Chapter 13

Solid Waste Disposal

Disposal of solid wastes is defined as placement of the waste so that it no longer impacts society or the environment. The wastes are either assimilated so that they can no longer be identified in the environment, as by incineration to ash, or they are hidden well enough so that they cannot be readily found. Solid waste may also be processed so that some of its components may be recovered, and used again for a beneficial purpose. Collection, disposal, and recovery are all part of the total solid waste management system, and this chapter is devoted to disposal.

DISPOSAL OF UNPROCESSED REFUSE IN SANITARY LANDFILLS

The only two realistic options for disposal are in the oceans and on land. Because the environmental damage done by ocean disposal is now understood, the United States prohibits such disposal by federal law, and many developed nations are following suit. This chapter is therefore devoted to a discussion of land disposal.

Until the mid-1970s, a solid waste disposal facilities was usually a *dump* in the United States and a *tip* (as in "tipping") in Great Britain. The operation of a dump was simple and inexpensive: trucks were simply directed to empty loads at the proper spot on the dump site. The piled-up volume was often reduced by setting the refuse on fire, thereby prolonging the life of the dump. Rodents, odor, insects, air pollution, and the dangers posed by open fires all became recognized as serious public health and aesthetic problems, and an alternative method of refuse disposal was sought. Larger communities frequently selected incineration as the alternative, but smaller towns could not afford the capital investment required and opted for land disposal.

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 (Fig. 13-1).

Sanitary landfilling 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. 13-2). The daily cover is between 6 and 12 in. thick depending on

Figure 13-1. The sanitary landfill.

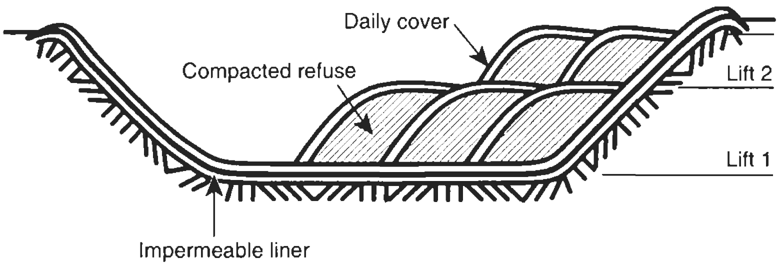

Figure 13-2. Arrangement of cells in an area-method landfill.

soil composition (Fig. 13-3), and a final cover at least 2 ft 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.

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.

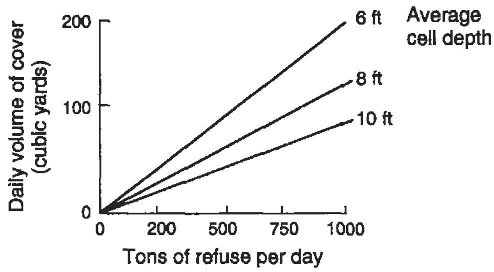

Figure 13-3. Daily volume of cover versus refuse disposal rate.

- *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?

Although daily cover helps to limit disease vectors, a working landfill still has a marked and widespread odor during the working day. The working face of the landfill must remain uncovered while refuse is added and compacted. Wind can pick material up from the working face, and the open refuse attracts feeding flocks of birds. These birds are both a nuisance and a hazard to low-flying aircraft using nearby airports. Odor from the working face and the truck traffic to and from the landfill make a sanitary landfill an undesirable neighbor to nearby communities.

Early sanitary landfills were often indistinguishable from dumps, thereby enhancing the "bad neighbor" image. In recent years, as more landfills have been operated properly, it has even been possible to enhance property values with a closed landfill site, since such a site must remain open space. Acceptable operation and eventual enhancement of the property are understandably difficult to explain to a community.

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 of Landfills

The landfill operation is actually a biological method of waste treatment. Municipal refuse deposited as a fill is anything but inert. In the absence of oxygen, anaerobic decomposition steadily degrades the organic material to more stable forms. This process is very slow and may still be going on as long as 25 years after the landfill closes.

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. Table 13-1 shows typical leachate composition. Should leachate escape the landfill, its effects on the environment may be severe. In a number of instances, leachate has polluted nearby wells to a degree that they ceased to be sources of potable water.

