UTTARAKHAND OPEN UNIVERSITY
Teenpani Bypass Road, Transport Nagar, Haldwani - 263 139
Phone No. : (05946) - 286002, 286022, 286001, 286000
Toll Free No. : 1800 180 4025
Fax No. : (05946) - 264232, email : <info@uou.ac.in>
http://www.uou.ac.in

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HAZARDOUS WASTES AND THEIR MANAGEMENT

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Hazardous Wastes and their Management

Department of Forestry and Environmental Science
School of Earth and Environmental Science

Uttarakhand Open University
Haldwani, Nainital (U.K.)

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Phone No.: (05946) - 286002, 286022, 286001, 286000
Toll Free No.: 1800 180 4025, Fax No.: (05946) - 264232,
e-mail: info@uou.ac.in, Website: http://www.uou.ac.in

Programme Coordinator

Dr. H.C. Joshi
Associate Professor
Department of Forestry and Environmental Science (SoEES),
Haldwani, Nainital (U.K.)

Editors

Dr. H.C. Joshi, Dr. Neha Tiwari, Dr. Beena Tewari Fulara,

Dr. Krishna Kumar Tamta, Dr. Preeti Pant, Dr. Deepti Negi, Dr. Khasti Dasila

Department of Forestry and Environmental Science (SoEES) Uttarakhand Open University, Haldwani

Units Written by	Unit No.
Dr. H.C. Joshi **	1, 2, 3, 5,6,11,12,13
Dr. Neha Tiwari *	4
Dr. Preeti Pant*	7
Dr. Khashti Dasila*	8
Dr. Deepti Negi*	9
Dr. Krishna Kumar Tamta*	10

***Assistant Professor (AC), Department of Forestry and Environmental Science, SoEES, Uttarakhand Open University, Haldwani.**
****Associate Professor, Department of Forestry and Environmental Science, SoEES, Uttarakhand Open University, Haldwani.**

Cover Page Design & Format Editing

Dr. Neha Tiwari
Department of Forestry and Environmental Science (SoEES), Uttarakhand Open University, Haldwani

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BLOCK 4: HAZARDOUS WASTES MANAGEMENT

Unit 01: The Hazardous Waste

Unit Structure

1.0 Learning Objectives

After the study of this unit, you will be able to:

- define of hazardous waste
- explain the sources of hazardous waste
- able to classify hazardous waste
- discuss composition and characteristics of hazardous waste
- describe hazardous products comingled with municipal solid wastes

1.1 Introduction

Hazardous waste are substances that have toxic, corrosive, or reactive qualities and that put people and the environment at risk. These materials may be gases, liquids, or solids.

They come from a variety of sources, including home activities, industries, and other developmental endeavors.

The environment and people are seriously threatened by hazardous wastes. When hazardous waste is improperly disposed of, it can contaminate the air, water, and soil, which can cause ecosystem disruption, biodiversity loss, and climate change. Hazardous waste exposure can lead to serious health problems in humans, such as cancer, birth defects, neurological damage, and respiratory problems. Hazardous waste containing lead, mercury, and asbestos poses specific health risks, including lung cancer, kidney damage, developmental delays, and other illnesses. Therefore, it is essential to ensure safe and proper disposal of hazardous wastes, minimize waste production, adhere to regulations, and inform the public about the dangers and significance of responsible hazardous waste management.

1.2 Definition and types

Hazardous waste is defined as the waste that poses threat to humans, their domesticated animal, or the surrounding environment due to its toxic, corrosive, or reactive properties. This type of waste can enter our environment in various forms such as liquids, solids, or gases. It can be generated from various industrial processes, household activities, and other sources. According to the United States Environmental Protection Agency (EPA), it is defined as a waste that exhibits one or more of the characteristics such as ignitability, corrosively, reactivity, or toxicity.

It is defined as any solid or combination of solids that because of its quantity, concentration, or physical, chemical, or infectious characteristics, may cause or significantly contribute to increase in mortality or increase in serious irreversible or incapacitating reversible illness, or pose a substantial hazard to human health or the environment if managed improperly.

Any waste is considered toxic or hazardous if they significantly contribute in mortality or increase in irreversible illness of serious nature; or its improper treatment, improper storage, improper transportation, improper disposal or otherwise poses a potential hazard to human health or the environment.

Various kinds of hazardous waste are as follows:

1) **Household Hazardous Waste**: Batteries (e.g., lead-acid, nickel-cadmium), Electronics (e.g., computers, phones, televisions), Paints and coatings (e.g., lead-based, solvent-based), Pesticides and insecticides (e.g., DDT, chlorpyrifos)
2) **Industrial Hazardous Waste:** Chemicals (e.g., solvents, acids, bases), Heavy metals (e.g., lead, mercury, arsenic), Petroleum products (e.g., used oil, gasoline), Asbestos-containing materials (e.g., insulation, brake pads)
3) **Agricultural Hazardous Waste:** Pesticide containers and residues, Fertilizer and pesticide application equipment, Animal waste and manure from industrial farms
4) **Construction and Demolition Hazardous Waste:** Asbestos-containing materials (e.g., insulation, roofing), Lead-based paints and coatings, Mercury-containing devices (e.g., thermostats, switches)

1.3 Characteristics of Hazardous Waste

Hazardous waste is a complex mixture of various substances, and its composition can vary widely depending on the source and type of waste. However, hazardous waste typically exhibits some common characteristics, such as the following:

1.3.1. Physical Characteristics

Among the physical characteristics of hazardous waste are:

- **Toxicity:** Hazardous waste contains toxic substances that can harm humans and their environment.
- **Corrosivity:** Hazardous waste can be corrosive and may cause damage to buildings, materials, and infrastructure.
- **Reactive and explosive**: Hazardous waste can be reactive, explosive, or undergo violent chemical reactions
- **Ignitability:** Hazardous waste can be ignitable, catching fire and burning easily.

1.3.2 Chemical Characteristics

The chemical characteristics of hazardous waste include:

- **Heavy Metals:** Hazardous waste may contain heavy metals like lead, mercury, arsenic, and cadmium.
- **Organic Compounds**: Hazardous waste can contain organic compounds like pesticides, herbicides, and volatile organic compounds (VOCs).
- **Inorganic Compounds:** Hazardous waste can contain inorganic compounds like acids, bases, and salts.
- **Radioactive Materials:** Hazardous waste can contain radioactive materials like uranium, thorium, and radon.

1.3.3 Biological Characteristics

- **Pathogens**: Hazardous waste can contain pathogens like bacteria, viruses, and fungi.
- **Toxic Microorganisms:** Hazardous waste can contain toxic microorganisms like those that produce toxins.
- **Toxicity:** Can cause harm or death to humans and animals.

Table 1 Characteristics of hazardous waste and associated risks

Characteristic	Key Features	Associated Risk
Ignitability	• Flashpoint <60Â°C (140Â°F); • oxidizers • compressed gases	Fire hazard Spreading toxic smoke particles.
Corrosivity	• pH less than or equal to 2 or greater than or equal to 12.5 • Liquid that causes corrosion in steel at the rate of 0.25 inches per year.	Destruction of containers; Leaching of other toxins. Dissolves other contaminants
Reactivity	• Unstable in normal conditions • Reacts violently with water • Forms explosive mixture in water • Results in toxic gases, vapors, or fumes when mixed with water • releases cyanide/sulfide gas. • Capable of detonation if heated under confinement or subjected to strong initiating source • detonation if heated under confinement or subjected to strong initiating source • Listed as Class A or B explosive	• Spontaneous explosions • Sudden release of lethal vapors. • React vigorously with air or water, to be • unstable to shock or heat, to generate toxic gases or to explode
Toxicity	Fails the TCLP test (leachate test); contains heavy metals/pesticides.	Long-term health hazards via groundwater contamination.

Table 2 - Maximum Concentration of Contaminants for the Toxicity Characteristics Contaminant Regulatory level (mg/L)

Arsenic	5.0	Hexachlorobenzene	0.13
Barium	100.0	Hexachlorobutadiene	0.5
Benzene	0.5	Hexachloroethane	3.0
Cadmium	1.0	Lead	5.0
Carbon tetra chloride	0.5	Lindane	0.4
Chlordane	0.03	Mercury	0.2
Chlorobenzene	100.0	Methoxychlor	10.0
Chloroform	6.0	Methyl ethyl ketone	200.0
Chromium	5.0	Nitrobenzene	2.0
o-cresol	200.0	Pentachlorophenol	100.0
m-cresol	200.0	Pyridine	5.0
p-cresol	200.0	Selenium	1.0
Cresol	200.0	Silver	5.0
2,4-D	10.0	Tetrachloroethylene	0.7
1,4-Dichlorobenzene	7.5	Toxaphene	0.5
1,2-Dichloroethane	0.5	Trichloroethylene	0.5
1,1-Dichloroethylene	0.7	2,4,5-Trichlorophenol	400.0
2,4-Dinitrotoluene	0.13	2,4,6-Trichlorophenol	2.0
Endrin	0.02	2,4,5-TP (Silvex)	1.0
Heptachlor (and its epoxide)	0.008	Vinyl chloride	0.2

1.4. Source of hazardous waste

The hazardous wastes come into our environment from a diversity of sources, which are normally categorized as per EPA as:

- Nonspecific sources

- Specific Sources and
- Commercial Sources.

1.4.1 Nonspecific source wastes

Those sources that generate hazardous waste as a secondary or byproduct or indirect result of their activities are known as nonspecific sources of hazardous waste. They are also denoting as "F" wastes since their EPA waste identification code begin with the letter F. Examples include wastewater treatment sludge from electroplating processes, spent halogenated solvents used in degreasing, and dioxin wastes, the majority of which are "acutely hazardous" wastes because of the risks they pose to the environment and human health. Among the solvents on the F list are benzene, carbon tetrachloride, trichloroethylene, and methylene chloride.

Solvent blends with 10% or greater are included in F list. Following are the sources sub-categories of F waste:

1. **Households:** Generate hazardous waste, including batteries, electronics, and household chemicals.
2. **Construction and demolition sites:** Produce hazardous waste, including asbestos, lead, and other construction materials.
3. **Vehicle maintenance and repair shops:** Generate hazardous waste, including used oil, filters, and other automotive chemicals.
4. **Agricultural activities:** Produce hazardous waste, including pesticides, fertilizers, and other agricultural chemicals.
5. **Medical facilities:** Generate hazardous waste, including medical supplies, chemicals, and pharmaceuticals.
6. **Research institutions:** Produce hazardous waste, including laboratory chemicals, biological agents, and other research materials.

1.4.2 Specific source wastes

Under this subcategory, those sources are included which generate hazardous waste directly as a result of their activities. Such sources are also called as "K" waste since their code begin with K letter. This includes a few specifically designated industries, such as the production of organic chemicals, petroleum refining, and wood preservation. Some of the examples of such wastes are waste waters, catalysts used in spent, and residues such as sludge produced during pigment production. Some of such sources are as follows:

1. **Chemical manufacturing plants:** Produce hazardous chemicals, such as pesticides, paints, and solvents.
2. **Petroleum refineries:** Generate hazardous waste, including used oil, petroleum products, and chemical residues.
3. **Mining and smelting operations:** Produce hazardous waste, including heavy metals, acids, and other chemicals.
4. **Pesticide and fertilizer manufacturing plants:** Generate hazardous waste, including pesticides, fertilizers, and chemical residues.
5. **Pharmaceutical manufacturing plants:** Produce hazardous waste, including pharmaceutical residues, chemicals, and solvents.
6. **Electronics manufacturing plants**: Generate hazardous waste, including electronic components, chemicals, and solvents.

1.4.3 Commercial chemical products

It includes certain commercial chemical products or manufacturing chemical intermediates and is represented by symbol P and U codes. The P and U lists include commercial pure grade chemicals as well as any formulations that contain either chemical as an active ingredient. The quantity at which the chemical is regulated distinguishes the P list from the U list. In contrast to the U list, which has a monthly waste generation of 25 kilograms, acute toxic wastes that accumulate or generate more than 1 kilogram are classified under this category. Chemicals like creosote and chloroform, acids like hydrochloric and sulfuric, and pesticides like DDT are all on this list. The EPA has also decided that the majority of mixtures of solid wastes and listed hazardous wastes are hazardous wastes and need to be handled as such. This holds true regardless of the proportion of listed hazardous wastes in the waste mixture. In the absence of such a rule, generators could simply dilute or mix the listed wastes with nonhazardous solid waste to avoid RCRA requirements. Hazardous waste also includes such wastes which derived from hazardous wastes or residues resulted from the treatment or storage or disposal of a hazardous waste. Types of Commercial Chemical Products are as follows:

- **Cleaning agents:** Detergents, disinfectants, and sanitizers for household, industrial, and institutional use.
- **Pesticides and herbicides:** Chemicals used to control pests, weeds, and diseases in agricultural, gardening, and public health applications.
- **Paints and coatings:** Chemicals used to protect, decorate, and enhance the appearance of surfaces, including paints, varnishes, and lacquers.
- **Adhesives and sealants:** Chemicals used to bond, seal, and protect surfaces, including glues, epoxies, and silicones.
- **Personal care products:** Chemicals used in the manufacture of cosmetics, toiletries, and pharmaceuticals, such as soaps, shampoos, and skin creams.
- **Food additives and ingredients:** Chemicals used to enhance the flavor, texture, and appearance of food products, including preservatives, flavorings, and colorants.
- **Pharmaceuticals and veterinary products:** Chemicals used in the manufacture of medicines, vaccines, and other products for human and animal health.
- **Fertilizers and soil amendments:** Chemicals used to promote plant growth, improve soil fertility, and control pests and diseases in agricultural and gardening applications.

1.5 Hazardous Waste and Hazardous Wastes products co-mingled with municipal solid wastes

1.5.1 Common Hazardous Products

1. **Batteries:** Alkaline, nickel-cadmium (Ni-Cd), nickel metal hydride (NiMH), and lithium-ion (Li-ion) batteries contain toxic heavy metals.
2. **Electronics:** Electronic waste (e-waste) like computers, phones, and televisions contain lead, mercury, cadmium, and other hazardous materials.

3. **Fluorescent lamps:** Compact fluorescent lamps (CFLs) and fluorescent tubes contain mercury.
4. **Thermometers and thermostats:** Some thermometers and thermostats contain mercury.
5. **Pesticides and herbicides:** Household pesticides and herbicides can contaminate soil and water.
6. **Paints and coatings:** Oil-based paints, varnishes, and coatings contain volatile organic compounds (VOCs) and heavy metals.
7. **Cleaning supplies:** Some cleaning products contain hazardous chemicals like ammonia, bleach, and quaternary ammonium compounds.
8. **Aerosol** cans: Aerosol cans containing paints, sprays, and other chemicals can be hazardous if not disposed of properly.
9. **Fire extinguishers:** Expired or damaged fire extinguishers can contain hazardous materials like carbon dioxide, halons, and dry chemicals.
10. **Household chemicals:** Chemicals like drain cleaners, oven cleaners, and furniture polish can be hazardous if not disposed of properly.
11. **Mercury-containing devices:** Devices like thermostats, thermometers, and fluorescent lamps contain mercury, which is a hazardous substance.
12. **Oil and fuel:** Used oil and fuel can contaminate soil and water if not disposed of properly

1.5.2 Risks Associated with Co-Mingling

1. **Environmental contamination:** Hazardous products can leak or spill during collection, transportation, or disposal, contaminating soil, water, and air.
2. **Fire and explosion risks:** Improperly disposed hazardous products can ignite or explode, causing fires and releasing toxic fumes.
3. **Human health risks:** Exposure to hazardous products can cause injuries, illnesses, and even death.

4. **Waste management challenges:** Co-mingling hazardous products with municipal solid waste can make it difficult to manage and dispose of waste properly.
5. **Air pollution:** Burning hazardous products can release toxic fumes into the air, contributing to air pollution.

1.5.3 Proper Disposal and Management

1. **Separate collection:** Collect hazardous products separately from municipal solid waste. Check with local authorities to see if they have special collection programs for hazardous waste.
2. **Designated facilities:** Dispose of hazardous products at designated facilities, such as household hazardous waste collection centers.
3. **Recycling and reuse:** Encourage recycling and reuse of hazardous products, like batteries and electronics.
4. **Participate in community collection events:** Participate in community collection events for hazardous waste.
5. **Follow manufacturer instructions:** Follow manufacturer instructions for disposing of hazardous products.
6. **Education and awareness:** Educate the public about the risks associated with co-mingling hazardous products and the importance of proper disposal. Educational and Awareness Programs may be developed for the purpose.
    - **Public education campaigns:** Conduct public education campaigns to raise awareness about the risks associated with co-mingling hazardous products.
    - **School programs:** Develop school programs to educate children about the importance of proper disposal of hazardous products.
    - **Community outreach:** Conduct community outreach programs to educate residents about the risks associated with co-mingling hazardous products.
    - **Collaborate with local authorities:** Collaborate with local authorities to develop and implement educational and awareness programs.

- **Develop educational materials:** Develop educational materials, such as brochures, posters, and websites, to raise awareness about the risks associated with co-mingling hazardous products.

1.6 Collection and storage

The methods and containers used for collecting hazardous waste are primarily determined by the type and characteristics of the waste. Hazardous waste must be handled, stored, and transported with caution. Additionally, waste must be evaluated for compatibility before being stored in the same container. The quantity of hazardous waste generated also affects how it is collected and stored. Waste can be stored and disposed of on a regular basis if it is produced in smaller quantities. However, a significant amount of hazardous waste must be transferred and disposed of every day. Fiberglass or glass-lined containers for caustic solutions or corrosive acids are among the containers used to collect or store hazardous waste. To prevent metals from reacting with the container, lined containers are utilized. Some other types of containers used in academic institutions, universities or laboratories are PVC-lined containers, single-walled drums, exotic metal drums made of nickel, stainless steel, and aluminum. Nitrogen-filled single-walled drums are used to store explosive, flammable, and reactive waste. EPA regulations state that hazardous waste collection and storage containers must be sealed or closed, unless waste needs to be added or removed. It is important to take precautions against container rupture, which could result in additional spills or leaks.

Hazardous waste is stored in two different types of areas such as satellite accumulation areas and central accumulation areas. It is important to gather and store liquid waste in a way that prevents vapor buildup, inhalation, and unintentional spills. Drum funnel screw lids or latching drum lids must be installed on the containers to avoid this. Latch drum lids are used for containers with open lids, while drum funnel screws are used for containers with closed lids. To keep the container sealed, leak-proof, and airtight, the lids should have a good gasket mechanism. Containers containing solid or semi-solid hazardous waste must have lids with fusible plugs and continuous gaskets. These plugs will assist in gathering the vapors that are escaping from the waste. Every lid and seal should be inspected on a regular basis because the chemicals in the containers will erode them and cause vapors to leak out.

Table 3 Collection equipment for various hazardous wastes

Waste Category	Required Collection Equipment & Accessories	Specialized Safety Requirements
Radioactive	Specialized trucks and railroad cars.	Concrete-encased lead containers; heavy-duty loading gear; distinct hazard markings.
Toxic Chemicals	Flatbed trucks (for drums); tractor-trailer tankers; railroad tank cars.	Specialized interior linings (glass, rubber, or fiberglass) to prevent corrosion or leaks.
Biological	Standard packer trucks or flatbed trucks (for drums).	Enhanced protocols to prevent physical contact between the waste and the collector.
Flammable	Flatbed trucks or large-volume tank trucks.	High-visibility vehicle coloring and printed safety warnings.
Explosives	Similar to toxic/flammable transport (drums or tankers).	Strict routing restrictions, specifically prohibiting transit through residential areas.

