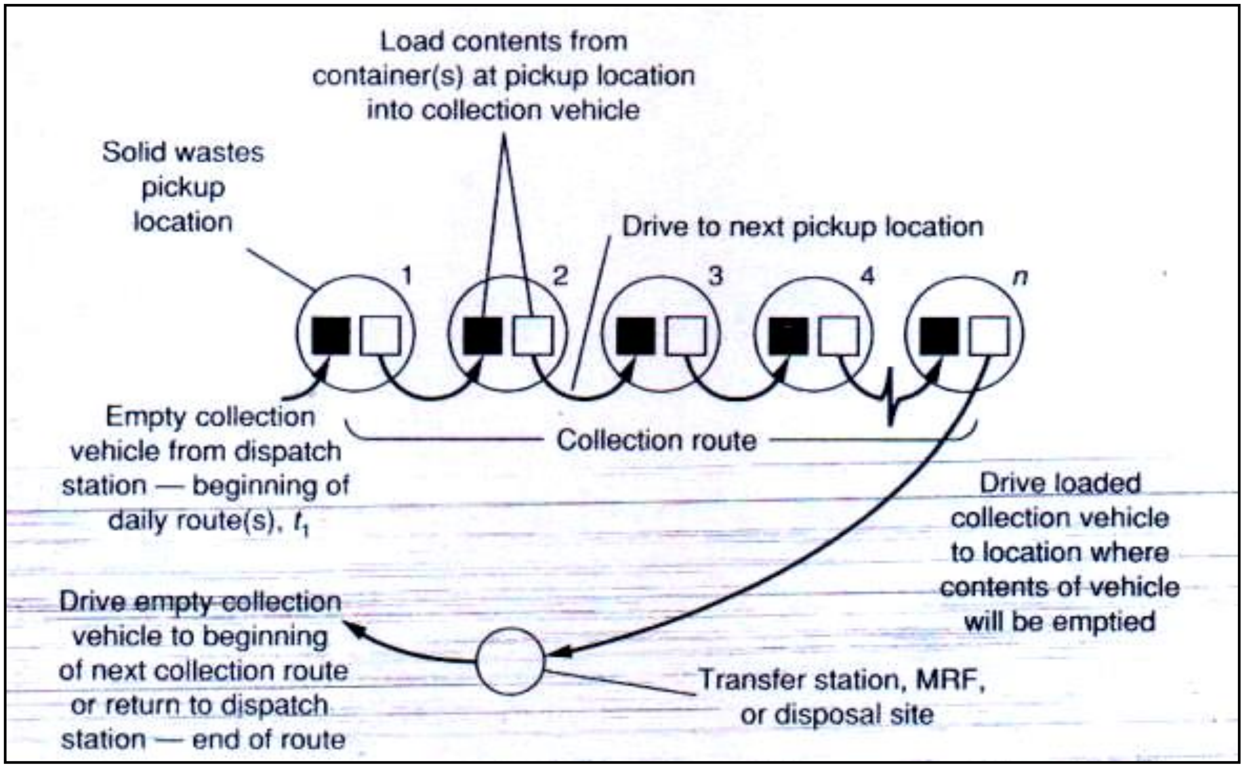


Fig.8.7 Schematic of operational sequence for stationary container system

Hauled Container Systems calculations

Haul time is given by the following equation

$$T_{hcs} = (P_{hcs}+s+h) \quad (8\text{-}1)$$

where Thcs = time per trip for hauled container system, h/trip

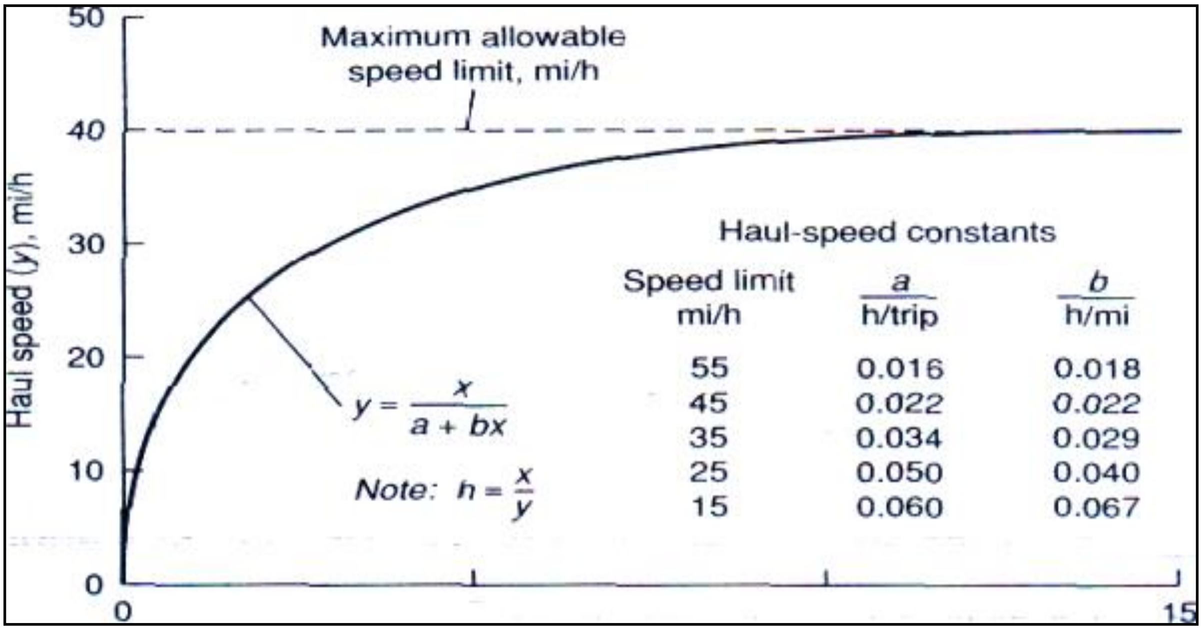
Phcs = pickup time per trip for hauled container system, h/trip

s= at-site time per trip, h/trip ,   h= haul time per trip, h/trip

For hauled container systems the pickup and at-site times are relatively constant, but the haul time depends on both haul speed and distance. From an analysis of a considerable amount of haul data for various types of collection vehicles (see Fig8.8), it has been found that the haul time h may be approximated by the following expression:

$$h = a + bx \quad (8\text{-}2)$$

where h = total haul time, h/trip , a = empirical haul-time constant, h/trip
b = empirical haul-time constant, h/mi , x = average round-trip haul distance, mi/trip



Round-trip haul distance (x). mi/trip

Fig. 8.8 Correlation between average haul speed and round-trip haul distance for waste collection vehicles.

