Solid Waste Management

Solid waste is the unwanted or useless solid materials generated from combined residential, industrial and commercial activities in a given area. For e.g. it may be yesterday's news paper, junk mail, today's meal scraps, pieces of bread, waste rice, racked leaves, dust, grass clippings, broken furniture, abandoned materials, animal manure, sewage sludge, industrial refuse or street sweepings etc.

Apart from this municipal waste, industrial processes produce chemical wastes, many of which contain toxic substances. In the nuclear power generation also radionuclides are produced as the waste.

The quantity of this material is increasing readily due to increase in human population and increase in the standards of living. United States produces more waste per person than any other country in the world. For example, in Bombay 7000 tons of municipal solid wastes are being produced every day. All this is contributed by the kitchen refuse, markets and slaughter house. These wastes have to be disposed off so that environment remains clean and healthy for inhabitation. Solid waste management includes the process of generation, collection, storage, transport and disposal or reuse and re-circulation or incineration or any relevant method of disposal (WHO, 1971). For the first time in India the municipal corporations have worked overtime to remove the filth produced due to the threat caused by the outbreak of plague disease in Surat city of Gujarat state, India, in the year 1994.

Changes in Municipal Solid Waste

Until the late 1940s, the bulk of municipal solid waste consisted of ashes from coal-burning furnaces and food wastes. The few scrap materials, such as metals and rags, that were recoverable were collected on a casual basis by scavengers. With the shift of the burgeoning population of the 1950s to cities, urban population densities increased, oil and natural gas heating grew in popularity, and society became increasingly industrialized. The two root causes for the increasing urgency of solid waste problems are urbanization and industrialization. Urbanization, (i.e., the influx of people to metropolitan areas) affects living habits and consequently waste characteristics. Also, with more people, the areas requiring solid waste collection have expanded and sites for waste disposal are farther away. Industrialization, because it generates inexpensive, laborsaving products, has created a "throwaway" society. During the 1960s and 1970s, new products appeared in abundance. Cans, bottles, plastic containers, appliances, tires, and many other items were considered to be cheaper to throw away than to reclaim. Recovery of material has become more difficult because of the use of numerous synthetic materials, bonded plastics, and nonferrous alloys. Packaging for convenience foods, hardware, household items, and other goods has created a vast array of material that is easy to discard. Solid waste increased significantly in quantity and complexity with the advent of the "throwaway" society and the growth of the packaged-and-processed food industry. Figure 14–1 indicates how solid waste has changed over the years. Of course, individual regions may show quite different trends, proportions, and qualities, and therefore studies of solid waste management problems should be based on site-specific surveys.

Today, food wastes are generated more by processing plants than by home or farm. While such wastes are a problem because of their large volume, high strength, seasonal nature, and rural location, the change has enabled better control through an industry-wide approach to waste disposal, with the costs being borne by the users of the products. The growth of the food-processing industry does not seem to have changed the amount of food wastes from urban residents, but the increase in packaging associated with convenience foods is certainly part of the reason for the growing per capita waste production.

CLASSIFICATION

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

1. ***Garbage***: Putrecible wastes from food, slaughterhouses, canning and freezing industries.

2. ***Rubbish***: non-putrecible wastes either combustible or non-combustible. These include wood, paper, rubber, leather and garden wastes as comustible wastes whereas the non-combustible wastes include glass, metal, ceramics, stones and soil.

3. ***Ashes***: Residues of combustion, solid products after heating and cooking or incineration by the municipal, industrial, hospital and apartments areas.

4. ***Large wastes***: Demolition and construction wastes, automobiles, furniture's, refrigerators and other home appliances, trees, fires etc.

5. ***Dead animals***: House holds pets, birds, rodents, zoo animals, and anatomical and pathological tissues from hospitals.

6. ***Sewage sludges***: These include screening wastes, settled solids and sludges.

7. ***Industrial wastes***: Chemicals, paints, sand and explosives.

8. ***Mining wastes***: Tailings, slug ropes, culm piles at mine areas

9. ***Agricultural wastes***: Farm animal manure, crop residues and others.

In India 29 million tons of MSW is produced every year. It is due to concentration of very high population in urban areas and added new type of wastes from shops, institute and factories. The solid wastes provide an attractive habitat for disease vector (as flies and rodents). It requires long time for decomposition in usual course that may cause air pollution as well as water pollution. Therefore, there is a need for the treatment of solid wastes.

