Chapter 6 Solid waste management

6.1. Introduction

Any material that is thrown away or discarded as useless and unwanted is considered *solid waste*. Solid wastes other than hazardous and radioactive materials are often called *municipal solid waste* (MSW) and consist of all the solid and semisolid material discarded by a community.

There is no question that *improper* disposal of solid waste can cause serious environmental or ecological damage. Air pollution can result from inadequate solid waste incineration. And soil contamination, as well as surface water and groundwater pollution, can be caused by the disposal of solid waste in improperly built landfill. These kinds of pollution can lead to a variety of diseases in humans, thereby threatening public health.

Improper solid waste disposal can also harbor rodents and insects, which may act as vectors of infectious diseases such as typhoid, plague, and dysentery. In addition, waste disposed in open dumps causes a variety of nuisances, including odors, fire hazards, and windblown debris.

Problems related to solid waste go beyond merely their proper disposal. In addition to many technical and environmental difficulties, administrative, economic, and political problems must be solved. The effort to address all these problems is usually referred to as the practice of *solid waste management*. In this context, management encompasses the planning, design, financing, construction, and operation of facilities for collection, transporting, processing, recycling, and final disposal of the residual solid waste material (see Figure 6.1).

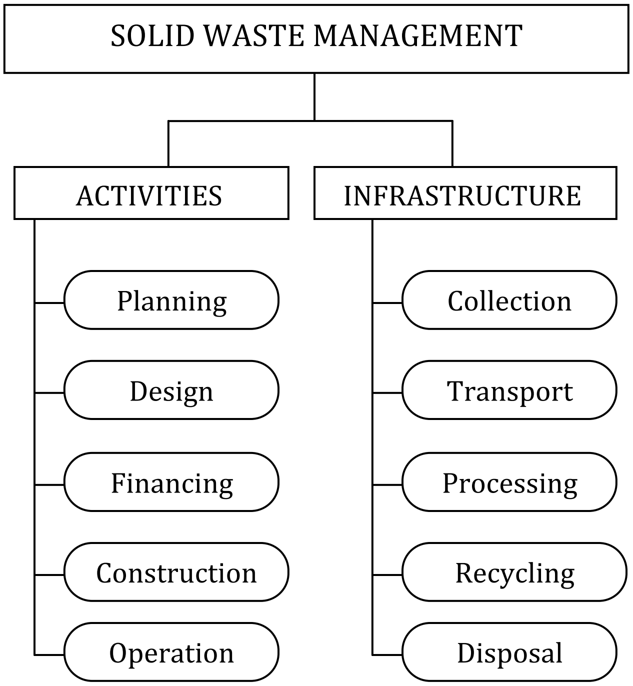

Figure 6.1 An overview of solid waste management

6.2 Solid waste Quantities and characteristics

The quantities of MSW generated in a community may be estimated by one of three techniques: input analysis, secondary data analysis, and output analysis. Input analysis estimates MSW based on use of a number of products. But obtaining waste characteristics' data from such information is often difficult and inaccurate. When possible, solid waste generation should be measured by output analysis—that is, by weighing the refuse deposited at the disposal site. Daily weight of refuse varies with the day of the week and the week of the year. Weather condition also affect refuse weight, since moisture content can vary widely depending on how much rainwater enters the waste. Secondary data may be used to estimate solid waste production by some empirical relationship.

Types of Solid Waste

Sources of MSW include private homes, commercial establishments, and institutions, as well as industrial facilities. However, MSW does not include industrial process wastes, construction and demolition debris, sewage sludge, mining wastes, or agricultural wastes.

MSW comprises two types of materials: refuse and trash. Refuse includes garbage and rubbish. Garbage contains putrescible or highly decomposable food waste, such as vegetable and meat scraps. Rubbish contains mostly dry, nonputrescible material, such as glass, rubber, metal cans, and slowly decomposable or combustible material such as paper, textile, or wood objects. Actually, less than 10% of refuse is garbage; most of it is rubbish. Trash includes bulky waste materials that generally require special handling and is therefore not collected on a routine basis. An old couch, mattress, television, or refrigerator and even a large uprooted tree stump are examples of trash items. The classification of different types of nonhazardous municipal solid wastes is illustrated in Figure 6.2.