The time per trip can be expressed as follows;

$$T_{hcs} = (P_{hcs} + s + a + bx) \qquad (8\text{-}3)$$

The pickup time per trip, Phcs, for the hauled container system is equal to

$$P_{hcs} = pc + uc + dbc \qquad (8\text{-}4)$$

where Phcs = pickup time per Trip, h/trip
pc = time required to pick up loaded container, h/trip
uc = time required to unload empty container, h/trip
dbc = time required to drive between container locations, h/trip

The number of trips that can be made per vehicle per day with a hauled container system, taking into account the off-route factor W, can be determined by using Eq. (8-5):

$$N_d = [H(1 - W) - (t_1 + t_2)]/T_{hcs}. \qquad (8\text{-}5)$$

where Nd = number of trips per day, trips/d
H = length of work day, h/d , W = off-route factor, expressed as a fraction
t1=time to drive from dispatch station (garage) to first container location to be serviced for the day, h
t2= time to drive from the last container location to be serviced for the day to the dispatch station (garage), h
Thcs= pickup time per trip, h/trip

The off-route factor in Eq- (8-5) varies from 0.10 to 0.40; a factor of 0.15 is representative for most operations.

Example 8-2 Determination of haul-speed constants.

The following average speeds were obtained for various round-trip distances to a disposal site. Find the haul-speed constants a and b and the round-trip haul time for a site that is located 11.0 mi away.

Round-trip distance (x), mi/trip	Average haul speed (y), mi/h	Total time ($h = x/y$), h
2	17	0.12
5	28	0.18
8	32	0.25
12	36	0.33
16	40	0.40
20	42	0.48
25	45	0.56

Solution

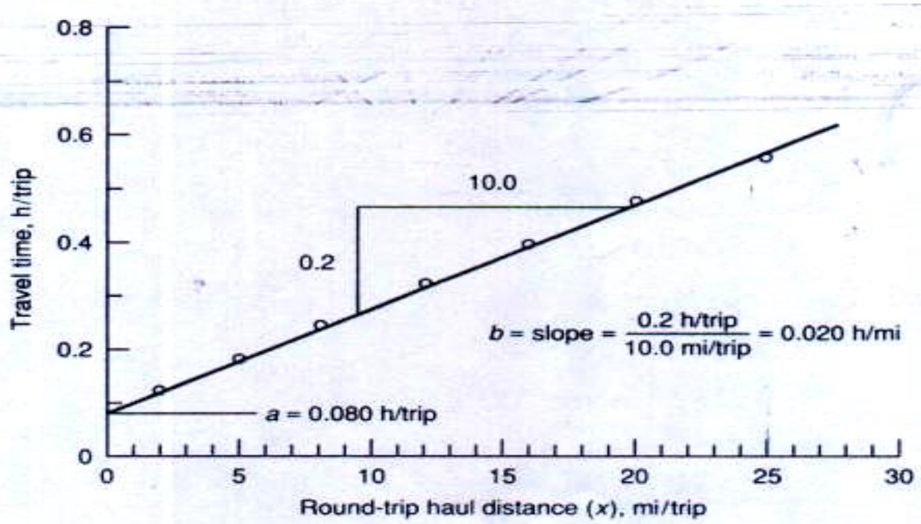
1. Linearize the haul-speed equation given in Fig. 8-16. The basis haul-speed equation (a rectangular hyperbola) is

$$y = \frac{x}{a + bx}$$

The linearized form of this equation is

$$\frac{x}{y} = h = a + bx$$

2. Plot x/y, which is the total haul travel time versus the round-trip distance as shown below.



3. Determine the haul-time constants a and b. When $x = 0$, a = intercept value = 0.080 h/trip, b = slope of line = (0.2 h/trip)/(10 mi/trip) = 0.020 h/mi (0.012 h/km).

Find the round-trip haul time for a site that is located 11.0 mi away.

Round-trip distance = 2(11.0 mi/trip) = 22 mi/trip & Round-trip haul time

$h = a + bx$

$= 0.080$ h/trip + (0.020 h/mi)(22 mi/trip) =0.52h/trip

Example 8-3 Analysis of a hauled container system. Solid waste from a new industrial park is to be collected in large containers (drop boxes), some of which will be used in conjunction with stationary compactors. Based on traffic studies at similar parks, it is estimated that the average time to drive from the garage to the first container location (t_1) and from the last container location (t_2) to the garage each day will be 15 and 20 min, respectively. If the average time required to drive between containers is 6 min and the one-way distance to the disposal site is 15.5 mi (speed limit: 55 mi/h), determine the number of containers that can be emptied per day, based on an 8-h workday. Assume the off-route factor, W, is equal to 0.15.