MISMANAGEMENT AND SIDE EFFECTS

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

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

Insects

A common transmission route of bacillary dysentery, amoebic dysentery and other diarrhoeal diseases are from human fecal matter spread through flies to food or water, thence to man. The breeding of mosquitoes in discarded tyres, tins, and jam bottles are reported.

Rats and other vertebrate vectors

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

Fire

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

Odor

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

Atmospheric Pollution

If PVC is a constituent of the refuse, the gases may include hydrogen chloride. In addition to pest nuisance and health hazards, the solid wastes also cause air pollution.

Visual Pollution

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

Water Pollution

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

PHYSICAL CHARACTERISTICS

A typical range of moisture content is 20-40% and it varies with the season of the year. Values greater than 40% are also not common. Moisture increases the weight of the solid wastes and therefore the cost of collection and transport increases.

CHEMICAL CHARACTERISTICS

Information of chemical characteristics is important in evaluating alternative processing and recovery options. Typically waste is considered as combination of combustible and noncombustible components. It includes Lipids, Carbohydrates, Proteins, Natural Fibers (These are the natural products contain cellulose and lignins that are relatively resistant to biodegradation. These are found in paper products, food and yard wastes), Synthetic Organic Materials.

METHODS OF TREATMENT / WASTE DISPOSAL

Disposal is the final stage in the solid waste management, and all the wastes whether they are residential, commercial or from any other sources are collected and transported to a disposal site. A wide range of options are available for the safe waste disposal. They are listed as follows. There are nine methods of treatment of solid wastes: (A) Open dumping (B) Landfill method (C) Incineration (D) Composting (E) Vermitechnology (F) Anaerobic digestion (G) Pyrolysis (H) Catalytic hydrogenation of solid waste (I) Hazardous solid waste management and treatment.

A. OPEN DUMPING

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

B) Landfill method

Landfill arises from the chemical changes brought about by bacteria and complete disposal of solid wastes by filling in the upper layer of the earth's mantle.

Important aspects in the design of land fills include : (i) Site selection (ii) Land filling (iii) Recovery of land fill gas (iv) Equipment requirements (v) Water pollution (vi) Control of hazards.

As per Indian Municipal (Managing and Handling rules, 2000), there is the following criteria for land filling:

(i) The area of landfill site should be large enough to last for 20-25 years.

(ii) The site shall be at least 0.5 Km away from habitation clusters, forest areas, monuments, national park, wetlands and places of important cultural, historical or religious interest.

(iii) Land fill site should be at least 20 Km away from airport including airbase. Municipal authorities shall obtain approval of airport/airbase authorities prior to the setting up of the landfill site.

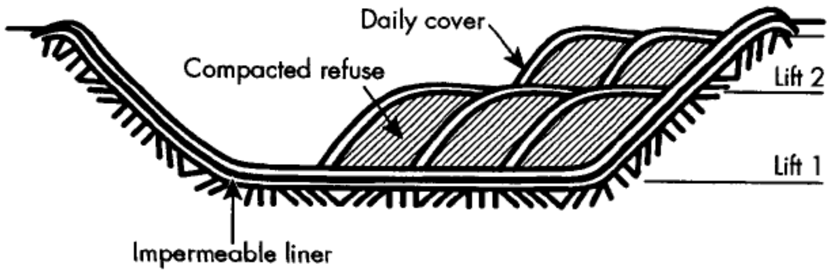
(iv) A 500 meter wide buffer zone of no-development be maintained around land fill site and shall be incorporated in the Town Planning Department.s land-use plans.

Water pollution : There is possibility of serious water pollution. In order to avert water pollution, the lowest level of the landfill should be no less than ten feet above the expected level of the high water table. In addition, proper surface drainage should be designed and established in order to prevent water from washing through the rubbish and re-entering the existing water routes.

