UNIT 4 TREATMENT OF SOLID WASTE

Structure

4.0 INTRODUCTION

In the past our ancestors disposed of their wastes simply by burying it into soil. The waste generated by early man was relatively less in quantity and mainly of biodegradable in nature, therefore burying was an appropriate technology for disposal. But modern man produces a large amount of waste with high level of complexity. So, in the present scenario burying all the waste is not an appropriate solution. As a huge amount of waste is generated every year and generation is growing with time in most of the countries of the world. The waste generation is the outcome of various domestic, commercial and industrial processes or activities. Improper disposal of this entire huge amount is a vast environmental problem with many dimensions such as production of foul odour, water and soil pollution. The treatment and disposal of solid wastes is one of the most important concerns for human. Mishandling of solid wastes may degrade the environment and cause effects on human health, and may cause loss of recoverable resources present in these wastes. Treatment of solid wastes helps in the reduction of the total volume, alters the form and makes it easier to handle. It can also help to recover certain useful resources or materials and as well as heat energy or biogas. This unit will familiarize you about various treatment methods used for solid wastes, hazardous wastes, biomedical wastes and e-wastes

4.1 OBJECTIVES

After reading this unit, you should be able to:

- describe various treatment methods for biodegradable solid waste;

- explain the process and stages of biogas generation;
- comprehend the physical, chemical, thermal and biological methods for treating hazardous waste;
- list the treatment methods for biomedical waste; and
- describe various treatment and disposal methods for e-waste.

4.2 AEROBIC AND ANAEROBIC TREATMENTS OF SOLID WASTES

Dear Learners, let us now read about aerobic and anaerobic treatments of solid wastes in the following lines.

4.2.1 Composting

Composting is one of the means of biodegradable solid waste minimization. It is the transformation of biodegradable organic matter by heterotrophic microorganisms (such as bacteria, fungi, actinomycetes and protozoa) into peat-like material termed as compost. For the smooth functioning of composting process main requirement is right microorganisms, feed material, nutrients for microorganisms, proper moisture content and temperature. Any unfavorable change in these parameters can influence the rate of composting process (Fig. 1). The composting process can be divided into two categories on the basis of the presence or absence of oxygen during the decomposition process.

a. Aerobically (in presence of oxygen)

The aerobic composting process occurs in the presence of ample oxygen. In aerobic composting, aerobic microorganisms oxidize organic matter and convert it into carbon-dioxide, ammonia humus and other stable organic products. In this process, microbes use carbon from organic materials as a source of energy and nitrogen is recycled. It is an exothermic process so the temperature of the composting pile arises during the process.

b. Anaerobically (in absence of oxygen)

Anaerobic composting involves a completely different set of microorganisms and conditions that does in aerobic composting. Anaerobic composting takes place in oxygen deficient conditions. In oxygen deficient conditions aerobes are unable to survive and another type of microbes called anaerobes replace them and decompose the waste. Here the anaerobic microorganisms, take carbon and nutrients from organic matter and break down the organic compounds. The main gases produced from the process are methane, carbon dioxide and hydrogen sulphide. Sometimes the unpleasant smell is produced from the pile due to the release of sulphur containing compounds like hydrogen sulphide; however slight sulphur smell can indicate that the decomposition process is working properly. This process usually takes longer time than aerobic composting.

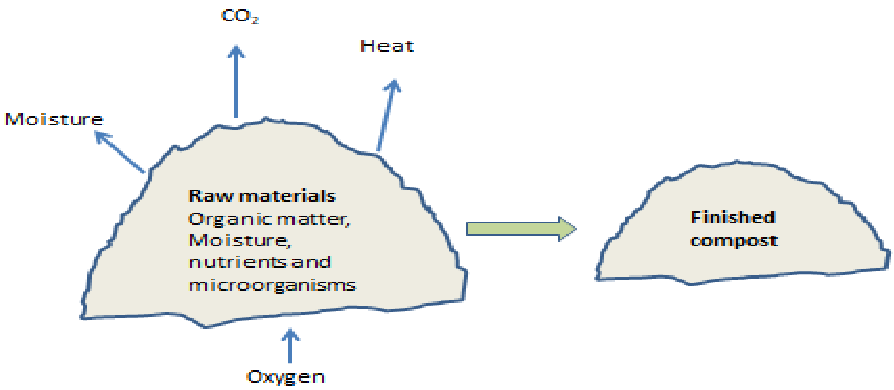

Fig. 1: Composting process

Key Factors that Affect the Composting Process

As mentioned earlier in this unit composting is a microbial dependent process. Similar to other biotic organism microbes present in composting also require, the right environment to live and flourish. For effective composting, microorganisms require oxygen, nutrients, proper moisture, pH and temperature.

Oxygen

In case of aerobic decomposition a large amount of oxygen is needed by microbes, particularly at the initial stage. Oxygen supply is necessary for aerobic composting and can be added through aeration. If the supply of oxygen, reduced during the composting process, it will affect the growth of aerobic microorganisms and decomposition of the material. Proper aeration helps in the removal unnecessary heat, moisture and other gases trapped in the pile. Thus, proper aeration is essential for efficient composting and can be attained by regulating different conditions like pile size, particle size, moisture content, ventilation and frequency of turning of feed.

Nutrient content

To sustain life processes microorganisms need some energy, they obtain the required energy and nutrients by degrading organic materials. A large number of nutrients are needed by microbes in composting, but among these C and N are the most critical. Among these C acts as a source of energy and basic building block material. C content share about 50% of the total mass of microbial cells. Another vital nutrient required by microbes for cell growth and function is N, it is a necessary constituent of proteins, nucleic acids, amino acids, enzymes and co-enzyme. The best proportion of these two elements for composting is about 30:1 or 30 parts carbon to 1 part nitrogen by weight. The C: N ratio decrease slowly during the process and in the finished compost it reduced around 10 - 15:1.

