Chapter 4
Materials Recovery and Recycling

Reduce, recycle, reuse and recover are the most important component of solid waste management. In the absence of these components, over a span of time there will be nothing left in the world for further use.

Material recovery practice varies from place to place. As discussed in a previous chapter municipal solid waste could comprise of paper, textile, ceramic, dust stones, leather, metal, glass, food waste and other decomposable organic materials. Countries like the UK, Switzerland, Austria and the Netherlands where key reasons for growing adoption of the 3R (Reduce, Recycle and Reuse) due to a scarcity of landfill capacity or sites. In Japan more than a quarter of a century of research was done on reuse demolished concrete, but relatively small concrete has been recycled due to the non-compliance with the prescribed standards.

In England, shoes, clothes, textiles and accessories which made up 4–5 % of the total domestic waste (DTI 2002) during 2003/2004 used for various purposes. There are about 6,000 banks in the UK out of which 85 % is run by charities to collect used cloths. In 1999 about 43 % went to second hand clothing, 22 % was used as filling materials, 12 % went to wiping cloths and 7 % went to fibre reclamation (Anne et al. 2006).

In the developing world waste recovery and recycling generally happen within a house itself. Many of the carry bags would be reused for filling useful material or waste before discarding them. Tins and jars of food materials would be used for storing groceries in kitchen or as toys for kids. The newspapers would often be used to wipe glass or table tops. Other uses of old paper are packaging or making pulp for manufacturing cardboard/paper.

Food wastes from restaurants are usually used for feeding cattles. Waste from slaughterhouse is used for dog biscuits or composting. The waste fish is often used for manufacturing poultry feed, while plastic material in recent days is used for mixing with bitumen while laying pavement to roads. Plastic can also be melted and remolded. If the organic material cannot be used as food it could be converted into energy.

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Fig. 4.1 Sophisticated waste reception at a waste processing plant

Dust and rubles can be used for making building blocks. The metallic component has huge demand all over the world due to its readily available market. The metallic component would be melted and remolded. Another option available for organic fraction waste is energy recovery by either incineration or another technique like pyrolysis.

Other major component namely glass can be melted for remolding. In many cases used bottles are washed and reused. But 100 % reuse and recycling is still not achieved by any country. Material recovery and recycling facilities could be sophisticated with highly organized reception centre as shown in Fig. 4.1 or could be just a place under trees.

Box 4.1 Zabbaleen.

The Zabbaleen (means "Garbage people" in Egyptian Arabic) have served as Cairo's informal garbage collectors since around 70–80 years. Spread out in seven different settlements in the Greater Cairo Urban Region with largest settlement being Mokattam village, nicknamed as "Garbage City". Migrants from the "Wahy" oases called Waheyya came to Cairo to collect the waste at the beginning of the last century, who received remunerations for the garbage collection. During 1930–1940s, new migrants from Upper Egypt came to Cairo in order to breed pigs on waste and started waste collection by signing contracts with the *Waheyya* (Lise 2010).

Informal recyclers often originate from social groups or belong to minorities. Examples of which include the Zabbaleen (Box 4.1) in Egypt, Basuriegos, Cartoneros, Traperos and Chatarreros in Colombia, Chamberos in Ecuador, Pepenadores, Catroneros and Buscabotes in Mexico, Buzos in Costa Rica and Cirujas in Argentina (Medina and Dows 2000; Berthier 2003). In a many countries the informal sector provides a waste collection service where there is no formal waste

Fig. 4.2 Waste segregation at point of collection

collection system in place (Coad 2003; Haan et al. 1998; Scheinberg 2001) with prime economic motivation being income that can be made by recycling the collected waste.

4.1 Segregation

Segregation of solid waste is carried out at: (1) source (residences, operation theatre, industries etc.), (2) the collection point (Figs. 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9), (3) transportation, (4) disposal point. It is at most important that non degradable fraction of solid wastes are segregated so as to carryout major biological processes enlisted in Fig. 4.10. The major segregation can happen at the point of collection itself.

In some places waste is usually packed in covers and thrown into bins meant for it. The segregation done at a collection point often generates additional income for waste collectors wherein the collectors usually keep papers, undamaged bottles, metal and plastic items separately for selling to scrap dealers.

Repeated segregations up to a maximum extent as demanded by market are practised in several parts of India where labour is available in abundance. This system basically works on the principle of segregation at every level. The degradable waste from residential and commercial areas is collected separately to avoid soiling of non-degradable waste which would reduce price during selling. The non degradable waste is segregated into different components. Materials like electric wire, which have copper as one of their components, will fetch higher value compared to others but the quantity might be very less requiring long accumulation period. Materials like paper or plastic cover may fetch lower cost but the quantity will be sufficient for disposal every day.

The organic waste is converted in useful product designed to generate zero waste at the end of processing. Such practice has been well practised in small self

Fig. 4.3 Segregated waste at zero waste plant where components of waste are segregated to the maximum possible extent

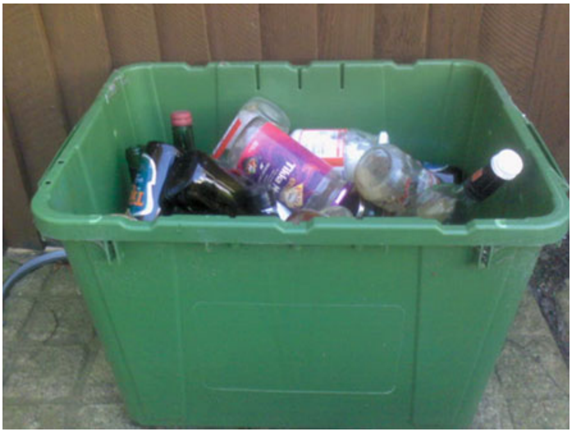


Fig. 4.4 Glass bottles collected in dedicated bin for recycling

Fig. 4.5 Large dedicated containers for collection of bottles

Fig. 4.6 Large dedicated containers for waste recycling

Fig. 4.7 Dedicated containers for collection of garden waste

hep groups across Vellor in India. The system is designed to be self sustainable at the planning stage itself. The waste quantity collected in technical university and large hospital does not require waste generator to pay for the service, while small colonies would be required to pay a nominal fee which may be as small as the cost

Fig. 4.8 Signs for dedicated containers (Fig. 4.9) at an office

Fig. 4.9 Dedicated containers for segregation at source

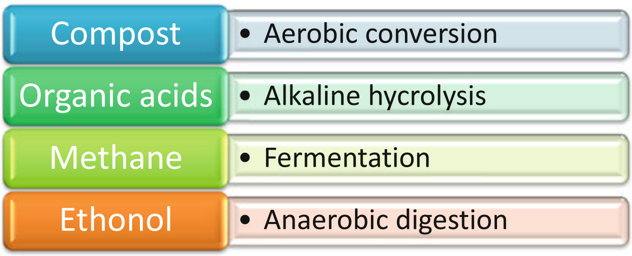


Fig. 4.10 Biological processes for the recovery of conversion products from solid waste

of a banana per month. In some places the service charges are paid by handing over old newspaper received over month to self help group which has huge established market.