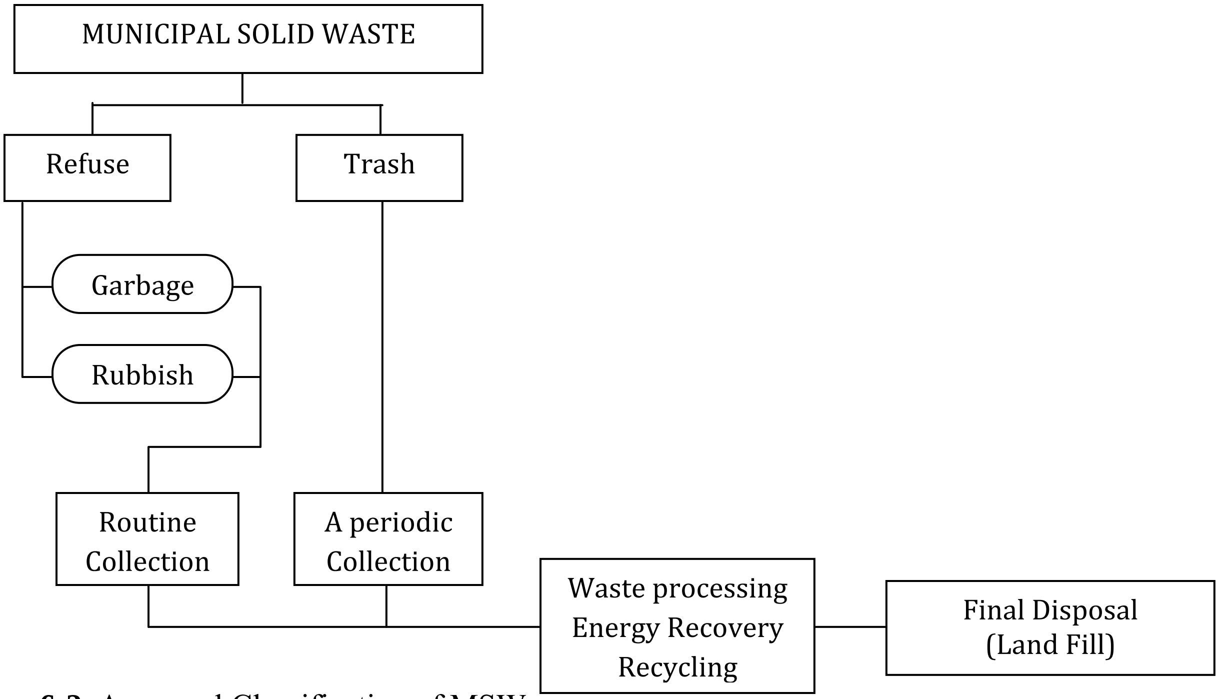

Figure 6-2. A general Classification of MSW

Characteristics of Municipal Solid Waste

Refuse management depends on both the characteristics of the site and the characteristics of the MSW itself: gross composition, moisture content, particle size, chemical composition, and density.

Gross composition may be the most important characteristic affecting MSW disposal, or the recovery of materials and energy from refuse. Refuse composition is expressed either "as generated" or "as disposed," since moisture transfer takes place during the disposal process and thereby changes the weights of the various fractions of refuse.

Residential MSW contains more newspaper; yard waste; disposable diapers; and textiles, rubber, and leather. Nonresidential MSW contains more corrugated cardboard, high-grade paper, wood, other plastics, and other metals. A typical per capital solid waste generated for residential ranges from 1 to 2 kg/day, commercial from 0.5 to 1.5 kg/day, and specially wastes of 0.8 kg/day

The moisture content of MSW may vary between 15 and 30%, and is usually about 20%. Moisture is measured by drying a sample at 77°C (170°F) for 24 h, weighing, and calculating as:

$$M = \frac{w - d}{w} \times 100$$

where

M = moisture content, percent,
w = initial, wet weight of sample, and
d = final, *dry* weight of sample.

The moisture content of municipal solid waste varies from 15% to 40 %, depending on the composition of the wastes and the weather (temperature, humidity, precipitation). The moisture content of individual components is shown in Table 6-1.