Solution

1. Determine the pickup time per trip using Eq. (8-4).

$$P_{hcs} = pc + uc + dbc$$

Use pc + uc = 0.4 h/trip (see Table 8-5)

$$dbc = 0.1 \text{ h/trip (given)}$$

$$P_{hcs} = (0.4 + 0.1) \text{ h/trip}$$

$$= (0.4 + 0.1) \text{ h/trip}$$

$$= 0.5 \text{ h/trip}$$

2. Determine the time per trip using Eq. (8-3).

$$T_{hcs} = (P_{hcs} + s + a + bx)$$

$$P_{hcs} = 0.5 \text{ h/trip (from Step 1)}$$

$$s = 0.133 \text{ h/trip (see Table 8-5)}$$

$$a = 0.016 \text{ h/trip (see Fig. 8-16)}$$

$$b = 0.018 \text{ h/trip (see Fig. 8-16)}$$

$$T_{hcs} = [0.5 + 0.133 + 0.016 + 0.018(31)] \text{ h/trip}$$

$$= 1.21 \text{ h/trip}$$

Vehicle	Pick-up loaded container and deposit empty container h/trip (pc+ ac)	Empty contents of loaded container h/container	At site time s h/trip
Hauled-container system	**0.4**		**0.133**
Stationary		**0.05**	**0.10**

Speed limit km/h	Speed limit mi/h	a h/trip	b h/km	b h/mi
88	**55**	**0.016**	**0.011**	**0.018**
72	**45**	**0.022**	**0.014**	**0.022**
56	**35**	**0.034**	**0.018**	**0.029**
40	**25**	**0.050**	**0.025**	**0.040**

3. Determine the number of trips that can be made per day using Eq. (8-5).

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

Use $H = 8$ h (given)

$W = 0.15$ (assumed)

$t_1 = 0.25$ h (given)

$t_2 = 0.33$ h (given)

$T_{hcs} = 1.21$ h/trip

$$N_d = [8(1 - 0.15) - (0.25 + 0.33)]/(1.21 \text{ h/trip})$$
$$= (6.8 - 0.58)/(1.21 \text{ h/trip})$$
$$= 5.14 \text{ trips/d}$$

Use $N_d = 5.0$ trips/d

4. Determine the actual length of the workday.

$$5 \text{ trips/d} = [H(1 - 0.15) - 0.58]/(1.21 \text{ h/trip})$$
$$H = 7.80 \text{ h (essentially 8 h)}$$

COLLECTION ROUTES

Once equipment and labor requirements have been determined, collection routes, must be laid out so that both the collectors and equipment are used effectively. In general, the layout of collection routes involves a series of trials. There is no universal set of rules that can be applied to all situations. Thus, collection vehicle routing remains today a heuristic (common sense) process. Some heuristic ارشادي guidelines that should be taken into consideration when lying out routes are as follows:

1. Existing policies and regulations related to such items as the point of collection —and frequency of collection must be identified.
2. Existing system characteristics such as crew size and vehicle types must be coordinated.
3. Wherever possible, routes should be laid out so that they begin and end near arterial streets, using topographical and physical barriers as route boundaries.
4. In hilly area, routes should start at the top of the grade and proceed downhill as the vehicle becomes loaded.
5. Routes should be laid out so that the last container to be collected on the route is located nearest to the disposal site.
6. Wastes generated at traffic-congested locations should be collected as early in the day as possible.
7. Sources at which extremely large quantities of wastes are generated should be serviced during the first part of the day.
8. Scattered pickup points (where small quantities of solid waste are generated) that receive the same collection frequency should, if possible, be serviced during one trip or on the same day.

Chapter 10

Disposal of Solid Wastes and Residual Matter

ULTIMATE DISPOSAL

Disposal on or in the earth s mantle is, at present, the only viable method for long-term handling. Landfilling is the method of disposal used most commonly for municipal wastes; land farming and deep well injection have been used for industrial wastes. There are only two alternatives available for the long-term handling of solid wastes and residual matter: disposal on or in the earth's mantle, and disposal at the bottom of the ocean. Although disposal in the atmosphere has been suggested as a third alternative, it is not a viable method because material discharged into the atmosphere is ultimately deposited either on the earth or in the sea by a variety of natural phenomena, the most important of which is rainfall.

Q. **Although disposal of solid waste in the atmosphere has been suggested as a third alternative, it is not a viable method**.

Ocean dumping of municipal solid wastes was commonly used at the turn of the century and continued until 1933 when it was prohibited.

Sanitary landfill means an operation in which, the wastes to be disposed of are compacted and covered with a layer of soil at the end of each day s operation. When the disposal site has reached its ultimate capacity, a final layer of 2 ft or more of cover material is applied.

Or, **Sanitary landfill** is an engineered facility for the disposal of municipal solid waste MSW designed and operated to minimize public health and environmental impacts. Landfilling includes monitoring of the incoming waste stream, placement, and compaction of waste and installation of landfill environmental monitoring and control facilities.

Landfill management incorporates the planning, design, operation, closure, and post closure control of landfills.

Chapter 10 Disposal of Solid Wastes and Residual Matter

A Cell is the term used to describe the volume of material placed in a landfill during one operating period, usually 1 day. A cell includes the solid waste deposited and the daily cover material.

A lift is a complete layer of cells over the active area of a landfill for the placement of surface water drainage channels, and for the location of landfill gas recovery piping.

ADVANTAGES AND DISADVANTAGES OF SANITARY LANDFILL

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

Chapter 10 Disposal of Solid Wastes and Residual Matter

Important Aspects in the Implementation of Sanitary Landfills

1. Site selection
2. Landfilling methods and operations
3. Occurrence of gases and leachate in landfills.
4. Movement and control of landfill gases and leachate.

Site Selection

Factors that must be considered in evaluating potential landfill sites are: (1) available land area (2) location restriction, (3) Site excess, (4) Haul distance (5) Soil conditions and topography, (6) climatological conditions, (7) surface-water hydrology, (8) geologic and hydro geologic conditions, (9) local environmental conditions, and (10) potential ultimate uses for the completed site.

(1) Available land area

In selecting potential land disposal sites, it is important to ensure that sufficient land area is available. Although there are no fixed rules concerning the area required, it is desirable to have sufficient area, including an adequate buffer zone to operate for at least 10 years at a given site. For shorter periods, the disposal operation becomes considerably more expensive.

Q. Landfill areas should be designed for at least 10 years.

For preliminary planning purposes, the amount of land area required can be estimated as illustrate in Example 10-1.