The zero waste concepts not only avoid pollution due to incineration and generation of methane/leachate from land fill, but it will also avoid environmental degradation due hauling waste to long distance. The area required depends on the quantity of waste. In practice small processing units are profitable and manageable due to low overhead cost as well as labour problem.

The system shown in Fig. 4.11 is practised in temple, university campus, hospital campus and residential area at Vellore is designed in such a way that the system is profitable. The organic fraction is fed to cattle. The cattle dung is fed to anerobic digester. The anaerobic digester converts dung into biogas and digested sludge which is ready for vermi-compost. The digested cow dung is used as *seed microorganism* to organic waste to speed up the degradation.

Table 4.1 shows example of price of waste components. As could be seen the different quality paper would fetch different price. The mix up of all quality paper would fetch cheapest quality paper. The logic hold good for plastic as well. As could be seen the good quality plastic would cost several times that of poor quality plastic. Hence rag picker always chooses material of higher values living behind huge litter of soiled plastic covers. Reusable material like beer bottle is sold on number basis rather than weight basis. The costly material like copper wire and WEEE is priced high. Prices in Table 4.1 do not make much sense in the developing countries because except for high cost components like metal, segregation of each components would be costly considering cost of manpower which is nearly 40 times higher than developing nations making it disposal in landfill site as the best option.

4.1.1 Hand Sorting

Hand sorting or *picking* is the most widely used method in all over the world. Scavengers all over the world carry out hand sorting after they pick the waste. Figure 4.12 shows waste segregation facility with provision for hand sorting and Fig. 4.13 shows a schematic diagram of hand sorting.

Sorting can be positive sorting or negative sorting. In the positive sorting, personnel will pick what is required from the conveyor belt. In the negative sorting, personnel will pick what is not required.

4.1.2 Screens

Screening is a process in which a series of uniform-sized openings allows separation of material smaller than that of the opening. Most popular screen for processing MSW is the trammel or rotary screen (Fig. 4.14). Diameter of trammel ranges between 0.6 and 3 m. A motor is attached to tromel at one end rotates the drum at about 10–15 r/min.

Another variation of screen is a disk screen (Fig. 4.15) wherein a series of disks mounted on shafts. As the shafts rotate undersized objects fall between the spaces

Fig. 4.11 Zero waste plant

Table 4.1 Example of prices of waste components in 2011 in India

Waste component	Quantity	Price
Aluminium scrap/can	1 kg	75.00
Beer bottle	1 No.	1.50
Broken glass	1 kg	4.00
Brown cartoon box	1 kg	4.50
Coconut shell	1 kg	2.00
Egg shell powder	1 kg	25.00
Glass bottle	1 kg	27.00
Iron scrap	1 kg	9.00
Magazine with good quality paper	1 kg	5.00
Magazine with poor quality paper	1 kg	3.00
Milk cover	1 kg	15.50
Oil cover	1 kg	6.50
Old slipper	1 kg	1.00
Pet bottle	1 kg	1.50
Plastic ice cup	1 kg	1.00
Plastic made up of recycled plastic	1 kg	3.25
Plastic made up of virgin plastic granules	1 kg	15.50
Poly vinyl chloride(PVC)	1 kg	25.00
Used note book	1 kg	9.00
Waste newspaper	1 kg	2.10
White pet bottle	1 kg	1.50

Fig. 4.12 Waste segregation facility with provision for hand sorting

of the disks and are collected in one hopper. The larger objects are carried along and deposited in a second hopper.

Another type of screen called vibrating screen (Fig. 4.16) consists of a flat screen which undergoes reciprocating or gyrating motion. Figure 4.17 shows vibratory screen with electro static separator and collection mechanism in a WEEE processing unit.

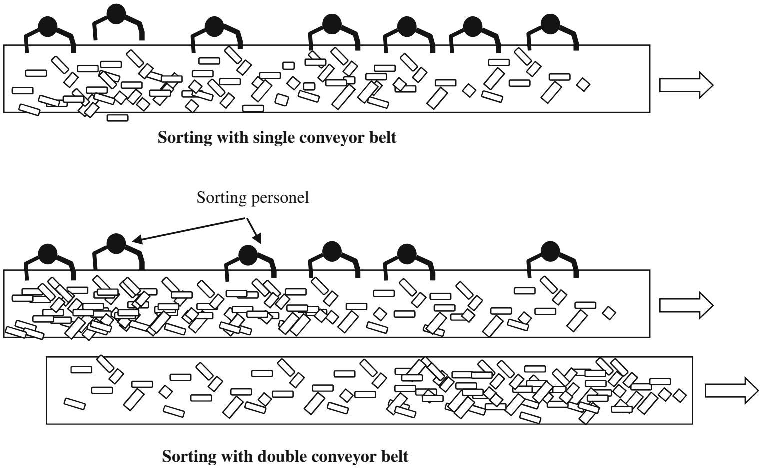


Fig. 4.13 Schematic diagram of hand sorting

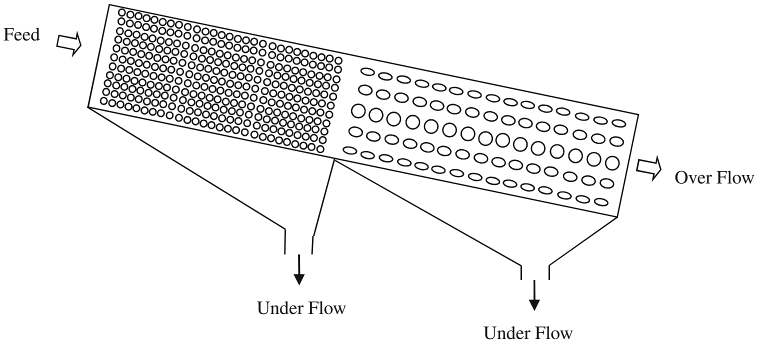


Fig. 4.14 Trommel

4.1.3 Air Classifiers

Air classifiers are used to separate the less dense material from denser fraction using air. In air classifiers less dense objects will be trapped in an upward current of air, while the more dense material will drop down. The less dense material entrapped in the air stream will be separated from the air. Usually, this is done with a *cyclone separator* (Fig. 4.18) *or a*n air knife classifier (Fig. 4.19).