Table 6-1. Typical components of solid waste

Components	Weight % of the total	Moisture (% by weight)	
		Range	Typical
Paper and cardboard	41	4-10	7
Food wastes	17	50-80	70
Yard wastes	10	30-80	60
Metal	7	2-6	3
Glass	5	1-4	2
Plastic	5	1-4	2
Ashes, dirt	8	6-12	8
Other rubbish	7	5-30	20

The density of MSW varies depending upon location, season, humidity, and so on. Table 6-3 shows some typical MSW densities. The density of mixed MSW is influenced by the degree of compaction, moisture content, and component composition.

The chemical composition of typical refuse is shown in Table 6-2**.**

Table 6-2. Proximate and Ultimate Chemical Analysis of MSW

	Proximate analysis (%)	Ultimate analysis (%)
Moisture	15-35	
Volatile matter	50-60	
Fixed carbon	3-9	
Noncombustibles	15-25	
Higher heat value	3000-6000 Btu/lb	
Carbon		15-30
Hydrogen		2-5
Oxygen		12-24
Nitrogen		0.2-1.0
sulfur		0.02-0.1

As generated density of solid waste ranges from 90 to 180 kg/m^3. Very typical is 130 kg/m^3. Compacted density is in the order of 300 kg/m^3 for poor compaction and 500-600 kg/m^3 for moderate compaction and 600-900 kg/m^3 for heavy compaction. The ratio of compacted as discarded density is called compaction ratio. Typical range is 2 – 4.

Table 6-3. Refuse Densities

	kg/m^3
Loose refuse	60-120
Dumped refuse from a collection vehicle	200-240
Refuse in a collection vehicle	300-400
Refuse in a landfill	300-540
Baled refuse	470-700

Example 6-1. The following are the particular of solid waste generated. Determine the total moisture content on wet and dry basis.

Components	% M/M	% water	For 100 kg moisture
Paper	40	6	2.4
Cardboard	33	6	1.98
Glass	5	0.5	0.025
Others	22	60	13.200
Total	100		17.605

Solution:

Assuming we have 100 kg solid waste the last column shows the moisture content in weight.

Thus, % moisture on wet basis = 17.605 %

And % moisture on dry basis $= \frac{17.605}{100-17.605} \times 100 = 21.37$ %

6.3. Collection

In most part of the world, solid waste is collected by trucks. These are usually packers, trucks that carry hydraulic rams to compact the refuse to reduce its volume and can thus carry larger loads. Collections are facilitated by the use of containers that are emptied into the truck with a mechanical or hydraulic mechanism. Commercial and industrial containers, “dumpsters,” either are emptied into the truck or are carried by truck to the disposal site.

Garbage grinders reduce the amount of garbage in refuse. If all homes had garbage grinders, the frequency of collection could be decreased. Garbage grinders are so ubiquitous that in most communities garbage collection is needed only once a week. Garbage grinders put an extra load on the wastewater treatment plant, but sewage is relatively dilute and ground garbage can be accommodated easily both in sewers and in treatment plants.

Pneumatic pipes have been installed in some small communities, mostly in Sweden and Japan. The refuse is ground at the residence and sucked through underground lines.

Kitchen garbage compactors can reduce collection and MSW disposal costs and thus reduce local taxes, but only if every household has one. A compactor costs about as much as other large kitchen appliances, but uses special high-strength bags, so that the operating cost is also a consideration. At present they are beyond the means of many households. Stationary compactors for commercial establishments and apartment houses, however, have already had significant influence on collection practices.

Transfer stations are part of many urban refuse collection systems. A typical system, as shown in Fig. 6-3, includes several stations, located at various points in a city, to which collection trucks bring the refuse. The drive to each transfer station is relatively short, so that workers spend more time collecting and less time traveling. At the transfer station, bulldozers pack the refuse into large containers that are trucked to the landfill or other disposal facility. Alternatively, the refuse may also be baled before disposal.