Temperature

Too high and too low temperature of compost piles affects microorganism growth and activity, and which affects the rate of decomposition of feed material. The temperature of the pile is dependent on numerous dynamics, including C: N ratio, surface area, moisture content and aeration. Most common ways used for regulating temperatures are aeration, turning, altering pile moisture contents and changing pile sizes. It is noticed that in initial stage temperature increase sharply as compared to later stages. During composting process, the rate of decomposition of organic matter increase, with increase of temperature.

pH Value

The pH value of compost material affects the composting process by affecting the microbial population and by controlling the availability of nutrients to microbes. The optimal pH range is 6.0 to 7.5 for most of the bacteria and 5.5 to 8.0 for most of the fungi. The pH value of material also affects the fate of N compounds during composting, if the pH value surpasses 8.5, it boosts the conversion of nitrogen compounds to ammonia. A combination of high temperature more than 40°C and pH below 6 severely also deters the composting process.

Moisture Content

All living organisms want water, therefore moisture is necessary to support metabolic functions of the microorganisms. For composting process materials should contain a moisture content of 40–65 percent. If the pile is too dry, the microorganisms may become inactive and the composting process will slow down. At greater than 60 percent moisture (too wet), there is not enough air for aerobic decomposition and anaerobic conditions develop. Excess moisture content may cause loss of nutrients, production of foul smell and slow down the composting process. In general, it is desirable to start the pile with slight high moisture content and in the end it should be 30%.

4.2.2 Vermicomposting

Vermicomposting is an anaerobic process for the treatment of organic solid wastes. It is a feasible, cost-effective biological method for the efficient management of the organic solid wastes. The end product of process is a well stabilized, aesthetically attractive, finely divided humus-like material with excellent structure, porosity, aeration, drainage and enhanced moisture holding capacity with the ability of increasing plant growth. Earthworms can feed on a variety of organic wastes such as crop residue, animal manure, sewage sludge, agricultural wastes, food wastes, industrial wastes etc. In this process microbes are responsible for biochemical degradation of organic matter and earthworms responsible for physical actions such as fragmentation, turnover and aeration. During the process earthworms and microbes modify biological, physical and chemical state of organic matter. Under favorable conditions (pH, temperature, aeration and moisture), earthworms ingest organic waste materials and egests a humus-like substance which is more homogeneous than the organic wastes.

During this process, vital plant nutrients (NPK) present in the waste materials is converted into such chemical forms which are much more soluble and available to plants than the parent organic waste substrate. The main benefit of this process is that, it can be done on any scale from household vermicomposting of organic waste to a community or city scale vermicomposting. The success of the vermicomposting process depends on a number of abiotic and biotic factors. The most important abiotic factors which affect the vermicomposting process includes moisture content, pH, temperature, aeration, feed quality, light, C: N ratio etc. Key biotic factors which affect the vermicomposting process include earthworms stocking density, microorganisms, enzymes etc.

Another process related to vermicomposting is vermiculture. It is rearing or cultivation of worms (earthworms) and is slightly different from vermicomposting. In vermiculture the main goal is to constantly increase the number of worms in order to obtain a sustainable harvest. However, in vermicomposting the main goal is to degrade the waste and produce compost.

Earthworms

Earthworms are the key essentials of vermicomposting process. There are more than 3300 species of earthworms present all over the world and about 550 species of earthworms are present in India. Different earthworm species have different habitat characteristics, ecological niches, lifestyle and life span. On the basis of the morpho-ecological characteristics earthworms have been classified into three categories (i.e. epigeic, endogeic and anecic). Commonly used earthworm species are *Eiseniafetida*, *Eiseniaandrei*, *Lumbricusrubellus*, *Eiseniahortensis*, *Eudriluseugeniae*, *Lumbricusterrestris* and *Perionyx excavates*. The selection of suitable species for vermicomposting and consequential utilization is necessary. The worm species should have high tolerance environmental factors, high feeding rate, high growth rate and easy to culture.

Steps in vermicomposting process

A detail of vermicomposting process is given in Fig. 2. The following steps are followed for vermicompost preparation:

- For vermicomposting setup first requirement is a cool, moist and shady site.
- Collect degradable material, chop and mix properly, and keep the mixture for partial decomposition for 2-3 weeks.
- Prepare 10-20 cm height bed, composed of partially decomposed material such as dry leaves/newspapers/grasses and kept at the bottom (Fig. 3).
- Add partially decomposed material on these beds (1-1.5hx2.5-3w feet) and add water to moist the material.
- The length of vermin-beds can be increased as per the availability of space and raw material availability.
- Then release earthworm (1500-2000) in the upper layer of bed and again sprinkle water.
- Beds should be kept moist by sprinkling water (daily) and by covering with gunny bags or some other material
- Bed should be turned once after 10-20 days for maintaining aeration and for proper decomposition.
- Vermicompost gets ready in 60-70 days depending upon the raw substrate.
- The finished product (vermicompost) is 3/4th of the raw materials used.