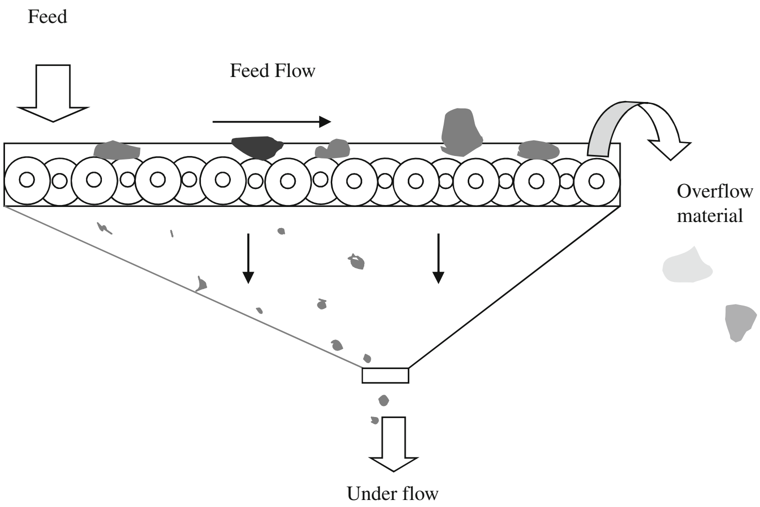


Fig. 4.15 Disc screen

4.1.4 Sink/Float Separators

Sink/float separator are used to separate heavy fraction from lighter fraction in which a fluid is used as media for separation. While the lighter fraction with specific density greater than that of fluid floats the heavier fraction sinks. Common fluids used are: water, water–methanol mixture, sodium chloride solutions and Zinc chloride solutions. Float baths are kept in a series based on specific gravity of materials to be sorted. Pumps are used for circulation and direct the flow. Disadvantage of this method are: (1) requires long retention period for flaky objects to settle, (2) needs wastewater treatment, (3) difficulty in controls as smaller flakes of heavier fraction may float and vice versa, (4) needs wetting of particle in order to avoid attachment of air bubbles to objects and flocculation, (5) density of aqueous solutions vary due to change in ambient temperature and evaporation, and (6) contamination of objects.

4.1.5 Inclined Tables

Inclined tables (Fig. 4.20) are table inclined at an angle convenient for sorting/processing waste. The tables may be provided with conveying belt. *Inclined tables* can be used to separate objects of various densities/sizes by washing down lighter objects down the inclined table along the incline.

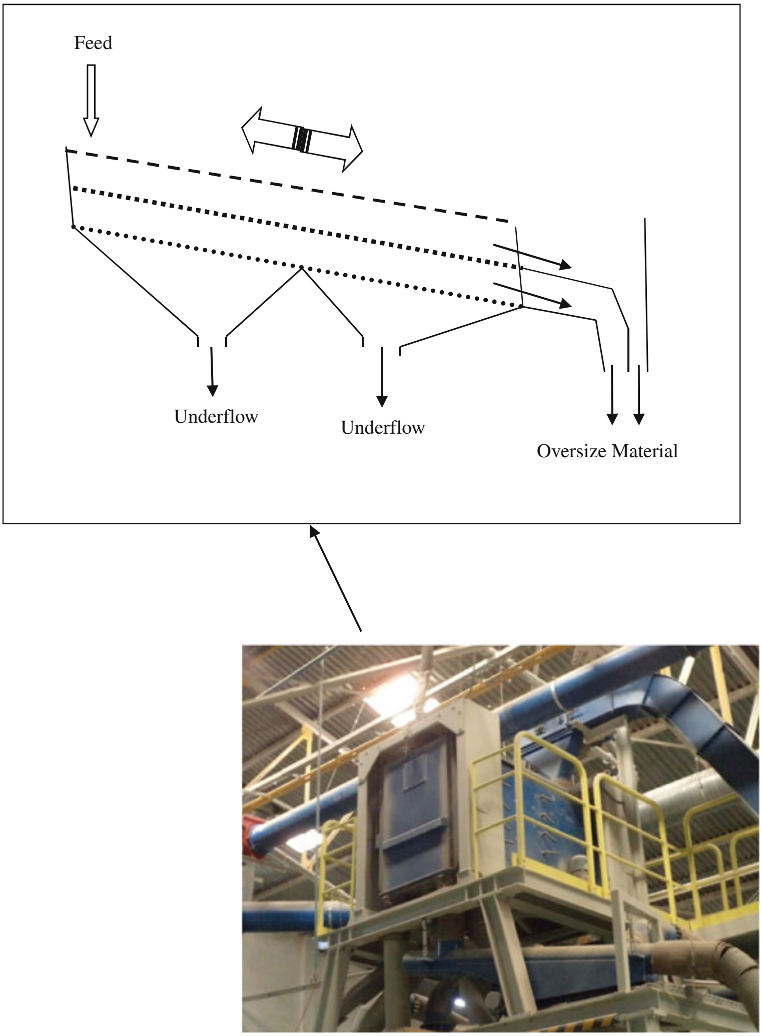


Fig. 4.16 Vibratory screen

4.1.6 Shaking Tables

Shaking tablesare tables shaken with a movement perpendicular to fluid flow. Under the effect of gravity, crosswise running water, inertia and friction, materials are stratified by weight and size.

Fig. 4.17 Vibratory screen with electro static separator and collection mechanism in a WEEE processing unit

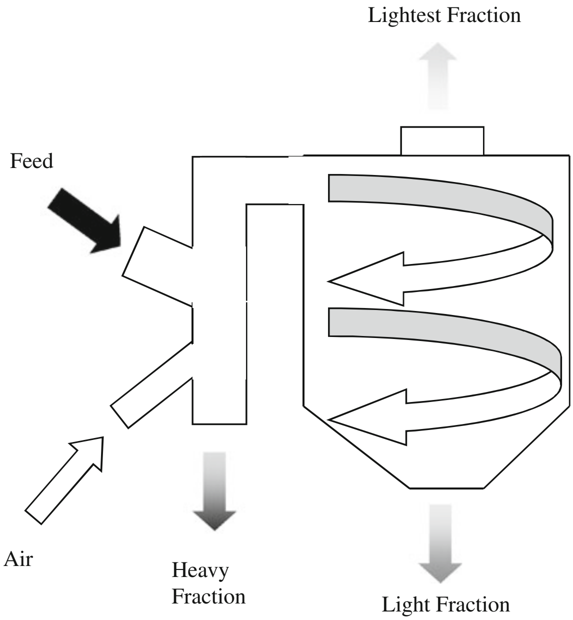


Fig. 4.18 Cyclone waste clessifier

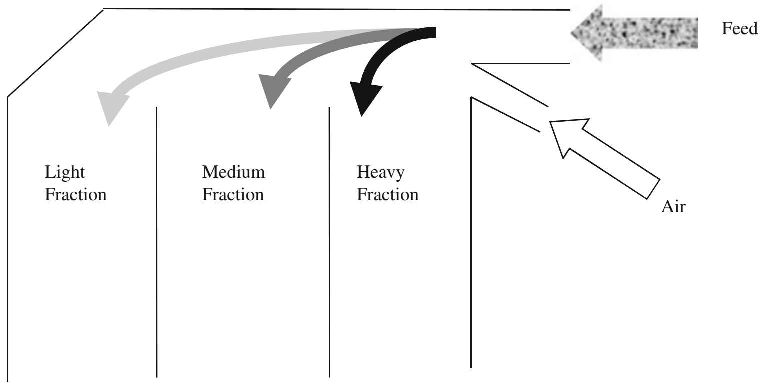


Fig. 4.19 Air knife classifier

Fig. 4.20 Inclined tables

4.1.7 Optical Sorting

The optical sorting can be done for: (1) differently coloured waste bags, (2) different components in waste. In the case of sorting coloured bags, users are provided with different coloured bags. The waste bags are collected and transported to sorting unit where they are transferred to a conveyor belt. The bags are sorted as they move using technology that recognises colour of bag. Automated waste sorting technology uses optical sensors to sort waste usually composed of plastics, paperboard, cans and glass. Sophisticated sorting equipments uses camera capable of recording length, width, area, shape, colour as well as surface structure. The data recorded are compared with objects described in database and ejects selected object as they pass under the camera.