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

$$C = P(1 - R) - S - E, \tag{13.1}$$

where

C = total percolation into the top soil layer (mm),
P = precipitation (mm),

Table 13-1. Typical Sanitary Landfill Leachate Composition

Component	Typical value
BOD_5	20,000 mg/L
COD	30,000 mg/L
Ammonia nitrogen	500 mg/L
Chloride	2,000 mg/L
Total iron	500 mg/L
Zinc	50 mg/L
Lead	2 mg/L
Total polychlorinated biphenyl (PCB) residue	1.5 μg/L
pH	6.0

Table 13-2. Percolation in Three Landfills[a]

Location	Precipitation, P (mm)	Runoff coefficient, R	Evapotranspiration, E (mm)	Percolation, C (mm)
Cincinnati	1025	0.15	568	213
Orlando	1342	0.07	1172	70
Los Angeles	378	0.12	334	0

[a]D. G. Tenn, K. J. Haney, and T. V. Degeare, *Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites* (U.S. Environmental Protection Agency, OSWMP, SW-168, Washington, DC 1975).

R = runoff coefficient,
S = storage (mm), and
E = evapotranspiration (mm).

The percolation for three typical landfills is shown in Table 13–2.

Using these figures it is possible to predict when landfills produce leachate. Clearly, Los Angeles landfills may virtually never produce leachate. Leaching through a 7.5-m (25-ft) deep landfill in Orlando, FL, might take 15 years, while a 20-m (65-ft) deep landfill in Cincinnati can produce leachate after only 11 years. Leachate production depends on rainfall patterns as well as on total amount of precipitation. The figures given for Cincinnati and Orlando are typical of the "summer thunderstorm" climate that exists in most of the United States. The Pacific Northwest (west of the Pacific Coast Range) has a maritime climate, in which rainfall is spread more evenly through the year. Seattle landfills produce leachate at approximately twice the rate of Cincinnati landfills, although the annual rainfall amount is approximately the same.

Gas is a second by-product of a landfill. Since landfills are anaerobic biological reactors, they produce CH_4 and CO_2. Gas production occurs in four distinct stages, as illustrated in Fig. 13-4. The first stage is aerobic and may last from a few days to several months, during which time aerobic organisms are active and affect the decomposition. As the organisms use up the available oxygen, the landfill enters the second stage, at which anaerobic decomposition begins, but at which methane-forming organisms have not yet become productive. During the second stage, the acid formers cause a buildup of CO_2. The length of this stage varies with environmental conditions. The third stage is the anaerobic methane production stage, during which the percentage of CH_4 progressively increases, as does the landfill interior temperature to about 55°C (130°F). The final, steady-state condition occurs when the fractions of CO_2 and CH_4 are about equal, and microbial activity has stabilized. The amount of methane produced from a landfill may be estimated using the semi-empirical relationship (Chian 1977)

$$\begin{aligned} &CH_aO_bN_c + \left(\tfrac{1}{4}\right)(4 - a - 2b + 3c)H_2O \\ &\quad \rightarrow \tfrac{1}{8}[4 - a + 2b + 3c]CO_2 + (4 + a - 2b - 3c)CH_4. \end{aligned} \tag{13.2}$$

Equation (13.2) is useful only if the chemical composition of the waste is known.

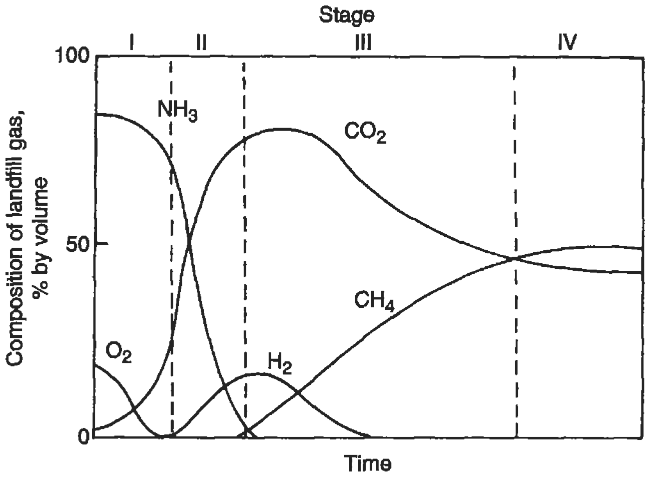

Figure 13-4. States in the decomposition of organic matter in landfills.