When collecting and storing hazardous waste, labeling is crucial. Information like the manufacturer's symbol, the year of production, the specifications, the capacity, and whether the containers are for a single trip or several. Large storage tanks are used to store waste, which is then pumped into the collection vehicle for disposal or treatment. On the other hand, sealed containers are moved to a collection vehicle and transported to a disposal or treatment location. Drum storage and collection containers, as well as short distances, are transported by flatbed trucks. Long-distance transportation uses railroad tanks, trailers, and larger tank trucks.

1.7 Segregation

The segregation process starts with separation of the hazardous waste materials based on their physical properties, such as sludge, organic materials, and aqueous materials. It depends on these forms as how these wastes will be treated and disposed of. The degree of hazardous waste segregation (Figure 1) is very important to follow the rules for how to treat, store, and get rid of different types of waste. It is not too hard to deal with wastes that are very separated.

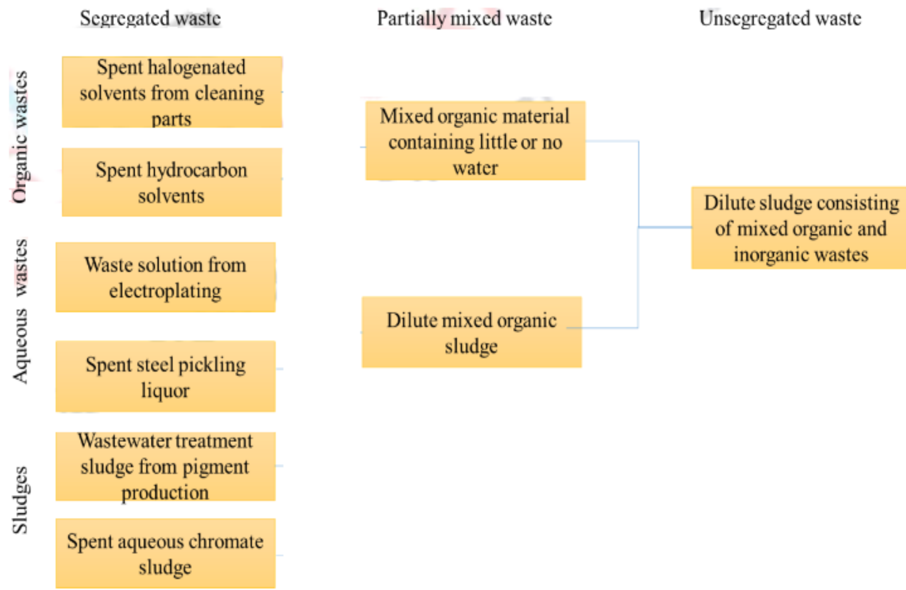

Figure 1 – Illustration of waste segregation (Source: Manahan 1993)

It is usually much easier and cheaper to deal with concentrated waste than waste that is spread out in a lot of water or soil. It is easier to deal with hazardous wastes when the original amounts are kept to a minimum and the wastes stay separate and concentrated. It is best to treat and throw away the waste after it has been separated and processed. It is possible for hazardous materials and waste to get into the environment because of the way the waste itself is. The physical properties of hazardous wastes, like how easily they evaporate and dissolve, play a big role in how they move through the environment. Hazardous wastes that are very volatile are more likely to move through the air, while those that are more soluble will move through water.

The volatility of the compound decides how hazardous waste components are spread out between the atmosphere, geosphere, and hydrosphere. Hazardous waste constituents are usually dissolved in water in the hydrosphere and sometimes in soil. This means that the way water holds the constituents affects how easily they move. For instance, even though ethyl alcohol evaporates faster and boils at a lower temperature than toluene, the vapor from toluene is easier to get out of the soil because it doesn't dissolve as well in water as ethanol does.

Chemical factors also help in transportation of waste. The clay minerals in the soil have strong binding affinity with some elements e.g., Cd, Hg, Pb, Zn etc., moderate affinity with

K, Mg, Fe, Si etc., and poor affinity with other elements like Na, Ca, Mn, B. It is important to note that how well iron and manganese stay in the soil depends a lot on their oxidation state. For example, the reduced forms of Fe and Mn don't stay in the soil well, but the oxidized forms of $Fe_2O_3.xH_2O$ and MnO_2 are insoluble and stay in the soil as solids.

1.8 Transfer station

Hazardous waste management (HWM) does not include a transfer station like municipal solid waste management does. This is because the vehicles engaged in the collection of hazardous waste carry the hazardous waste directly to the treatment or disposal site. Therefore, there is no need of transfer station in HWM.

1.9 Interesting Facts

- Effective identification and labeling of hazardous wastes by the generators is essential to the effective operation of any manifest-based system
- Most hazardous waste comes from industrial sources
- Methylene chloride, a common solvent from industrial process is a probable carcinogen commonly used in paint removers
- Recycling and waste minimization may be the best ways to deal with hazardous waste
- Techniques for waste minimization may include audits, better inventory management, production process/equipment modifications, and operational/maintenance procedures.
- The recycling of waste through waste exchanges is one aspect of industrial ecology and another way to address the issue of hazardous waste disposal
- The EPA's Industrial Toxics Project is a non-regulatory program initiated in 1990 to accomplish overall reductions for seventeen toxic chemicals detailed in the government's
- Toxics Release Inventory (TRI), including cadmium, lead, mercury, trichloroethylene, and toluene.

Hazardous waste containers

Source: http://www.waste360.com/special-waste/wvu-agrees-pay-fine-resolve-hazardous-waste-violations

Material safety data sheet

Source: http://blog.idrenvironmental.com/how-to-choose-the-right-hazardous-waste-storage-container

The following tips on how to get rid of hazardous waste are based on what the EPA says: Reactive wastes should be kept apart from each other.

• To keep corrosive waste from corroding, it should be put in plastic or plastic-lined steel drums.

• A corrosion resistance guide can help in figuring out if the waste and drum material are compatible.

• When rinsing a container on site, make sure the rinse water is characterized and contained before it is thrown away.

• Be aware of the production process, as it may change the makeup of the waste that is created.

• Pay attention to temperature changes in the material, as some chemicals can expand when heated.

• Containers that are used often should be given specific materials.

Summary

The toxic, corrosive, or reactive properties of hazardous waste pose serious environmental, health, and economic risks. It can pollute soil, water, and air, causing long-term environmental and health issues. Poor hazardous waste disposal can cause fires, explosions, and chemical pollution.

Hazardous waste comes from industrial, household, agricultural, and construction and demolition projects. Waste can be liquids, solids, gases, or sludges containing heavy metals, pesticides, and volatile organic compounds. The US Environmental Protection Agency (EPA) regulates hazardous waste generation, storage, transportation, treatment, and disposal.

Preventing environmental contamination and human health risks requires proper hazardous waste management and disposal. Separate hazardous waste from non-hazardous waste, store it in compatible containers, and dispose of it at approved treatment and disposal facilities. Recycling, waste minimization, and sustainable practices can also reduce hazardous waste risks.

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Unit 02: Classification of Hazardous Wastes

Unit Structure

2.0 Learning Objectives

After the study of this unit, you will be able to explain:

- the various ways of the classification of hazardous wastes
- the internationally accepted ways of classification of hazardous waste

2.1 Introduction

It's crucial to classify hazardous wastes so that we can discover, handle, and get rid of them in a way that doesn't hurt people or the environment. Hazardous waste can come from various sources such as farming, industrial activities, and even everyday use. To make sure that hazardous wastes are handled and thrown away safely, they are divided into classes depending on their qualities, makeup, and possible threats. Classification systems, such as the Basel Convention's, help in sorting of hazardous wastes into classes. This makes it easier to come up with excellent methods for dealing with trash and decreases the risks that come with various kinds of trash.

Properly classifying hazardous wastes is important for following the rules, protecting public health, and keeping the environment clean. A well-organized classification system helps people who make garbage, people who regulate it, and people who handle it to understand the specific risks that come with each form of waste and to make strategies for how to handle, store, transport, and get rid of it. By correctly identifying hazardous wastes, stakeholders can also find ways to reduce, recycle, and recover these wastes, which lowers the health and environmental hazards that come with them.

2.2 Classification of Hazardous Wastes

Hazardous waste can be classified in a variety of ways. Some of the important into several categories based on its characteristics, composition, and potential risks to human health and the environment.

2.2.1 Classification as Per EPA Regulations

The United States Environmental Protection Agency (EPA) classifies hazardous waste into four main categories:

Ignitability (D001): Waste that can catch fire and burn easily, such as flammable liquids and solids.

Corrosivity (D002): Waste that can cause damage to materials and infrastructure, such as acids and bases.

Reactivity (D003): Waste that can explode, release toxic gases, or undergo violent chemical reactions, such as explosives and oxidizers.

Toxicity (D004-D043): Waste that contains toxic substances, such as heavy metals, pesticides, and industrial chemicals.

2.2.2 Classification based on Characteristics of Wastes

Hazardous waste can also be classified based on its physical and chemical state or characteristics:

1. **Liquid waste:** Waste in liquid form, such as solvents, fuels, and chemicals.
2. **Solid waste:** Waste in solid form, such as sludge, residues, and contaminated soil.
3. **Sludge waste:** Waste in semi-solid form, such as industrial sludges and wastewater treatment sludge.
4. **Gaseous waste:** Waste in gaseous form, such as industrial process gases and contaminated air.

2.2.3 Classification Based on Generators of Wastes

Hazardous waste can also be classified based on the type of generator:

1. **Industrial waste:** Waste generated from industrial processes, such as manufacturing, mining, and construction.
2. **Household hazardous waste:** Waste generated from household activities, such as cleaning, painting, and gardening.
3. **Medical waste:** It is the kind of waste that is produced by healthcare facilities, including clinics, hospitals, and laboratories.
4. **Agricultural waste:** It is a waste that is generated from agricultural activities, such as farming, fertilizers or use of pesticides.

2.2.4 Classification Based on Category of Waste

Hazardous waste is classified into six broad categories based on its type. The waste categories are detailed below:

1. **Radioactive wastes:** Materials that release ionizing radiation are referred to as radioactive substances, and the waste produced by these materials is known as radioactive wastes. Despite being classified as a distinct group, they are still investigated as hazardous waste because of the detrimental effects they have on living things. Additionally, they remain in the environment for a very long time. Their half-life dictates how long they last in the environment.
2. **Biomedical wastes:** Biomedical wastes have two characteristic properties i.e., their toxicity and infectivity. Biomedical wastes fall under the hazardous waste category due to its toxic nature. Some of the key sources of biomedical wastes are hospitals, nursing homes, clinics, and research centers.
3. **Chemicals:** These can be metals, organic or synthetic, basic or acidic, or salts. Toxic chemicals are very dangerous for humans and their environment. A waste stream should be deemed hazardous if it contains these wastes at levels that are equal to or higher than threshold values.

4. **Flammable wastes:** Substances that are flammable may be solid, liquid, or gas. Flammable wastes include things like organic sludges, plasticizers, and solvents. These wastes require special handling because they are hazardous.

5. **Explosives:** Industries and ordinance factories are the main sources of such substances.

6. **Household hazardous wastes:** Humans produce a lot of hazardous materials in their daily lives, which are then disposed of along with other domestic wastes. Oil paints, nail polish, latex, paints, batteries, cleaning agents, e-waste, pesticides, chlorinated and non-chlorinated solvents, and many more are the examples of hazardous waste produced by households.

2.2.5 Classification according to Basel Convention

This classification System is a widely used framework for classifying hazardous wastes. It is a simple, yet effective way to categorize hazardous wastes. The Basel Classification System classifies hazardous wastes based on the following criteria:

- **Toxicity**: Wastes that contain toxic substances, such as heavy metals, pesticides, or industrial chemicals.
- **Flammability**: Wastes that are flammable or can ignite easily, such as solvents, fuels, or oils.
- **Reactivity**: Wastes that are reactive or can explode, such as explosives, fireworks, or chemical reactants.
- **Corrosivity**: Wastes that are corrosive or can damage materials, such as acids, bases, or other corrosive substances.
- **Infectiousness**: Wastes that contain infectious agents, such as medical waste or biological agents.

Accordingly based on the above-mentioned criteria, the hazardous wastes are categorized into three main categories:

I. Y1-Y45: Wastes that are considered hazardous due to their intrinsic properties, such as toxicity, flammability, or reactivity.

II. Y46-Y47: Wastes that are considered hazardous due to their potential to cause harm to human health or the environment.

III. Y48: Wastes that are not considered hazardous, but may still pose some risks.

The wastes are further categorized as a list of specific wastes that are considered hazardous and these are as follows:

<u>Y1-Y18: Wastes from Specific Industries</u>

Y1-Y5: Wastes from the production and processing of metals, such as lead, mercury, and cadmium.

Y1: Metal and metal-bearing waste, such as lead, mercury, and cadmium.

Y2: Waste from making and using chemicals, like pesticides and herbicides.

Y3: Wastes from making and processing fuels like gasoline, coal, and oil.

Y4: Waste from making and processing plastics, rubber, and fabrics.

Y5: Waste from making and processing paper, cardboard, and other products made from cellulose.

Y6-Y13: Wastes from the production and processing of chemicals, such as pesticides, herbicides, and solvents.

Y6: Trash that comes from making and processing glass, ceramics, and other products made from minerals.

Y7: Waste from making and processing photographic and radiographic materials.

Y8: Waste from making and using explosives and fireworks.

Y9: Waste from making and using pesticides and herbicides.

Y10: Waste from making and processing drugs.

Y11: Waste from making and processing cosmetics and toiletries.

Y12: Trash from making and processing food and drinks.

Y14-Y18: Wastes from the production and processing of fuels, such as coal, oil, and gasoline.

Y13: Trash that comes from making and processing tobacco products.

Y14: Trash from making and processing leather and textiles.

Y15: Waste that comes from making and processing wood and wood products.

Y16: Waste from making and processing cement and lime.

Y17: Trash left over from making and processing asbestos.

Y18: Waste from making and processing other products made from minerals.

Y19-Y45: Wastes from Specific Processes

Y19: Wastes from treating metals and metal-containing wastes.

Y20: Trash that comes from treating chemicals and chemical-based trash.

Y21-Y30: Wastes from the production and processing of plastics, rubber, and textiles.

Y21: Trash that comes from treating fuels and fuel-based trash.

Y22: Waste from treating plastics, rubber, and textiles.

Y23: Waste from the processing of paper, cardboard, and other cellulose-based materials.

Y24: Trash from the processing of glass, ceramics, and other mineral-based trash.

Y25: Waste from the processing of photographic and radiographic materials.

Y26: Trash from dealing with fireworks and explosives.

Y27: Waste from getting rid of herbicides and pesticides.

Y28: Waste from the processing of drugs.

Y29: Waste from cleaning and using cosmetics and toiletries.

Y30: Waste from processing food and drinks.

Y31-Y40: Wastes from the production and processing of paper, cardboard, and other cellulose-based products.

Y31: Waste from the processing of tobacco products.

Y32: Waste from cleaning leather and textiles.

Y33: Waste from treating wood and wood products.

Y34: Waste from the processing of lime and cement.

Y35: Waste from working with asbestos.

Y36: Waste from the processing of other mineral-based goods.

Y37: Wastes from the processing of batteries and accumulators.

Y38: Trash from fixing electrical and electronic devices.

Y39: Garbage from fixing up cars.

Y40: Trash from working with materials used in aerospace and defense.

Y41-Y45: Wastes from the production and processing of glass, ceramics, and other mineral-based products.

Y41: Waste that comes from dealing with radioactive materials.

Y42: Waste from dealing with infectious materials.

Y43: Waste from dealing with sick materials.

Y44: Waste from treating sharps and other medical waste.

Y45: Waste from the treatment of other dangerous materials.

The benefits of the Basel Convention's Classification System include:

- **Simplified classification:** The system provides a simple and straightforward way to classify hazardous wastes.
- **International consistency:** The system is widely adopted and provides a consistent framework for classifying hazardous wastes across countries.
- **Improved waste management:** It ensures that the hazardous wastes are managed and disposed of in such a way that they do not cause harm to ecosystems i.e., in environment friendly manner.

The Basel Convention includes three annexes that provide additional information on hazardous wastes.

Annex I: Lists wastes that are considered hazardous and require special handling and disposal i.e., categories of wastes to be controlled

a) Waste Streams	
1	Clinical wastes
2	Pharmaceutical industries make waste when they make and prepare drugs.
3	Pharmaceuticals, drugs, and medicines that are no longer needed from stores, hospitals, clinics, and other places.
4	Waste produced during the making, mixing, and usage of biocides and phytopharmaceuticals
5	Waste that comes from making, mixing, and using wood preservatives and chemicals

6	Waste generated during the synthesis, formulation, and application of organic solvents
7	Waste generated during heat treatment and tempering processes utilizing cyanides
8	Mineral oils that are no longer useful
9	Waste oils, water, hydrocarbons, mixes of water and hydrocarbons, and emulsions
10	Waste materials that have polychlorinated biphenyls (PCBs), polychlorinated terphenyls (PCTs), and polybrominated biphenyls (PBBs) in them
11	Waste tarry residues from distillation or any other type of pyrolytic treatment
12	Waste created during making and using paints, inks, dyes, pigments, varnish, etc.
13	Wastes generated during the manufacturing and application of resins, latex, adhesives, and glues.
14	Chemical wastes generated from research, development, or educational operations that are uncharacterized or novel, with unknown impacts on humans and the environment.
15	Explosive wastes that aren't covered by any other laws
16	Waste that comes from making and using photographic chemicals
17	Things that are thrown away when metals and polymers are treated on the surface
18	Leftover materials from the disposal of industrial trash
b) Wastes containing its constituents as HW	
19	Metal carbonyls
20	Beryllium; beryllium compounds
21	Hexavalent chromium compounds
22	Copper compounds
23	Zinc compounds
24	Arsenic compounds
25	Selenium compounds
26	Cadmium compounds
27	Antimony compounds
28	Tellurium compounds
29	Mercury compounds
30	Thallium compounds

31	Lead compounds
32	Inorganic florine compounds excluding calcium floride
33	Inorganic cyanides
34	Acidic solutions or solid acids
35	Basic solutions or solid bases
36	Asbestos (dust and fibres)
37	Organic phosphorus compounds
38	Organic cyanides
39	Phenols; phenol compounds including chlorophenols
40	Ethers
41	Halogenated organic solvents
42	Organic solvents excluding halogenated solvents
43	Polychlorinated dibenzofuran
44	Polychlorinated dibenzo dioxin
45	Organ halogen chemicals excluding those specified in this Annex (e.g., Y39, Y41, Y42, Y43, Y44)

Annex II: Categories of Wastes Requiring Special Consideration i.e, non-hazardous waste , but may still associated with some risks

46	Household waste that has been gathered
47	Leftover materials from burning household trash

Annex III: List of waste that is Hazardous because it is toxic, flammable, or reactive

UN Class	Code	Characteristics
1	**H1**	**Explosive**
		An explosive substance or waste is a solid or liquid (or a mix of solids and liquids) that can chemically react to make gas at a temperature, pressure, and speed that can hurt things around it.
3	**H3**	**Flammable liquids**
		The terms "flammable" and "inflammable" are synonymous. Flammable liquids are liquids, mixtures of liquids, or liquids that contain solids in solution or suspension (like paints, varnishes, lacquers, etc., but not including substances or wastes that are classified as dangerous for other reasons) that give off a flammable vapor at temperatures of no more than 60.5ºC in a closed cup test or 65.6ºC in an open cup test. (Results from open-cup tests and closed-cup tests aren't exactly the same, and even results from the same test can vary, therefore rules that account for these changes would be in line with this description)

4.1	**H4.1**	**Flammable solids**
		Solids, or waste solids, that aren't categorized as explosives but can easily catch fire when transported or cause or contribute to fire through friction.
4.2	**H4.2**	**Substances or wastes liable to spontaneous combustion**
		Things or garbage that can heat up on their own as they are transported, or that can heat up when they come into contact with air and subsequently catch fire.
4.3	**H4.3**	**Substances or wastes which, in contact with water emit flammable gases**
		Things or garbage that can catch fire on their own or give off dangerous amounts of flammable gasses when they come into contact with water.
5.1	**H5.1**	**Oxidizing**
		Substances or wastes that may not be flammable on their own, but can cause or help the burning of other things by giving off oxygen.
5.2	**H5.2**	**Organic Peroxides**
		Organic materials or wastes that have the bivalent-o-o-structure are thermally unstable and can break down in an exothermic, self-accelerating way.
6.1	**H6.1**	**Poisonous (Acute)**
		Things or trash that can kill or seriously hurt someone or hurt their health if they are swallowed, breathed in, or come into touch with skin.
6.2	**H6.2**	**Infectious substances**
		Substances or wastes containing living microorganisms or their toxins that are known or suspected to induce disease in animals or humans.
8	**H8**	**Corrosives**
		Chemicals or wastes that can severely harm living tissue when they come into contact with it, or that can leak and cause significant damage to other items or the means of transport; they may also pose other risks.
9	**H10**	**Liberation of toxic gases in contact with air or water**
		Things or wastes that can release hazardous gasses in harmful amounts when they come into contact with air or water.
9	**H11**	**Toxic (Delayed or chronic)**
		Substances or wastes that may cause delayed or long-term consequences, including cancer, if they are inhaled in, eaten, or come into contact with the skin.
9	**H12**	**Ecotoxic**
		Substances or wastes that, if discharged, pose or may pose immediate or delayed detrimental effects on the environment through bioaccumulation and/or toxic effects on biotic systems.
9	H13	After disposal, it can produce another material, such as leachate, that has any of the following properties.