Based on the requirement a range of spectroscopic methods are available for sorting. Examples include infrared spectroscopy, Raman Spectroscopy, laser induced plasma spectroscopy, and laser induced thermal impulse response, sliding spark spectroscopy, X-ray fluorescence spectroscopy.

4.1.8 Sorting by Differential Melting Temperature

This method is used for separation of commingled plastic by using a heated roll/belt separator on which separation takes places by selective thermo adhesion.

4.1.9 Sorting by Selective Dissolution

In this method separation of different material is achieved by selection of solvent and control of temperature. For example, the same solvent can be used for Polypropylene (PP), Polystyrene (PS), LDPE, HDPE and PVC as these materials will dissolve at different temperatures. Advantages of this method is that the recovered plastic is chemically near to the virgin plastic.

4.1.10 Magnetic Separation

Magnets are used to segregate magnetic materials from the other material. A magnet is placed at a strategic location near a conveyor belt, carrying the refuse. Figure 4.21 shows magnetic separator and Fig. 4.22 shows schematic diagram of alternative arrangements that can be adopted for magnetic separation. Materials which are attracted towards magnet are separated from the waste stream.

4.1.11 Eddy Current Separators

Eddy current separators (Fig. 4.23) are used for non-ferrous metals from non-metallic fraction. When a non-ferrous metal, passes above the separator, the magnets in the shell rotate at high velocity resulting in eddy currents in nonferrous metal which in turn creates magnetic field around the nonferrous metal. The polarity of magnetic field will be the same as that of the rotating magnet, causing nonferrous metals to be repelled away from magnet. Such repulsion results in the trajectory of the nonferrous material greater than that of non-metal fraction, allowing the nonferrous and non-metal streams to be separated. The ratio of

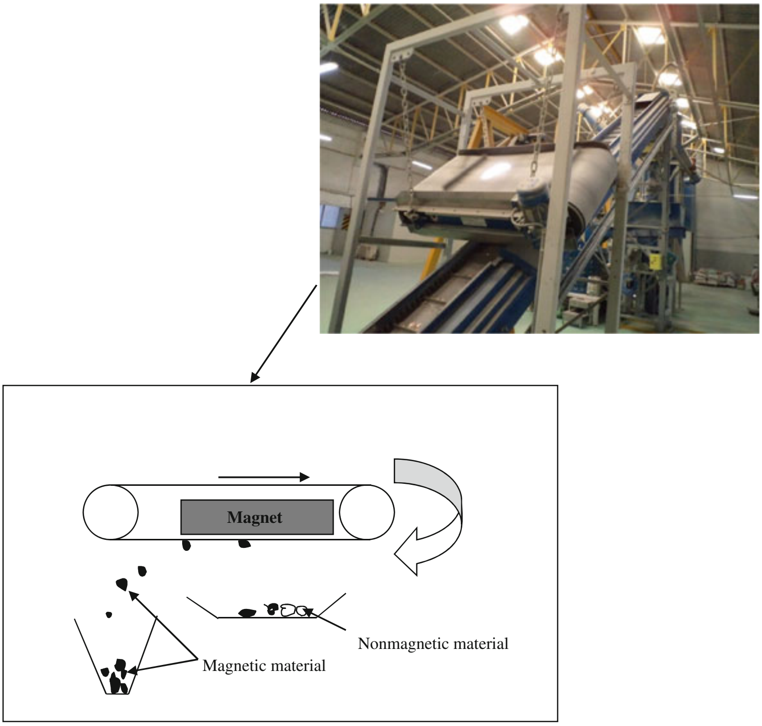
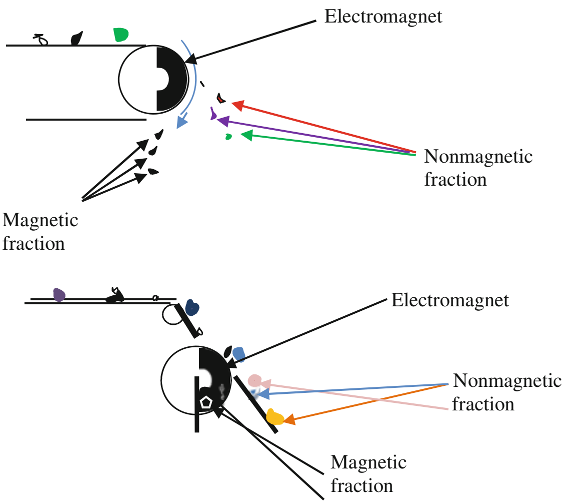


Fig. 4.21 Magnetic separator

Fig. 4.22 Schematic diagram of alternative arrangements that can be adopted for magnetic separation



electrical conductivity and density of the material is the main criteria for an eddy separation. The materials with higher ratio of conductivity to density will be separated easily compared to those with lower ratios.

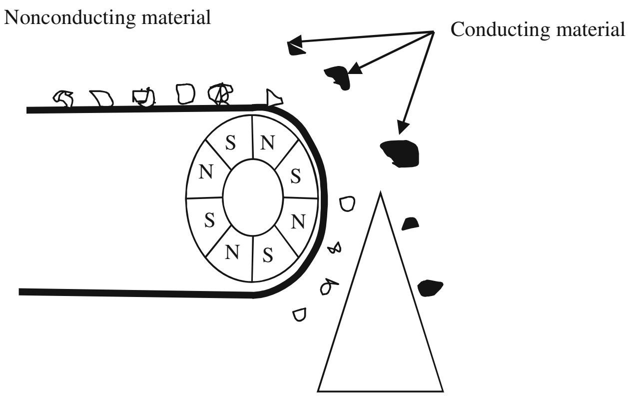


Fig. 4.23 Schematic diagram of eddy current separator

4.1.12 Electrostatic Separators

Electrostatic sorting has been used since the 1970s for sorting mixed plastic waste. In this method plastic material is separated through differences in electrostatic charges in different types of plastic. The materials are sorted by charging the objects and collecting them which rely on the extent of electric charge the materials acquire.

4.1.13 Shredding

Shredding is used for size reduction. There are many types of shredders. Hammer mill shredder consists of a central rotor with pinned radial hammers. Another type of shredder is known as a hog, used in pulp and paper manufacturing is used to shred green waste. Shear shredders are used to slice whole tires. Knife shredder (Fig. 4.24) is used for cutting material into small pieces.