Example/ 10-1: Estimate the required landfill area for a community with a population of 31000. Assume that the following conditions apply

1. Solid waste generation is 1.5 kg/ capita/d
2. Compacted density of solid waste in the landfill 500 kg/M^3
3. Average depth of compacted solid waste 3.5 M
4. The land should be working for at least 10 years

Solution:

$$\frac{31000 \text{ capita x } 1.5 \text{ kg/capita/ d}}{500\frac{kg}{M3}\, x\ 3.5M} = 26.571 \text{ m}^2\text{/d}$$

26. 571 m2 /d x 365 d/1 year x 10 years = 96 985.7 17 m^2

96 985. 717 x 0.25= 24246.428 m^2

96 985.717 + 24 246.428 = 121 232.1455 m^2

Or 96 985.717 x 1.25= 121 232.1455 m^2/ 10 000 m^2/hectar = 12.1232 hectar

Note The actual site requirements will be greater than the value computed, because additional land is required for site preparation, access roads, utility access. etc. Typically, this allowance varies from 20 to 40 percent.

Q. The actual site requirements in landfill designed area will be greater than the value computed.

2. Location Restrictions

Location restrictions refer to where landfills can be located. Restrictions now apply with respect to siting landfills near airports, in floodplains, in wetlands, in areas with known faults, in seismic impact zones, and in unstable areas. All current restrictions must be reviewed carefully during the preliminary siting process to avoid expending time and money evaluating a site that will not conform with the regulatory requirements.

The following criteria are suggested in siting a new landfill site.

1. Lake or Pond: No landfill should be constructed within 200 metres of any lake, pond or lagoon. This is to avoid the contamination of water through runoff wastewater or the water body itself.
2. River: No landfill should be constructed within 100 M of a river or stream.
3. Flood Plain: No landfill should be constructed within a 100-Year flood plain. However, if a properly designed protection embankment is constructed around the landfill, the landfill could be build in flood plains.

4. Buffer Zones: A landfill site should be at least 500 M away from the declared area.
5. Wetlands: No landfill should be constructed within wetlands.
6. Ground Water Table: A landfill should not be constructed in areas where the water table is less than 2 M below ground surface.
7. Airports: No landfill should be constructed within the limits prescribed by the Civil Aviation Act regulation.لائحة قانون الطيران المدني

(3) site excess

As the number of operating landfills continues to decrease, new landfills that are being sited are increasing in size. Because land areas of suitable size are often not near existing developed roadways and cities, construction of access roadways and the use of long haul equipment has become a fact of life and an important part of landfill siting. Rail lines often pass nearby remote sites that are suitable for use as landfills; thus, there is renewed interest in the use of rail haul for transporting wastes to these remote sites.

(4) Haul distance,

Although minimum haul distances are desirable, but it is not the only factor that must be considered.

Other factors should be considered in sire selection. These include collection route, local traffic patterns, and" characteristics of the routes' to and from the disposal site, and access conditions.

(5) Soil conditions and topography

Because it is necessary to provide cover material for each day's landfill and a film layer of cover after the filling is completed, data must be obtained on the amount and characteristics of soils in the area of landfilling.

Q. **The soil material that is used as a daily and final cover is responsible for the solid waste decomposition.**

Q. **Data must be obtained on the amount and characteristics of soils in the area of landfilling**

(6) Climatological conditions,

Where freezing is severe, landfill cover material must be available in stockpiles, because excavation is impractical. Wind and wind patterns must be considered carefully in landfilling site selection. To avoid blowing or flying paper, windbreaks must be established. The specific form of windbreak depends on local conditions. Ideally, prevailing winds should blow toward the filling operation.

Q. **Where freezing is severe, landfill cover material must be available in stockpiles**.

Q. **Wind and wind patterns must be considered carefully in landfilling site selection.**

Q. windbreaks must be established in landfills

Q. Prevailing winds should blow toward the filling operation.

(7) surface-water hydrology

The local surface-water hydrology of the area is important in establishing the existing natural drainage and runoff characteristics. Other conditions of flooding must also be identified.

(8) Geologic and hydro geologic conditions

Geologic and Hydro geologic conditions are perhaps the most important factors in establishing the environmental suitability of the area for a landfill site. Data are required to assess the pollution potential of the proposed site and to establish what must be done to the site to ensure that the movement of leachate and gases will not impair the quality of ground water or other subsurface or bedrock aquifers.

Q. Data are required to assess the pollution potential of the proposed site.

(9) Local environment conditions

While it was possible to build and operate landfill sites in close proximately to both residential and industrial developments, they must be operated carefully if they are to be environmentally acceptable with respect to noise, odor, dust, vector control, hazards to health and property values. To minimize the impact of landfilling operations, landfills should be located in remote areas where adequate buffer zones surrounding the landfill can be maintained.

Q. It is possible to build and operate landfill sites in close proximately to both residential and industrial developments and yet environmentally acceptable

Q. Landfills should be located in remote areas

(9) Potential ultimate uses for the completed site.

One of the advantages of a landfill is that, once it is completed, a sizable area of land becomes available for other purposes. Because the ultimate use affects the design and operation of the landfill, this issue must be resolved before the layout and design of the landfill are started. For example, if the completed landfill is to be used as a park or golf course, a staged planting program should be initiated and continued as portions of land filing.

Q. Potential ultimate uses for the completed site must be resolved before the layout and design of the landfill are started

(2)**Landfilling methods and operations**

To use the available area at a landfill site effectively, a plan of operation for the placement of solid wastes must be prepared. Various operational methods have been developed, primarily based on field experience. The methods used to fill dry areas are substantially different from those used to fill wet areas.