DISPOSAL OF UNPROCESSED REFUSE IN SANITARY LANDFILLS

The sanitary landfilling operation involves numerous stages, including siting, design, operation, and closing. Typically, refuse is unloaded, compacted with bulldozers, and covered with compacted soil. Sanitary landfilling is the compaction of refuse in a lined pit and the covering of the compacted refuse with an earthen cover. The landfill is built up in units called *cells* (Figure 13-2). The daily cover is between 6 and 12 inches thick depending on soil composition (see the following figure), and a final cover at least 2 feet thick is used to close the landfill. The liner is made of plastic (typically PVC) and a layer of clay that further reduces the chance of leakage into the groundwater of the liquid produced by the landfill during the decomposition of the waste. The liquid produced is collected by pipes laid into the landfill as it is constructed. Gases produced by the decomposing waste must be collected and either vented or collected and burned. When the landfill is full, a cover must be placed on it such that the seepage of rainwater into the landfill is minimized.

A land fill continues to subside after the closere, so that permanent structures cannot be built onsite without special foundations. Vegetation must then be established on the landfill. Closed landfills have potential uses as golf courses, playgrounds, tennis courts, winter recreation or parks and greenbelts. Effect of a landfill on groundwater must be monitored by wells sunk around it. In effect, the landfill will continue to cost the community many years after the last waste is deposited.



Arrangement of cells in an area-method landfill

The advantages of a well planned and operated landfill are :

(i) It requires a relatively small capital investment.

(ii) It may reclaim fallow land.

(iii) It minimizes odour and fire nuisance, etc.

(iv) It denies access to the wastes to the flies that are already to the site.

The disadvantages are:

(i) It frequently requires longer and more costly hauls than other methods.

(ii) It requires more land than some other methods that makes it difficult to obtain suitable sites at reasonable cost in big cities.

(iii) Operational problems may occur during inclement weather, and

(iv) If proper action is not taken it causes health hazards as insects and rodents may breed.

(v) There is possibility of water moving through the system.

Control of leachate.

Once the capacity of the refuse to absorb liquid has been reached (or even before), leachate migrates through the underlying soil toward the groundwater table. The maximum rate of percolation through the soil occurs when its field capacity is reached and at that point the soil no longer absorbs water. Under this condition, the rate of liquid travel through a uniform soil is proportional to the hydraulic gradient that causes the flow. This relationship, known as *Darcy's law*, can be expressed as

$$Q = KSA$$

where Q = quantity of liquid flowing through area A per unit time = nvA

K = coefficient of hydraulic conductivity (dependent on soil type)

S = hydraulic gradient (i.e., the change in elevation of the "free" water surface between the two points being considered divided by the distance through which the liquid must travel)

A = gross cross-sectional area through which the flow passes

v = velocity at which the liquid travels through the soil

n = soil porosity i.e., void volume divided by total volume of the soil mass

Approximate values of porosity and hydraulic conductivity are listed in the following Table.

VALUES OF POROSITY AND HYDRAULIC CONDUCTIVITY

Soil type	Porosity %	Hydraulic conductivity	
		Description	K(cm/s)[a]
Gravel	25–40	High permeability	Over 1×10^{-1}
Sand to fine sand	25–50	Medium permeability	1×10^{-1} to 1×10^{-3}
Silty sand to dirty sand	30–50	Low permeability	1×10^{-3} to 1×10^{-5}
Silt	35–50	Very low permeability	1×10^{-5} to 1×10^{-7}
Clay	40–70	Practically impervious	Less than 1×10^{-7}

[a]Because of the widespread use of cm/s for soil systems, these units have been retained here. Conversion factors are as follows:

$$\text{cm/s} \times 1.97 = \text{ft/min}$$
$$\text{cm/s} \times 2880 = \text{ft/day}$$
$$\text{cm/s} \times 21{,}200 = \text{gpd/ft}^2$$

(C) Incineration

This process was practiced for the long time to reduce solid waste and lower transporting costs to disposal site and accommodating the wastes for a greater number of people. When refuse is burnt in an open area, a dense smoke often covers the site and neighbouring land. Old-fashioned incinerators without air pollution control equipment are little better than open burning. Apart from particulate matter that constitutes smoke, the gaseous discharges from the incomplete combustion may include SO2, NOx and various gases. Burning of solid wastes in open dumps or use of improperly designed incinerators produce excessive pollution. Studies revealed that emission from the uncontrolled burning leads to the production of particulate matter, sulfur oxides, nitrogen oxides, carbon monoxides, lead and mercury. Discharge of arsenic and cadmium are to be controlled. Polychlorinated dibenzofurans are called as dioxins and furans. These are of more concern about their toxicity as carcinogens and mutagens. Plastics have a high heating value, about 32000 KJ/kg, which makes them very suitable for incineration. However, among the plastics Polyvinyl chloride (PVC) when burnt produces dioxin and acid gas. The trace gases produced during the burning of plastic are proved to be carcinogenic.