Many shredders are available in the market varying from automobile shredders to paper shredders. The particular shredding process will depend on the material to be shredded. The shredders can be used for Paper, WEEE, vehicle parts, RDF, waste wood etc. Each year, 30 million vehicles are scrapped all over the world (Ahmed 2009) and Auto shredder residue (ASR) arising from shredding of automobiles comprises of heterogeneous mixture of metals, plastics, rubber, glass, wood, dust etc., Rotary shear shredders are the most common pre-shredder used for scrap tires which will have two counter rotating shafts. The shredded tires are further processes by grinding machines to generate granules.

There are two major categories of shredders used for shredding MSW—low speed, high torque (LSHT) shredders and high speed, low torque (HSLT) shredders (hammer mills) (Fig. 4.25).

Fig. 4.24 Knife shredder

Fig. 4.25 *Low* speed, *high* torque shredders

Vertical hammer mill use high speed rotating shafts at 700–1,200 rpm equipped with fixed/pinned hammers. Hammer mills use impact forces to convert waste into smaller particles. Low speed, high torque shredders use shear cutting and tearing forces.

Fig. 4.26 Pulveriser

High-speed impact Horizontal-shafthammermill will comprise feed hopper whrein material is fed to a hammer circle. The hammers, attached to a shaft, impact the feed material, and break it into smaller pieces. Further below the hammer circle will be a series of cast grates, wherein the material is torn between the hammers and the grates, until its size is reduced to pass through the grates.

Vertical-shaft ring grinders are gear-type device which grinds the feed material.

In a flail mill material is fed through a feed chute. The flails are attached to a rotating shaft which function as knives wherein paper is torn and ripped, glass is pulverized into very fine sizes whereas cans pass through the mill relatively unaffected.

A pulverizer utilizes a breaker plate and hammers along with impact bars and impact plates that assist in the pulverization of fragile materials (Fig. 4.26).

A granulator or knife shredder will have long knives for cutting materials into small pieces for later separation.

Paper shredders are used to cut paper into strips or fine particles. Sizes of paper shredders range from few pages to million pages per hour and can be built into a *shredding truck*. Shredder can either electrically powered or hand operated. *Strip-cut* shredders use rotating knives for generating narrow strips. *Cross-cut* shredders use two rotating drums to cut parallelogram/rectangular/rhombus shaped shreds. *Particle-cut* shredders cut paper into tiny pieces. *Cardboard* shredders shred cardboard into strips or a mesh pallet. *Disintegrators* and *granulators* cut the paper at random till the paper pieces are capable of passing through a mesh. In *Pierce and Tear* type of shredder rotating blades pierce and then tear the paper.

4.1.14 Pulping

Waste pulpers are used for grinding organic matter like cardboard, food scraps, and paper, with water. The pulp is then processed to produce dry pulp by removing the moisture content. Capacities of waste pulpers may vary from 125 to 2,000 kg/hr and capable of reducing the waste volume by 70–85 % their by reducing waste transportation costs. The food wastes are segregated from paper and cardboard waste so that pulp from food waste can be used for animal feed. Dry pulp can be mixed with other feed materials.

Waste pulpers are used in educational facilities, restaurants, health care facilities, casinos, cruise ship lines, manufacturing plants, and in-flight kitchens. Pulpers can be used for waste from industries as well.

Food waste pulping facilities will have the potential for foul odour and rodent/pest infestations. Advantages of waste pulping are: (1) reduction in volume of waste, (2) reduction in number of waste pickups, (3) reduction in labour, and (4) Elimination of the need to segregate paper from food waste. Disadvantages include high initial cost and energy costs.

4.1.15 Crushing

Waste crushers can be used for variety of material like bottle, drums, can, cars, concrete, tyre etc. Based on the material to be crushed, crushing equipment is selected. Waste crusher can be mobile or stationary. Construction waste generated by construction activities are of two types: (1) inert, (2) non inert. The non inert waste comprises of bamboo, timber, vegetation, etc. The inert waste comprises of construction debris, rubble, aggregate, etc. The inert material can be crushed and screened on-site their by reusing aggregate, gravel, concrete etc. The crushing plant comprises of jaw crusher, belt conveyor as well as screening machines.

4.1.16 Baling

Balers are used for baling corrugated cardboard, paper, aluminum cans, plastic containers etc. Balers are available in a wide range of sophistication. Bales of waste are tied with wire/string of durable material like iron or nylon. Some high-power balers form bales which will retain its shape without strings/wires.

4.1.17 Ballistic Separators

Ballistic Separators are used for segregating large materials such as plastic bottles, metal cans from waste stream. The separator consists of a series of oscillating paddles in pairs wherein large objects move backwards and light fractions move forward. The angle is set as per material separation requirements.

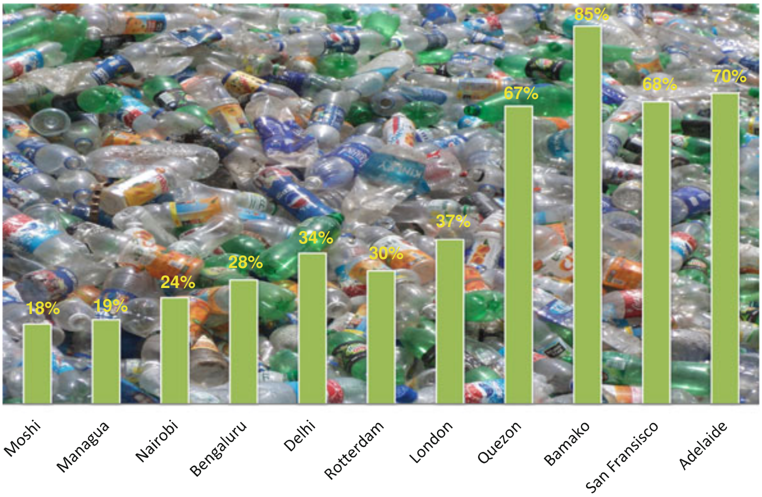


Fig. 4.27 Recycling in percentage at various cities across the world

4.2 Reuse and Recycle

Reuse and recycle is the oldest waste management practice that the mankind has adopted in the civilisation. For example, man used bones as tools. In India even today charcoal and crushed brick is used for cleaning teeth by many poor people. During the past 10–20 years, the developed countries are rediscovering the worth of recycling as part of their waste management systems and these countries have invested in physical infrastructure and communication strategies to amplify recycling rates (UN-habitat 2010). The newspaper is used for packaging and old bottles are recycled for refilling beverages. Used cloths which are waste for affluent people are used by poor all over the world. The USA, Germany, France and the Netherlands use bottom ash from waste incinerators for road construction (Mullen 1990; Chandler et al. 1997).

Industrial waste like coal combustion residues, steel slag, and red mud (of bauxite) can be used in concrete, bricks, blocks, and tiles. Similarly gypsum produced as waste from industry can be used for manufacture of gypsum board and cement.