The principal methods used for dry landfilling areas may be classified as

1. Area **2**. Trench **3**. Depression

The Area Method: The filling operation is usually started by building an earthen levee (سـد ارضـي) against which wastes are placed in thin layers and compacted. Each layer is compacted as the filling progress until the thickness of the compacted wastes reaches a height varying from 6 to 10 feet (1.8 to 3) m at that time or at the end of each day operation a 6 to 12 in (15 to 30) cm layer of cover material is placed over the completed fill. The cover material must be hauled in by truck from adjacent land. Successive lifts are placed on top of one another until the final grade in the ultimate plan is reached. A final layer of cover material is used when the fill reaches the final design height.

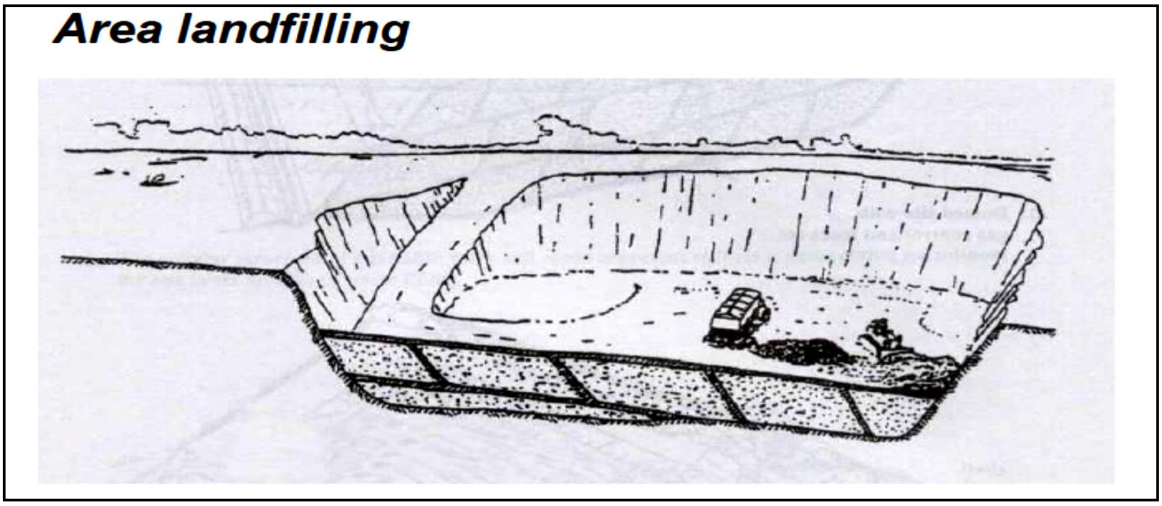


Fig. 10.1 Area landfill

The Trench (خندق) Method *:* is ideally suited to areas where an adequate depth of cover material is available and where water table is well below the surface. A portion of the trench is dug with a bulldozer and the dirt is stock piled to form an embankment behind the first trench. Wastes are then placed at the trench spread into thin layers and compacted. The operation continues until the desired level is reached. Cover material is obtained by excavating an adjacent trench.

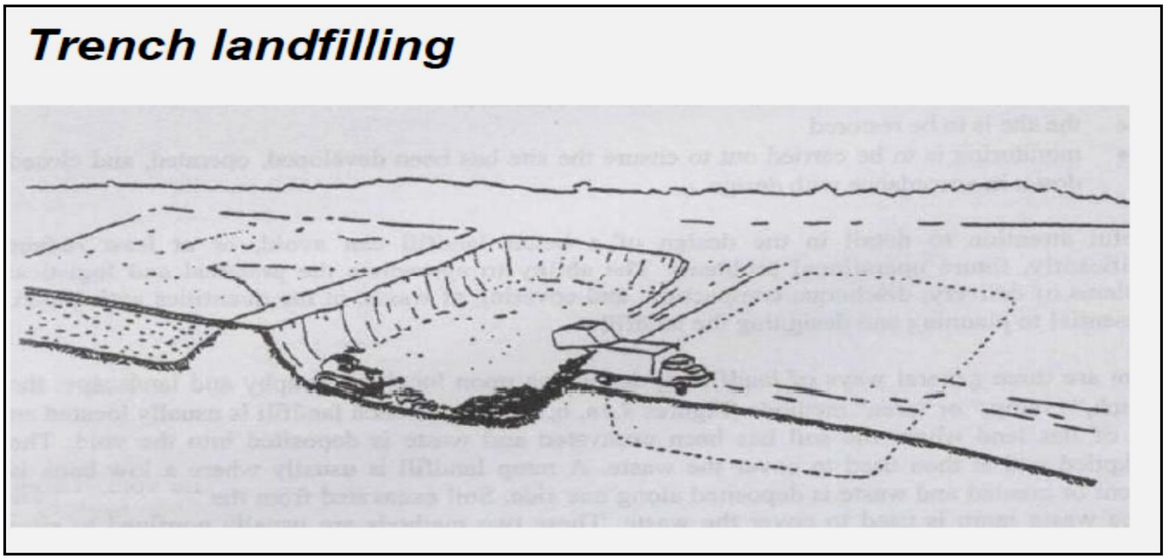


Fig. 10.2 Trench method

***Depression Method**:* Where artificial depression occurs, it is often possible to use them effectively for Landfilling operations. The techniques to place and compact solid wastes in depression landfills vary with the characteristics of the site. The availability of adequate material to cover the individual lifts and to provide a final cover over the entire landfill is very important. Borrow pits and abandoned quarries may not contain sufficient soil for intermediate cover, so that it may have to be imported.

Fig. 10.3 Depression landfilling

Landfilling with milled solid waste: Milling of solid waste before placing in a landfill may have advantages and disadvantages

Advantages

1. Daily cover of earth is not necessary (where available cover material is in short supply)
2. The lower layer can be left exposed until the next layer is placed
3. Odors and blowing litter have not been a problem (rats can not survive on milled solid wastes containing up to 20% food wastes

Disadvantages

1. There are additional costs associated with the milling and related ancillary facilities.
2. Even if this method of operation is adopted, some type of landfill will be required for the wastes that cannot be milled effectively.
3. By leaving the landfill uncovered, the movement leachate maybe accelerated and thus may become a limiting factor.