The advantages of this process is that

(i) Land required per ton of solid waste is less compared to that required land fill (less than one third).

(ii) In the process ashes left over in the combustion chamber can be used for fertilizer, aggregates and materials recovery.

The two main disadvantages of the process are

(i) Capital, equipments and operating costs are very high

(ii) Possibility of high pollution in air.

(D) Composting

It is an anaerobic /aerobic microbial driven process that converts organic wastes into sanitary humus like material. This material can then be safely returned to the natural environment. This method is actually a low moisture, solid fermenting process. It leads to volume reduction of 50% of waste. Using compost improves soil structure, texture and aeration and increases the soil's water-holding capacity. Compost loosens clay soils and helps sandy soils retain water. Adding compost improves soil fertility and stimulates healthy root development in plants. The organic matter provided in compost provides food for microorganisms, which keeps the soil in a healthy, balanced condition. It contains about 15% N2, 1% P2O5, 0.8% K2O, 30% C and 40% ash.

The process is carried out by oxidizing the volatile matter in the biodegradable organic fraction of solid waste. Air acts as a source of oxygen and aerobic bacteria acts as a catalyst. The change occurring during the process may be represented as:

Biomass + O_2 (Aerobic/bacteria) $\rightarrow$ CO_2 + H_2O + Organic manure

Compost materials: Almost any organic material is suitable for a composting .

Raw materials should normally be blended to approximately 35:50 (by weight) carbon to nitrogen ratio by weight. For composting a proper ratio of carbon-rich materials, or "browns", and nitrogen-rich materials, or "greens" is mixed. Among the brown materials are dried leaves, straw, and wood chips. Nitrogen materials are fresh or green, such as grass clippings and kitchen refuse.

Kitchen refuse includes melon rinds, carrot peelings, tea bags, apple cores, banana peels which can successfully compost all forms of kitchen waste. However, meat, meat products, dairy products, and high-fat foods like salad dressings and peanut butter, can present problems. Meat scraps and the rest will decompose eventually but will smell bad and attract pests. Egg shells are a wonderful addition, but decompose slowly, so should be crushed.

The C/N ratio is very important for the process to be efficient. The micro organisms require carbon as an energy source and nitrogen for the synthesis of some proteins. If the correct C/N ration is not achieved, then application of the compost with either a high or low C/N ratio can have adverse effects on both the soil and the plants. A high C/N ratio can be corrected by dehydrated mud and a low ratio corrected by adding cellulose.

Moisture content greatly influences the composting process. Optimal water content should be 40 to 60% range. The microbes need the moisture to perform their metabolic functions. If the waste becomes too dry the composting is not favoured. If however there is too much moisture then it is possible that it may displace the air in the compost heap depriving the organisms of oxygen and drowning them.

A high temperature is desirable for the elimination of pathogenic organisms. However, if temperatures are too high, above 75^{o}C then the organisms necessary to complete the composting process are destroyed. Optimum temperatures for the process are in the range of 50-60^{o}C with the ideal being 60^{o}C.

(E) Vermitechnology

Waste biomass from domestic, agriculture, urban and industrial sources is the main cause of organic pollution in developing countries which can be used for vermitechnology.

It has the following advantages:

(i) Vermitechnology is a natural and eco-friendly process

(ii) Vermitechnology facility can be designed and operated to minimize environmental impacts by controlling odors and bio aerosols

(iii) It can replace high-cost inorganic fertilizers in developing countries

(iv) It can improve soil quality by supplying humus forming organic materials. It can supply essential nutrients (apart from nitrogen, phosphorus and potassium that were drawn from soil through vegetation).

(i) Vermitechnology Process

Preparation and Loading: Vermitechnology or vermicompost can be practiced in small scale under indoor environment or in commercial scale under outdoor environment. Vermitechnology can be done in earthen pits, concrete tanks, and plastic/ wooden crates or in tin containers. For establishing a small unit at home scale or in a courtyard, a regular flow of organic wastes like kitchen waste, crop waste, animal waste etc. may be available. Generally, a container/box/bin made of wood/tin/plastics or two or three chambered containers can be used for vermitechnology depending on the amount of wastes generated in a family.