After the extraction of oil from oil palm fruit, husks and shells are used in captive power plants. Similar use can be seen in sugar mills wherein bagasse (leftovers after extraction of juice from sugar cane) is used as fuel for cogeneration. Coconut fibres can be used for making rope or fibre-cement board. The finely ground glass with a particle size finer than 38 μm and can be used as a substitute for Portland cement in concrete (Safiuddin et al. 2010). The construction and demolition waste can be used for embankments, pavement and concrete.

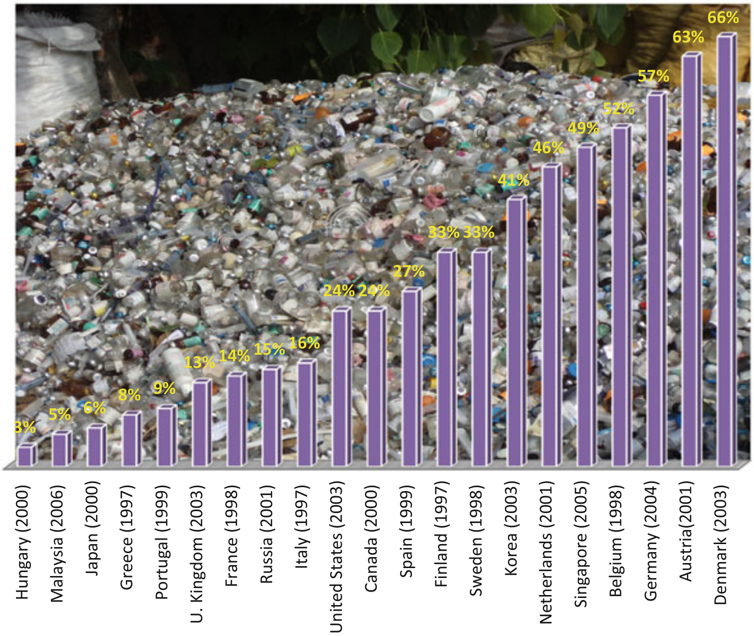


Fig. 4.28 Recycling in percentage at various countries

Recycling/reuse which is also referred as valorisation in some literature has been practiced throughout the world. As per UN-habitat (2010) the recycling is carried out in various cities as shown pictorially in Fig. 4.27. Data collected and published by Saleh (2011) depicting recycling achieved in various countries is given in Fig. 4.28. Many developing and transitional nations have active informal sector which is engaged in reuse and recycling. Not only does such arrangement provide livelihoods to vast numbers of the poor people, but they save the city nearly 15–20 % of its waste management expenditure (UN-habitat 2010).

The European Union (EU) is in forefront with respect to the efforts across the Europe to minimize waste by issuing numerous specific directives and therefore there is rise in recycling from 11 % between 1985 and 1990–29 % in 2000 (Saleh 2011; Slater and Frederickson 2001). In USA more than 71 % of corrugated boxes, 82 % newspapers, 56 % office papers, 44 % aluminum beverage cans (Hristovski et al. 2007) are recycled. 31 % of MSW being composted representing 23 % of all material recovered (Saleh 2011). MSW recycling increased from 15.6 % in 2002–2003 to 19.0 % in 2003–2004 in the UK (Saleh 2011). There are more than 160 community recycling sites in the UK (Garg et al. 2009). Nearly 66 % of the total waste was recycled in Denmark during 2003 and about 57 % of waste was recycled during 2004 in Germany (Saleh 2011). The recycling increased from 50 to 77 % between 1985 and 2000 in Netherlands (Saleh 2011).

Fig. 4.29 An example of reusing. Bins used for chemicals are being used for growing plants

Fig. 4.30 Storage yard before recycling

Large quantity of waste materials discarded during petroleum exploration industry. As per studies conducted by (Souza et al. 2011) solid petroleum waste (SPW) can replace natural clay material up to 30 wt %. Studies conducted by Paola (2011) revealed that fennel and lemon wastes can provide substantial enzyme production yields whereas carrot waste supported Poly-Hydroxybutyric Acid production.

Table 4.2 shows example of using of some of the components of waste. Figure 4.29 shows an example of reusing wherein bins used for chemicals have been used for growing plants. Figure 4.30 shows a storage yard before recycling. Figure 4.31 shows chemical bins, printed flex sheets used for advertisement kept for sale. Agro-waste like baggage, rice straw, wheat straw, and rice husk, saw mill waste, ground nut shell, jute, cotton stalk, vegetable residues can be used for manufacture of particle boards, insulation boards, wall panels, roof sheets, fibrous building panels and bricks.

Fig. 4.31 Chemical bins, printed flex sheets used for advertisement kept for sale

Recycling was never a new approach in developing countries as one man's waste is resource for other person. Considering poverty in developing countries nothing will be wasted as long as it can earn or save some money. But during 1980s recycling of waste was favored against disposal in developed countries. In 2009, recycling which included about 9,000 curbside recycling and around 3,000 yard trimmings composting programs recovered 33.8 % of MSW generation in 2009 (USEPA 2010).

Figure 4.32 shows waste processing at a typical material recycling facility in developing country which is more machine dependent. The methods for recovering recyclable from MSW are: (1) source separation, (2) separation of comingled waste at MRFs, (3) Separation at MRF preceded by front end processing facilities.

4.2.1 Aerobic and Anaerobic Treatment

Aerobic treatment is a process wherein waste is degraded by bacteria in the presence of oxygen. In the case of anaerobic treatment degradation is carried out in

Table 4.2 Examples uses of some of the components of waste

Waste	Use
Coconut shell	Activated carbon, fuel
Egg shell	Plant feed, source of calcium
Used printed flex sheet used in hording	Blanket, mat, tarpaulin to cover agricultural product, water proofing in roofs
Used chemical drums	Growing plants, container for water in houses
Glass pieces	To place it on compound walls for added security
Food waste	Composting, animal feed
Newspaper	Packaging
Dried skin of citrus fruits	Fragrance agents in floor/toilet cleaners

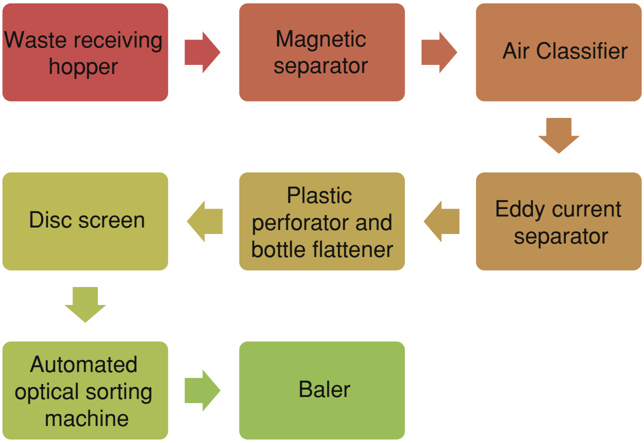


Fig. 4.32 Waste processing at a typical material recycling facility

the absence of oxygen. The subsequent paragraphs discuss some of the widely used aerobic and anaerobic treatment methodologies.