Dumping in wet areas

Swamps and marshes, tidal areas and ponds, pits, or quarries are typical wet areas that have been used as landfill-sites. Because of problem associated with contamination of local groundwater, the development of odors and structural stability, the design of landfills in wet areas requires special attention. Yet direct filling of wet areas is no longer considered acceptable, because of concern over the possibility of groundwater contamination by both leachate and gases from landfills and the development of odors.

Q. The design of landfills in wet areas requires special attention.

Q. Direct filling of wet areas is no longer considered acceptable,

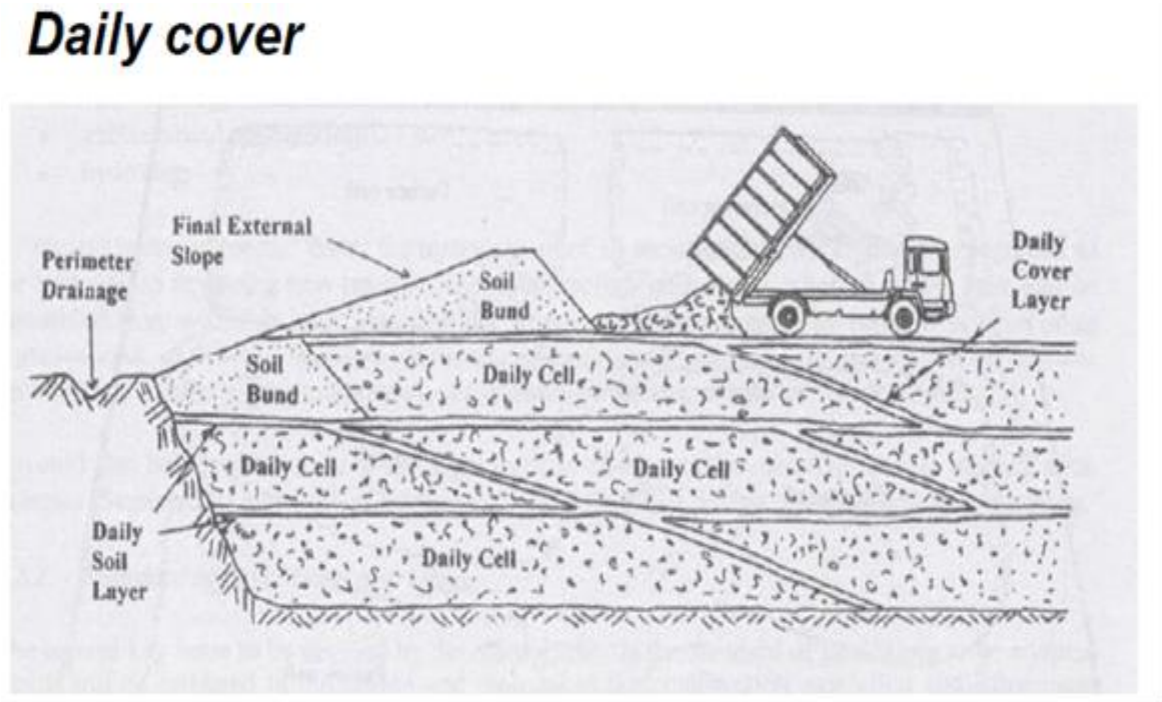


Fig. 10.4 Daily cover

Reactions occurrence of gases and Leachate in Landfills

The following biological, physical, and chemical events occur when solid wastes are placed in a sanitary landfill:

1. Biological decay of organic materials either aerobically or anaerobically, with evaluation of gases and liquids
2. Chemical oxidation of waste materials
3. Escape of gases from the fill
4. Movement of liquids caused by differential heads
5. Dissolving and leaching of organic and inorganic by water and leachate moving through the fill
6. Uneven settlement caused by consolidation (تماسك) of material into voids.

Decomposition in landfills

The organic biodegradable components in solid wastes begin to undergo bacterial decomposition as soon as they are placed in a landfill. Initially, bacterial decomposition occurs under aerobic conditions because a certain amount of air is trapped within the landfill. However, the oxygen in the trapped air is soon exhausted, and the long-term decomposition occurs under anaerobic conditions. The principal source of both the aerobic and anaerobic organisms responsible for the decomposition is the soil material that is used as a daily and final cover.

Gases in Landfills

Landfill gas is composed of a mixture of hundreds of different gases. By volume, landfill gas typically contains 45% to 60% methane and 40% to 60% carbon dioxide. Landfill gas also includes small amounts of nitrogen, oxygen, ammonia, sulfides, hydrogen, carbon monoxide, and non-methane organic compounds (NMOCs) such as trichloroethylene, benzene, and vinyl chloride. Table 2-1 lists "typical" landfill gases, their percent by volume, and their characteristics.

How is landfill gas produced?

Three processes—bacterial decomposition, volatilization, and chemical reactions—form landfill gas.

- **Bacterial decomposition.** Most landfill gas is produced by bacterial decomposition, which occurs when organic waste is broken down by bacteria naturally present in the waste and in the soil used to cover the landfill. Organic wastes include food, garden waste, street sweepings, textiles, and wood and paper products. Bacteria decompose organic waste in four phases, and the composition of the gas changes during each phase.

  Volatilization. Landfill gases can be created when certain wastes, particularly organic compounds, change from a liquid or a solid into a vapor. This process is known as volatilization. NMOCs in landfill gas may be the result of volatilization of certain chemicals disposed of in the landfill.
- **Chemical reactions.** Landfill gas, including NMOCs, can be created by the reactions of certain chemicals present in waste. For example, if chlorine

bleach and ammonia come in contact with each other within the landfill, a harmful gas is produced.

Mixing **bleach** and **ammonia** can be deadly. When combined, these two common household cleaners release toxic chloramine **gas**. Exposure to chloramine **gas** can **cause** irritation to your eyes, nose, throat, and lungs. In high concentrations, it can lead to coma and death.