Before putting household waste in the container, a layer of coconut coir/leaf mould/peat moss/banana stem peels of biodegradable in nature should be placed as first layer of 3-4 inch in thickness as vermibed. Thereafter, the household waste particularly kitchen waste can be added continuously in layers. Earthworm can consume all kind of household wastes like yard waste, tea bags, vegetable and fruit waste, pulverized egg shells etc. Waste like garlic and onion scales, citrus foods, bones, meats, dairy products and other household chemicals like metals, plastic, glass, soap, insecticide etc may be avoided. The efficiency of composting can be improved by reducing particle size and increasing surface area of the waste. Therefore, waste material may be dumped after grinding or blending. A good mixture preferably equals proportion, of brown (dry and dead organic waste like straw, weeds etc) and greens (fresh plant or kitchen waste materials) would be best for balanced nutrition to earthworm. On an average, a container of size 2 feet in width, 3 feet in length and 12 inch in depth can accommodate 1 kg of earthworm (approximately 2000 adults) which can recycle minimum half a kg of organic waste in a day.

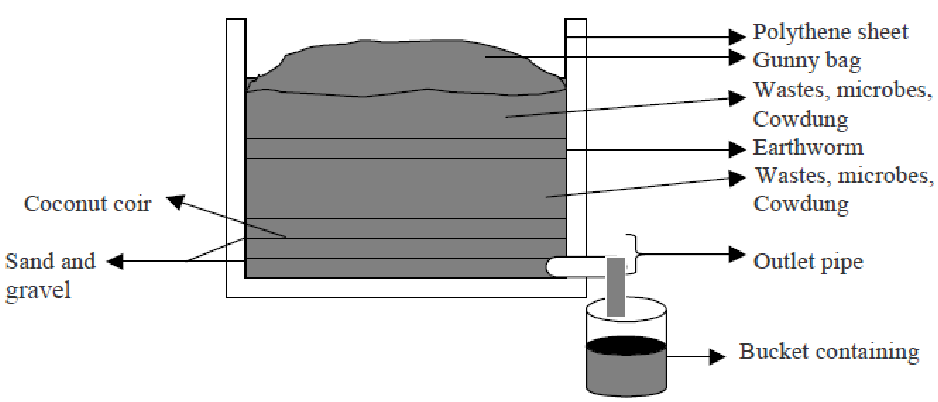


Fig. Schematic structure of compost unit.

Maturity and Harvesting

When the vermicompost starts maturing show a definite change in physical appearance of compost material. At maturity the material will be soft, spongy, dark brown in color with earthy odor (no foul smell). The maturity can be judged by C: N ratio, BOD, nitrate-N, VFA (volatile fatty acids) and ratio of reducing sugars etc.

After harvesting of vermicompost, earthworms can be separated either by manually or by screening through a net of 2 mm in size. The harvested vermicompost is spread on a screen where the earthworm gets separated and remains above the screen, while the vermicompost moves downwards through a series of plates. During the movement hot air blows with air temperature of about 50° C to bring down the moisture content of compost to a desired level. Finally, the dried compost falls on a conveyor belt, which is bagged, in the same unit. After earthworm separation the moisture is brought to 20-25 % level before bagging. During dry season the vermicompost gets dried under open sun while, during rainy season, drying under open condition become.

Effect on soil properties

Soil biological components is favorably influenced by the addition of vermicompost. Addition of vermicompost replenish the organic matter content of soil and increase the availability of moisture to the plant and thus reduce the number of irrigation needs. In clay soil, the addiction of vermicompost increases the permeability to water.

RECOVERY RECYCLING AND REUSE

Recovery and reuse have become inevitable in the present scenario. Energy costs are rising, making energy recovery more attractive and more economical, and the disposal cost will rise as social pressure for environmentally-sound waste disposal increase making recovery a better alternative. Recycling reduces the cost inputs and enhances the profit margin. Recycling also adds to sustainable development as it leads to lesser use of nature resources and it can also be used as a label to promote the acceptability of the product.

Reduce, Reuse, Recycle

Methods of waste reduction, waste reuse and recycling are the preferred options when managing waste. There are many environmental benefits that can be derived from the use of these methods.