4.2.2 Composting

Composting is a method of reusing known since times immemorial. Waste composting is a technology for treating organic fraction. But all the facilities are not operated smoothly. Of the 19 facilities contacted by Renkow (1998), one facility was stopped due to cost problems and liability, one was forced to close because of odour problems, and one was shut down due to technical problems. The cost of the mechanical turner and shelters are the major investment needed.

Composting of solid waste involves three steps namely, (1) preparation, (2) decomposition, and (3) product preparation.

Waste segregation		Waste segregation is done to separate biodegradable fraction of waste. Shredded to reduce size of waste component for proper handling and increase surface area so that microbes can decompose at a faster rate.
Composting in windrows	  	Windrows of organic material are formed either in dedicated shelter or in open atmosphere. Humidity is maintained by spraying water; temperature is maintained by proper mixing and passing heat through heaps; pH is maintained by adding lime or other basic material. Commercially available microorganism or old compost is added to inoculate microorganism.
Screening		Screening is carried out to separate larger non degraded fraction.
Packaging		The final fine particles of compost are packed and marketed.

Fig. 4.33 Large scale composting

Composting is the decay of organic material by microorganism in artificially controlled facility. The composting is suitable for biodegradable fraction of a waste stream. The method is not suitable for wastes that are too wet during which dry waste may have to be added or the leachate in the waste be drained. Issues of methane emission, flies and odour from poorly managed compost plants may need to be tackled. Improper waste segregation there will lead to entry of toxic substance into the stream of MSW affecting activity of micro-organism.

The two composting processes used are windrow-based composting and in-vessel composting. In the windrow system, waste is formed into windrows that are 1–2 m high (Fig. 4.33). These windrows are turned time to time by means of an automatic turning machine or manually. In order to maintain a constant temperature. Water is added to maintain optimum moisture content. After a required level of decomposition is attained, the composted material will be ready for use in agricultural application. Windrows can also be aerated by passing air through pipes into the windrows. An idealised version of windrow compost is one that could be housed in a shelter. The shelter would be provided with the ventilation equipment or kept open depending on climatic conditions of the areas. The innovation and cost saving have led to the use of plastic sheets to cover the windrows to protect the windrows from rain and other elements of weather. Plastic litter and other disintegrated materials in the compost product can be removed by screening.

The in-vessel or compost tanks are constructed with provision for drainage and aeration (Fig. 4.34). In in-vessel systems decay of organic materials is carried out in large sophisticated vessels built for speeding biological decay by controlling oxygen, temperature, moisture content and carbon to nitrogen ratios. Usually

Fig. 4.34 Composting tanks

coarse material of 40 mm makes the bottom layer, over which pebbles of smaller dimensions and gravels are placed to avoid water logging, easy for drainage. While it is essential to maintain pH, humidity and temperature at optimum level, field conditions may not allow this. But as a precautionary principle citrus fruits and other acidic substances may be segregated to avoid drop in pH. Occasional spraying of water to maintain humidity is essential. Proper ventilation ensures optimum temperature by avoiding heat build-up due to bacterial activity within the tank (Fig. 4.34).

Factors affecting composting are shown in Table 4.3. The time required for composting varies from one to 3 months. Addition of nitrogen source like urea may be required to optimise the process. Increase in temperature would increase the rate of biological activity. But the rate of activity of enzymes and microorganism would decrease if the increase in temperature rise is more than the optimum temperature required for species responsible for composting. The activity of cellulose enzyme will reduce at temperature more than 70 °C. Optimum temperature for nitrification is 30–50 °C beyond which nitrogen loss will occur.

Vermicomposting is a process of composting in which earthworms are used for conversion of waste into compost (Fig. 4.35) The vermicomposting is carried out at 10–32 °C (temperature in the pile of waste). The process is quicker than composting as the material passes through the gut of earthworm. Vermicompost is superior to conventionally produced compost. Worms can be used as a high-quality animal feed.

Disadvantage of vermicompost is that it requires more labour and space as worms do not operate in waste heap more than a meter in depth. The worms are vulnerable change in temperature, pH, toxic substance and other inhibiting factors like water logging. Vermicompost requires more worms and, hence, worms need to be procured prior to starting vermicompost plant.

Vermicomposting needs bedding with high absorbency, good bulking potential and high carbon to nitrogen ratio. Worms respire through their skins and hence

Segregation		
Composting Tanks/windrows		
Vermicomposting		
Screeing		
Vermicompost ready for despatch		

Fig. 4.35 Vermicomposting process

must have a moist environment. The bedding must be capable of absorbing and retaining water. Flow of air is reduced or eliminated if the material is packed too tightly leading to reduced oxygen in bedding. Rapid degradation and associated heating is not favourable to worms and could be fatal. Some of the materials that

Table 4.3 Important factors affecting composting of waste

Factors	Comment
Waste size	For optimum results it is necessary that size be in the range of 45–75 mm
Seeding	Seeding like animal dung, sewage sludge, compost or commercially available microbes will enhance speed of decomposing. The seeding required would vary from 1 to 5 % by weight
Mixing/turning	Required to avoid drying, caking, air channeling. The requirement of mixing and turning depends on waste type
Moisture content	Moisture content of 50–60 % would give the optimum results
Temperature	For best result the temperature required is between 50 and 60 °C depending on type of waste. Beyond 66° the activity of bacteria would be reduced to great extent
Carbon to nitrogen ratio	Carbon to nitrogen ratio between 50 and 60 would be optimum
pH	It is desirable to maintain a pH between 6 and 8

can be used for beds are coconut fibre, hay, straw, paper, bark, corrugated card board, saw dust, wood chips, dry leaves, corn stalks and corn cobs.

Earthworms consume organic matter and reduce the volume by 40–60 %. The earthworms consume the biodegradable matter and generate excreta referred as vermi-castings. Each earthworm weighs approximately 0.5–0.6 g, eats organic matter equal to its body weight and generates cast equivalent to around 50 % of the organic matter it consumes in a day.

Vermicomposting provides the growth enhancing hormones and nutrients and, are required for plant growth. Plant products grown with vermicompost have been reported to be of good quality.

Normally the beds are 75–90 cm thick with provision of filter for draining excess water. The bed should be with uniform height through out the length and width. The bed width should be sufficient to allow easy access to the centre of the bed and, hence, 1.5 m wide is recommended and practiced. Length and width of bed do not matter as long as the temperature of 20–30° and moisture content of 40–50 % are maintained. The number of earthworms introduced varies between 300 and 400 worms per m^3 of bed volume for optimum result.