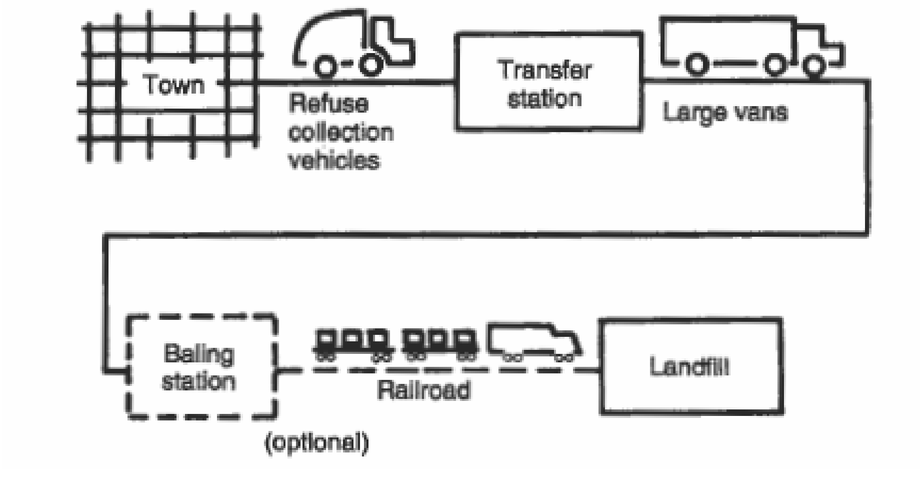

Figure 6-3. Transfer station method of solid waste collection.

Cans on wheels, often provided by the community, are widely used for transfer of refuse from the household to the collection truck. The cans are pushed to the curb by the householder and emptied into the truck by a hydraulic lift. This system saves money and has reduced occupational injuries dramatically. Garbage collection workers suffer higher lost-time accident rates than other municipal or industrial workers.

Route optimization may result in significant cost saving as well as increased effectiveness. Software is available for selecting least-cost routes and collection frequencies. An optimal route is one in which collection takes place without waste travel.

Although sophisticated routing programs are available, it is often just as easy to develop a route by common sense or *heuristic* means. Some heuristic rules for routing trucks are:

- Routes should not overlap.
- Routes should be compact and not fragmented.
- The starting point of the route should be as close to the truck garage as possible.
- Heavily traveled streets should be avoided during rush hours.
- One-way streets that cannot be traversed in one line should be looped from the
- Dead-end streets should be collected when the truck is on the right side of the
- Collection should be downhill on hills, so the truck can coast.
- Long straight paths should be routed before looping clockwise.
- For certain block patterns, standard paths, as shown in Fig. 6-4, should be used.
- U-turns should be avoided.

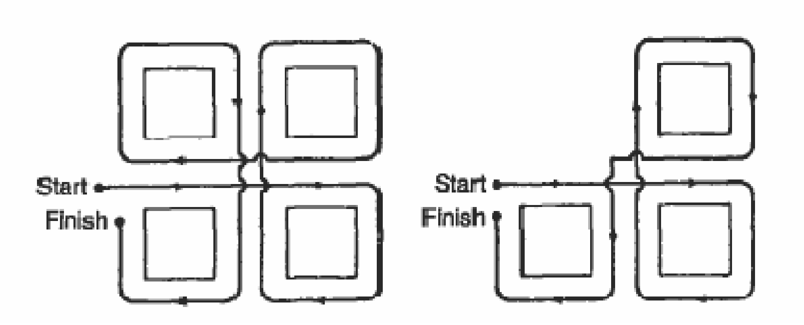

Figure 6-4. Heuristic routing examples.

Example 6-2. A residential are of about 40 ha contains 400 single-family residences and 8 ha with multiple-family units housing 400 people. With two curb-side pickups per week, how many trips on each collection day would one packer truck need to make to serve this area if its capacity is 5 tones? Assume four residents per single-family unit.

Solution

Population served: Single family at 4 residents per unit = 1600 people

Multiple family at 50 residents per hectare = 400 people

Total = 2000 people

Waste quantity: Assume the residential per capital waste generation is 1.1 kg/day. Then the amount each collection day is

$$2000 \times 1.1 \times \frac{7}{2} = 7700\ kg = 7.7\ tones$$

Thus on a normal collection day, when half the weekly waste is collected, one packer truck with a 5 tone capacity would have to make two trips to serve the area in question.

6.4. Solid Waste Processing

Municipal solid waste may be treated or processed prior to final disposal. Solid waste processing provides several advantages. First, it can serve to reduce the total volume and weight if waste material that requires final disposal. In addition, waste processing changes its form and improves its handling characteristics. Processing can also serve to recover natural resources and energy in the water material for reuse, or recycling. The most widely used municipal water treatment processes include *incineration, shredding, pulverizing, baling,* and *composting*.