Summary

Effective classification of hazardous wastes is essential for ensuring compliance with regulatory requirements, preventing environmental contamination, and protecting public health. A well-structured classification system enables waste generators, regulators, and waste management operators to identify the specific risks associated with each type of waste, and to develop appropriate strategies for handling, storage, transportation, and disposal. By accurately classifying hazardous wastes, stakeholders can also identify opportunities for waste minimization, recycling, and recovery, ultimately reducing the environmental and health impacts associated with these wastes.

The Basel Convention classifies hazardous waste into several categories based on its characteristics, composition, and potential risks to human health and the environment. The Convention lists specific wastes that are considered hazardous, including clinical wastes, pharmaceuticals, pesticides, and industrial chemicals. It also categorizes wastes based on their characteristics, such as explosiveness, flammability, toxicity, and corrosivity.

The Basel Convention's classification system is widely adopted and provides a consistent framework for classifying hazardous wastes across countries. The system includes three annexes that provide additional information on hazardous wastes. Annex I lists wastes that are considered hazardous and require special handling and disposal. Annex II categorizes wastes that require special consideration, such as household wastes. The wastes that are listed in Annex III are those that have hazardous properties, such as flammability and toxicity.

REFERENCE

- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, UNEP

Unit 03: Hazardous Waste and Environment

Unit Structure

3.0 Learning Objectives

After completion of this unit, learner will be able to:

- Explain the environmental impacts of hazardous waste
- Describe the human health impacts of hazardous waste
- Analyze the economic impacts of hazardous waste
- Discuss the social impacts of hazardous waste

3.1 Introduction

The proper management of hazardous waste is a pressing global concern due to its profound and lasting impacts on the environment, wildlife, and human health. Hazardous waste poses an existential threat to all living organisms, causing immediate and long-term harm that extends beyond environmental and health consequences to have social and economic repercussions. The effects of hazardous waste are not limited by geographical boundaries or generations, and its impact can be felt by communities near disposal sites, leading to population displacement, property devaluation, and disruption of social and economic structures. Effective management of hazardous waste is crucial to mitigate these far-reaching consequences and ensure a sustainable future.

The substantial increase in hazardous waste over the years necessitates robust systems and mechanisms for proper handling and disposal. Although definitions of hazardous waste vary across countries, a generic definition encompasses wastes that pose a significant threat to the environment or human life. Hazardous waste is unsafe due to its non-degradable nature, persistence in the environment, and long-term detrimental effects on human and animal health, as well as natural resources. Various sources generate hazardous waste, including industrial manufacturing, batteries, agricultural activities, domestic waste, mines, healthcare facilities, and contaminated sites. Additionally, hazardous wastes can emerge from waste oil, solvents, acids, toxic paints, chlorinated solvents, heavy metals, pesticides, and wastewater treatment sludge, posing significant environmental and health risks. Effective management and regulation are crucial to mitigate these risks.

The alarming environmental and health impacts of hazardous waste have prompted international and regional organizations to take decisive action. Over the years, various frameworks, guidelines, and regulations have been established to ensure the proper management, handling, and disposal of hazardous waste. These initiatives aim to minimize the risks associated with hazardous waste and promote sustainable environmental practices.

The Basel Convention, adopted in 1989, is a notable example of international cooperation. This global treaty regulates the transboundary movement of hazardous waste, aiming to prevent the export of hazardous waste from developed countries to developing countries. Additionally, the United Nations Environment Programme (UNEP) has developed guidelines and frameworks for the management of hazardous waste, including the UNEP Technical Guidelines for the Environmentally Sound Management of Waste.

Regional organizations have also taken significant steps to address the issue. The European Union's Waste Framework Directive sets out a framework for waste management, including provisions for the management of hazardous waste. Similarly, the Organization for Economic Co-operation and Development (OECD) has developed guidelines and recommendations for the management of hazardous waste, including the OECD Guidelines for the Testing of Chemicals. These international efforts demonstrate a growing recognition of the need for coordinated action to address the environmental impacts of hazardous waste.

3.2 Environmental Impacts

3.2.1 Impact on Ecology and Environment

Hazardous waste has a devastating impact on the ecology and environment, posing a significant threat to the delicate balance of ecosystems. The improper disposal of hazardous waste can contaminate soil, water, and air, leading to long-term environmental damage. This can result in the destruction of habitats, loss of biodiversity, and disruption of ecosystem services. For instance, the release of toxic chemicals into waterways can harm aquatic life, while the contamination of soil can affect plant growth and animal health.

The generation and disposal of hazardous waste have become a critical environmental issue worldwide. Hazardous waste is defined as any waste material that poses a threat to human health or the environment due to its toxic, corrosive, flammable, or reactive properties. The improper management of hazardous waste can have severe consequences, including environmental pollution, human health problems, and economic losses. It is essential to understand the impact of hazardous waste on the ecology and environment to develop effective strategies for its prevention, management, and disposal.

3.2.2 Air Pollution

There are different pollutants chiefly named as biological, chemical and radioactive responsible for the air pollution. Which have severe effects on both indoor and outdoor atmosphere. The pollutants which are responsible for the air pollution are categorized as biological, chemical and radioactive pollutants.

In-Door Air Pollution: Pathological and laboratory wastes are a significant source of indoor pollution, harboring pathogens that can persist in the environment for extended periods.

These microorganisms can be mitigated through fumigation or sterilization of rooms, reducing the pathogen load. Additionally, other indoor air pollutants, such as tobacco smoke, pose a significant threat to human health due to their complex mixture of pollutants. Furthermore, factors like air velocity, temperature, and humidity also play a crucial role in shaping the indoor environment and affecting human well-being. Effective management of these factors is essential to maintaining a healthy indoor environment.

Out-Door Air Pollution: Out-Door Air Pollution: Outdoor air pollution caused by hazardous waste is a significant environmental and health concern. The improper disposal of hazardous waste can lead to the release of toxic chemicals into the atmosphere, contaminating the air we breathe. These pollutants can come from various sources, including industrial facilities, waste disposal sites, and vehicles transporting hazardous materials. Once released into the air, these pollutants can travel long distances, affecting not only local communities but also regional and global air quality.

The health and environmental impacts of outdoor air pollution caused by hazardous waste are far-reaching and devastating. Exposure to these pollutants can lead to respiratory problems, cardiovascular disease, and even cancer. Moreover, outdoor air pollution can also damage ecosystems, harming plants and animals, and affecting the overall biodiversity of an area. Furthermore, hazardous waste-related air pollution can also contribute to climate change, as some pollutants, such as methane and nitrous oxide, are potent greenhouse gases. Therefore, it is essential to adopt effective strategies for managing hazardous waste and reducing outdoor air pollution to protect both human health and the environment.

3.2.3 Water Pollution

Water pollution by hazardous waste is a significant environmental issue that poses serious risks to human health, aquatic life, and the ecosystem as a whole. Hazardous waste, including industrial chemicals, pesticides, heavy metals, and other toxic substances, can contaminate surface water, groundwater, and soil, leading to widespread pollution. The improper disposal of hazardous waste, whether intentional or unintentional, can result in devastating consequences, including the destruction of aquatic habitats, the contamination of drinking water sources, and the loss of biodiversity.

- ***80% of the world's wastewater is released into the environment without adequate treatment (WHO).***
- ***1 in 5 people worldwide lack access to safe drinking water (UN).***
- ***Water pollution is responsible for 1.8 million deaths annually (WHO).***
- ***Hazardous waste is responsible for 10-20% of global water pollution (UNEP)***
- ***The world's most polluted rivers are the Ganges, Indus, and Mekong, which receive massive amounts of industrial and agricultural waste (WWF)***
- ***The Great Lakes, the world's largest freshwater ecosystem, receive over 100,000 pounds of toxic pollutants annually (EPA).***
- ***The global cost of water pollution is estimated to be over $1.3 trillion per year (WHO)***
- ***Water pollution affects over 1 billion people worldwide, causing health problems, economic losses, and environmental degradation (UN).***
- ***Hazardous waste in water can cause cancer, neurological damage, and reproductive problems (WHO).***
- ***Proper waste management and treatment can reduce water pollution by up to 90% (EPA).***

Industrial processes, such as manufacturing and chemical production, can generate large quantities of hazardous waste, which can contaminate surface water and groundwater if not disposed of properly. Agricultural activities, such as pesticide application and fertilizer use, can also lead to water pollution by hazardous waste. Mining operations, including coal mining and metal mining, can result in the release of heavy metals and other toxic substances into surface water and groundwater.

The effects of water pollution by hazardous waste can be severe and long-lasting, impacting both human health and the environment. Exposure to hazardous waste in water can cause a range of health problems, including cancer, neurological damage, and reproductive issues. Aquatic life can also be severely impacted, with many species unable to survive in polluted water. The ecosystem as a whole can be disrupted, leading to changes in water quality, reduced biodiversity, and decreased ecosystem function. In addition, water pollution by hazardous waste can also have significant economic impacts, including damage to fisheries, tourism, and other industries that rely on clean water.

3.2.4 Soil Pollution

Soil pollution by hazardous waste is a significant environmental issue that poses serious risks to human health, ecosystems, and the economy. Hazardous waste, including industrial chemicals, pesticides, heavy metals, and other toxic substances, can contaminate soil through improper disposal, industrial activities, and agricultural practices. According to the United Nations Environment Programme (UNEP), approximately 20% of the world's agricultural land is contaminated with heavy metals, pesticides, and other pollutants.

- **20% of the world's agricultural land is contaminated with heavy metals, pesticides, and other pollutants (UNEP).**
- **1 in 5 cancers are caused by environmental pollutants, including soil pollution (WHO).**
- **Exposure to lead in soil can cause developmental delays, learning disabilities, and behavioural problems in children (WHO).**
- **Soil pollution can reduce crop yields by up to 50% (FAO).**
- **The global cost of soil pollution is estimated to be over $10 trillion per year (UNEP).**

Soil pollution by hazardous waste can have severe impacts on human health, ecosystems, and the economy. Exposure to hazardous waste in soil can cause a range of health problems, including cancer, neurological damage, and reproductive issues. For example, exposure to lead in soil can cause developmental delays, learning disabilities, and behavioral problems in children. According to the World Health Organization (WHO), approximately 1 in 5 cancers are caused by environmental pollutants, including soil pollution. Soil pollution can also impact ecosystems, reducing biodiversity, altering nutrient cycles, and affecting soil fertility. In addition, soil pollution can have significant economic impacts, including reduced crop yields, decreased property values, and increased costs for soil remediation.

3.2.5 Radioactive Pollution

Radioactive pollution by hazardous waste is a significant environmental concern that poses severe risks to human health, ecosystems, and the economy. Hazardous waste, including radioactive materials, can contaminate the environment through improper disposal, industrial accidents, and natural disasters. Radioactive pollution can have devastating impacts on human health, including increased risk of cancer, genetic mutations, and reproductive problems. According to the World Health Organization (WHO), exposure to radioactive materials can cause a range of health effects, from mild symptoms like nausea and diarrhea to severe conditions like cancer and death.

The impacts of radioactive pollution by hazardous waste are far-reaching and can have severe consequences for the environment, human health, and the economy. Radioactive pollution can contaminate soil, water, and air, leading to widespread environmental damage. For example, the Chernobyl nuclear disaster in 1986 released large quantities of radioactive materials into the environment, contaminating a significant area around the plant. The disaster had severe impacts on human health, with increased incidence of cancer, thyroid disease, and other health problems. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the Chernobyl disaster released an estimated 50 tons of radioactive material into the environment, contaminating over 200,000 square kilometers of land.

- ***The world's nuclear power plants generate over 10,000 tons of radioactive waste annually, which must be carefully managed and disposed of to prevent environmental contamination. (World Nuclear Association)***
- ***The Chernobyl nuclear disaster released an estimated 50 tons of radioactive material into the environment, contaminating over 200,000 square kilometers of land. (UNSCEAR)***
- ***Radioactive pollution can increase the risk of cancer by up to 50%, depending on the level and duration of exposure. (WHO)***
- ***The global cost of radioactive pollution is estimated to be over $100 billion per year, including costs associated with environmental remediation, healthcare, and economic losses. (UNEP)***
- ***Radioactive pollution can contaminate soil, water, and air, leading to widespread environmental damage, including the destruction of ecosystems and the loss of biodiversity. (EPA)***

3.3 Human Health Impacts

3.3.1 Cancer and Other Diseases

Exposure to hazardous waste has been linked to an increased risk of cancer, neurological damage, and other diseases. Hazardous waste is a significant environmental pollutant that poses serious health risks to humans. Exposure to hazardous waste has been linked to an increased risk of various diseases, including cancer. In this article, we will explore the relationship between hazardous waste and cancer, as well as other diseases.

Hazardous waste contains toxic chemicals that can cause cancer. The International Agency for Research on Cancer (IARC) has classified many of these chemicals as carcinogenic to humans. Some of the most common carcinogenic chemicals found in hazardous waste include:

- **Benzene:** A solvent found in petroleum products; benzene has been linked to an increased risk of leukemia.
- **Polychlorinated** biphenyls (PCBs): These chemicals were widely used in electrical equipment and have been linked to an increased risk of liver cancer.

> - ***1 in 5 cancers are caused by environmental pollutants, including hazardous waste.***
> - ***20% of global deaths are caused by environmental pollutants, including hazardous waste***
> - ***1.7 million people die each year from environmental pollutants, including hazardous waste.***
> - ***the economic cost of environmental pollution is estimated to be $1.3 trillion per year.***
>
> ***WHO***

- **Dioxins:** These highly toxic chemicals are formed during the incineration of hazardous waste and have been linked to an increased risk of liver cancer.

According to the World Health Organization (WHO), exposure to hazardous waste has been linked to an increased risk of various types of cancer, including:

- **Leukemia:** Exposure to benzene and other solvents has been linked to an increased risk of leukemia.
- **Lymphoma:** Exposure to PCBs and other chemicals has been linked to an increased risk of lymphoma.
- **Liver cancer:** Exposure to dioxins and other chemicals has been linked to an increased risk of liver cancer.

In addition to cancer, hazardous waste has been linked to an increased risk of other diseases, including:

- **Neurological damage:** Exposure to hazardous waste has been linked to an increased risk of neurological damage, including cognitive impairment, memory loss, and mood disorders.
- **Respiratory problems:** Exposure to hazardous waste has been linked to an increased risk of respiratory problems, including asthma and bronchitis.
- **Reproductive problems:** Exposure to hazardous waste has been linked to an increased risk of reproductive problems, including birth defects, miscarriage, and infertility.

3.3.2 Birth Defects and Reproductive Problems

Hazardous waste is a significant environmental pollutant that poses serious health risks to humans, particularly to pregnant women and their unborn babies. Several chemicals found in hazardous waste have been linked to birth defects and reproductive problems, some of which are as follows:

Dioxins: Dioxins are highly toxic chemicals that can cause birth defects and reproductive problems.

Furans: Furans are highly toxic chemicals that can cause birth defects and reproductive problems.

Polychlorinated biphenyls (PCBs): PCBs are highly toxic chemicals that can cause birth defects and reproductive problems.

Pesticides: Pesticides, such as DDT and dieldrin, have been linked to birth defects and reproductive problems.

Exposure to hazardous waste has been linked to an increased risk of birth defects and reproductive problems:

A) Birth Defects

Birth defects are structural or functional abnormalities that occur during fetal development. Exposure to hazardous waste has been linked to an increased risk of various birth defects, including:

- **Neural tube defects:** Exposure to hazardous waste has been linked to an increased risk of neural tube defects, such as spina bifida and anencephaly.
- **Heart defects:** Exposure to hazardous waste has been linked to an increased risk of heart defects, such as atrial septal defects and ventricular septal defects.
- **Cleft palate and cleft lip:** Exposure to hazardous waste has been linked to an increased risk of cleft palate and cleft lip.
- **Limbs defects:** Exposure to hazardous waste has been linked to an increased risk of limbs defects, such as clubfoot and polydactyly.

B) Radioactive Pollution by Hazardous Waste: A Devastating Consequence

Reproductive problems refer to any issues that affect the reproductive system, including infertility, miscarriage, and stillbirth. Exposure to hazardous waste has been linked to an increased risk of various reproductive problems, including:

- **Infertility:** Exposure to hazardous waste has been linked to an increased risk of infertility in both men and women.
- **Miscarriage:** Exposure to hazardous waste has been linked to an increased risk of miscarriage.
- **Stillbirth:** Exposure to hazardous waste has been linked to an increased risk of stillbirth.
- **Low birth weight:** Exposure to hazardous waste has been linked to an increased risk of low birth weight.