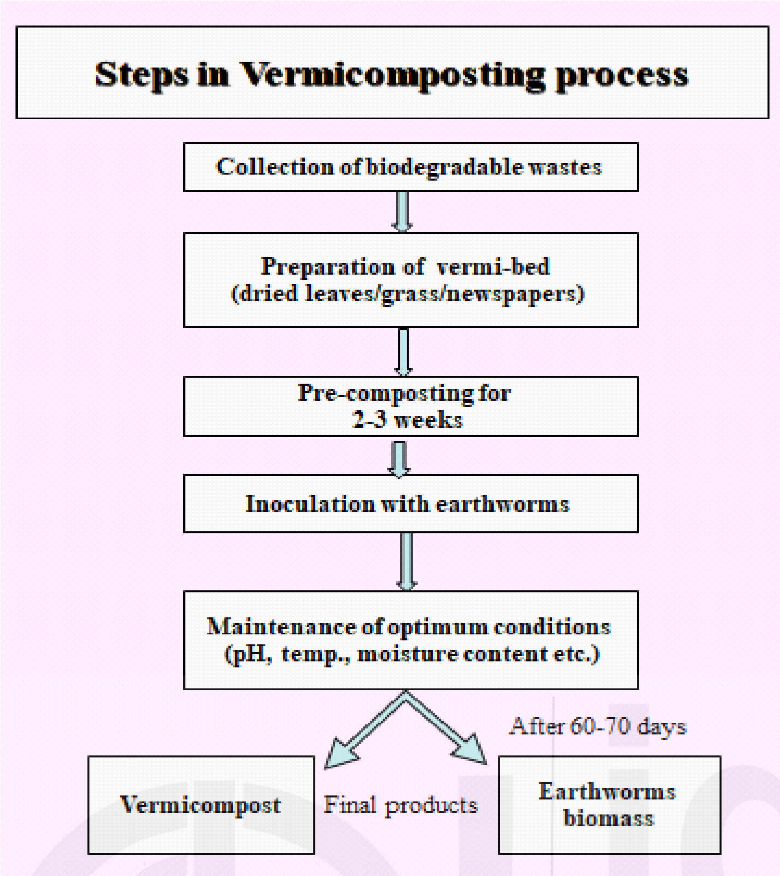

Fig.2: Steps in vermicomposting process

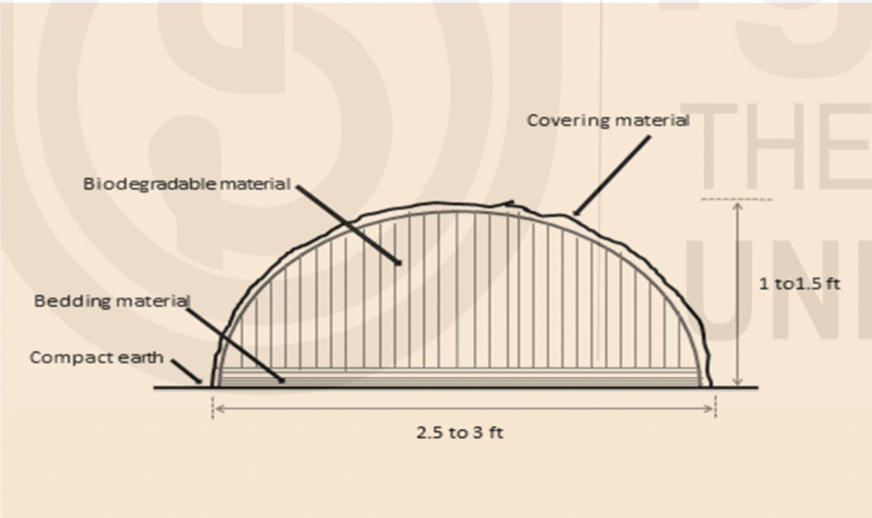

Fig. 3: Vermicomposting setup

4.2.3 Biogas Generation

Biogas is a mixture of methane (CH_4), carbon-dioxide and some other gasses. These gases are produced when microbes degrade biological/organic material in the absence of oxygen, in a process known as anaerobic digestion. Biogas generation is a natural process and usually occurs in nature, for example at the bottom of lakes, in marshes and wetlands, in slurry pits and in the rumen of ruminants. The degradation biological/organicmaterial is mostly done by the fermentation process which is carried out by various groups of microorganisms such as bacteria, fungus and actinomycetes. But anaerobic bacteria are the dominant group of microorganisms involved in biogas generation process.

Anaerobic digester systems have been used for decades for the treatment of municipal wastewater sludge, industrial and agricultural wastes. These systems are designed in such a way to enhance the growth of anaerobic bacteria that generate methane and carbon-dioxide. An anaerobic digester or biogas plant is an airtight chamber that facilitates the anaerobic degradation of biodegradable waste materials. These digesters are cubical or cylindrical in shape and are made from concrete, brick, steel or plastic. A variety of biodegradable materials like agricultural waste, manure, municipal waste, sewage sludge, plant material, green waste or food waste, can be used in the anaerobic digestion process. Normally, using organic wastes as the major input, the systems produces biogas that contain 50 to 60% methane, 25 to 50% carbon-dioxide, 1 to 10% N_2 and may have small amounts of other gases such as hydrogen sulfide (<1%), moisture, hydrogen, ammonia etc.

Steps of Anaerobic Digestion Systems

Various phases of anaerobic degradation take place simultaneously in a single-stage process. However, as the bacteria involved in the various phases of degradation have different requirements in terms of habitat (pH value and temperature).

1) ***Hydrolysis:*** In the ûrst step, large and complex organic compounds like starches, cellulose, proteins and fats are converted into simpler sugar chains, amino acids and fatty acids. It is a relatively slow process and it can affect the rate of the overall anaerobic digestion process, especially when solid organic waste was used as the substrate. During the process a number of extracellular (outside the cell) enzymes are produced by various specific bacteria to catalyze the decomposition of the material.

2) ***Acidogenesis (Formation of acid):*** During this step acid forming bacteria transform the decomposed organics to ammonia, hydrogen, carbon-dioxide, hydrogen sulfide, shorter volatile fatty acids, carbonic acids, alcohols, as well as small amounts of other by-products. Some amount of higher organic acids (propionic and butyric acid) is also formed during this stage, which is then converted into acetic acid and hydrogen by acetogenic bacteria.

3) ***Acetogenesis (Formation of acetic acid)*** Acetogenesis is the formation of acetate, a derivative of acetic acid. In this step the intermediate products are then converted into precursors of biogas (acetic acid, hydrogen gas and carbon dioxide) by acetogens.