Sanitary Landfills

The term *sanitary landfill* was first used for the method of disposal employed in the burial of waste ammunition and other material after World War II, and the concept of burying refuse was used by several Midwestern communities. The sanitary landfill differs markedly from open dumps: open dumps are simply places to deposit wastes, but sanitary landfills are engineered operations, designed and operated according to acceptable standards.

Sanitary land filling is the compaction of refuse in a lined pit and covering of the compacted refuse with an earthen cover. Typically, refuse is unloaded, compacted with bulldozers, and covered with compacted soil. The landfill is built up in units called cells (Fig. 6.5). The daily cover is between 6 and 12 in. thick depending on soil composition, and a final cover at least 2ft thick is used to close the landfill. A landfill continues to subside after closure, so that permanent structures cannot be built on-site without special foundations. Closed landfills have potential uses as golf courses, playgrounds, tennis courts, winter recreation, or parks and greenbelts. The sanitary landfilling operation involves numerous stages, including siting, design, operation, and closing.

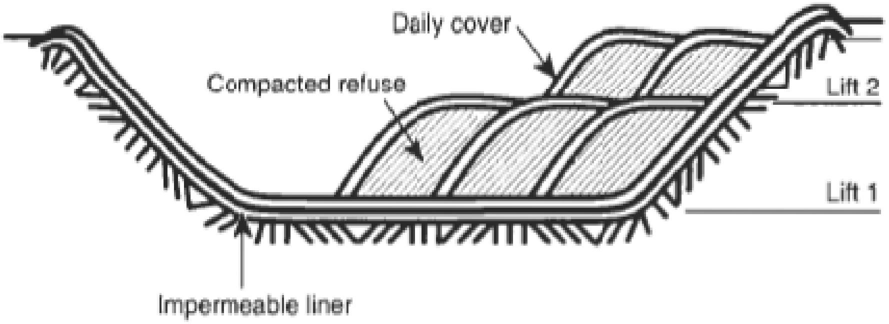

Figure 6-5. Arrangement of cells in an area-method landfill

Siting Landfills

Siting of landfills is rapidly becoming the most difficult stage of the process since few people wish to have landfills in their neighborhoods. In addition to public acceptability, considerations include:

- *Drainage:* Rapid runoff will lessen mosquito problems, but proximity to streams or well supplies may result in water pollution.

- *Wind:* It is preferable that the landfill be downwind from any nearby community.
- *Distance from collection.*
- *Size:* A small site with limited capacity is generally not acceptable since finding a new site entails considerable difficulty.
- *Rainfall patterns:* The production of leachate from the landfill is influenced by the weather.
- *Soil type:* Can the soil be excavated and used as cover?
- *Depth of the water table:* The bottom of the landfill must be substantially above the highest expected groundwater elevation.
- *Treatment of leachate:* The landfill must be proximate to wastewater treatment facilities.
- *Proximity to airports:* All landfills attract birds to some extent, and are therefore not compatible with airport siting.
- *Ultimate use:* Can the area be used for private or public use after the landfilling operation is complete?

Some other restrictions include, for example, a landfill should be more than:

30 m from streams,
160 m from drinking water wells,
65 m from houses, schools, and parks, and
3,000 m from airport runways.

Design of Landfills

Modern landfills are designed facilities, much like water or wastewater treatment plants. The landfill design must include methods for the recovery and treatment of the leachate produced by the decomposing refuse, and the venting or use of the landfill gas. Full plans for landfill operation must be approved by the appropriate state governmental agencies before construction can begin.

Since landfills are generally in pits, the soil characteristics are of importance. Areas with high groundwater would not be acceptable, as would high bedrock formations. The management of rainwater during landfilling operations as well as when the landfill is closed must be part of the design.

Operation

Two basic methods are commonly used in operating MSW landfills. They are termed the *area method* and the *trench method*.

In the area method, the solid waste is deposited on the surface, compacted, then covered with a layer of compacted soil at the end of the working day. Use of the area method is seldom restricted by topography; flat or rolling, canyons, and other types of depression are all acceptable. The cover material may come from on or off site.