3.3.3 Neurological Damage by Hazardous Wastes: A Silent Epidemic

Hazardous wastes, including industrial chemicals, pesticides, heavy metals, and other toxic substances, can cause severe neurological damage, affecting millions of people worldwide. Neurological damage refers to the harm caused to the brain, spinal cord, and nervous system, leading to a range of health problems, from mild cognitive impairment to severe neurological disorders. Exposure to hazardous wastes can occur through various routes, including inhalation, ingestion, and skin contact, and can affect people of all ages, from children to adults. For example, exposure to lead, a common hazardous waste, can cause irreversible brain damage, leading to reduced IQ, learning disabilities, and behavioral problems in children. Here are some examples of neurological damage caused by hazardous wastes:

- **Lead Poisoning:** Exposure to lead, commonly found in hazardous wastes such as batteries, paints, and pesticides, can cause severe neurological damage, including reduced IQ, learning disabilities, and behavioral problems in children.
- **Mercury Poisoning:** Exposure to mercury, commonly found in hazardous wastes such as thermometers, fluorescent light bulbs, and industrial processes, can cause neurological damage, including tremors, muscle weakness, and cognitive impairment.
- **Pesticide Poisoning:** Exposure to pesticides, commonly used in agriculture and gardening, can cause neurological damage, including Parkinson's disease, Alzheimer's disease, and other neurodegenerative disorders.
- **Solvent-Induced** Encephalopathy: Exposure to solvents, commonly found in hazardous wastes such as cleaning products, paints, and adhesives, can cause neurological damage, including cognitive impairment, memory loss, and mood disorders.
- **Heavy Metal Poisoning:** Exposure to heavy metals, commonly found in hazardous wastes such as industrial processes, mining, and waste disposal, can cause neurological damage, including cognitive impairment, neurological disorders, and birth defects.

3.4 Economic Impacts

Hazardous waste can have significant economic impacts on individuals, communities, and societies as a whole. The economic costs of hazardous waste can be substantial, ranging from direct costs such as cleanup and remediation to indirect costs such as health impacts and lost productivity.

3.4.1 Direct Economic Impacts

1. Cleanup and Remediation Costs: The cost of cleaning up and remediating hazardous waste sites can be extremely high, ranging from millions to billions of dollars.

2. Waste Disposal Costs: The cost of disposing of hazardous waste can be significant, particularly if it requires specialized treatment and disposal facilities.

3. Environmental Damage: Hazardous waste can cause significant environmental damage, including contamination of soil, water, and air, which can have long-term economic impacts.

3.4.2 Indirect Economic Impacts

1. Health Impacts: Exposure to hazardous waste can have significant health impacts, including increased risk of cancer, neurological damage, and other health problems, which can result in significant economic costs.

2. Lost Productivity: Hazardous waste can also have indirect economic impacts, including lost productivity due to illness, injury, or death.

3. Property Value Impacts: Hazardous waste can also impact property values, making it more difficult to sell or develop properties near contaminated sites.

3.5 Social Impacts

Hazardous waste has far-reaching social impacts that affect communities, individuals, and society as a whole. The effects of hazardous waste on human health, the environment, and the economy have significant social implications.

3.5.1 Community Displacement and Migration

Hazardous waste contamination can lead to community displacement, as residents may be forced to relocate due to health concerns. Hazardous waste contamination can lead to community displacement, as residents may be forced to relocate due to health concerns. This displacement can result in the loss of community identity, social networks, and cultural heritage. For example, the Love Canal disaster in the United States led to the relocation of over 900 families, causing significant social and emotional trauma.

3.5.2 Loss of Trust and Social Unrest

Hazardous waste contamination can erode trust in government and industry, leading to social unrest and conflict. Communities may feel betrayed by the failure of regulatory agencies to protect their health and environment. This loss of trust can lead to protests, demonstrations, and other forms of social activism.

3.5.3 Environmental Justice and Health Disparities

Hazardous waste contamination can disproportionately affect vulnerable populations, including low-income communities and communities of color. Hazardous waste contamination can have significant economic impacts on local communities. Contamination can reduce property values, making it difficult for residents to sell their homes. Local businesses may also suffer, as contamination can deter customers and investors. For example, the contamination of the Houston Ship Channel in Texas, USA, led to significant economic losses for local businesses and residents.

3.5.4 Psychological Impacts on Communities

Hazardous waste contamination can also have significant psychological impacts on communities. Residents may experience anxiety, depression, and post-traumatic stress disorder (PTSD) due to the trauma of living in a contaminated environment. Children may also be affected, with studies showing that exposure to hazardous waste can lead to cognitive and behavioral problems.

3.2.6 Occupational Hazards

Hazardous waste can pose significant occupational hazards to workers involved in its handling, transportation, treatment, and disposal. These hazards can result in serious health problems, injuries, and even death. Workers in various industries, including waste management, chemical manufacturing, construction, and emergency response, are at risk of exposure to hazardous waste. The types of occupational hazards associated with hazardous waste include chemical hazards, physical hazards, biological hazards, and radiological hazards. Chemical hazards can cause respiratory problems, skin irritation, and other health issues, while physical hazards can result in explosions, fires, and falls. Biological hazards can lead to infections, and radiological hazards can cause cancer and other health problems. There have been several instances of occupational hazards associated with hazardous waste, highlighting the need for stringent regulations and enforcement. The Bhopal disaster in India in 1984, which resulted in the deaths of thousands of workers and nearby residents due to exposure to toxic chemicals, is a stark reminder of the devastating consequences of occupational hazards. The Love Canal disaster in the United States in the 1970s, which resulted in the contamination of soil and water with toxic chemicals, posing health risks to workers and nearby residents, is another example. The asbestos exposure cases in the construction and manufacturing industries, which have resulted in serious health problems, including lung cancer and mesothelioma, further emphasize the need for stringent regulations and enforcement to protect workers from occupational hazards associated with hazardous waste.

Preventing and protecting workers from occupational hazards associated with hazardous waste is crucial. Employers must provide workers with personal protective equipment (PPE), such as gloves, masks, and suits, to prevent exposure to hazardous waste. Workers should also receive training and education on the hazards of hazardous waste and how to handle it safely. Engineering controls, such as ventilation systems and containment structures, should be used to prevent exposure to hazardous waste. Additionally, employers must comply with relevant regulations and standards for handling hazardous waste. Workers should also be aware of the potential hazards associated with hazardous waste and take necessary precautions to protect themselves. Regular medical check-ups and monitoring of workers' health can also help identify any potential health problems early on.

Summary

Hazardous waste poses significant environmental, health, and economic risks. Its improper disposal can contaminate soil, water, and air, leading to long-term environmental damage and health problems. The environmental impacts of hazardous waste are far-reaching, including the contamination of soil, water, and air, destruction of habitats, loss of biodiversity, and disruption of ecosystem services.

The health impacts of hazardous waste are equally alarming, with exposure linked to an increased risk of cancer, neurological damage, and reproductive problems. Hazardous waste has also been linked to birth defects, miscarriage, and stillbirth, as well as neurological damage, including cognitive impairment and mood disorders. Furthermore, hazardous waste can have significant economic impacts, including direct costs such as cleanup, remediation, and waste disposal, as well as indirect costs like health impacts, lost productivity, and property value impacts.

In addition to environmental, health, and economic impacts, hazardous waste can also have significant social impacts. Community displacement and migration can occur due to hazardous waste contamination, leading to loss of trust and social unrest. Environmental justice and health disparities can also arise, with vulnerable populations disproportionately affected by hazardous waste. Moreover, hazardous waste can have psychological impacts on communities, including anxiety, depression, and post-traumatic stress disorder (PTSD).

Hazardous waste also poses significant occupational hazards to workers involved in its handling, transportation, treatment, and disposal. These hazards can result in serious health problems, injuries, and even death. Employers must provide personal protective equipment (PPE) and training to workers, as well as implement engineering controls, such as ventilation systems and containment structures, to prevent exposure to hazardous waste. Compliance with regulations and standards, as well as regular medical check-ups and monitoring of workers health, are also crucial to preventing and protecting workers from occupational hazards associated with hazardous waste.

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Unit 4: Hazardous Wastes Sampling

Unit Structure

4.0 Learning Objectives

After completion of this unit, you will be able to:

- understand the concept of sampling of hazardous waste;
- understand sampling safety concerns;
- understand about surface contamination sampling;
- understand about different equipments used in hazardous waste management;
- understand about the importance of determination of the amount of hazardous waste

4.1Introduction

The process of gathering and examining waste materials that could endanger human health or the environment is known as hazardous waste sampling. Finding the kind, amount, and characteristics of hazardous materials in the waste requires this procedure. Ensuring regulatory compliance and evaluating hazards for storage, transportation, treatment, and disposal are the primary goals of hazardous waste sampling. assisting with pollution management and site cleanup initiatives. Analyzing the wastes' physical and chemical characteristics is a requirement of any hazardous waste management system. The majority of the features that are of concern are chemical ones, and the MoEF has established regulation criteria that cannot be matched or surpassed in the case of some chemical pollutants. The crucial step of gathering representative waste samples for the determination of analytical parameters is also included in the analysis and characterization of hazardous wastes.

4.2 Sampling of hazardous waste

The plan for sampling the waste is the first and possibly most important component of a program created to assess the waste's physical and chemical characteristics. It makes sense since analytical investigations are frequently seen as the main component of the waste characterization program due to their expensive and complex equipment. However, analytical data produced by a scientifically flawed sample plan have little utility, especially in the event of regulatory processes, despite their sophistication and high cost. Safety is of utmost importance when sampling hazardous waste, which entails gathering potentially harmful items for analysis. Because hazardous waste is poisonous, reactive, corrosive, or combustible, incorrect sampling can seriously endanger both the environment and human health. Important safety issues consist of:

Chemical Exposure: Exposure to hazardous vapors, fumes, or dust through direct contact or inhalation can have immediate or long-term negative health impacts.

Physical Risks: Sampling may take place in hazardous areas including cramped quarters, shaky terrain, or close to moving machinery.

Reactivity Risks: When incompatible materials are mixed during sampling, hazardous gasses may be released or there may be explosions or fires.

Failure of Personal Protective Equipment (PPE): Exposure and contamination may result from inadequate or incorrectly employed PPE.

Environmental Contamination: Water, soil, or air may get contaminated by spills or leaks that occur during sampling.

4.2.1 Selecting sampling methods

To be representative, a sample must be collected and handled in a way that preserves its original physical form and composition and prevents contamination or changes in concentration of the parameters to be analyzed. This can only be accomplished by adopting an appropriate sampling plan, methodology, technique, and use of appropriate sample collection equipment. Sampling is the physical collection of a representative portion of the entire waste. The fundamental principle behind the collection of a representative sample is to ensure that the sample being collected exhibits the average properties of the whole or the bulk of the waste. A sample must accurately represent the average physical and chemical characteristics of the entire waste from which it is taken in order to provide useful data. The integrity be upheld and that it will be examined as a part of a clearly defined program for quality control and assurance. It goes without saying that different sample methods and approaches will be used due to the variety of wastes and waste storage and management situations.

4.2.2 Sampling strategies/planning

To obtain a representative sample that can yield scientifically viable data, a sampling strategy must be developed and implemented. These strategies should be chosen or prepared before actual sampling in order to plan and coordinate sampling activities, maximize data accuracy, and minimize errors due to poorly chosen sampling procedures. At the very least, a sampling strategy should cover the following topics: the goals of sample collection, the sampling approach, the types of samples required, the selection of sampling locations, the number of samples, the frequency of sampling, the sample collection and handling techniques to be used, the physical and chemical properties of the wastes, and special circumstances or considerations.

Hazardous wastes have a wide range of physical and chemical characteristics and are complicated and diverse. Typically, waste samples are taken from ponds, piles, tanks, drums, and other processing or transportation equipment, like conveyor belts. It is crucial to carry out representative sampling. A sampling plan or protocol that guarantees the right number of samples will be collected at the right frequency and that minimizes sample loss or degradation is necessary to guarantee representative sampling. Before beginning the sampling process, a plan should be created that addresses the goal, sites, sample size, and other details. The appropriate use of descriptions, the quantity and frequency of samples, decontamination techniques, and handling methods should all be covered in the sampling strategy.

4.2.3 Sampling equipment

The selection of equipment totally depends on the physico-chemical properties of the waste material. The physical properties of the waste particularly influence the selection of the equipment, such as the waste is freely flowing, highly viscous liquids, crushed, powdered or whole solid matrices, contained in soils, open dumps, etc. Although, chemical properties also influence the selection of the equipment, the person taking the sample should ensure that the equipment is made of materials that are not only compatible with the waste but also resistant to interactions that could change or skew the trash chemical or physical properties. Different types of sample collection equipment are used for sampling, some of them are: Composite Liquid Waste Sampler (Coliwasa), Grain Sampler, Weighted Bottle, Dipper, Thief, Trier, Auger, Scoops and Shovels.

Table 1: List of different sampling equipments used for collecting different waste units

S. No.	Name of equipment	Waste unit
1.	Push tube	Piles, containers/cohesive solids, sludges
2.	Spoon	Impoundments, piles, containers/solids, sludges
3.	Scoop with bracket/conduit	Impoundments, piles, containers, tanks/liquids, solids, sludges
4.	Sediment sampler	impoundments, piles/solids, sludges
5.	Auger	Impoundments, piles, containers/solids
6.	Coliwasa	Impoundments, containers, tanks/liquids
7.	Bacon bomb	Impoundments, tanks/liquids
8.	Split-spoon	Piles/solids

4.3 Determination of the amount of hazardous waste

An essential part of effective waste management is the determination of the amount of hazardous waste. It entails determining, measuring, and recording the amount of hazardous waste produced, kept, processed, or disposed of at a facility. Precise measurement guarantees adherence to environmental standards, promotes appropriate management, and aids in waste reduction strategies. Numerous techniques are used to determine the amount of hazardous waste, including flow measurement (for liquid waste), volume estimation, direct weighing, and record-based computations (using production or material usage data).

Regular monitoring and proper documentation help in tracking trends, reporting to regulatory bodies, and designing suitable treatment or disposal systems. This process is essential for protecting human health and the environment. To be representative, a sample must be collected and handled in a way that preserves its original physical form and composition and prevents contamination or changes in concentration of the parameters to be analyzed.

Check your progress

1. Explain the process of sampling of hazardous waste.
2. Explain the sampling selecting methods in detail.
3. What is the different sampling equipments used in hazardous waste management.
4. Write a short note on determination of the amount of hazardous waste.

Answers:

1. See section 4.2
2. See section 4.2.1
3. See section 4.2.3
4. See section 4.3

Summary

This unit describes the concept of sampling of hazardous waste and the different equipments used in hazardous waste management. The process of gathering and examining waste materials that could endanger human health or the environment is known as hazardous waste sampling. Analyzing the wastes' physical and chemical characteristics is a requirement of any hazardous waste management system. The majority of the features that are of concern are chemical ones, and the MoEF has established regulation criteria that cannot be matched or surpassed in the case of some chemical pollutants. The selection of equipment totally depends on the physico-chemical properties of the waste material. Different types of sample collection equipment are used for sampling, some of them are: Composite Liquid Waste Sampler (Coliwasa), Grain Sampler, Weighted Bottle, Dipper, Thief, Trier, Auger, Scoops and Shovels. Although, chemical properties also influence the selection of the equipment, the person taking the sample should ensure that the equipment is made of materials that are not only compatible with the waste but also resistant to interactions that could change or skew the trash chemical or physical properties. An essential part of effective waste management is the determination of the amount of hazardous waste. It entails determining, measuring, and recording the amount of hazardous waste produced, kept, processed, or disposed of at a facility. Numerous techniques are used to determine the amount of hazardous waste, including flow measurement, volume estimation, direct weighing, and record-based computations.

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Unit 05: Hazardous Waste Transportation

Unit Structure

5.0 Learning Objectives

After the completion of this unit, the leaner should be able to:

- discuss the modes of transportation of hazardous wastes
- advantages / disadvantages of different modes of transportation of hazardous waste
- have awareness on the regulatory complexities associated with movement of hazardous wastes
- Understand the general nature of the regulations imposed upon transport of hazardous wastes by different regulatory agencies

5.1 Introduction

The transport of hazardous waste from its origin to treatment and disposal sites has been significantly hindered by mismanagement, resulting in substantial environmental risks, including health hazards for humans animals, and other living organisms. Historically, there have been numerous transportation incidents that posed serious threats to environmental integrity and public safety. Over time, as various regulatory bodies emerged, particularly in the late 1970s and early 1980s, many hazardous waste producers sought to avoid the rising costs associated with compliant waste management by improperly disposing of their waste. This period witnessed an increase in illegal midnight dumping activities. Truck operators adapted their vehicles with concealed dumping mechanisms, allowing them to discharge liquid waste during transport. Abandoned trailers filled with hazardous waste containers were often left in remote locations, contaminating rural and desert landscapes with toxic substances, thereby endangering the local ecology.

As regulatory agencies matured and gained expertise, non-compliant transporters were phased out. Regulatory efforts have mostly switched toward preventing accidents and guaranteeing emergency response readiness, monitoring import-export activities, and tracking waste transportation from generation to final disposal, even though unlawful actions still require the attention of law enforcement. This development represents a major advancement in the proper and safe handling of hazardous waste. A complete approach is necessary for the effective management of hazardous waste, whether it is off-site at a Treatment, Storage, and Disposal Facility (TSDF) or on-site at the generator's property. It includes:

- Proper segregation and characterization of waste
- Maximizing recyclables / recoverable waste for reuse
- immobilizing waste through treatment / destruction, such as incineration, as needed
- Ensuring minimal environmental impact upon disposal

However, the critical interface between waste generation, transportation and disposal must not be overlooked. This phase is vital for mitigating environmental damage and safeguarding public health. The main obstacles in the nation's waste management are predominantly institutional and behavioral, rather than technical. Significant concerns related to hazardous waste management encompass:

- Inadequate segregation of hazardous waste (from less polluting or recyclable waste, increasing waste volume and treatment costs)
- Missed opportunities to recover valuable materials and reduce raw material investments

Small and medium-scale industries are significant contributors to waste generation, but the scarcity of common disposal facilities forces many to dump waste on-site. This often results in illegal dumping due to insufficient storage space and inadequate environmental safeguards, posing substantial environmental and health risks. Although some states, such as Andhra Pradesh, Gujarat, and Maharashtra, have pioneered common facilities, the widespread issue of inadequate waste management necessitates further action. Hazardous waste transporters are crucial players in the hazardous waste management system. They are responsible for safe movement of hazardous waste from its source to its final destination via various modes of transportation, including highways, railways, ships or aero planes. Their role involves transporting hazardous waste from the site of its generation to facilities that are meant for recycling, treatment, storage and disposal. In order to ensure the safe and effective transportation of hazardous materials, they may also carry treated hazardous waste to other locations for additional treatment or disposal.

5.2 Risk during Transportation

Transporting hazardous waste poses significant risks to human health, the environment, and the transportation infrastructure. These risks can be categorized into several types:

5.2.1 Environmental Risks

- **Spills and leaks:** Hazardous waste can spill or leak during transportation, contaminating soil, water, air and whole ecosystem and habitats of important species.
- **Soil and groundwater contamination:** Leaks or spills can contaminate soil and groundwater, posing long-term environmental risks particularly to the local community.
- **Air pollution:** Hazardous waste transportation can release toxic chemicals into the air, contributing to air pollution.

5.2.2 Human Health Risks

- **Exposure to toxic chemicals:** Transportation accidents or spills can expose people to toxic chemicals, causing injury or death.
- **Respiratory problems:** Inhaling toxic chemicals can cause respiratory problems, such as asthma or other breathing difficulties.
- **Cancer risk:** Long-term exposure to toxic chemicals can increase the risk of cancer.