4) ***Methanogenesis:*** Methanogenesis is the most important step in the entire anaerobic digestion process; here methane gas is generated from acetic acid, hydrogen and carbon-dioxide. In this process of methane generation two different groups of bacteria are responsible, one group reduces acetic acid to methane and the other produces methane from carbon dioxide and hydrogen. Methanogenic bacteria are completely dependent on the acetogenic and acidogenic bacteria to survive, as these organisms provide

acetic acid, carbon-dioxide and hydrogen to methanogens. Some of the major species reported in methanogenesis process are *Methanobacterium formicicum, Methanobacterium bryantic, Methanobrevibacterrum inantium, Methanobrevibacter arboriphilus,Methanobrevibacter smithii and Methanococcus vannielli.*

Environmental Conditions in the Biogas Digester

Methane producing microbes are very sensitive to environmental conditions and any alteration in these conditions can influence the production of biogas (Table 1). Some of the conditions are discussed below:

Retention time

Retention time or hydraulic retention time is the average time that a given volume of material stays in a digester. Retention time is an important operational parameter for the anaerobic reactors, which can affect the conversion of biodegradable material into biogas. The production of methane gas from the digester is dependent on retention time of input material. It is one of the most important factors affecting the economics of a digester. The theoretical retention time for a digester can be calculated by dividing the average slurry holding capacity by the amount of the substrate added daily. Retention time depends on various factors like feed material characteristics, vessel geometry, moisture content, temperature of process, etc. The ideal retention time may vary between 30 and 90 days depending upon the substrate.

Oxygen

Anaerobic digestion is the totality of the collective interaction of various microbial groups. Anaerobic digestion, as the name itself expresses, is a process that occurs in environments without oxygen. Oxygen is commonly supposed as a toxic agent in anaerobic digestion, especially to the acetogenic and methanogenic microorganisms, which are obligate anaerobes.

pH Value

Methanogenic bacteria are very sensitive to pH and pH values outside of the ideal range affect their metabolic activities and growth. The optimal value of pH should be in between 6-7 for input material. After stabilization of the methane production level in a digester, the pH range remains maintained in the range of 7.2 to 8.2. The pH in a biogas digester is also a function of the retention time.

Temperature

Methanogens are very sensitive to too high and too low temperature; optimum temperature is 35°C. If the temperature is too high or too low than their optimum range, the relevant microorganisms may be inhibited or, in extreme cases, suffer irreversible loss. The microorganisms involved in decomposition can be divided into three groups on the basis of their temperature optima i.e. psychrophiles 0 to 20°C, mesophiles 15 to 45°C and thermophiles 40 to 65°C.

Nutrients

The biogas production process is dependent on the growth of microorganisms. For the optimal growth of these microorganisms, nutrients are needed in sufficient amounts and at the right proportions. The carbohydrates and lipid content of organic substrate mostly provide carbon, oxygen and hydrogen, while nitrogen and sulphur are supplied via proteins and phosphorus from nucleic acids and phospholipids.

Carbon/Nitrogen Ratio (C/N)

Carbon/Nitrogen (C/N) ratio is expressed as the relationship between the amount of carbon and nitrogen present in organic substrate. Microorganisms need both nitrogen and carbon for assimilation into their cell structures. The optimum C/N ratio for anaerobic digestion is ranging from 20 to 30. When the C/N ratio is too high, the nitrogen will be consumed rapidly by the microorganism and will no longer react in the unused carbon content present in the material.

Table 4.1: Factors affect the biogas generation

Factors	Optimal value
pH	6.5 to 8.0 (near neutral pH is best suitable)
Temperature	35 ^{o}C (not less than 15 and higher than 45)
C: N ratio	20-40:1 (optimal C: N ratio is 30:1)
Retention period	30-60 day (depends on feed material, season and type of plant)
Water content	60-75%
Particle size	As small as possible
Toxic substances	Pesticides, fungicides, insecticides or other harmful chemicals
Mixing	Periodically mixing required to prevent scum formation in digester

4.3 TREATMENT OF HAZARDOUS WASTES

The aim of this section is to discuss the various treatment methods adopted for hazardous wastes. There are a numerous methods are present in the management of hazardous wastes. The most preferred option is to reduce the amount of hazardous waste at its source or to recycle the materials for any other productive use or as a raw material for another process. However, these options are not considered as the final solution to the problem of hazardous-waste disposal. After the application of these solutions (volume reduction and recycling/reuse) the waste further requires treatment for the safe storage and disposal of remaining hazardous waste. During the treatment, hazardous waste is transformed into less harmful materials by using physical, chemical, biological and thermal processes, followed by proper disposal of residues. During hazardous waste management, selection of treatment technology should be done carefully on the basis of physical and chemical characteristic of waste, nature and type of waste, level of treatment required and cost of treatment. The main purpose of hazardous waste treatment is to reduce the harm that can be caused by such wastes to humans and to the environment. Hazardous waste treatment can be classified as physical, chemical, biological and thermal.

1. Physical Treatment

Physical treatment methods were derived from observations of the physical forces of nature. These operations can be used individually or in combination with other treatment technologies as pre or post treatment. Physical treatment is a separation process that is used for separation and/or concentration of the hazardous waste to cut the volume of material needing further treatment or disposal. The most commonly used physical treatment methods are discussed in detail in this section.

Filtration

Filtration is a common and well-developed an economical process, in which solid particles are separated from a liquid using a porous medium. Energy needed for filtration process is very less and working parameters are also well defined. However, in most of the cases it is not a main treatment process and is often used in combination with other process such as flocculation, precipitation and sedimentation.

Dewatering

Dewatering removes free liquids present in hazardous waste and reduce waste volume for more stable and economical transport, and incineration. This method is generally applied on hazardous sludge's. Usually sludge generated from different industries contains 1 – 30% of solids by weight. The commonly used sludge dewatering processes are rotary drum vacuum filters, belt filter presses, and plate and frame filter presses. In dewatering process the purpose is to concentrate the solids into a phase or solid form for further treatment or disposal.

Encapsulation

In the encapsulation process hazardous waste is packed in containers made of water-resistant and non-reactive materials. Sulfur polymer stabilization/ solidification, chemically bonded phosphate ceramic encapsulation, and polyethylene encapsulation is some of the established methods used for the hazardous waste treatment. Sometimes when the wastes are less hazardous, then we simply mix the waste with lime, fly ash and water to convert it into a cement like material. Encapsulation of hazardous waste materials is commonly used in the treatment of heavy metals (such as arsenic, mercury, nickel and chromium), polychlorinated biphenyls (PCBs) and radioactive materials.