The trench method is used on level or gently sloping land where the water table is low. In this method a trench is excavated; the solid waste is placed in and compacted; and the soil that was taken from the trench is then laid on the water and compacted. The depth depends on the location of the groundwater and/or the character of the soil. trenches should be at least twice as wide as the compacting equipment so that the treads or wheels can compact all the material on the working area.

Landfill gases. The principal gaseous products emitted from a landfill (methane and carbon dioxide) are the result of microbial decomposition. During the early life of the landfill, he predominant gas is carbon dioxide. As the landfill matures, the gas is composed almost equally of carbon dioxide and methane. Because the methane is explosive, its movement must be controlled.

Leachate

The liquid produced during decomposition, as well as water that seeps through the groundcover and works its way out of the refuse, is known as leachate. This liquid, though relatively small in volume, contains pollutants in high concentration. Should leachate escape the landfill, its effects on the environment may be severe.

The amount of leachate produced by a landfill is difficult to predict. The only available method is water balance: the water entering a landfill must equal the water flowing out of the landfill, or leachate. The total water entering the top soil layer is:

$$C = P\,(1\text{-}R)\text{-}S\text{-}E$$

where

C = total percolation into the top soil layer (mm),
P = precipitation (mm),
R = runoff coefficient,
S = storage (mm), and
E = evapotranspiration (mm).

Volume of gas produced. The following reaction is assumed to represent the overall methane fermentation process:

$$C_aH_bO_cN_d + nH_2O \longrightarrow x\,CH_4 + y\,CO_2 + w\,NH_3 = z\,C_5H_7O_2N + \text{energy}$$

where $C_aH_bO_cN_d$ is the empirical formula for the biodegradable organic matter and $C_5H_7O_2N$ is the empirical chemical formula of bacterial cells.

The maximum theoretically landfill gas yield (neglecting bacterial cell conversion) may be estimated as:

$$C_aH_bO_cN_d + (1/4)(4a - b - 2c + 3d)H_2O \longrightarrow (1/8)(4a + b - 2c + 3d)\,CH_4$$
$$+ (1/8)(4a - b + 2c + 3d)\,CO_2 + dNH_3$$

For the purpose of analysis, the MSW may be divided into two classes: rapidly biodegradable and slowly biodegradable. Food waste, newspaper, office paper, cardboard, leaves, and leafy trimmings fall into the first category. Textiles, rubber, leather, tree branches, and wood fall into the second category.

For typical MSW an empirical chemical formula is developed for these categories:

- Rapidly decomposable = $C_{68}H_{111}O_{50}N$
- slowly decomposable = $C_{20}H_{29}O_9N$

6.5. Reuse, Recycling, and Resource Recovery

Reuse of materials involves either the voluntary continued use of a product for a purpose for which it may not have been originally intended, such as the reuse of coffee cans for holding nails, or the extended use of a product, such as retreading automobile tires.

Recycling is the collection of a product by the public and the return of this material to the industrial sector. This is very different from reuse, where the materials do not return for remanufacturing. Examples of recycling are the collection of newspapers and aluminum cans by individuals and their collection and eventual return to paper manufacturers or aluminum companies.

Recovery differs from recycling in that the waste is collected as mixed refuse, and then the materials are removed by various processing steps. For example, refuse can be processed by running it under a magnet that is supposed to remove the steel cans and other ferrous materials. This material is then sold back to the ferrous metals industry for remanufacturing. Recovery of materials is commonly conducted in a *materials recovery facility* **(**MRF**,** pronounced "murph").

Recovery

Most processes for separation of the various materials in refuse rely on a characteristic or property of the specific materials and this characteristic is used to separate the material from the rest of the mixed refuse.

The separation process can be facilitated by decreasing the particle size of refuse, thus increasing the number of particles and achieving a greater number of "clean" particles.

Shredding

Size reduction, or *shredding***,** is brute force breaking of particles of refuse by swinging hammers in an enclosure. *two* types of shredders are used in solid waste processing: the vertical and horizontal hammermills.