Waste reduction and reuse

Waste reduction and reuse of products are both methods of waste prevention. They eliminate the production of waste at the source of usual generation and reduce the demands for large scale treatment and disposal facilities. Methods of waste reduction include manufacturing products with less packaging, encouraging customers to bring their own reusable bags for packaging, encouraging the public to choose reusable products such as reusable plastic and glass containers, backyard composting and sharing and donating any unwanted items rather than discarding them.

All of the methods of waste prevention mentioned require public participation. In order to get the public onboard, training and educational programmes need to be undertaken to educate the public about their role in the process. Also the government may need to regulate the types and amount of packaging used by manufacturers and make the reuse of shopping bags mandatory.

Recycling

Recycling refers to the removal of items from the waste stream to be used as raw materials in the manufacture of new products. Thus from this definition recycling occurs in three phases: first the waste is sorted and recyclables collected, the recyclables are used to create raw materials. These raw materials are then used in the production of new products.

Recyclable materials

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

Batteries and Tyres

Battery reprocessing includes breaking the batteries, neutralizing the acids and chipping the containers for recycling. Ground tyres can be used as substitutes for asphalt for road laying and to produce recycled rubber. Tyres can be heated to recover steel (from radials) and bitumen, each tyre has organic matter whose fuel value is equivalent to nearly 2.5 gallons of petroleum.

General Expressions for Material Recovery

In separating any one material from a mixture, the separation is termed *binary* because only two outputs are sought. When a device is to separate more than one material from a mixture, the process is called *polynary*.

The following figure shows a binary separator receiving a mixed feed of x_0 and y_0. The objective is separation of the x fraction: The first exit stream is to contain the x component, but the separation is not perfect and contains an amount of contamination y_1. This stream is called the *product* or *extract*, while the second stream, containing mostly y but also some x, is the *reject*. The percent of x recovered in the first output stream, $R_{(x_1)}$, may be expressed as

$$R_{(x_1)} = \frac{x_1}{x_0} \times 100$$

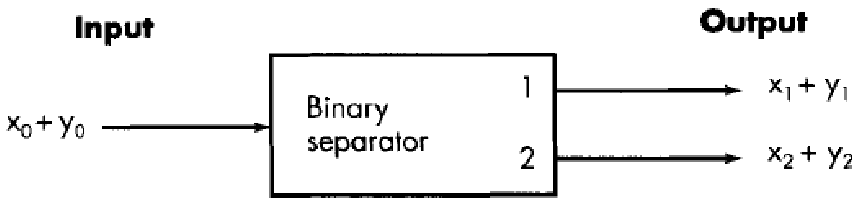


Fig. Definition of a binary separator

$R_{(x_1)}$ alone does not describe the performance of the binary separator adequately. If the separator were turned *off*, all of the feed would go to the first output; the extract would be $x_0 = x_1$, making $R_{(x_1)} = 100\%$. However, in this case there would have been no separation. Accordingly, the *purity* of the extract stream as percent must be considered and can be defined as

$$P_{(x_1)} = \left(\frac{x_1}{x_1 + y_1}\right)100$$

A separator might extract only a small amount of pure x, so that the recovery, $R_{(x_1)}$, would also be very small. The performance of a materials separator is assessed by both recovery and purity and may thus be characterized by an additional parameter, the separator efficiency $E_{(x,y)}$, as

$$E_{(x,y)} = \left(\frac{x_1}{x_0} \times \frac{y_2}{y_0}\right)^{1/2} \times 100$$

A binary separator, a magnet, is to separate a product, ferrous materials, from a feed stream of shredded refuse. The feed rate to the magnet is 1000 kg/hr and contains 50 kg of ferrous materials. The product stream weighs 40 kg, of which 35 kg are ferrous materials. What is the percent recovery of ferrous materials, their purity, and the overall efficiency?

The variables in Equations are

$x_0 = 50$ kg $\qquad y_0 = 1000 - 50 = 950$ kg
$x_1 = 35$ kg $\qquad y_1 = 40 - 35 = 5$ kg
$x_2 = 50 - 35 = 15$ kg $\qquad y_2 = 950 - 5 = 945$ kg

Then

$$R_{(x_1)} = \left(\frac{35}{50}\right)100 = 70\%$$

$$P_{(x_1)} = \left(\frac{35}{35 + 5}\right)100 = 88\%$$

$$E_{(x,y)} = \left(\frac{35}{50}\right)\left(\frac{945}{950}\right)100 = 70\%$$