Sedimentation

It is a physical method in which suspended particles present in a liquid settle down due to gravity. It has been used in liquid hazardous waste treatment for the removal of oil, biological solids and chemically precipitated solids. The concentration of solids and their characteristics determines the type of settling. Sedimentation process is of two types i.e. continuous and batch process. Out of these two, continuous process is the most preferred process, especially when a large amount of liquid waste is to be treated.

Coagulation and Flocculation

Coagulation and flocculation methods enable the removal of suspended and colloidal particles from liquids. These processes occur in sequential steps, allowing particle collision and growth of flocs. These processes also include the chemical process of contact and adhesion whereby the colloidal particles present in water form larger-size flocs, permitting them to be more easily removed by sedimentation. Thus, the process is used in two stages; the first stage is a solid-liquid separation (settling, flotation or filtration) and the second stage is sedimentation. Commonly used chemicals for coagulation and flocculation includes **Aluminum chloride, Aluminum sulfate, Polyaluminum chloride, Aluminum chlorohydrate, Ferric sulfate, Ferrous sulfate, Ferric chloride** and poly electrolytes.

Adsorption

Adsorption is a surface phenomenon in which molecular species deposit onto the surface of adsorbent. Common examples of adsorbents are activated carbon, clay, silica gel, colloids, metals, etc. Adsorption is a reversible process, thus the adsorbent can be regenerated and reused by applying heat and steam, or solvent. Temperature, pressure and surface area are the main factors that influence the rate of adsorption. Activated carbon is usually used as adsorbent to remove and concentrate volatile organic carbons from diluted air and water streams.

Distillation

Distillation is an energy demanding and expensive process and has only restricted use for the treatment of liquid hazardous wastes. This technique can possibly be acceptable only in circumstances where valuable product recovery is possible. Usually leachate produced from hazardous waste landfill and other toxic liquid wastes are treated with this technology.

Evaporation

The evaporation process is used to reduce the volume of liquid wastes. In this treatment the primary objective is the removal of water from waste. This process is very useful if waste heat is available. Frequent applications of evaporation include treatment of radioactive liquids and hazardous sludge's produced from industries. Note that this process is applicable only when one of the components is essentially nonvolatile.

2. Chemical Treatment

During a chemical treatment process various properties of a chemical are used to modify or reduce its hazardous elements. In this process chemical reactions change the properties of hazardous waste and convert the waste into less hazardous new compounds (by products) which are safer to treat and dispose off. Some of the commonly used chemical processes are discussed in this section.

Acid-base Neutralization

During this process acidic and basic waste streams react to neutralize the waste and to lessen corrosive characteristics of the waste. Neutralization reactions are most common chemical practice used in the treatment of hazardous waste, in which an acidic waste is reacted with an alkali waste. For example, sulphuric acid containing wastes is usually treated with sodium carbonate (soda ash) to neutralize it. Neutralization before landfill disposal is essential to avoid inter reactions of wastes in landfill. As this is an exothermic process, thus it may cause damage to liners of landfill due to temperature.

Oxidation and Reduction

In oxidation process a common oxidizing agent like hydrogen peroxide or calcium hypochlorite is used to oxidise a hazardous compound. A common example of oxidation of hazardous waste is the reaction of cyanide waste (generated from metal finishing and gold process tailings) with calcium hypochlorite. Reduction process is used to convert inorganic substances into a lesser toxic form using a reducing agent. Reduction of toxic hexavalent chromium to trivalent chromium (chrome waste from metal plating) by using ferrous sulphate is the example of this process.

Precipitation

Chemical precipitation is the most common method for removing of metallic cations from wastewater. In this technique hazardous heavy metals present in wastewater are converted into an insoluble form. However, sometimes it is also for removal of anions such as fluoride, cyanide, and phosphate, as well as organic molecules. For example, sodium hydroxide is used for the removal of cadmium from wastewater through the precipitation of cadmium as its hydroxide.

Ion exchange

Ion exchange is a chemical process in which mobile ions from an external solution are exchanged for ions that are electrostatically bound to the functional groups contained within a solid matrix. Ion exchange isa comparatively costly process compare to other competing processes we discussed earlier like precipitation, flocculation and sedimentation. These processes are most suitable for mixed waste streams containing suspended solids. Removal of anionic nickel cyanide complex and chromate ions from waste solutions is one of the examples of use of ion exchange process.

3. Biological Treatment

Biodegradable wastes can be treated by biological treatment. The effectiveness of this treatment method depends on the ability of microorganisms to degrade a waste. Bioremediation is the commonly used biological treatment of biodegradable hazardous wastes. Wastes that are non-biodegradable are not degraded by microbes; however, they can be removed in a different manner such as adsorption of pollutants on microbial mass. These microbial masses or flock can be removed with sludge. Metal pollutants at low concentration are removed in this manner. Inorganic wastes like acids are immediately toxic to microbes and are not treated by using biological treatment.

Some enzymes released from microorganisms are also capable of converting hazardous waste substances into non-hazardous products. Enzymes derived from microorganisms are capable to convert pesticides into less toxic and persistent products. This intracellular conversion of hazardous substances into non-hazardous products depends on various factors such as temperature and, presence of organic content, moisture and nutrients in waste. Biological treatments may be used after physical or physico-chemical processes, to further refine waste streams. The use of microorganisms under optimized conditions helps in the mineralization of hazardous organic substances, for example the use of pseudomonas under aerobic conditions break down phenols.

4. *Thermal Treatment*

The thermal treatment method involves the application of high temperature to process the hazardous waste. Commonly this involves the combustion of waste materials. It also reduces the volume and allows opportunities for the recovery of energy from the waste.