A semi-empirical equation often used to estimate the power requirements for shred**ders** was developed by Bond (Bond 1952). The specific energy Wrequired to reduce a unit weight of material 80% finer than some diameter ***LF*** to **a** product 80% finer than some diameter Lp, where both ***LF*** and ***Lp*** are in micrometers (pm), is expressed as

$$W = 10W_i\left[\frac{1}{\sqrt{L_P}} - \frac{1}{\sqrt{L_F}}\right]$$

where W_i is the Bond *work index,* a factor that is a function of the material processed for a given shredder and a function of shredder efficiency for a given material. W has the dimension of kilowatt hours/ton (kwh/ton) if Lp and L_F are in micrometers.

Example 6-3. Determine the power required for shredding the waste with the following particulate.

L_p = 2 cm, L_F = 30 cm and W_i = 400

Also determine power for processing 100 tones per day of waste.

Solution

Power requirement: $W = 10 \times 400\left[\frac{1}{\sqrt{0.02\times10^6}} - \frac{1}{\sqrt{0.3\times10^6}}\right]\ kWh/ton$

W = 20.9813 kWh/ton

For 100 tones power = 20.9813 kWh/ton x 100 ton/24 hr

= 87.42 kW

Screens

Screens separate material solely by size and do not identify the material by any other property. Consequently, screens are most often used in materials recovery as a classification step before a materials separation process.

The *trommel,* shown in Fig. 6-6, is the most widely used screen in materials recovery. The charge inside the trommel behaves in three different ways, depending on the speed of rotation. At slow speeds, the trommel material is *cascading:* not being lifted but simply rolling back. At higher speed, *cataracting* occurs, in which centrifugal force carries the material up to the side and then it falls back. At even higher speeds, *centrifuging* occurs, in which material adheres to the inside of the trammel. Obviously, the efficiency of a trommel is enhanced when the particles have the greatest opportunity to drop through the holes, and this occurs during cataracting. Trommel speed is often designed **as** some fraction of the critical speed, defined as that rotational speed at which the materials will just begin centrifuging, and calculated as

$$\mu_c = \sqrt{\frac{g}{4\pi^2 r}}$$

where

η_c = critical speed (rotation/s),
g = gravitational acceleration (cm/s^2), and
r = radius of drum (cm).

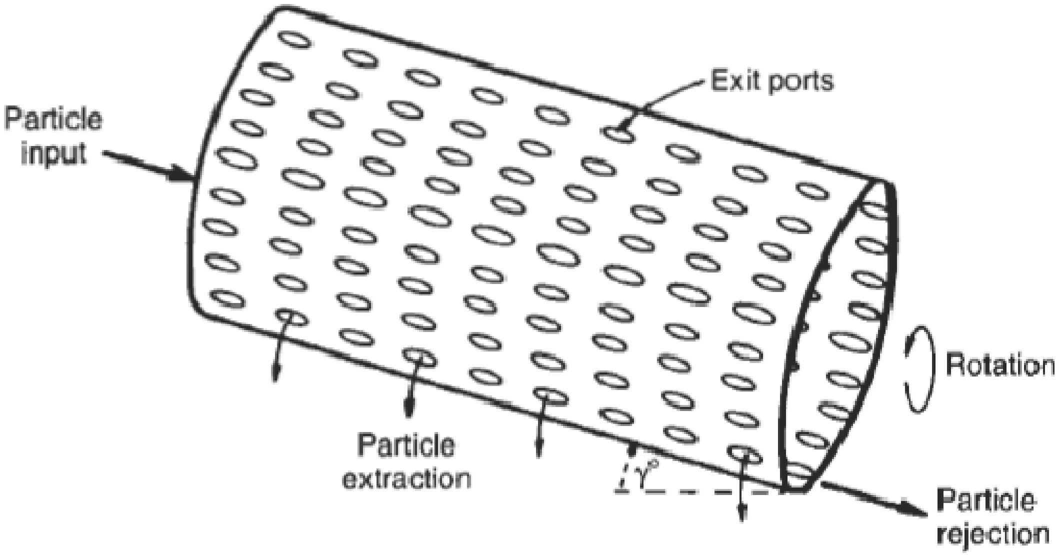

Figure 6-6. Trommel screen

EXAMPLE 6-4. Find the critical speed for **a** 3-m-diameter trommel:
Solution

$$\mu_c = \sqrt{\frac{980}{4\pi^2(150)}} = 0.407 \text{ rotations/s.}$$

Air Classifiers

Materials may be separated by their aerodynamic properties. In shredded MSW, most of the aerodynamically less dense materials are organic, and most of the denser materials are inorganic; thus air classification can produce a refuse-derived fuel (RDF) superior to unclassified shredded refuse.