Table 2-1: Typical Landfill Gas Components

Component	Percent by Volume	Characteristics
methane	45–60	Methane is a naturally occurring gas. It is colorless andodorless. Landfills .e the single largest source of U.S. man-made methane emissions
carbon dioxide	40–60	Carbon dioxide is naturally found at small concentrations in the atmosphere (0.03%). It is colorless, odorless, and slightly acidic.
nitrogen	2–5	Nitrogen comprises approximately 79% of the atmosphere. It is odorless, tasteless, and colorless.
oxygen	0.1–1	Oxygen comprises approximately 21% of the atmosphere. It is odorless, tasteless, and colorless.
ammonia	0.1–1	Ammonia is a colorless gas with a pungent odor.
NMOCs (non-methane organic compounds)	0.01–0.6	NMOCs are organic compounds (i.e., compounds that contain carbon). (Methane is an organic compound but is not considered an NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethyl-benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.
sulfides	0–1	Sulfides (e.g., hydrogen sulfide, dimethyl sulfide, mercaptans) are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulfides can cause unpleasant odors even at very low concentrations.
hydrogen	0–0.2	Hydrogen is an odorless, colorless gas.
carbon monoxide	0–0.2	Carbon monoxide is an odorless, colorless gas.

Source: Tchobanoglous, Theisen, and Vigil 1993; EPA 1995

The high initial percentage of carbon dioxide is the result of aerobic decomposition. Aerobic decomposition continues to occur until the oxygen in the air initially present in the compacted wastes is depleted. Thereafter, decomposition will proceed anaerobically. After about 18 months, the composition of the gas remains reasonably constant.

Leachate in Landfills

Leachate may be defined as liquid that has percolated (ينفذ الى) through solid waste and has extracted dissolved or suspended materials from waste. The liquid portion of the leachate is composed of the liquid produced from the decomposition of the wastes and liquid that has entered the landfill from external sources, such as surface drainage, rainfall, ground water and water from underground springs and the liquids already exist the waste.

Leachate Movement

Under normal conditions, leachate is found in the bottom of a landfill and will percolate to the underlying strata.

A **landfill liner** is intended to be a low permeable barrier, which is laid down under engineered landfill sites. Until it deteriorates تدهور , the liner retards migration of leachate, and its toxic constituents, into underlying aquifers or nearby rivers, causing spoilation of the local water. The bottom liner prevents waste from coming in contact with the outside soil, particularly the groundwater.

In MSW landfills, the liner is usually some type of durable, puncture-resistant synthetic plastic (polyethylene, high-density polyethylene, polyvinylchloride). The use of clay has been the favored method in reducing or eliminating the percolation of leachate. Membrane liners have also been used but they are expensive and require care so that they will not be damaged during the filling operations. The use of appropriate surface slop (1 to 2 percent) and adequate drainage surface infiltration can be used effectively as shown in figure 10.5

Fig. 10.5 Leachate collection

Settlement of Landfills

The settlement of landfills depends on the initial compaction, characterization of the wastes, degree of decomposition, and effects of consolidation when the leachate and gases are formed in the landfill. The height of the completed fill will also influence the initial compaction and degree of consolidation. It has been found in various studies that about 90% of ultimate settlement occurs within the first 5 yr. The placement of concentrated loads on completed landfills is not recommended.

Gas Movement

Under ideal condition, the gas generated from a landfill should be either vented to the atmosphere or in larger landfills collected for the production of energy. Over 90% of the gas volume produced from the decomposition of solid wastes consists of methane and carbon dioxide. When methane concentration present in the air between 5-15 percent, methane will be explosive.

Because only limited amounts of oxygen are present in a landfill when methane concentration reaches this critical level, there is little danger that the landfill will explode.

However, if vented into the atmosphere in an uncontrolled manner methane can accumulate (because its specific gravity is less than that of the air) below buildings or in other enclosed spaces close to a sanitary landfill and may cause explosions.

Both methane and CO_2 have been found in concentrations up to 40% at lateral (جـانبي) distances of up to 120 m from the edges of the landfills. With proper venting methane should not pose a problem.

Because CO_2 is about 1.5 times as dense as air and 2.8 times as dense as methane, it tends to move toward the bottom of the landfill through the under laying formation until it reaches the ground water. As a result, the concentration of CO_2 at the bottom of the landfill may be high for years.

Because carbon dioxide is readily soluble in water, it usually lowers the pH, which in turn can increase the hardness and mineral content of the ground water through the solubilization of calcium and magnesium carbonates.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

Control of Gas Movement

- Control techniques
  - Passive extraction systems
    - Driven by natural pressure gradient within the landfill
  - Active system
    - Design a vacuum to direct the flow and control gas flow.

Gas Collection System (GCS)

- Extraction wells
- Vacuum Pumps
- Flare

Fig. 10.6 Gas piping

EXA. 10.2

Find the amount of land required in a sanitary landfill to dispose of urban waste of a city of 40 000 in population, knowing that: amount of waste generation = 2.5 kg/capita/d, density of landfill waste=500 kg/m^3 and waste is filled into a depth of about 3 m.