Incineration

Incineration is the burning of organic in controlled temperature condition may be used as a hazardous waste treatment process. During incineration wastes are converted into ash, flue gas, and heat, which can be used to generate electricity. Incineration of hazardous wastes is usually used as a pre-treatment step prior to its final disposal. After incineration the volume of hazardous waste is also reduced by 50-90%, waste is detoxified and this saves space in landfills. In incineration, burning of organics occurs in two steps, in the first step, volatile matter is driven off leaving the residue to burn to ash and in a second step the volatiles are combusted. Incinerators are designed accordingly. For most wastes a temperature above 800-900^{o}C is enough, but for wastes with high thermal stability temperature greater than 1100^{o}C.The gaseous emissions and fly ash produced during hazardous waste incineration is the major public health concern. Major pollutants produced from incineration of hazardous wastes are carbon monoxide, hydrocarbons, sulphur dioxide, hydrogen chloride, heavy metal fume, dioxins, polycyclic aromatic hydrocarbons (PAHS) and particulates.

Pyrolysis

Pyrolysis is the thermochemical decomposition of organic material at high temperature and in the absence of oxygen or in presence of inert gases. Hazardous waste materials such as PCB's and dioxin are dissociated into their elemental constituents when subjected to high temperatures by a plasma arc. After cooling under controlled conditions, the elemental constituents will recombine into elemental forms and simple, non-hazardous compounds.

Plasma arc

Plasma arc is a thermal process in which a plasma torch is used to produce very high temperatures (above 10000°C) necessary to break the chemical bonds present in the waste material. To generate an electric arc high voltage current is passed between the two electrodes. Initially the waste is heated then melted and finally vaporized. This is mainly used for the treatment of hazardous liquids and gases such as some of the halogenated organics.

Vitrification

Vitrification is a proven thermal method in which hazardous waste is heated to a temperature even greater than for incineration processes to convert the waste into melted mixture (glass like substance). This practice is very common for the treatment and disposal of hazardous radioactive wastes produced from nuclear reactors. For e.g. amorphous borosilicates is an option for nuclear waste storage. During the process, hazardous waste is dried, heated, and then mixed with glass forming substances and heated again (> 1000°C temperature) to convert into the glass like material. The melted glassy material is then discharged into a containment container, sealed, decontaminated, sent for storage or disposal.

Check Your Progress 1

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

1. According to you what should be the best way to treat biodegradable solid wastes?

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2. Enlist various factors that can affect biogas production in anaerobic digestion process.

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3. Explain the aspects required for thermal treatment of hazardous wastes. Write a note on any hazardous waste pollution episode happened in the past.

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4.4 TREATMENT STRATEGIES FOR BIOMEDICAL WASTES

Any waste generated during diagnosis, treatment or immunization of human beings or animals is called biomedical waste. The main sources of biomedical waste are health care establishments, including hospitals, nursing homes, veterinary hospitals, clinics, dispensaries, blood banks, animal houses and medical research institutes. Inappropriate management of biomedical waste can cause severe human health impacts and environmental problems such as pollution of air, water and land. There are several legislations and guidelines related to biomedical waste management are present in India. In biomedical wastes (management and handling) rules 2016, categorization of biomedical wastes has been done according to colour code and type of waste with treatment/ disposal options, which are mentioned in Table 2. Various techniques are used for the treatment and disposal of biomedical waste. Some of key treatment methods are discussed below:

Incineration

As discussed in previous sections of this unit, incineration is the burning of waste in controlled temperature conditions. Incineration results in a very signiûcant reduction of waste volume and weight. Moisture content should be below 30 percent for incineration process. If the conditions of combustion are not properly controlled, toxic gases like carbon monoxide, oxides of nitrogen and dioxins will also be produced. The main advantage of incineration is no pretreatment of waste is required.

Thermal Inactivation

In thermal inactivation process infectious biomedical waste is treated with high temperatures to remove infectious agents. This method is commonly used for large volumes of wastes, especially liquid infectious wastes. Ina container liquid waste is collected and heated by heat exchangers or a steam jacket surrounds the container. The temperature and duration of the treatment process depend on the type of infectious waste. After this treatment, the contents can be discharged into the sewage system for further treatment.

Autoclaving

In autoclaving heat and pressure is applied on contaminated waste in a closed system, over a period of time to sterilize. It is commonly used to destroy infectious agents that may be present in biomedical waste before disposal in a traditional landfill. Autoclaves can be used to process more than 80% of generated biomedical waste and used at different scales to meet the needs of any medical institute. It is an effective process for the inactivation of all microorganisms and most of the microbial spores in a small amount of waste. Typical operating conditions for an autoclave requires a 60 minute cycle at 121 °C (minimum) and 1 bar (100 kPa).

Microwaving

In microwaving, microbial inactivation occurs as a result of the heat generated (due to electromagnetic radiation) during the process. Microwave is suitable for those wastes that contain some moisture, as the moisture allows the heat to penetrate deeper, and the steam sterilizes. The microwaves quickly heat the water contained within the waves and the infectious constituents are damaged by heat conduction. Treatment of medical waste through exposure to microwaves is less expensive than incineration.

Chemical Disinfection

Chemical disinfectants are normally used for killing microorganisms and inactivating hazardous pathogens. It is the ideal treatment method for liquid infectious wastes such as blood, urine, stools, or hospital sewage. The main factors that should be considered during this treatment are: kind of microorganism, degree of contamination, quantity of material, type of disinfectant, interaction time, temperature and pH. Some commonly used chemical includes, dissolved chlorine dioxide, bleach (sodium hypochlorite), peracetic acid, and dry inorganic chemicals.

Irradiative Process

The irradiation process is infected biomedical waste is exposed to gamma rays that are lethal to microorganisms. Irradiation technologies consist of a radioactive isotope of cobalt, or ultraviolet beams, or electron beams. The irradiation method requires a dedicated place, as there are no mobile treatment modules that use radiation. The major significant difference irradiation and microwave technology is the extraction of electrons from the orbit in this technology.

Shredding

In this process waste is reshaped or cut into smaller pieces so as to make the wastes distorted. This helps in inhibition of reuse of biomedical waste and also indicates that the wastes have been disinfected and are safe for disposal. This also reduces the bulk of waste, making transportation easy. A shredder is to be used for the shredding of recyclable contaminated wastes.