5.2.3 Infrastructure Risks

- **Damage to roads and bridges:** Hazardous waste transportation can damage roads and bridges, particularly if there are accidents or spills.
- **Disruption of transportation systems:** Accidents or spills can disrupt transportation systems, causing delays and economic losses.
- **Increased maintenance costs:** Hazardous waste transportation can increase maintenance costs for roads and bridges.

5.2.4 Social Risks

- **Community concerns:** Hazardous waste transportation can raise concerns among local communities, particularly if there are accidents or spills.
- **Economic impacts:** Accidents or spills can have negative economic impacts on local businesses and communities.
- **Reputation damage:** Companies and Government involved in hazardous waste transportation can suffer reputational damage if there are accidents or spills.

5.3 Modes of HW Transportation

Hazardous waste transportation involves the movement of hazardous materials from one location to another, typically from a generator's site to a treatment, storage, or disposal facility. There are several modes of transportation used for hazardous waste:

- Truck Transport
- Rail Transport
- Marine Transport

- Air Transport
- Pipeline Transport

5.3.1 Highway Shipment of HWs or transport via trucks

Truck transport of hazardous waste is a critical component of the waste management industry, requiring specialized equipment, trained personnel, and adherence to stringent regulations. Most of the hazardous waste transportation, approximately 90% of all hazardous waste shipments, is accomplished via trucks though highways and generally fit into one of the following three categories:

- Generators transporting their wastes to treatment, storage, and disposal (TSD) facilities
- Contract haulers collecting wastes from generators and transporting the wastes to TSD facilities
- TSD facilities collecting wastes from generators and transporting the wastes to their facilities

The most adaptable mode is thought to be highway transportation. TSD facilities and most industrial sites are accessible by tank trucks. Although 55-gal barrels are used to transport huge amounts of hazardous waste in non-bulk and less-than-truckload (LTL) shipments, cargo tanks are the primary means of transporting bulk hazardous materials. Generators are believed to prefer keeping control of their wastes by transporting them in company-owned or operated vehicles because to the enormous liabilities that can result from unintentional release, inappropriate handling, and illegal disposal. Alternatively, if the facility's trucking operation picks up and transports their waste, generators may feel more assured that it will arrive at the approved TSD facility (Wentz 1989, p. 268). The reduction in the number of small, locally based waste-hauling businesses is likely mostly due to these factors. Although titanium, nickel, or stainless steel can be used to build cargo tanks, steel or aluminum alloys are mostly used.

Hazardous waste is transported by truck to treatment, storage, and disposal facilities (TSDFs), as well as to recycling and recovery facilities. Several types of trucks are used for hazardous waste transportation, including:

- **Tank trucks:** Used for transporting liquids, such as chemicals and fuels.
- **Box trucks:** Used for transporting solids, such as drums and containers.
- **Dump trucks:** Used for transporting bulk hazardous waste, such as contaminated soil.
- **Flatbed trucks:** Used for transporting oversized or irregularly shaped hazardous waste.

Trucks used for hazardous waste transportation should be equipped with specialized safety features and equipment, such as:

1. **Hazardous materials placards:** Displayed on the truck to indicate the type of hazardous material being transported.
2. **Emergency response equipment:** Such as fire extinguishers, spill response kits, and first aid kits.
3. **Securement systems:** Used to prevent shifting or falling of hazardous waste during transport.
4. **Leak detection systems:** Used to detect leaks or spills during transport.

In order to ensure safe and compliant transportation of hazardous waste, transport companies and drivers should follow some best practices, such as:

- **Proper training:** Ensure that drivers and personnel are properly trained on hazardous waste transportation regulations and safety procedures.
- **Regular maintenance:** Regularly maintain trucks and equipment to prevent accidents and spills.
- **Secure loading and unloading:** Ensure that hazardous waste is properly secured during loading and unloading operations.
- **Accurate documentation:** Maintain accurate records of hazardous waste transportation, including manifests, bills of lading, and driver logs.
- **Emergency response planning:** Develop and implement emergency response plans in case of accidents or spills during transportation.

5.3.2. Transport of HW via Railways

Rail transport is a vital component of the hazardous waste management industry, offering a safe and efficient mode of transportation for large quantities of hazardous materials. This article provides an in-depth examination of rail transport of hazardous waste, including its benefits, regulations, safety measures, and best practices. Rail transport offers several advantages over other modes of transportation. The benefits include:

- **Capacity:** Railcars can transport large quantities of hazardous waste, making it an ideal mode for bulk shipments.
- **Efficiency:** Rail transport is generally faster than truck transport, reducing transit times and increasing the speed of delivery.
- **Safety:** Rail transport is considered one of the safest modes of transportation, with a lower incident rate compared to truck transport.
- **Cost-effectiveness:** Rail transport can be more cost-effective than truck transport, particularly for large shipments.

To ensure safe rail transport of hazardous waste, certain safety measures are implemented. These measures include the following:

- **Proper packaging and labeling:** Hazardous waste is properly packaged and labeled to prevent leaks or spills during transport.
- **Secure loading and unloading:** Hazardous waste is securely loaded and unloaded from railcars to prevent accidents.
- **Railcar inspection and maintenance**: Railcars are regularly inspected and maintained to ensure they are in good working condition.
- **Emergency response planning:** Rail transport personnel are trained in emergency response procedures in case of accidents or spills.

In order to ensure safe and compliant rail transport of hazardous waste, the following best practices are recommended:

- **Proper training:** Ensure that rail transport personnel are properly trained on hazardous waste transportation regulations and safety procedures.

- **Regular audits and inspections:** Conduct routine audits and inspections in order to make sure that rules and safety requirements are being followed.
- **Accurate documentation:** Maintain accurate records of hazardous waste transportation, including manifests, bills of lading, and railcar inspection records.
- **Communication and coordination:** Ensure effective communication and coordination between rail transport personnel, hazardous waste generators, and regulatory agencies.

Rail transport is a critical component of the hazardous waste management industry, which offers a safe and efficient mode of transportation for large quantities of hazardous materials. By understanding the benefits, regulations, safety measures, and best practices associated with rail transport of hazardous waste, generators and transporters can ensure compliant and safe transportation of hazardous wastes.

5.3.3 Maritime Transport of HW

Maritime transport plays a vital role in the global economy, with millions of tons of goods, including hazardous waste, being transported by sea every year. The maritime transport of hazardous waste is a complex and highly regulated industry, requiring specialized ships, equipment, and personnel. This article provides an in-depth examination of maritime transport of hazardous waste, including its benefits, regulations, safety measures, and best practices. Maritime transport offers several advantages for the transportation of hazardous waste over other means of transportation, such as:

- **Cost-effective option:** Maritime transport allows for the transportation of large quantities of hazardous waste, making it a cost-effective option.
- **Global reach:** Maritime transport enables the transportation of hazardous waste across the globe, connecting major ports and trade routes.
- **Reduced risk of accidents:** Maritime transport is considered a relatively safe mode of transportation, with a lower risk of accidents compared to land-based transportation.

- **Environmental benefits:** Maritime transport can be a more environmentally friendly option compared to land-based transportation, with lower greenhouse gas emissions per ton of cargo.

The maritime transport of hazardous waste is regulated by various international and national agencies, including:

- **International Maritime Organization (IMO):** Develops and implements global standards for the safe and environmentally sound transportation of hazardous waste by sea.
- **International Convention for the Prevention of Pollution from Ships (MARPOL):** It is for the regulation of prevention of pollution from ships, which also includes hazardous waste transportation.
- **Basel Convention:** Regulates the transboundary movement of hazardous waste, including its transportation by sea.
- **National regulations:** Countries have their own national regulations and guidelines for the maritime transport of hazardous waste.

Safety Measures

Several safety measures are needed in order to ensure safe maritime transport of hazardous waste. These safety measures include the following:

- **Proper packaging and labeling:** Hazardous waste is properly packaged and labeled to prevent leaks or spills during transport and labelling will help managing the risk efficiently and timely in the event of any leakage.
- **Secure loading and unloading:** Hazardous waste is securely loaded and unloaded from ships to prevent accidents.
- **Ship design and construction:** Ships are designed and constructed to meet specific safety standards for the transportation of hazardous waste.
- **Crew training and competence:** Crew members must be trained and competent in handling hazardous waste and responding to any emergencies out of hazardous waste.

Certain best practices are also recommended to ensure safe and compliant maritime transport of hazardous waste. These best practices are:

- **Proper documentation:** Maintain accurate and complete documentation, including manifests, bills of lading, and cargo declarations.
- **Regular inspections and maintenance:** Regularly inspect and maintain ships and equipment to ensure they are in good working condition.
- **Communication and coordination:** Ensure effective communication and coordination between ship-owners, operators, and regulatory agencies.
- **Emergency response planning:** Develop and implement emergency response plans in case of accidents or spills.

Several types of ships are used for the maritime transport of hazardous waste, including:

- **Tankers:** Used for transporting liquids, such as chemicals and fuels.
- **General cargo ships:** Used for transporting solids, such as drums and containers.
- **Bulk carriers:** Used for transporting bulk hazardous waste, such as contaminated soil.
- **Specialized ships:** Used for transporting specialized hazardous waste, such as radioactive materials.

Maritime transport plays a critical role in the global hazardous waste management industry, offering a safe and efficient mode of transportation for large quantities of hazardous materials. By understanding the benefits, regulations, safety measures, and best practices associated with maritime transport of hazardous waste, ship-owners, operators, and regulatory agencies can ensure compliant and safe transportation of hazardous wastes.

5.3.4 Air Transport of Hazardous Waste

Air transport is an important part of the worldwide hazardous waste management sector because it is a quick and easy way to move dangerous goods. But transporting hazardous garbage by air is a very complicated and highly regulated procedure that needs special tools, skilled workers, and strict safety rules to be followed. This page goes into great detail about the air transport of hazardous waste, covering its pros and cons, rules, safety measures, and best practices. There are a number of benefits to using air transport to move hazardous waste, such as:

- **Speed:** Air transport is the fastest way to get things from one place to another, so it can quickly take hazardous waste to treatment, storage, and disposal
- **Global reach:** Air transport makes it possible to move dangerous trash all over the world by connecting key airports and trade routes.
- **Security:** Air transport is very safe since it has many layers of protection to keep people from getting to or interfering with hazardous waste.
- **Reliability:** Air travel is a dependable way to get around, with a high percentage of on-time delivery and a low chance of delays or cancellations.

Regulations and Guidelines

The air transport of hazardous waste is regulated by various international and national regulations and guidelines. These include:

- The International Air Transport Association (IATA) establishes and enforces rules for the safe transport of dangerous goods by air around the world.
- The International Civil Aviation Organization (ICAO) is in charge of both international air travel and the movement of dangerous goods.
- Federal Aviation Administration (FAA): This group makes sure that air travel in the United States is safe, including the transport of dangerous goods.
- National rules: Each country has its own rules and guidelines for the safe transfer of hazardous waste by air.

Safety Measures

There are a number of safety steps that need to be taken to make sure that hazardous trash can be safely transported by air. These are:

- **Proper packaging and labelling:** Hazardous garbage is wrapped and labelled correctly so that it doesn't leak or spill while being moved.
- **Safe loading and unloading:** Hazardous waste is loaded and unloaded from planes in a safe way to avoid accidents.

- **Design and build of aircraft:** Aircraft are designed and built to satisfy certain safety criteria for moving dangerous materials.
- **Training and skills of the crew:** Crew members are trained and skilled in how to handle dangerous materials and deal with emergencies.

Apart from appropriate safety measures, safe and compliant air transport of hazardous waste is only possible when certain best practices are required. These are:

- **Proper documentation:** Maintain accurate and complete documentation, including manifests, bills of lading, and cargo declarations.
- **Regular inspections and maintenance:** Regularly inspect and maintain aircraft and equipment to ensure they are in good working condition.
- **Communication and coordination:** Ensure effective communication and coordination between airlines, handlers, and regulatory agencies.
- **Emergency response planning:** Develop and implement emergency response plans in case of accidents or spills.

The air transport of hazardous wastes is accomplished by several types of aircraft. These aircraft are as follows:

- **Cargo aircraft:** Used for transporting large quantities of hazardous waste, such as bulk chemicals or fuels.
- **Passenger aircraft:** Used for transporting small quantities of hazardous waste, such as medical waste or laboratory samples.
- **Specialized aircraft:** Used for transporting specialized hazardous waste, such as radioactive materials or infectious substances.

Challenges and Opportunities

The air transport of hazardous waste presents several challenges, including:

- **Regulatory complexity:** The air transport of hazardous waste is subject to multiple regulations and guidelines, which can be complex and difficult to navigate.
- **Safety risks:** The air transport of hazardous waste poses safety risks, including the risk of accidents, spills, or leaks.

- **Environmental concerns:** The air transport of hazardous waste raises environmental concerns, including the risk of pollution or contamination.

Despite these challenges, the air transport of hazardous waste also presents many opportunities, these are:

- **Increased efficiency:** Air transport can increase the efficiency of hazardous waste management, enabling rapid delivery of hazardous waste to treatment, storage, and disposal facilities.
- **Improved safety:** Air transport can make handling hazardous waste safer by lowering the chances of spills, accidents, or leaks.
- **Enhanced compliance:** Air transport can enhance compliance with regulations and guidelines, ensuring that hazardous waste is transported in accordance with national and international standards.

The air transport of hazardous waste is thus, a complex and highly regulated process, which requires specialized equipment, trained personnel, and adherence to stringent safety standards. By understanding the benefits, regulations, safety measures, and best practices associated with air transport of hazardous waste, airlines, handlers, and regulatory agencies can ensure safe and compliant transportation of hazardous wastes.

5.3.5 Transport of Hazardous Waste though pipelines

Pipelines are an important part of the waste management sector because they provide a safe and efficient way to move huge amounts of hazardous pollutants. Pipelines are often used to move dangerous waste, such as chemicals, fuels, and other harmful materials. This page goes into great detail about transporting hazardous waste through pipelines, covering its benefits, rules, safety measures, and best practices. When it comes to moving hazardous waste, pipeline transport has a number of benefits, such as:

- **Safety:** Pipelines are seen to be one of the safest ways to get around because they are less likely to have accidents and spills than other ways.
- **Efficiency:** Pipelines make it possible to move huge amounts of dangerous waste quickly, which cuts down on transit times and speeds up delivery.

- **Cost-effectiveness:** Moving a lot of dangerous rubbish by pipeline can be cheaper than other ways of carrying goods from one place to another.
- **Environmental benefits:** Pipelines can assist safeguard the environment when carrying hazardous material by making spills and leaks less likely.

Regulations and Guidelines

There are many international and national agencies that keep an eye on the transit of hazardous waste through pipelines. These include:

- **Pipeline and Hazardous Materials Safety Administration (PHMSA):** It makes sure that pipelines and the transportation of dangerous materials in the US are safe.
- **The Environmental Protection Agency (EPA)** is in charge of managing dangerous waste, including moving it through pipelines.
- The **Occupational Safety and Health Administration (OSHA)** makes sure that the workplace is safe and that the people who work on pipelines are healthy.
- **The International Organization for Standardization (ISO)** makes rules for the safe transit of hazardous materials and pipelines around the world.

To make sure that hazardous waste may be safely transported by pipeline, numerous safety procedures are in place, such as:

- **Designing and building pipelines:** Pipelines are designed and built to fulfil certain safety criteria, such as choosing the right materials, making the walls thick enough, and protecting against corrosion.
- **Regular checks and repairs:** Pipelines are checked and repaired on a regular basis to make sure they are in good operating order, which lowers the chance of leaks and spills.
- **Systems for finding leaks:** Advanced systems for finding leaks are used to find leaks and spills, which lets people respond quickly and limit the damage to the environment.
- **Planning for emergencies:** Pipeline operators make and carry out plans for what to do in case of accidents or spills. This makes sure that they can respond quickly and have the least effect on the environment.

In addition to safety measures, there are several best practices that should be followed to make sure that hazardous waste is safely and legally transported by pipeline. Here are some best practices:

- **Proper documentation:** Keep all of your paperwork, such as manifests, bills of lading, and pipeline inspection reports, up to date and correct.
- **Regular training and competency:** Make sure that the people who work on the pipeline are trained and skilled enough to handle hazardous materials and deal with crises.
- **Communication and coordination:** Make sure that pipeline operators, regulatory agencies, and emergency responders can talk to and work with each other well.
- **Continuous improvement:** Always look at and improve the safety and operations of pipeline transportation by using new technology and best practices.

Types of Pipelines Used: There are many kinds of pipelines that can be used to move hazardous waste, such as the following:

- **Liquid pipelines:** These are used to move liquids like chemicals and gasoline.
- **Gas pipelines:** These are used to move gases like hydrogen and natural gas.
- **Slurry pipelines:** These are used to move slurries, like coal and mineral concentrates.

There are the challenges and opportunities that come with moving dangerous trash by pipeline:

- **Regulatory complexity:** There are many rules and procedures that apply to the transportation of hazardous waste by pipeline, and they can be difficult to understand and follow.
- **Safety risks:** Transporting hazardous waste by pipeline is dangerous since it could leak, spill, or explode.
- **Environmental issues:** The transfer of hazardous material through pipelines presents environmental issues, such as the possibility of pollution and contamination.

Even with these problems, moving hazardous trash by pipeline also opens up some new possibilities. These are as follows:

- **Greater efficiency:** Pipeline transportation can make hazardous waste management more efficient by allowing huge amounts of hazardous material to be moved quickly.
- **Improved safety:** Pipeline transportation makes managing hazardous waste safer and lowers the chance of leaks and accidents.
- **Environmental benefits:** Pipeline transportation can make managing hazardous waste less harmful to the environment by lowering the chances of pollution and contamination.

Moving hazardous trash through pipelines is an important part of the waste management industry since it offers a safe and efficient way to move huge amounts of hazardous materials. Pipeline operators, regulatory agencies, and emergency responders may make sure that hazardous waste is safely and legally moved from one place to another by learning about the benefits, rules, safety measures, and best practices for pipeline transportation of hazardous waste.

5.4 Off-Site and On-site Transportation of Hazardous Wastes

Off-site transportation of hazardous waste (HW) is moving hazardous waste from where it was made to a treatment, storage, or disposal facility (TSDF), which is usually far away. Transporting hazardous wastes (HW) is quite dangerous for both people and the environment since they can be toxic, combustible, explosive, or corrosive. So, HW transportation needs to be carefully planned and carried out to avoid accidents and lower hazards. The reasons for off-site transportation are

- Make sure that HW is transported safely to meet the needs of those who live there, handle it, and transport it.
- Follow safety rules set by the government and other countries, such as rules about labelling.

5.4.1 Importance of Proper Transportation

- The way things are packaged and shipped has a big effect on how likely accidents or spills are to happen.
- Quickly finding out what spilled is important for safe and effective crisis management
- The chances of a spill are higher when loading, transporting, and unloading

5.4.2 Regulatory Requirements

HW transportation rules control the transit of HW outside of installations, from generators' sites to treatment, storage, and disposal Facilities (TSDFs). These are the transportation needs for off-site:

- The containers must be made of a leak-proof material that is also mechanically stable.
- The container needs to be labelled so that people can tell what kind of trash it is, what the prospective danger is, and what steps to take or first aid to give in case of an unintentional spill.
- The vehicle that carries the trash should be clearly marked with information about the waste, including the possible hazard, the steps that need to be taken in case of an unintentional leak, the phone number of the person to call or the controlling agency in case of an emergency, and so on.
- Choosing a collector or transporter: This is necessary to make sure they have the right technical capabilities and other qualifications.
- License or manifest to carry application and "No Objection Certificate" papers
- Emergency procedures to know what to do in case of spills or accidents; and
- You have to pay fees and fines if you don't have a license or don't follow the rules.