Eisenia fetida, Eudrilus eugeniae, Perionyx excavatius are some of the best species for used for vermicompost. The life of earth worms is about two years. One earthworm would reach reproductive stage in about 6 weeks and worms at the reproductive stage will lay egg capsule every 7–10 days and three to seven worms will come out of each capsule. Hence the multiplication of worms in optimum environment is very fast. Fully grown worms can be separated and dried to make ‘worm meal’ for use in animal feed as it comprises of 70 % of protein (Keralaagriculture 2011).

The worms should be fed with waste that provides nutrition to worms waste should not contain material that generates heat due to decomposition. The waste should also be devoid of excess moisture, grease, salt and chemical that is detrimental to worms. Extreme pH would also affect worms and hence the waste should

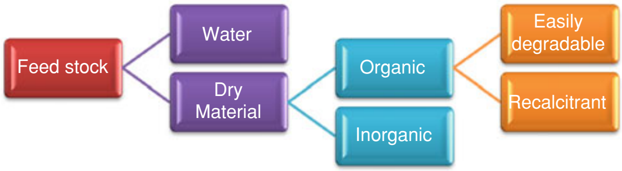


Fig. 4.36 Components of feedstock

be devoid of citrus fruits and other acidic substances. Hence it is advisable to pre-compost partially prior to introduction of worms. For optimization of the vermicompost it would be necessary to have batches of one month after which the compost need to sieved and larger fractions be returned to vermicompost pit. Worms are food for birds, moles, ants, centipede, ants and mites. Hence it is essential that worms are protected by covering or constructing beds in sheds. In spite of the above constraints vermin compost is carried out massively as the vermicompost stimulates the plant growth (Atiyeh et al. 2000) and provide resistance to plant deceases (Glenn 2012).

4.2.2.1 Anaerobic Digestion

Anaerobic Digestion (AD) system was used by the Assyrians in the 10th century BC and in Persia during the 16th century (Christian and Dübendorf 2007). Most of the AD system was done in anaerobic ponds prior to 1920. The industrialization of AD system started in 1859 by the first AD system in Bombay (Now Mumbai), India. The energy crisis in 1973 and 1979 triggered development of AD systems for methane production. Industrial countries are now using the technology for treatment of municipal as well as industrial waste.

Volatile fatty acids (VFA) generated by hydrolysis-acidification should properly be balanced in AD system as methanogenic bacteria are sensitive to presence of VFA. Production of VFA higher than the methanogenic rate will lead to failure of the AD system due to accumulation of VFA.

Figure 4.36 shows the components of feed stock. The organic matter can be divided easily degradable (like proteins, fats and carbohydrates) or can be recalcitrant (like lignin and cellulose). Fats are decomposed to glyceride and organic acids hence the presence of too much fat in the feedstock will lead to accumulation of organic acids resulting in decrease of pH and inhibition of degradation. Carbohydrates are degraded into mono-saccharides or acidic acids. Feedstock rich in starch/saccharide will be quickly converted into acids leading to drop in pH and digester will turned into irreversible state of acidification. Proteins consist of nitrogen, sulfur and phosphorus resulting in generation of ammonium and hydrogen sulfide.

Each bacteria culture has its own optimum temperature range and hence a temperature fluctuation should be avoided. Variability in feedstock will affect the performance and as such variation does not allow microbes to get acclimatised.

4.2.3 Road Making

The use of waste materials in asphalt pavement represents an optimistic outlet for such materials. Use of such material comes with property needs and technical restriction. Such needs and restrictions lead to processing cost which is higher than cost of virgin aggregates. Glass, steel slag, scrap tyre and plastic can be used for road making (Yue et al. 2007). While scrap tyre and plastic can be used as binder all the four material mentioned can be used as aggregate.

Use of 10–15 % crushed glass with 4.75 mm maximum size in surface course has shown satisfactory performance in asphalt pavements (Yue et al. 2007). The same equipment and method designed for conventional asphalt can be used for asphalt with recycled glass (Airey et al. 2004; CWC 1996; FHWA 1997; Maupin 1998; Su and Chen 2002). Anti-strip agent, usually 2 % hydrated lime, is added to maintain the stripping resistance. Glass in asphalt of higher content and larger size is likely to result in inadequate friction and bonding strength(Yue et al. 2007).

The angular shape, hardness and rough surface makes steel slag substitute coarse aggregates in asphalt. Scrap tyre can be used by dissolving crumb rubber in the bitumen as binder modifier. Portion of fine aggregates can be replaced with ground rubber. Plastics can be used either as aggregate by replacing a part of aggregates, or as a binder modifier.

4.2.4 Removal and Recovery Method

In this method waste is blended with solvent and subject to distillation treatment for recovering organic fraction which has combustible value. Organic acids formed during anaerobic digestion was recovered using freezing and thawing, centrifugation, filtration as well as evaporation (Farah et al. 2009).

4.2.5 Stabilization

In this method waste is mixed with solidification agent such as cement/asphalt before land disposal. The procedure is adopted elaborately for hazardous waste fraction in order to safeguard environment from possible leachate generation and reaction with in compatible substances. A more details discussion on the topic is done in Chap. 7.

4.2.6 Deactivation

This treatment is primarily used for corrosive wastes and explosives. In this method corrosive and explosive wastes are blended with suitable chemicals prior to disposal in land fill to avoid possible reaction in the landfill.

4.2.7 Metal Removal and Recovery

This method involves precipitation of heavy metals from semisolid waste like sledges followed by recovery of metal from precipitate. Metal ions form complexes with water-soluble polyelectrolytes, which can be precipitated with polybases for recovery of metals (Jellinek and Ming 2003). Hydroxide and Carbonate precipitation could be used for recovery of manganese (Wensheng et al. 2010).

4.2.8 Aqueous Treatment

This treatment includes biological treatment, wet air oxidation, chemical oxidation/reduction. In this method waste is subject to treatment after mixing with water. Biological treatment can be aerobic or anaerobic which is already discussed in Sect. 4.2.1.

4.2.9 Plastic Granulating

Some materials (e.g., plastic bottles) can be shredded by slow-speed shears to reduce size of plastic objects. The process is called plastic granulating.

4.2.10 Emerging Biological Technologies

Out of many emerging technologies bio-drying, aerated static pile composting, mechanical waste biological waste treatment, and aerated static pile composting are commonly used.

In bio-drying biodegradable waste is rapidly heated in the initial stages of composting to remove moisture (Choi et al. 2001; Navaee-Ardeh et al. 2006; Sugni et al. 2005; Velis et al. 2009). In the mechanical waste biological waste treatment, waste is sorted out in the first step followed by mixing, moistening and biological degradation (GTZ 2003). In aerated static pile composting, perforated channelled concrete floor with piping is used for supplying oxygen to the degradable fraction of solid waste.

Feeding of MSW to larvae constitutes a benefit for low income countries. Black soldier fly, Hermetia illucens, has been studied and found that waste can be reduced from 65.5 to 78.9 % and prepupae can be used as additive in animal feed (Stefan et al. 2011).

Biologically produced hydrogen (or bio-hydrogen) can be produced by wide variety of microorganisms under anoxic conditions (Gustavo 2008).

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