Deep Burial

Deep burial disposal is allowed only in remote or rural areas where there is no access to common biomedical waste treatment facility. For deep burial a pit or trench should be dug of more than 2 m deep. Add waste into the pit upto its half depth and then covered with a layer of lime or other chemical disinfectant, before filling the rest of the pit with soil. The deep burial facility should be distant from habitation and not be prone to flooding or erosion.

Table 4.2.Categories of biomedical wastes, their treatment and disposal methods

Category	Waste type	Type of container/bag	Treatment and disposal method
Yellow	(a) Human Anatomical Waste	Yellow coloured non-chlorinated plastic bags	Incineration or Plasma Pyrolysis or deep burial
	(b) Animal Anatomical Waste		
	(c) Soiled Waste		
	(d) Expired or Discarded Medicines	Yellow coloured non-chlorinated plastic bags or containers	Returned back to the manufacturer or supplier for incineration.
	·(e) Chemical Waste	Yellow coloured containers or non-chlorinated plastic bags	Incineration or Plasma Pyrolysis or Encapsulation
	·(f) Chemical Liquid Waste	Separate collection system, leading to the effluent treatment system	After resource recovery, the chemical liquid waste shall be pre-treated before mixing with other wastewater.
	(g) Discarded linen, mattresses, beddings contaminated with blood or body fluid.	Non-chlorinated yellow plastic bags or suitable packing material	Non- chlorinated chemical disinfection followed by incineration or Plasma Pyrolysis or for energyre covery.
	(h) Microbiology, Biotechnology and other clinical laboratory waste	Autoclave safe plastic bags or containers	Pre-treat to sterilize with non-chlorinated chemicals on-site thereafter sent for Incineration.
Red	Contaminated Waste (Recyclable) (a) Wastes	Red coloured non-chlorinated plastic	Autoclaving or micro-waving/ hydroclaving

	generated from disposable items such as tubing, bottles, intravenous tubes and sets, catheters, urine bags, syringes, vaccutainers and gloves.	bags or containers	followed by shredding or mutilation and then sent to registered or authorized recyclers Plastic waste should not be sent to landfill sites.
White (Translucent)	Waste sharps including Metals: Needles, syringes with fixed needles,scalpels, blades, or any other contaminated sharp object that may cause puncture and cuts. This includes both used, discarded and contaminated metal sharps	Puncture proof, Leak proof, tamper proof containers	Autoclaving or Dry Heat Sterilization followed by shredding or mutilation or encapsulation and sent for final disposal to authorized iron foundries or sanitary landfill or designated concrete waste sharp pit.
Blue	Glassware: Broken or discarded and contaminated glass including medicine vials and ampoules except those contaminated with cytotoxic wastes.	Cardboard boxes with blue colored marking	Disinfection (by soaking the washed glass waste after cleaning with detergent and Sodium Hypochlorite treatment) or through autoclaving or microwaving or hydroclaving and then sent for recycling.

Source: Biomedical wastes (Management and Handling Rules, 2016)

4.5 TREATMENT AND DISPOSAL OF E-WASTE

E-waste is a broad term covering all electrical and electronic equipment (EEE) that have been disposed of by their original users. Discarded electronics devices like televisions, computers and its accessories, CDs, batteries, switches, telephones, ACs, mobile phones, electronic toys, refrigerators, microwave ovens, washing machines, dryers, and even aircraft parts are the main components of e-wastes. Computer and its accessories related wastes account for about 25 percent of e-waste. E-waste is several folds more hazardous than many other wastes because electronic devices contain a large number toxic chemicals and metals such as mercury, cadmium, lead chromium, beryllium, polyvinyl chlorides, antimony and phthalates. Long-term exposure to these toxic materials harms the kidney, bones, nervous systems, reproductive system and endocrine systems. On the other hand, e-waste also contains numerous valuable components, such as precious metals and various plastics. Thus the recovery of profitable materials and appropriate treatment is essential prior to disposal.

Treatment of E-wastes

There is no proper method for the treatment of e-waste is available, but through reuse, recycling and recovery option we can reduce the hazardous content of the E-waste. Recovered e-waste fractions can be used as secondary raw materials. E-waste treatment can be done at these three levels (level I, II and III). The treatment technologies used in the three levels are mainly based on material flow. In this material flow from one level to another level at each level there is an outflow of material into two streams i.e. recovered materials and discarded materials. These materials may be used as input for the next level. After the III level treatment the output materials are disposal facilities (landfilling or incinerators).The efficiency of operations at I and II level determines the quantity of residues going to disposal facilities.

Treatment at Level-I

In level–I input material is e-waste items like televisions, refrigerators, mobile phones and personal computers. At this level (I) of treatment of e-wastes there are three units operations, including decontamination, dismantling, and segregation. All the three unit operations used in this level are dry processes and work in absence of water.

a. **Decontamination:** This is the first treatment step at level-I, here the input hazardous e-waste is transformed into non-hazardous. This can be attained by the removal of all types of liquids and gases (if any) under negative pressure, their recovery and storage.

b. **Dismantling:** Dismantling is a breaking process and it could be manual or automated or a combination of both methods. This step is a serious labour intensive process, especially if it is manual dismantling

c. **Segregation:** In this step the dismantled components are separate out into hazardous and non-hazardous components of e-waste fractions to be sent to level-III treatment.

Two outputs are generated from this level. First are decontaminated e-wastes consisting of segregated non-hazardous e-waste like plastic, metals, cathode ray tube (CRT), circuit board and cables. Second is segregated hazardous waste such as CFC, Hg, switches, batteries and capacitors.