On-site transportation: In most cases, it implies transferring little amounts of things across short distances. But on-site mobility is a big problem because it happens so regularly and people don't obey the guidelines. The Hazardous Wastes (Management & Handling) Rules, 1989, as changed, and the Environment (Protection) Act, 1986, say how to package, label, and move hazardous wastes. The individual who owns or administers a facility is in charge of making sure that the HWs are packed in a form that makes them safe to handle, store, and ship. The labels and packaging need to be easy to read and able to withstand many types of weather and physical conditions. These standards are aimed to make it easier to move hazardous waste safely, whether it's on-site or off-site, in a way that follows the law.

5.4.3 Packaging

For at least six months, the containers must be able to sustain regular handling without losing their integrity. Hazardous material packaging generally needs to adhere to the following specifications:

In order to prevent hazardous wastes or substances from spilling during transportation due to jerks and vibrations caused by uneven road surfaces, all packaging materials, including containers, must be strong, constructed, and of a type that prevents them from breaking open or becoming defective during transportation; repackaging materials, including those used for fastening, must not be impacted by the contents or form a dangerous combination with them. Packaging material should be such that there will be no significant chemical or galvanic action among any of the material in the package.

The following specifications must be met by the containers used to package hazardous wastes:

- The mild steel container must have a roll-on/roll-off cover and an appropriate corrosion-resistant coating. It can be easily handled by an articulated crane or a hook lift system for a wide range of wastes. For a range of wastes, alternative packaging methods such as collecting in 200-liter plastic drums, cardboard cartons, PP and HDPE/LDPE containers, etc., are equally effective. All of these containers, nevertheless, ought to be able to be handled mechanically.
- It must be impervious to leaks.
- Generally speaking, the liquid HW containers need to be fully closed and sealed. Air vents shouldn't be necessary because there shouldn't be any gas production from chemical reactions inside the container; expansion brought on by temperature changes often doesn't require them.
- A strong lid or canvas should be placed over the container to prevent spills, dust, and other emissions, as well as to reduce the production of odors during loading and transit.

- Waste containers should be able to withstand stress loads brought on by vibrations, pavement undulations, etc.
- When being transported and emptied, the container should be simple to handle.
- Handling containers by hand should be avoided wherever possible to reduce dangers. Use material handling equipment instead, such as pallets, lift gates, forklifts, and drum dollies.
- Correct loading and unloading: Don't roll drums onto or off of cars.
- Storage needs: Make sure the frame can sustain the weight of the containers for multi-tier storage.
- Reusing containers: If multipurpose containers are cleaned, tested, and found to be defect-free, they can be used again.
- Secure loads: To stop movement and loss, properly put and fasten loads on vehicles with straps, clamps, or other tools.
- Container design: Verify that containers can be safely loaded onto cars and are made for safe transportation.
- Waste segregation: To guarantee correct disposal, gather and pack different types of waste separately.
- No dilution: To prevent jeopardizing disposal procedures, hazardous waste generators should not dilute wastes, particularly organic wastes.

By following these guidelines, hazardous waste generators and handlers can minimize risks and ensure safe transportation and disposal of hazardous wastes.

5.4.4 Labeling

Labeling regulations fall into two categories:

The first step involves labeling individual transport containers, which can range in size from pint-sized to tank-sized, and the second step involves labeling transport vehicles. The current contents of every container containing hazardous material must be prominently indicated. For the markings to be unremovable, they must be securely fastened and waterproof. When the contents change, the previous content labels must be removed. Containers must be marked correctly.

HW-containing containers must be marked with the phrase "HAZARDOUS WASTE™" in English, Hindi, or vernacular. The waste kind, code number, origin (name, address, and generator phone number), hazardous property (such as flammable), and hazardous property symbol (such as the red square with flame emblem) must all be listed on the label.

The label needs to be resistant to the impacts of sun and rain. Containers must be labeled in order to monitor garbage from the point of generation to the point of disposal. The requirements for labeling are as follows:

- The name and address of the facility's operator and occupier, where it is being taken for treatment and eventual disposal, should be listed on the label. For example, containers must be labeled with a generic label in accordance with Form 8 of the HW (M & H) Rules, 1989 and as amended.
- Emergency contact phone numbers, such as those of the relevant SPCB/PCC regional officer, fire station, police station, and other agencies, must be prominently displayed.

Generally speaking, the waste's origin or source must be listed on the label. He alone is in charge and will be aware of the type of waste, potential hazards, and appropriate actions to take in the event of an accident, spill, etc. The collector/transporter, who comes in second, must be aware of the risks and know how to reduce them.

5.4.5 Collection and transportation of HW

The waste generator, the operator of a facility for treatment and disposal of HW, and the transporter are all responsible for making sure that HW is safely transported to the Treatment, Storage, and Disposal Facility (TSDF). Before giving the waste to the transporter, the following rules must be followed:

- The person or company that makes the hazardous waste must make sure that it is packaged in a way that makes it safe to handle, store, and transport. The labels on the packaging should be easy to see, and the material used for packaging should be able to handle physical and weather conditions. The generator should make sure that information about the wastes' properties, such as how corrosive, flammable, reactive, and toxic they are, is available. The Central Government's Motor Vehicles Act, 1988, and other guidelines should be followed when transporting hazardous wastes.

- All containers for hazardous waste must have a generic label like the one shown in Form 8 of the Hazardous Waste (Management & Handling) Rules, 1989, as changed.
- The transporter can't take hazardous waste from an occupier (generator) unless the generator gives them six copies (with color codes) of the manifest (Form 9) as required by Rule 7 of the HW (M & H) Rules, 1989, as modified. The transporter must give the generator a signed and dated copy of the manifest and keep the other four copies for future use as required by the Hazardous Wastes (Management & Handling) Rules, 1989.

  Copy 1 (White): The occupier must send this to the SPCB/PCC.

  Copy 2 (Yellow): The transporter must sign it and the occupant must keep it.

  Copy 3 (Pink): The person in charge of a facility should keep this.

  Copy 4 (Orange): The operator of the facility must provide this back to the carrier after accepting garbage.

  Copy 5 (Green): After disposal, the operator of the facility must send this to the SPCB/PCC.

  Copy 6 (Blue): The operator of the facility must give this back to the occupant after it has been thrown away.
- When waste is moved between states, the occupier (the person who made the waste) must rigorously follow the manifest system as required by Rule 7 (5) of the HW (M & H) Rules, 1989 and any changes made to them. If hazardous wastes need to be moved to a facility for treatment, storage, and disposal in a state other than the one where they were made, the generator must get a "No Objection Certificate" from the State Pollution Control Board or Pollution Control Committee of the Ut's where the facility is located (as required by Rule 7 (6) of HW (M&H) Rules).
- The generator must give the transporter the right information on Form 10, also known as the Transport Emergency (TREM) Card, on how dangerous the wastes are and what to do in case of an emergency.
- When collecting garbage from waste collection points, ports, or ICDs, the operator of a facility (registered recyclers or re-processors of hazardous waste) must also follow the manifest system as required by Rule 7 of the HW (M&H) Rules.

5.4.6 Responsibilities of the HW transporter

It is the responsibility of Transporter of hazardous wastes that s/he:

- Should obtain permission from SPCB for transport of hazardous waste as well as any other permission that may be required under the Motor Vehicles (Amendment) Act of 1988.
- The vehicles used for transport must be built in a way that allows them to safely handle and move hazardous waste of different types.
- The transporter must respect all the rules for moving hazardous waste set forth in the HW (M & H) Rules, 1989, and any changes made after then.
- Always moving the trash in closed containers
- Only dropping off the trash at certain places.
- Letting the SPCB/PCC, local authorities, occupier/operator of a facility, and other people who need to know right away if there is a spill, leak, or other mishap during transportation
- The transporter must teach the driver what to do in case of an emergency while transporting garbage.
- Cleaning up if there is contamination.
- Vehicles must be cleaned in specific places, such as TSDF/CETPs or other places where wastewaters can be treated.

5.5 Transportation

Here are the rules for moving hazardous waste:

- The vehicle used for transportation must follow the rules stated in the Motor Vehicles Act of 1988 and the rules that go along with it.
- The transporter must have the right copies of the certificate (a valid permission from the appropriate SPCB/PCC for the waste generator or facility operator to move hazardous waste) in order to move hazardous waste.

- The transporter must have a valid "Pollution Under Control Certificate" (PUCC) while moving HW, and it must be clearly shown.
- The best color for vehicles is blue, and there should be a white strip 15 to 30 cm wide going down the middle of the body. This is to make it easier to find.
- The vehicle should have mechanical handling tools that are needed to safely move and handle the waste.
- The phrase "HAZARDOUS WASTE" must be written in Vernacular Language, Hindi, and English on all sides of the vehicle.
- The name of the operator of the facility or the transporter, as the case may be, must be shown.
- Emergency phone numbers and the TREM Card must be clearly displayed in Form 10 of the HW (M & H) Rules, 1989, since they have been changed.
- If the individual containers don't have them, the vehicle must have roll-on/roll-off lids.
- It is against the law to carry passengers, and only people who work for the waste carriers are allowed in the cabin.
- As required by Rule 7 of the Hazardous Waste (M & H) Rules, 1989, as modified, the transporter must have documents of manifest for the wastes while they are being moved.
- The vehicles will only be used for moving dangerous garbage and nothing else.
- Every car must have a first-aid kit, spill control gear, and a fire extinguisher.
- The HW transport vehicle must only go as fast as the Motor Vehicles Act says it can to avoid any problems while transporting HW.
- The driver must have at least passed the 10th grade (SSC) in school. The driver of the transport vehicle must have a valid heavy vehicle driving license from the State Road Transport Authority and at least five years of experience moving chemicals.

- The driver(s) must be well-trained on how to deal with emergencies and safety issues that come up when transporting hazardous wastes. • The trucks must be built in such a way that there is no spillage during transit.

Summary

Moving hazardous waste is risky for humans, the environment, and transportation. Adequate risk management reduces these risks and ensures hazardous waste is delivered safely. Transporting hazardous garbage has several dangers. Spills and leaks damage land, water, and air, affecting the environment over time. When moving hazardous substances, individuals can be injured or killed and have long-term health issues including cancer.

Hazardous waste transport harms the environment, people, and infrastructure, including roads and bridges, causing transportation systems to break down and cost money. Transporting hazardous material may cause locals to worry, especially if accidents or spills occur. To decrease dangers, hazardous waste manufacturers, carriers, and regulators must cooperate together to carry hazardous waste safely and legally.

International and national bodies, such as the Basel Convention, regulate hazardous waste transportation. The US Resource Conservation and Recovery Act (RCRA) regulate hazardous waste transportation. The Hazardous Materials Transportation Act (HMTA) regulates hazardous waste transport in the US. The IMO ensures safe international transit of hazardous materials.

Transportation of hazardous trash may be made safer via several methods. Properly packaging and labeling hazardous trash prevents leaks during transit. To avoid accidents, load and unload hazardous waste from vehicles carefully. Regular maintenance is needed to keep transportation vehicles safe and running smoothly. Driver training and certification ensure drivers know how to handle dangerous materials and respond to circumstances.

When transporting hazardous materials, risk evaluation and mitigation are crucial. Risk management involves finding hazards, assessing their likelihood and severity, formulating strategies to mitigate them, and implementing them. Hazardous waste generators, transporters, and regulators can work together to transport hazardous waste safely and legally by understanding the hazards, rules, and best practices, as well as risk assessments and risk reduction.

Moving hazardous waste endangers individuals, the environment, and the transportation infrastructure. Good risk management reduces these risks and ensures hazardous waste is delivered securely. By implementing best practices, risk assessments and mitigation, and following the law, hazardous waste sources, carriers, and regulators can ensure safe and legal transit.

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Unit 06: Storage of Hazardous Waste

Unit Structure

6.0 Learning Objectives

At completion of this unit, the leaner should be able to:

- Understand the importance of hazardous waste storage
- Identify the key components of hazardous waste storage facilities
- Learn about the design and construction requirements
- Comprehend the safety and security measures
- Understand the regulatory framework

6.1 Introduction

Hazardous waste storage refers to the temporary holding of hazardous waste in a controlled environment, pending its treatment, disposal, or recycling. This type of storage involves the containment of hazardous waste in a manner that prevents leakage, spills, or other releases into the environment. Hazardous waste storage facilities are designed to manage the unique risks associated with hazardous waste, including chemical reactivity, flammability, and toxicity. These facilities are typically equipped with specialized containment systems, such as tanks, drums, or impoundments, and are subject to strict regulations and guidelines to ensure the protection of human health and the environment. Effective hazardous waste storage is critical to preventing environmental contamination, reducing the risk of accidents and injuries, and promoting sustainable waste management practices.

Proper storage of hazardous waste is crucial for protecting human health, the environment, and the economy. Improper storage can lead to severe consequences, including environmental contamination, human health risks, and economic costs. For instance, leaks or spills from improperly stored hazardous waste can contaminate soil and groundwater, posing long-term environmental risks. Additionally, hazardous waste can release toxic chemicals into the air and water, causing pollution and harm to human health and the environment.

The importance of proper storage of hazardous waste cannot be overstated. Exposure to toxic chemicals from improperly stored hazardous waste can cause injury, illness, or even death. Furthermore, improper storage can result in costly cleanup efforts, liability, and regulatory fines. Companies and individuals responsible for improper storage of hazardous waste can face significant economic burdens, damage to their reputation, and erosion of public trust. In contrast, proper storage of hazardous waste can prevent environmental contamination, reduce human health risks, and save costs. Proper storage demonstrates a commitment to environmental responsibility and helps maintain public trust. Moreover, proper storage can minimize the risk of accidents, injuries, and illnesses, ensuring a safer working environment and community. Therefore, it is essential to prioritize proper storage of hazardous waste to protect human health, the environment, and the economy.

It is a critical component of waste management that requires careful planning, design, and operation to prevent environmental contamination, human health risks, and economic costs. This chapter provides an overview of the importance of proper storage of hazardous waste, the benefits of proper storage, and the consequences of improper storage.

6.2. Types of Hazardous Waste Storage Facilities

Hazardous waste storage facilities are designed to hold hazardous waste temporarily until it is treated, disposed of, or recycled. There are several types of hazardous waste storage facilities, each with its own unique characteristics and design features. Various types of storage facilities include surface impoundments, landfills, tank systems and container storage facilities.

6.2.1 Surface impoundments

Surface impoundments are shallow pools or ponds used to store hazardous waste. They are typically lined with an impermeable material to prevent leakage into the soil and groundwater.

6.2.2 Landfills

Landfills are excavated sites used to dispose of hazardous waste. They are designed to prevent leakage and are typically lined with an impermeable material.

6.2.3 Tank systems

Tank systems are used to store hazardous waste in above-ground or underground tanks. They are designed to prevent leakage and are typically equipped with secondary containment systems.

6.2.4 Container storage facilities

Container storage facilities are used to store hazardous waste in containers, such as drums or tanks. They are designed to prevent leakage and are typically equipped with secondary containment systems.

6.2.5 Waste Piles

Waste piles are used to store hazardous waste in a pile or mound. They are typically used for temporary storage and are designed to prevent leakage and erosion.

6.5.6 Drip Pads

Drip pads are used to store hazardous waste in a controlled environment. They are typically used for temporary storage and are designed to prevent leakage and erosion.

A comparative overview of various storage facility is given in the table 1 below:

Table 1: Comparison of Hazardous Waste Storage Facilities

Facility Type	Description	Advantages	Disadvantages
Surface Impoundments	Shallow pools or ponds	Low cost, easy to construct	Potential for leakage, limited capacity
Landfills	Excavated sites	High capacity, can be designed for long-term storage	Potential for leakage, high cost
Tank Systems	Above-ground or underground tanks	High capacity, can be designed for long-term storage	Potential for leakage, high cost
Container Storage Facilities	Containers, such as drums or tanks	Flexible, can be used for temporary or long-term storage	Limited capacity, potential for leakage
Waste Piles	Pile or mound	Low cost, easy to construct	Potential for leakage, erosion, and fire
Drip Pads	Controlled environment	Low cost, easy to construct	Limited capacity, potential for leakage

6.3. Design and Construction of Storage Facilities

The design and construction of storage facilities for hazardous waste are very crucial in preventing environmental contamination, human health risks, and economic costs. The following are key considerations for designing and constructing storage facilities:

- Site selection and preparation

- Liner and cover systems
- Leachate collection and removal systems
- Ventilation and gas management systems
- Secondary Containment Systems
- Monitoring and Inspection Systems
- Security Systems
-`Emergency Response Planning

6.3.1 Site Selection and Preparation

Site selection and preparation are critical steps in the development of a hazardous waste storage facility. The site selected must be suitable for storing hazardous waste, taking into account factors such as geological and hydrological characteristics, environmental sensitivity, and proximity to populated areas. A thorough site assessment must be conducted to identify potential environmental risks and develop strategies to mitigate them. This includes evaluating the site's geology, hydrology, and ecology, as well as assessing the potential for natural disasters such as floods and earthquakes.

Once a suitable site has been identified, preparation can begin. This involves clearing and grading the land, installing necessary infrastructure such as roads, utilities, and drainage systems, and constructing any necessary buildings or structures. The site must also be prepared to prevent erosion and sedimentation, and to ensure that the storage facility can be operated safely and efficiently. Additionally, measures must be taken to prevent unauthorized access to the site and to ensure that the facility is secure. By carefully selecting and preparing the site, the risks associated with storing hazardous waste can be minimized, and the facility can be operated in a safe and environmentally responsible manner.

6.3.2 Liner and Cover Systems

Liner and cover systems are important components of hazardous waste storage facilities, serving as a barrier between the waste and the environment. A liner system is an impermeable layer that prevents leakage of hazardous waste into the soil and groundwater, while a cover system prevents infiltration of precipitation and minimizes the release of hazardous waste into the environment. Liner systems can be made of clay, synthetic materials, or a combination of both, and are designed to be durable and long-lasting. Cover systems, on the other hand, can be made of soil, synthetic materials, or a combination of both, and are designed to be impermeable and resistant to erosion. The liner and cover systems work together to provide a double layer of protection against environmental contamination, and are an essential part of ensuring the safe and environmentally responsible storage of hazardous waste. Regular inspection and maintenance of the liner and cover systems are also crucial to ensure their integrity and effectiveness over time.

6.3.3 Leachate Collection and Removal Systems

Leachate collection and removal systems are a critical component of hazardous waste storage facilities, designed to manage the liquid waste that seeps through the stored waste and into the soil. Leachate can contain high concentrations of toxic chemicals, heavy metals, and other pollutants, posing a significant threat to groundwater and surface water quality. To mitigate this risk, leachate collection and removal systems are installed to capture and remove the leachate from the storage facility. These systems typically consist of a network of perforated pipes, collection trenches, and pumps that collect the leachate and transport it to a treatment facility for proper disposal. Effective leachate collection and removal systems are essential to preventing environmental contamination, protecting public health, and ensuring compliance with regulatory requirements. Regular monitoring and maintenance of these systems are also crucial to ensure their optimal performance and prevent system failures.