The rate of gas production from sanitary landfills may be controlled by varying the particle size of the refuse by shredding before placing the refuse in the landfill, and by changing the moisture content. Gas production may be minimized with the combination of low moisture, large particle size, and high density. Unwanted gas migration may be prevented by installing escape vents in the landfill. These vents, called "tiki torches," are kept lit and the gas is burned off as it is formed. Improper venting may lead to dangerous accumulation of methane. In 1986, a dozen homes near the Midway Landfill in Seattle were evacuated because potentially explosive quantities of methane had leaked through underground fissures into the basements. Venting of the accumulated gas, so that the occupants could return to their homes, took three weeks.

Since landfills produce considerable quantities of methane, landfill gas can be burned to produce electric power. Alternatively, the gas can be cleaned of CO_2 and other contaminants and used as pipeline gas. Such cleaning is both expensive and troublesome. The most reasonable use of landfill gas is to burn it as is in some industrial application like brickmaking.

Closure and Ultimate Use of Landfills

Municipal landfills must be closed according to state and federal regulations. Such closure includes the permanent control of leachate as well as gas, and the placement of an impermeable cap. The cost of closure is very high and must be incorporated in the tipping fee during the life of the landfill. This is one of the primary factors responsible for the dramatic increase in landfill tipping fees.

Figure 13-5. A motel built on a landfill that experienced differential settling.

Biological aspects of landfills as well as the structural properties of compacted refuse limit the ultimate uses of landfills. Landfills settle unevenly, and it is generally suggested that nothing at all be constructed on a landfill for at least two years after closure, and that no large permanent structures ever be built. With poor initial compaction, about 50% settling can be expected in the first five years. The owners of the motel shown in Fig. 13-5 learned this the hard way.

Landfills should never be disturbed. Disturbance may cause structural problems, and trapped gases can present a hazard. Buildings constructed on landfills should have spread footings (large concrete slabs) as foundations, although some have been constructed on pilings that extend through the fill onto rock or some other strong material.

VOLUME REDUCTION BEFORE DISPOSAL

Refuse is bulky and does not compact easily, so that volume requirements of landfills are significant. Where land is expensive, the costs of landfilling may be high. Accordingly, various ways to reduce refuse volume have been found effective.

In the right circumstances, burning of refuse in waste-to-energy facilties (discussed in the next chapter) is an effective treatment of municipal solid waste. Burning reduces the volume of waste by a factor of 10 to 20, and the ash is both more stable and more compactable than the refuse itself.

Pyrolysis is combustion in the absence of oxygen. The residues of pyrolysis, combustible gas, tar, and charcoal, have economic value but have not yet found acceptance

as a raw material. The tar contains water that must be removed; the charcoal is full of glass and metal that must be separated. These separations render the by-products too expensive to be competitive. Pyrolysis reduces the volume considerably, produces a stable end product, and has few air pollution problems. On a large scale, such as for some of our larger cities, pyrolysis as a method of volume reduction has significant advantages over incineration. Pyrolysis may also be used for sludge disposal, thus solving two major solid waste problems for a community. Such systems, however, remain to be proven in full-scale operation.

Another method of volume reduction is baling. Solid waste is compressed into desk-sized blocks that can then be handled with fork lifts and stacked in the landfill depression. Because of the high density of the refuse (on the order of 2000 lb/yd^3), the rate of decomposition is slow and odor is reduced. Baled refuse does not therefore require daily cover, further saving landfill space. Local and state regulations may, however, require baled refuse landfills to provide daily cover, which substantially reduces the cost advantages of baling.

CONCLUSION

This chapter begins by defining the objective of solid waste disposal as the placement of solid waste so that it no longer impacts society or the environment. At one time, this was fairly easy to achieve: dumping solid waste over city walls was quite adequate. In modern civilization, however, this is no longer possible, and adequate disposal is becoming increasingly difficult.

The disposal methods discussed in this chapter are only partial solutions to the solid waste problem. Another solution would be to redefine solid waste as a resource and use it to produce usable goods. This idea is explored in the next chapter.

PROBLEMS

13.1 Suppose that the municipal garbage collectors in a town of 10,000 go on strike, and as a gesture to the community, your college or university decides to accept all city refuse temporarily and pile it on the football field. If all the people dumped refuse into the stadium, how many days must the strike continue before the stadium is filled to 1 yard deep? Assume the density of the refuse as 300 lb/yd^3, and assume the dimensions of the stadium as 120 yards long and 100 yards wide.

13.2 If a town has a population of 100,000, what is the daily production of wastepaper?

13.3 What would be some environmental impacts and effects of depositing dewatered (but sloppy wet) sludge from a wastewater treatment plant into a sanitary landfill?