Air classifiers principally use difference in terminal settling velocity as advantage for separation of particles. The fraction escaping with the air stream is the product or *overflow,* the fraction falling out the bottom is the reject or *underflow.*

Magnets

Ferrous material may be removed from refuse using magnets, which continually extract the ferrous material and reject the remainder.

Composting

Both aerobic and anaerobic decomposition can extract useful products biochemically from RDF. In the anaerobic system, refuse is mixed with sewage sludge and the mixture is digested. Operational problems have made this process impractical on a large scale, although single household units that combine human excreta with refuse have been used.

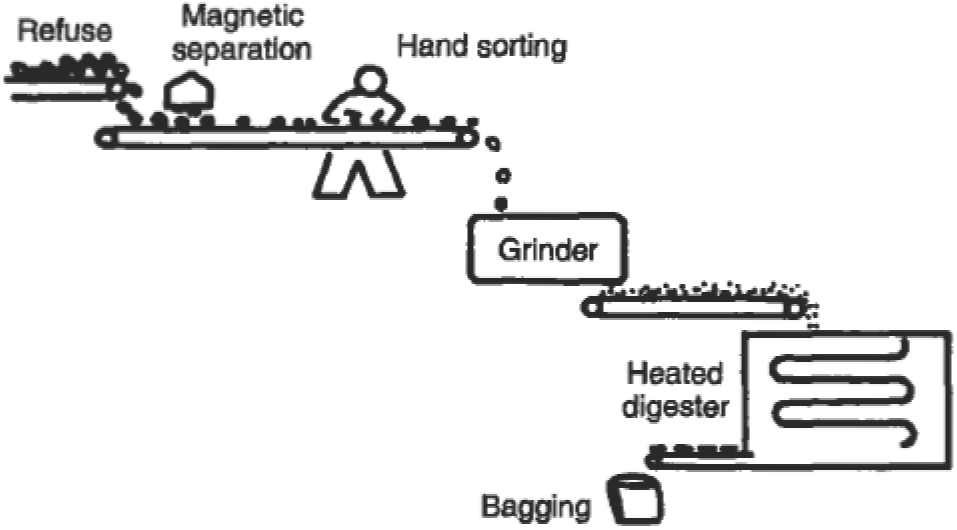

Figure 6.7 Mechanical composting operations.

Aerobic decomposition of refuse is better known as *composting* and results in the production of a useful soil conditioner that has moderate fertilizer value. The process is exothermic and at a household level has been used as a means of producing hot water for home heating. On a community scale, composting may be a mechanized operation, using an aerobic digester (Fig. 6-7) or a low-technology operation using long rows of shredded refuse known as *widrows*. Windrows are usually about 3 m wide at the base and 1.5 m high. Under these conditions, known as *static* pile *composting* (Fig. 6-8), sufficient moisture and oxygen are available to support aerobic life. The piles must be turned periodically to allow sufficient oxygen to penetrate all parts of the pile or, alternatively, air can be blown into the piles.

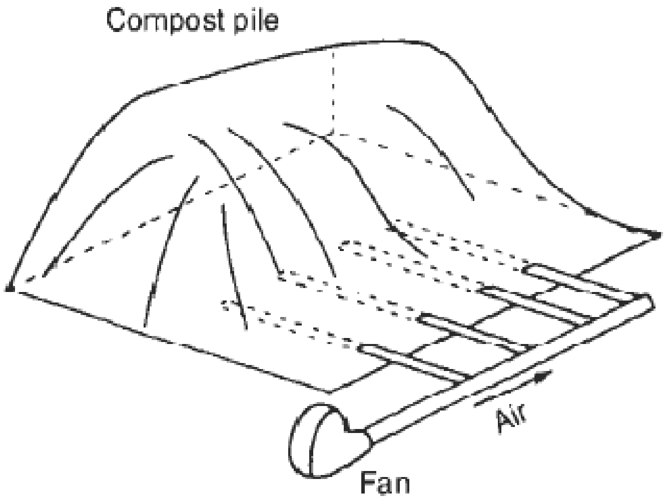

Figure 6-8 Static pile composting