Treatment at level-II

In this level the input is waste generated from level-I i.e. decontaminated e-waste consisting segregated nonhazardous materials like plastic, metals, CRT, circuit board and cables. In this step the decontaminated waste is further separated and purified small sized parts. There are three main unit operations at level-II of e-waste treatment.

a. Hammering

The major aim of this step is to produce the desired particle size of e-waste. The main advantage of this process is its simplicity and it can be used on different scales, which make it appropriate for processing various types of electronic waste.

b. Shredding

The separation and recovery are critical elements of e-waste shredding process. Shredders are used to cut recyclable metal and plastic, into smaller pieces.

c. Special Treatment Processes

This step consists of special treatment processes according to the e-waste. For example electromagnetic and eddy current separation processes based onvarious elements like electrical conductivity, magnetic properties and density to separate ferrous, nonferrous metal.

Treatment at level-III

In this level segregated hazardous wastes generated from level-I is treated. Here e-waste treated to recover recyclable ferrous, nonferrous metals, plastics and other items of economic value. The main recovery methods are focused on ferrous and nonferrous metal recovery. Some of the unit operation processes used at this level are magnetic separators, acid wash, cyclic separators, pyrometallurgical recovery and bioleaching.

Disposal of E-wastes

Main and commonly used disposal options for e-wastes are:

Landfilling

This is one of the most commonly used methods of e-waste disposal, after the recovery of useful materials from the waste. In simple landfilling, pits or trenches are made on the flat surfaces and e-waste is buried in it, which is covered by a thick layer of soil. However, modern landfills are located, designed, operated and monitored to ensure compliance with regulations. Here techniques such as secure landfill are provided with some facilities such as impermeable liner made up of plastic or clay or concrete, a leachate collection basin that collects and transfer the leachate to wastewater treatment plant. They are also designed to protect the environment from contaminants.

Incineration

As discussed earlier, it is a combustion process under controlled conditions; here waste materials are burned in specially designed incinerators at a temperature greater than 900°C. Benefit of incineration of e-waste is the decrease of waste volume. Main problem associated with incineration is the emission of various pollutants during the combustion process. A significant amount of heavy metals such as cadmium and mercury is produced from e-waste incineration plant's emission. Furthermore, some amount of these heavy metals is moved into slag and exhaust gas residues, which may come back to the environment on disposal.

Check Your Progress 2

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

1. Explain the advantages and disadvantages of incineration method.

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2. Make a table of various toxic substances present in e waste and their potential effects on humans.

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4.6 LET US SUM UP

In this unit we have learnt that vermicomposting, composting and anaerobic digestion are suitable processes for the management of biodegradable solid wastes. In anaerobic digestion, biogas is produced when microbes (mainly bacteria) ferment or breakdown biological or organic material in the absence of oxygen. Hazardous waste can be treated by physical, chemical, biological and thermal methods. The chemical, thermal, and biological treatment methods outlined above change the molecular form of the waste material. Physical treatment, on the other hand, concentrates, solidifies, or reduces the volume of the waste. Normally wastes are subjected to a combination of these methods for effective and safe disposal. You have also learned about the classification of biomedical wastes according to colour code and type of treatment and disposal needed for particular wastes. For the treatment of e-wastes three levels treatment is used based on material flow. Landfilling and incineration are suitable disposal options for e-waste.

4.7 KEY WORDS

Aerobic process : Process that requires oxygen (air) is known as aerobic.

Anaerobic process : Process that occurs in the absence of oxygen (air) is known as anaerobic.

Hazardous waste : A waste or combination of wastes that can pose a substantial or potential hazard to human health or the environment when improperly managed. Substances classified as hazardous wastes possess at least one of four characteristics; ignitability, corrosivity, reactivity, or toxicity.

Treatment : Process of removal of pollutants from wastes, which reduce its potential harm to people and the environment.

Heavy metal : A metal of relatively high density, such as mercury, cadmium, arsenic, chromium and lead.

Microbes : Microbes are microscopic organisms, which may exist in its single-celled form or in a colony of cells; examples are algae, viruses, bacteria, fungi, and protozoa.

pH : A measure of the acidity or alkalinity of a liquid or solid material.

4.8 REFERENCES AND SUGGESTED READINGS

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4.9 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress 1

Your answer should include the following points:

1) The best way to treat biodegradable organic solid wastes is either composting/vermicomposting or biogas generation through anaerobic process.

2) Anaerobic digestion or methane formation can be affected by several factors as we have discussed in detail in this unit, it includes anaerobic environment, suitable pH, optimum temperature, moisture, C/N ratio, retention period etc.

3) To answer the first part of this question reads the thermal treatment section of this unit.

A case study related to hazardous waste pollution: Love Canal episode.

In 1942, Hooker Chemicals and Plastics Corporation (now Occidental Chemical) purchased the site of the Love Canal. Then the industry used the site as a landfill and disposed of about 22,000 tons of hazardous wastes into the Love Canal from 1942 to1953. In 1953 Hooker Chemicals and Plastics Corporation sells sites to the Niagara Falls school board for a price of $1.00. Soon an elementary school was constructed on the Love Canal property. After that, residential neighborhood was settled around the Canal area. In 1995-96, ground water level raised in that area due to abnormal precipitation. Some parts of the Hooker landfill subsided, 55-gallon drums surfaced, ponds and other surface water area became contaminated, basements began to ooze an oily residue, and noxious chemical odors permeated the area. Later, various Agencies examine the area and reported the presence of more than 400 harmful chemicals in air, water, and soil samples in and around the Love Canal area. In April 1978, New York Department of Health declares Love Canal a threat to human.

Answers to Check Your Progress 2

Your answer should include the following points:

1) The main advantage of incineration process is the decrease of waste volume. Incineration reduces the need for landfills. Main problem associated with incineration is the emission of various pollutants during the combustion process. In addition to this incineration is a costly method for the treatment of wastes.

2) You can make a table of various toxic metals present in e-wastes, for example, mercury is present in e-waste (e.g.in mobile phones) and may contribute to brain and kidney damage. Likewise, television and computer monitors normally contain hazardous materials such as lead, mercury, and cadmium, while nickel, beryllium, and zinc can often be found in circuit boards. These toxic substances may cause several disorders in human beings.