Solution

2.5 kg/capita/d X 365 d X 40000 capita= 36500000 kg total amount of waste

36500000 kg/500 kg/m^3 = 73000 m^3

73000 m^3 /3m =24333.333 m^2 /2500 m^2 /donme =9.73 donme

EXA.3.10

Find the amount of land required in a sanitary landfill to dispose of urban waste knowing that:
City population = 176119
Waste generation rate = 0.875 kg/capita/d,
density of landfill waste= 560 kg/m^3
waste is filled into a depth of about 8.5 m.
The landfill site is to be used for 13 years and 25% should be added as area necessary for construction facilities

Solution

0.875 kg/capita/d X 176119 capita =154104 kg/d X 365 day/year =56247960 kg /560 kg/$m^{3.}$ = 100442.78 m^3 /yr

100442.78 m^3 /yr X 13 yr =1305756.1 m^3 / 8.5 m =
153618.36 m^2 /10 000 = 15.3618 Hectares

15.3618 X .25 =3.840 Hectares +15.3618 = 19.202 Hectares

Example 4.10 Determination of density of compacted solid wastes without and with waste diversion. Determine the specific weight in a well-compacted landfill for solid wastes with the characteristics given in the table below. Also, determine the impact of a resource recovery program on landfill area requirements in which 50 percent of the paper and 80 percent of the glass and tin cans are recovered

Solution: use 1000 1kg basis

1. Set up a computation table with separate columns for (1) the weight of the individual solid waste components, (2) the volume of the wastes as discarded, (3) the compaction factors for well-compacted solid wastes, and (4) the compacted volume in the landfill. The required table, based on a total weight of 1000 kg, is given below.

2. Compute the compacted specific weight of the solid wastes.

1000 kg / 29.445 m^3 = 34 kg/m^3

3 . Determine the compacted specific weight in the landfill in which 50% of the paper and 80 percent of the glass and tin cans are recovered

Component	% Wt	Wt kg (1)	Density kg/m3	Vol. m3(2)	Compacti--on factor(3)	Vol. m3 (4)
Food waste	**9**	**90**	**18.0**	**5.00**	**0.33**	**1.64**
Paper	**34**	**340**	**5.1**	**66.60**	**0.15**	**9.9**
Cardboard	**6**	**60**	**3.1**	**19.30**	**0.18**	**3.47**
Plastics	**7**	**70**	**4**	**17.50**	**0.10**	**1.75**
Textile	**2**	**20**	**4**	**5.00**	**0.15**	**0.75**
Rubber	**0.5**	**5**	**8**	**0.62**	**0.3**	**0.18**
Leather	**0.5**	**5**	**10**	**0.50**	**0.3**	**0.15**
Garden trimming	**18.5**	**185**	**6.5**	**28.40**	**0.2**	**5.68**
Wood	**2**	**20**	**15.0**	**1.33**	**0.3**	**0.39**
Glass	**8**	**80**	**12.1**	**6.61**	**0.4**	**2.64**
Tin cans	**6**	**60**	**5.5**	**10.90**	**0.15**	**1.63**
Non ferrous materials	**0.5**	**5**	**10**	**0.50**	**0.15**	**0.075**
ferrous materials	**3**	**30**	**20**	**1.50**	**0.3**	**0.45**
Dirt, ashes,brick	**3**	**30**	**30**	**1.00**	**0.75**	**0.75**
Total	**100**	**1000**		**153.4**		**29.445**

Determine the weight of waste after resource recovery
Weight remaining = 1000-(340 x 0.5+ 80 x 0.8 + 60 x 0.80) = 718 kg
Determine the volume and compacted specific weight of waste after resource recovery.
Volume remaining = 29.445 m3 - (9.9 m3 x 0.5 +2.64 m3 x 0.80+ 1.63 m3 x 0.8)= 29.445 m3 - (4.95 +2.11+1.304) m3 =
Compacted specific weight = 718 kg x / m3= ------kg/m3

Example 10.5 Find the amount of land required in a sanitary landfill to dispose of urban waste of city of 40000 in population, knowing that
Amount of waste generation = 2.0 kg/capita/d
Refuse is filled into a depth of about 3 m.
The landfill site is to be used for 10 years
25% should be added as area necessary for construction facilities
Based on 1000 kg sample of waste

component	Typical composition%	Density kg/m3
Food waste	15	18.0
Paper	40	5.1
Cardboard	4	3.1
Plastics	3	4
Textile	2	4
Rubber	0.5	8
Leather	0.5	10
Garden trimming	12	6.5
Wood	2	15.0
Glass	8	12.1
Tin cans	6	5.5
Non-ferrous metals	1	10.0
Ferrous metals	2	20
Dirt, ashes, brick, etc.	4	30

Example 10.6

Find the amount of land required in a sanitary landfill to dispose of urban waste of city of 120 000 in population, knowing that
Amount of waste generation = 2.2 kg/capita/d
Density of solid waste as discarded= 200 Kg/m3
Compaction factor in landfill = 0.3
Refuse is filled into a depth of about 4 m.
The landfill site is to be used for 5 years including 25% for other services (access roads, storages…etc

10.7 A). Determine the impact of a resource recovery program on landfill area requirement, in which 40% of the paper, 60% of the glass, and 80% of tin cans are recovered. Knowing that the previous land fill was designed for a city of 40 000 in population,
Amount of waste generation = 2.5 kg/capita/d
refuse is filled into a depth of about 3 m.
The landfill site is to be used for 13 years

component	Typical composition%	Density kg/m3
Food waste	15	18.0
Paper	40	5.1
Cardboard	4	3.1
Plastics	3	4
Textile	2	4
Rubber	0.5	8
Leather	0.5	10
Garden trimming	12	6.5
Wood	2	15.0
Glass	8	12.1
Tin cans	6	5.5
Non-ferrous metals	1	10.0
Ferrous metals	2	20
Dirt, ashes, brick, etc.	4	30

B) If the site above were to be constructed in three lifts what is the new area

10.8 Find the amount of land required in a sanitary landfill to dispose of urban waste of city of 120 000 in population, knowing that: Amount of waste generation = 2.2 kg/capita/d
Waste is filled into a depth of about 4 m.
The landfill site is to be used for 10 years including 25% for other services (access roads, storages etc.)

Based on 100 kg sample of waste

Component	Percent by mass	Typical density kg/m^3	Compaction factor
Food waste	15	290	0.33
Paper	45	85	0.15
Cardboard	10	50	0.18
Plastics	10	65	0.10
Garden trimming	10	105	0.2
Wood	5	240	0.3
Tin cans	5	90	0.15
Total	100		

Transfer Station

Transfer Station served by rail Transport (Jatznick).

Rail Transport.