6.3.4 Ventilation and Gas Management Systems

Ventilation and gas management systems are essential components of hazardous waste storage facilities, designed to control and manage the movement of gases within the facility. These systems are critical for preventing the buildup of explosive or toxic gases, which can pose a significant threat to human health and safety. Ventilation systems, including fans, blowers, and ducts, are used to circulate air and remove gases from the facility, while gas management systems, such as gas collection and treatment systems, are used to capture and treat gases emitted from the stored waste. These systems work together to maintain a safe and healthy environment within the facility, prevent accidents and injuries, and minimize the release of hazardous gases into the atmosphere. Regular monitoring and maintenance of ventilation and gas management systems are also crucial to ensure their optimal performance and prevent system failures.

6.3.5 Secondary Containment Systems

Secondary containment systems are safety feature in hazardous waste storage facilities, and are designed in a way so that it may provide an additional layer of protection against environmental contamination in the event of a primary containment failure. These systems consist of a secondary barrier, such as a dike, berm, or containment wall, that surrounds the primary containment vessel or area. The secondary containment system is designed to capture and hold any leaked or spilled hazardous waste, preventing it from escaping into the environment. This provides a critical window of time for facility operators to respond to the spill or leak, contain it, and prevent further environmental damage. By providing an additional layer of protection, secondary containment systems play a vital role in preventing environmental contamination, protecting public health, and ensuring compliance with regulatory requirements.

6.3.6 Monitoring and Inspection Systems

Monitoring and inspection systems enable operators to detect and respond to potential problems before it becomes a major problem. These systems typically include a range of sensors, cameras, and other monitoring equipment that provide real-time data on factors such as temperature, pressure, and moisture levels. Regular inspections are also conducted to visually examine the facility's infrastructure, including tanks, pipes, and containment systems, for signs of damage or deterioration. By monitoring and inspecting the facility, operators can quickly identify and address any issues, such as leaks or spills, and prevent environmental contamination. Additionally, monitoring and inspection systems help ensure compliance with regulatory requirements and provide valuable data for optimizing facility operations and improving safety.

6.3.7 Security Systems

Security systems play a vital role in hazardous waste storage facilities, ensuring the protection of people, the environment, and the facility itself from unauthorized access, theft, vandalism, and other security threats. A comprehensive security system typically includes multiple layers of protection, such as perimeter fencing, gates, and access controls, as well as surveillance cameras, motion detectors, and alarm systems. These systems are designed to detect and deter potential security breaches, while also providing a rapid response capability in the event of an incident. Additionally, security systems are often integrated with other facility systems, such as fire suppression and environmental monitoring systems, to provide a unified and effective security posture. By implementing robust security systems, hazardous waste storage facilities can minimize the risk of security incidents, protect against environmental damage, and ensure compliance with regulatory requirements.

6.3.8 Emergency Response Planning

Emergency response planning in hazardous storage facility ensures that people are prepared to respond quickly and effectively in the event of an emergency. A comprehensive emergency response plan outlines procedures for responding to various types of incidents, such as fires, spills, leaks, and natural disasters. The plan identifies key personnel and their roles, outlines communication protocols, and specifies the equipment and resources needed to respond to an emergency. Regular training exercises and drills are also conducted to ensure that personnel are familiar with the plan and can respond confidently and effectively in an emergency situation. Furthermore, the plan is reviewed and updated regularly to ensure that it remains relevant and effective, and that it complies with regulatory requirements. By having a well-developed emergency response plan in place, hazardous waste storage facilities can minimize the risks associated with emergencies, protect human health and the environment, and reduce the likelihood of costly cleanups and regulatory penalties.

6.3.9 Regulatory Compliance

Regulatory compliance is a critical aspect of operating a hazardous waste storage facility, as it ensures the protection of human health, the environment, and the facility itself. Compliance with relevant laws, regulations, and standards is mandatory, and facilities must adhere to strict guidelines governing the storage, handling, and disposal of hazardous waste. This includes obtaining and maintaining necessary permits and licenses, implementing safety protocols and emergency response plans, conducting regular inspections and monitoring, and maintaining accurate records of waste storage and disposal. Failure to comply with regulatory requirements can result in severe penalties, fines, and even facility closure, emphasizing the importance of prioritizing regulatory compliance in hazardous waste storage facilities. In India, hazardous waste storage facilities are subject to strict regulatory compliance requirements, which are enforced by various government agencies, including the Central Pollution Control Board (CPCB) and the State Pollution Control Boards (SPCBs). The primary legislation governing hazardous waste management in India is the Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2016, which outlines the procedures for storage, transportation, and disposal of hazardous waste. Additionally, facilities must comply with the Environment (Protection) Act, 1986, and the Water (Prevention and Control of Pollution) Act, 1974. Compliance requirements include obtaining necessary permits and licenses, maintaining accurate records of waste storage and disposal, conducting regular environmental monitoring, and implementing safety and emergency response plans. Facilities that fail to comply with regulatory requirements may face penalties, fines, and even closure, highlighting the importance of ensuring regulatory compliance in hazardous waste storage facilities in India.

6.4. Safety and Security Considerations

6.4.1 Fire protection and prevention

Fire protection and prevention are essential in storage facility as many of the hazardous substances may catch fire easily which can have devastating consequences for human health, the environment, and the facility itself. Storage facilities must implement robust fire protection and prevention measures, including the installation of fire suppression systems, such as sprinkler systems, foam systems, and clean agent systems in order to mitigate the risk of fires, Facilities must also conduct regular fire risk assessments, develop comprehensive fire emergency response plans, and provide regular fire safety training to the staff engaged in different sections of the facility. Additionally, facilities must ensure that all electrical equipment, and other potential ignition sources are properly maintained, inspected, and controlled. Furthermore, facilities must store hazardous waste in a manner that minimizes the risk of fire, such as storing combustible materials in separate areas, using fire-resistant containers, and maintaining adequate aisle space. Regular inspections and maintenance of fire protection equipment, as well as compliance with relevant fire safety standards and regulations, are also essential to ensuring effective fire protection and prevention

6.4.2 Explosion prevention and protection

Hazardous waste storage facilities may have flammable and combustible materials which can create a high risk of explosion. The facilities must implement robust explosion prevention and protection measures, including the use of explosion-proof electrical equipment, intrinsically safe systems, and spark-proof materials in order to mitigate this risk. Facilities must also ensure proper ventilation, dust control, and housekeeping practices to prevent the accumulation of explosive atmospheres. Additionally, facilities must conduct regular hazard assessments, develop comprehensive explosion prevention and protection plans, and provide regular training to personnel on explosion risks and prevention measures. Explosion protection systems, such as explosion venting, suppression systems, and containment systems, must also be installed and maintained to prevent or minimize the effects of an explosion. Furthermore, facilities must comply with relevant explosion protection standards and regulations. In India, the Petroleum and Explosives Safety Organization (PESO) and the Directorate General of Mines Safety (DGMS) regulate explosion prevention and protection in hazardous storage facilities. The Explosives Act, 1884, and the Factories Act, 1948, are key statutes governing explosion prevention and protection. Additionally, facilities must comply with relevant Indian Standards, such as IS 5571:2010 and IS 5780:2002, which provide guidelines for explosion prevention and protection in hazardous areas. By adhering to these regulations and guidelines, hazardous storage facilities in India can minimize the risk of explosions and ensure a safe working environment.

6.4.3 Personnel safety and training

Personnel safety and training are essential components of hazardous waste storage facility operations, as well-being of employees, contractors, and visitors depends on it. Facilities must provide comprehensive training programs that equip personnel with the knowledge, skills, and attitudes necessary to perform their jobs safely and effectively. This includes training on hazard recognition, risk assessment, and control measures, as well as procedures for emergency response, spill cleanup, and waste handling. Personnel must also be trained on the use of personal protective equipment (PPE), including respirators, gloves, and eye protection. Regular refresher training and drills are necessary to ensure that personnel remain competent and confident in their abilities. Additionally, facilities must establish a safety culture that encourages personnel to report hazards, near-miss incidents, and accidents, and to participate in continuous improvement initiatives. By prioritizing personnel safety and training, hazardous waste storage facilities can minimize the risk of accidents, injuries, and illnesses, and ensure a safe and healthy work environment.

6.4.4 Security measures for unauthorized access

Security measures are crucial to prevent unauthorized access in hazardous waste storage facilities. This ensures not only protection of the facility's assets but also the surrounding community and environment. Facilities must have robust security measures, including physical barriers such as perimeter fencing, secure gates and access points, and surveillance cameras. Access control systems, including biometric authentication, card access systems, and key management systems, must also be implemented to ensure only authorized personnel enter the facility. Additionally, personnel screening measures, including background checks, security clearances, and visitor management policies, must be enforced. Emergency response planning, including intrusion detection systems, alarm systems, and emergency response plans, is also essential. Regular security audits, including vulnerability assessments and security audits, must be conducted to identify and address potential security vulnerabilities. By implementing these security measures, hazardous waste storage facilities can prevent unauthorized access, protect their assets, and ensure the safety of their personnel, the surrounding community, and the environment.

6.5. Environmental Monitoring and Control

Environmental monitoring and control are essential components of hazardous waste storage facility operations, as they help prevent environmental contamination and ensure compliance with regulatory requirements. Facilities must implement a comprehensive environmental monitoring program to track and manage potential environmental impacts, including air and water pollution, soil contamination, and ecosystem disruption. This program should include regular monitoring of environmental parameters such as air quality, water quality, soil moisture, and weather patterns. Facilities must also implement controls to prevent environmental contamination, including secondary containment systems, spill response plans, and waste management practices. Additionally, facilities must conduct regular environmental audits and risk assessments to identify potential environmental hazards and implement corrective actions. Furthermore, facilities must comply with relevant environmental regulations and standards, including those related to air and water quality, hazardous waste management, and ecosystem protection. By implementing effective environmental monitoring and control measures, hazardous waste storage facilities can minimize their environmental footprint, prevent contamination, and ensure a safe and healthy environment for surrounding communities. Monitoring of the groundwater, surface water, air and soil is done on regular intervals. The purpose of this kind of monitoring is as follows:

- Groundwater monitoring is conducted to detect potential contamination from hazardous waste storage facilities. This involves collecting and analyzing groundwater samples from monitoring wells to check for parameters such as pH, temperature, conductivity, and contaminant concentrations. Regular monitoring helps identify any changes in groundwater quality, enabling prompt corrective actions to prevent further contamination.
- Surface water monitoring involves collecting and analyzing water samples from nearby surface water bodies, such as rivers, lakes, or wetlands. This helps detect any potential contamination from hazardous waste storage facilities. Parameters monitored include pH, temperature, turbidity, and contaminant concentrations. Regular monitoring ensures that surface water quality is maintained and any changes are addressed promptly.
- Air quality monitoring is essential to detect potential air pollution from hazardous waste storage facilities. This involves collecting and analyzing air samples to check for parameters such as particulate matter, volatile organic compounds (VOCs), and other pollutants. Regular monitoring helps identify any changes in air quality, enabling prompt corrective actions to prevent further pollution.
- Soil monitoring involves collecting and analyzing soil samples to check for parameters such as pH, contaminant concentrations, and other physical and chemical properties. Regular monitoring helps detect any potential soil

contamination from hazardous waste storage facilities. This enables prompt corrective actions to prevent further contamination and protect ecosystem health.

6.6 Regulations and Standards

The storage of hazardous waste poses significant environmental and health risks, necessitating stringent regulations and standards to ensure safe and responsible management. In India, as well as globally, various laws, regulations, and standards have been established to govern the storage, handling, and disposal of hazardous waste. These regulations and standards provide a framework for facility operators, industries, and governments to follow, ensuring the protection of human health, the environment, and natural resources. Briefly the key regulations and standards relevant to hazardous waste storage in India and worldwide, including international conventions, national laws, and industry-specific guidelines are as follows:

A) National Rules and Regulations in India

- The Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2016: Regulates the management, handling, and transboundary movement of hazardous waste.
- The Environment (Protection) Act, 1986: Provides a framework for environmental protection, including hazardous waste management.
- The Factories Act, 1948: Regulates the safety and health of workers in factories, including those handling hazardous substances.
- IS 3034:2013: Code of practice for storage and handling of hazardous chemicals.
- IS 12433:2003: Code of practice for safety in chemical plants, including hazardous waste storage.

B) International Rules and Regulations

- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1989): Regulates the transboundary movement of hazardous waste.

- International Maritime Organization (IMO) Regulations: Regulates the storage and transportation of hazardous waste by sea.
- International Organization for Standardization (ISO) 14001:2015: Environmental management system standard that includes requirements for hazardous waste management.
- Occupational Safety and Health Administration (OSHA) Regulations (USA): Regulates the safety and health of workers handling hazardous substances, including storage and handling requirements.
- Globally Harmonized System of Classification and Labelling of Chemicals (GHS): Provides a standardized system for classifying and labelling hazardous chemicals.

Summary

Hazardous waste storage facilities are designed to hold hazardous waste temporarily until it is treated, disposed of, or recycled. These facilities are subject to strict regulations and guidelines to ensure the protection of human health, the environment, and natural resources. Various types of hazardous waste storage facilities exist, including surface impoundments, landfills, tank systems, container storage facilities, waste piles, and drip pads.

The design and construction of hazardous waste storage facilities are critical to preventing environmental contamination and ensuring safe operations. Key considerations include site selection and preparation, liner and cover systems, leachate collection and removal systems, ventilation and gas management systems, secondary containment systems, monitoring and inspection systems, security systems, emergency response planning, and regulatory compliance.

Safety and security considerations are essential in hazardous waste storage facilities. This includes fire protection and prevention, explosion prevention and protection, personnel safety and training, and security measures for unauthorized access. Facilities must also implement environmental monitoring and control measures to prevent environmental contamination and ensure compliance with regulatory requirements.

Regulations and standards governing hazardous waste storage facilities are stringent and varied. In India, key regulations include the Hazardous Waste (Management, Handling and

Transboundary Movement) Rules, 2016, and the Environment (Protection) Act, 1986. Internationally, conventions such as the Basel Convention and standards like ISO 14001:2015 provide a framework for safe and responsible hazardous waste management.

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Unit 7: Disposal of Hazardous Wastes

Unit Structure

7.0 Learning Objectives

After going through this unit, you will be able to understand:

- Different disposal methods used for the management of hazardous waste.
- Disposal of household hazardous wastes; proper and improper disposal methods.
- First aid procedures related to hazardous waste exposure.

7.1 Introduction

The policies and practices aimed at managing hazardous waste materials in a way that minimizes harm to both people and the environment are referred to as hazardous waste management. Hazardous waste was once frequently handled by burning it or simply disposing of it in open spaces. However, these practices resulted in significant environmental issues: open dumping contaminated soil and water, while incineration and burning emitted airborne pollutants such nitrogen oxides, particulate matter, and offensive odors.

Municipal incinerators with energy recovery systems were originally employed in a few places in North America and Europe, but their use declined because of their high operating costs. More recently, the stringent air pollution control regulations have further reduced the usage of incineration for hazardous garbage.

Hazardous waste worries have only grown as a result of the fast expansion of industry. Waste produced by both domestic and commercial sources can provide major environmental and health hazards. Effective management of hazardous waste is therefore more crucial than ever.

To assure the safe and responsible treatment of hazardous materials, developed nations often implement a standard waste management approach that consists of a number of clearly defined processes. Figure 1 lists these procedures.

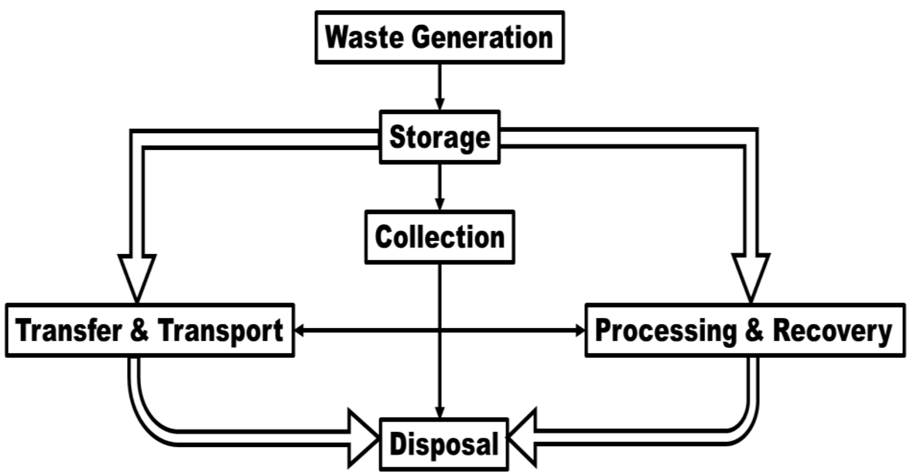


Figure 1: Hazardous Waste Management Processes

7.2 Disposal Methods for Hazardous Waste Management

Disposal is the most essential phase in the proper management of hazardous waste. This is achieved through a number of methods, including secure landfills, deep well injection, and bedrock disposal, all of which are meant to keep hazardous material contained and protect the environment.

7.2.1 Secure landfill

In the past, harmful substances often leaked into the earth when hazardous waste was dumped in traditional landfills. Over time, these substances may find their way into natural water systems and result in serious environmental problems. To prevent this, modern landfills that handle hazardous waste are constructed with protective barriers that collect and confine any potentially harmful elements in the waste.

Hazardous waste is now typically stabilized, consolidated, and then disposed of in landfills designed for that purpose. The process used depends on the type of garbage being handled. A hazardous waste landfill is one particular place where this type of trash is safely stored underground.

As seen in Figure 2, an effective landfill design includes sealed waste drums, two layers of impermeable liners, and a dual leachate collection system. The upper layer helps keep leachate, a liquid that drains from the waste, from building up, while the lower layer serves as a backup system. Both levels collect leachate and use a network of pipelines to deliver it to a treatment plant for safe processing.

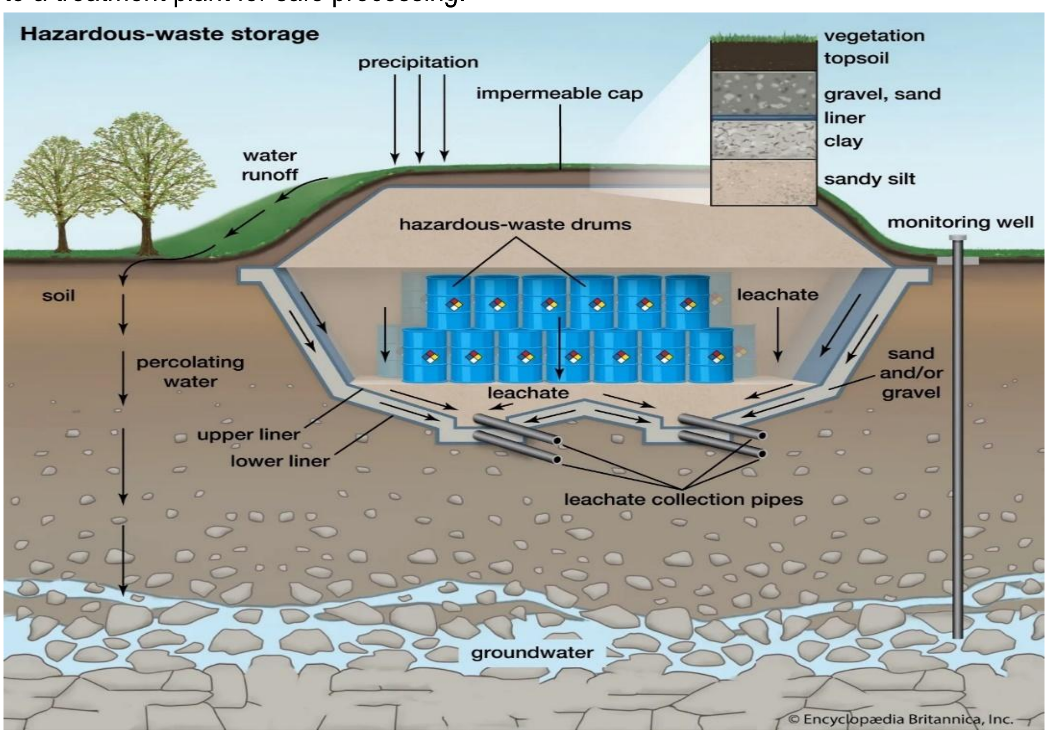


Figure 2: Secured Landfill for Hazardous Waste Management

https://www.britannica.com/technology/hazardous-waste-management/Treatment-storage-and-disposal#/media/1/257926/19284

Once filled, a landfill is covered with an impermeable lid to further minimize the possibility of environmental effect and leachate generation. This layered, sealed technique helps manage hazardous waste as safely and responsibly as feasible.

Leachate, the liquid that drains from landfills, contains several potentially dangerous substances.

Its main components can be divided into several categories:

- Major elements and ions include things like calcium, magnesium, iron, sodium, ammonia, carbonate, sulfate, and chloride.
- Examples of trace metals include calcium, lead, nickel, chromium, and manganese.
- An enormous range of biological materials
- Other biological agents, including microorganisms

The main source of leachate is hazardous waste, especially from industrial sources. Of all its components, the presence of heavy metals is the most concerning. Even trace levels of these metals can be harmful to the environment and human health if improperly handled.

7.2.2 Deep well disposal

Another technique for disposing of liquid industrial waste is deep well injection, as seen in Figure 3. This method involves injecting treated or untreated liquid waste into underground rock formations that are far from potable water sources. The goal is to safely contain the trash far below the earth's surface.

This is achieved by applying high pressure to push the liquid through the pores and fissures of suitable rock strata, such as sandstone or cracked limestone. These layers were specifically chosen to let the garbage spread since they are porous and permeable. They are also encircled by less porous materials, such shale, which help prevent the garbage from rising or contaminating nearby water supplies.

Often requiring minimal prior waste treatment, deep well injection is regarded as a cost-effective substitute. However, there are risks involved. If the well or adjacent rock fails, hazardous materials could eventually spill and contaminate underground water supplies.

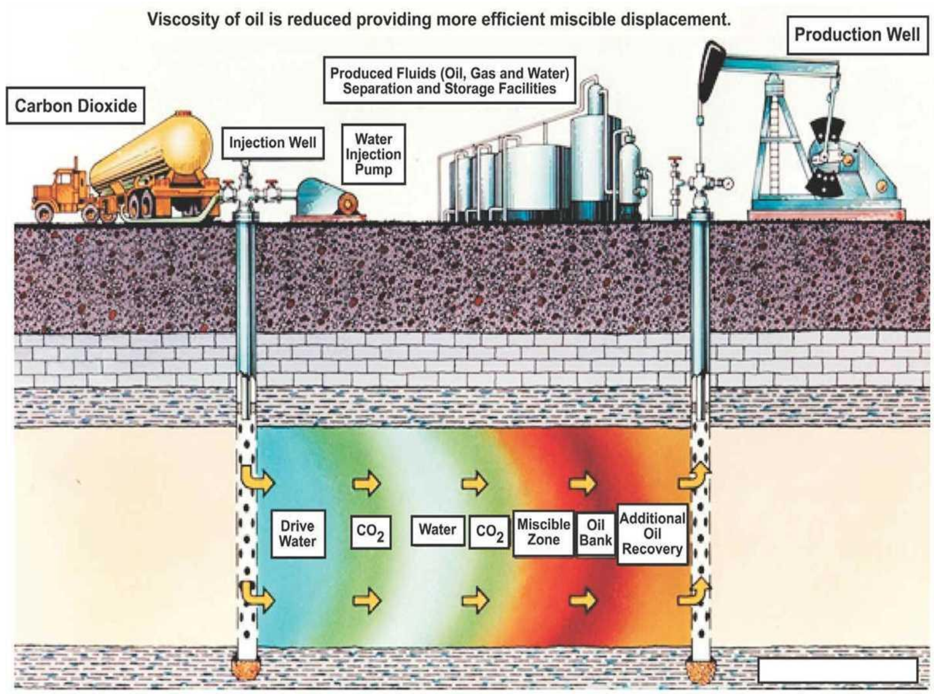


Figure 3: Deep well injection technique for disposing of liquid industrial waste
(The Anatomy of a Water Well: A Detailed Diagram)

7.2.3 Bedrock disposal

Scientists are investigating a variety of rock types as potential host materials, with the primary application for bedrock disposal being solid hazardous waste. Figure 4 shows the architecture of a bedrock disposal site, sometimes called a repository, which is based on the multiple barrier concept. This technique helps prevent leaks and protect against groundwater intrusion by enclosing the hazardous waste in several layers of different materials.

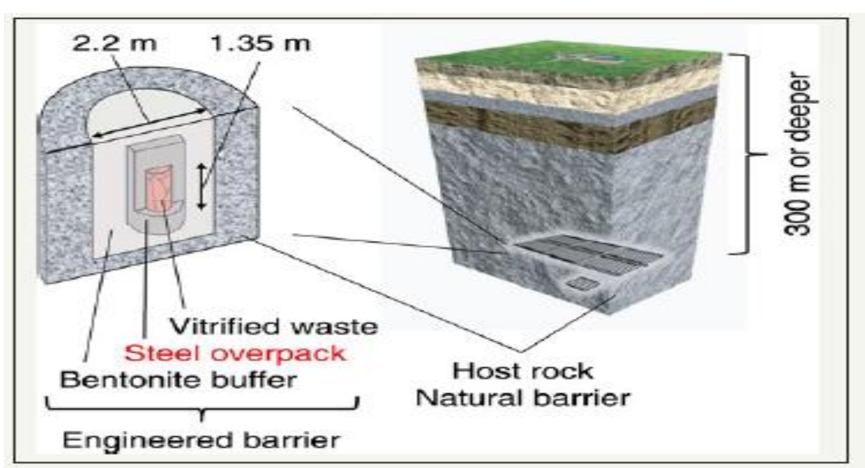


Figure 4: Bedrock Disposal of Radioactive Waste

It is important to choose the appropriate host rock, because certain geological traits are more appropriate than others. Stability, impermeability, and resistance to corrosion are important considerations. This method is very well-liked for disposing of high-level radioactive waste. In some cases, the waste is encapsulated in corrosion-resistant metals such as copper or stainless steel or sealed in stainless steel canisters and then buried deep within stable rock formations.

Shale, thick basalt (such the Columbia River Plateau basalt), granite, volcanic tuff, salt deposits, and other bedrock materials are considered suitable for this purpose due to their long-term stability and isolation properties.

Terminal Questions

1. Which of the following is a modern method for disposing of hazardous waste?
A. Open burning

B. Deep well injection

C. Ocean dumping

D. Open dumping

2. Assertion (A): Modern secure landfills are designed with impermeable liners and leachate collection systems.

Reason (R): These features prevent hazardous materials from leaking into the soil and water sources.

A. Both A and R are true, and R is the correct explanation of A.

B. Both A and R are true, but R is not the correct explanation of A.

C. A is true, but R is false.

D. A is false, but R is true.

3. True or False: Deep well injection of hazardous waste is completely risk-free and does not require geological consideration.

4. Bedrock disposal is mainly used for __________ hazardous waste and involves enclosing it in __________ materials deep within stable rock formations.

5. Match the Following:

Column A	Column B
1. Leachate	A. Deep underground injection
2. Deep Well Injection	B. Hazardous liquid from landfills
3. Bedrock Disposal	C. Disposal method for solid radioactive waste
4. Secure Landfill	D. Two impermeable liners and leachate system

7.3 Household hazardous Waste

HHW is defined by the Environmental Protection Agency (EPA) in the United States as any home product that, if improperly handled, could endanger human health or the environment. The fact that HHW is frequently disregarded in home waste systems is even more alarming. It is handled the same as ordinary trash unless it is picked up separately.

One major issue is that home hazardous waste (HHW) is still not segregated from ordinary household trash in the majority of the world. Even though it might only make up a small amount of our trash, household hazardous waste (HHW) is frequently the most harmful type. Many of us are unaware that common household materials like paints, batteries, cleaning supplies, outdated medications, insect repellents, and pesticides can be dangerous. Even though we only discard little amounts of these items, improper handling can have a significant negative influence on both the environment and human health.

Households are responsible for up to 67% of the 540 million tons of municipal solid waste (MSW) generated yearly, according to estimates from the Organization for Economic Cooperation and Development (OECD) countries. However, HHW only accounts for about 1% of that massive quantity by weight, while some studies have discovered that it can range from less than 0.01% to 3.4%. Inconsistent monitoring techniques, small sample sizes, and variations in how nations define and quantify HHW are the causes of this large range. However, the most widely used number is 1%.

Much of this hazardous waste is disposed of in landfills together with ordinary household garbage. However, hazardous, combustible, corrosive, and reactive compounds are not intended for safe disposal in landfills. These materials have the potential to leak, burn, or release toxic gases when combined with other garbage. They might eventually even contaminate neighboring soil and water, endangering the ecosystem and local populations. This indicates that it is not regulated or monitored and typically winds up in landfills, or worse, poured down drains, disposed of outside, or burned. Strict hazardous waste laws would apply if the same materials were made in a manufacturing or commercial setting.

The Unnoticed Risks of Poor Disposal

There can be major repercussions when HHW is carelessly disposed of or thrown into normal bins. Leachate, a poisonous liquid that is produced when rainwater seeps through landfill debris and combines with dangerous materials, is one of the main causes for concern. Ecosystems and sources of drinking water may be harmed by the hazardous compounds that this leachate may introduce into groundwater. According to studies, leachate from mixed municipal garbage can include persistent organic pollutants, heavy metals, and pharmaceutical residues-many of which are harmful to human health.

Following are the repercussions arises by the careless disposal of HHW:

- Chemical leakage from landfills contaminating groundwater
- pollution of surface water resulting from runoff into lakes, rivers, or drains
- Air pollution caused by burning dangerous materials
- Health risks to people, particularly to children, pets, and sanitation workers who are exposed to harmful substances at home

Hazardous compounds are not intended for use in municipal treatment facilities. Therefore, HHW just goes through the system and ends up in the environment whether it is flushed, poured down the sink, or buried.

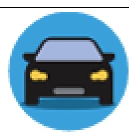
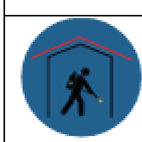
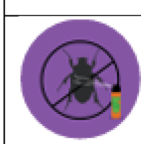
The problem is significantly more urgent in many emerging nations. According to the United Nations, 20–80% of residential waste is disposed of in open spaces, waterways, or outdoors due to inadequate or nonexistent waste management systems. Communities are exposed to serious health dangers and unhygienic circumstances as a result. To put it in context, India alone produces more than 200,000 tonnes of household hazardous trash annually, yet because of improper segmentation and a lack of awareness, a large portion of it still winds up in the general waste stream.

In many countries, e-waste, infectious materials, and even small quantities of radioactive waste from households are classified as household hazardous waste. There is a noticeable difference in India, though. The following are examples of home hazardous waste as defined by the Solid Waste Management Rules, 2016:

- discarded batteries
- Expired medications
- Containers for paint and pesticides
- Tube lights and CFLs
- Used mercury thermometers, needles, and syringes

In contrast, e-waste and radioactive materials are subject to separate regulations, whereas soiled diapers and sanitary products are classified as sanitary trash.

Table 1: List of Domestic Hazardous Waste

	**Cleaners for the home**	Drain cleaners, wood and metal polishes and cleaners, toilet cleaners, tile and shower cleaners, laundry bleach, and oven cleaners
	**Supplies for painting**	Stains and finishes, paint thinners and turpentine, furniture strippers, oil or enamel-based paint, latex or water-based paint, adhesives and glues, paint removers and strippers, fixatives, and other solvents
	**Automotive items**	Automotive batteries, starter fluids, air conditioning refrigerants, motor oil, gasoline additives, transmission, and braking fluid antifreeze
	**Indoor pesticides**	Houseplant pesticides, moth repellents, flea repellents and shampoos, cockroach repellents and baits, ant repellents and baits, pet care goods, and pet food items
	**Insecticides in the home**	Wood preservatives, fungicides, insecticides, and herbicides

	**Additional flammable items**	Cigarette butts, lighter fluids, compressed gas cylinders, kerosene diesel fuel gas/oil mixture, and shoe polish
	**Miscellaneous**	Batteries, computer parts, fluorescent lightbulbs, abandoned PVC toys, mercury thermometers or thermostats, and end-of-life electronics

7.4 Disposal Method for Household Hazardous Waste (HHW) management

7.4.1 Proper Disposal Method

7.4.1.1 Differentiating Waste at its Beginning

The first step in properly disposing of household hazardous waste (HHW) is to separate it from ordinary garbage. It's crucial to keep hazardous and nonhazardous garbage separate. We can manage hazardous materials more effectively, save public health and the environment, and even save money by grouping related products together. For instance, if stored separately, arsenic-treated wood can be burned safely in facilities with pollution controls, lowering the danger of cancer that would arise from simply disposing of it in a landfill. Cleaning supplies and insecticides are frequently kept apart in many affluent nations. Unless they contain mercury, which requires special care, the majority of items can also be burned safely.

7.4.1.2 Hazardous Material Recycling and Reuse

Certain hazardous materials can still be recycled or used for other purposes, which gives them value. For instance:

- It is possible to purify and repurpose leftover antifreeze as engine coolant.
- Old motor oil can be converted into low-quality gasoline or purified into new oil.
- Lead that can be recycled into new batteries is found in lead-acid batteries, such as automobile batteries.

- Dry cell batteries (such as AA or AAA) must be handled cautiously and gathered in large quantities because they contain a number of heavy metals that are more difficult to remove.
- Fluorescent tubes are gathered for recycling in countries like the EU, particularly Germany. With the exception of the bright powder, which is more difficult to handle, the majority of their components are reusable.

7.4.1.3 Sharing Excessive Items

Give leftover paint or wood preservatives to someone who can use them instead than discarding them, provided they are still in excellent shape. In several nations, community initiatives and organizations assist in gathering and distributing these surplus goods.

7.4.2 Improper Disposal Method

How the Environment Is Affected by Improper HHW Disposal: Inappropriate disposal of household hazardous waste (HHW) can release dangerous chemicals into the air, water, and land. These interrelated natural elements are frequently in direct touch with waste treatment facilities that handle HHW. Therefore, contamination can spread swiftly if these facilities are unable to safely decompose the dangerous compounds.

The way pollutants get into the water: Pollutants from the air can enter rivers and lakes through precipitation. Chemicals may leak into groundwater through soil absorption, also known as percolation. Wastewater treatment facilities occasionally discharge cleaned water straight into lakes or rivers; nevertheless, if dangerous materials aren't completely eliminated, they accompany the water. Chemicals can enter natural water bodies directly if they are dumped down drains, particularly stormwater drains.

HHW air pollution: HHW has the ability to emit harmful gasses into the atmosphere.

This may occur during:

- controlled incineration, or burning, of dangerous substance.
- Uncontrolled flames brought about by inappropriate disposal or storage. These gases, which can seriously endanger both human and animal health, may originate from the chemicals employed to manufacture the products in the first place.

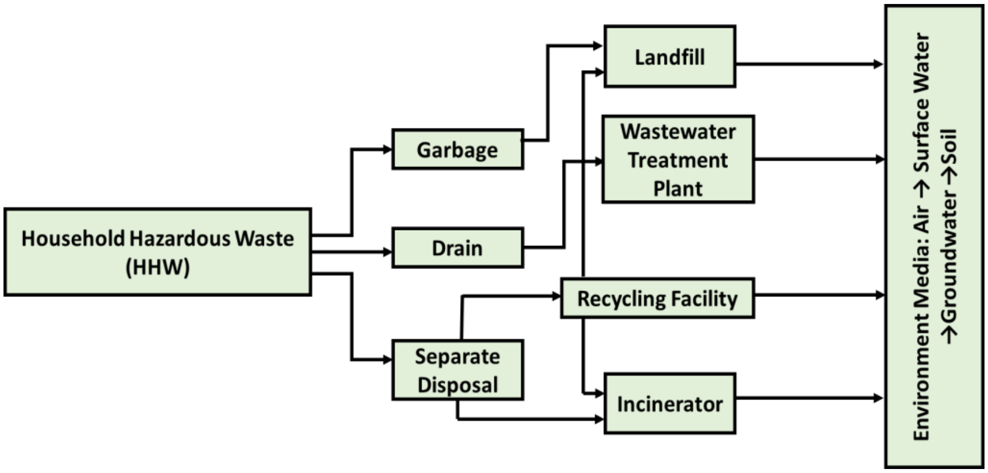


Figure 5: Household Hazardous Waste Management

7.5 India's Household Hazardous Waste Regulations

- India has implemented some regulations to shield the environment and people from the damaging impacts of hazardous waste. The Solid waste Management (SWM) Rules, 2016 are the primary legislation governing the management of this type of garbage, which states that:

  Section 1(a)- Waste in every home needs to be divided into three categories:

  1. biodegradable (similar to leftover food)

  2. Non-biodegradable (such as packaging and plastic)

  3. Hazardous household garbage (such as used paints, batteries, pesticides, or cleansers)

  Section 15(i)- In accordance with local government regulations, these wastes should be placed in the appropriate bins and given to approved garbage collectors.

  Section 15(j)- Local Authorities' Role: Collection facilities for hazardous home waste must be established by local governments. In accordance with State Pollution Control Board (SPCB) or Pollution Control Committee (PCC) instructions, they must also make sure that this trash is securely stored and delivered to treatment or disposal facilities.

- In accordance with the Hazardous and Other Wastes (Management & Transboundary Movement) Rules, 2016, hazardous waste must be handled and disposed of using techniques such as: land disposal, burning, co-processing in accordance with CPCB (Central Pollution Control Board) regulations (such as using waste as fuel in cement plants).

- E-Waste Management Rule, 2022 and Battery Waste Management Rule, 2022: Numerous HHW items, including used batteries, electrical appliances, CFLs, and chargers, are covered by Extended Producer Responsibility (EPR) according to:

1. E-Waste Management Rule, 2022
2. Battery Waste Management Rule, 2022

According to these guidelines, producers must: Establish take-back procedures or collecting centers.

Make certain that registered recyclers handle or dispose of hazardous fractions appropriately.

7.6 Household Hazardous Waste (HHW) Disposal in India

Common Hazardous Waste Treatment, Storage, and Disposal Facilities (CHW-TSDFs) are responsible for the scientific management of the majority of domestic/household hazardous waste (DHW/HHW). These facilities are built using cutting-edge technology to handle hazardous waste in a safe and environmentally responsible manner. They usually consist of incinerators with pollution control systems, secured (engineered) landfills, or both.

7.6.1. HHW Secured Landfills

Specialized disposal locations created to reduce their negative effects on the environment are known as secured landfills. They must be built in accordance with stringent pollution control authority criteria, which include:

- Systems of liners to stop leaks into the soil
- Systems for collecting and removing leachate
- Layers for leak detection
- Systems for removing gas
- Capping systems, daily/intermittent covers, and stormwater drainage
- At the base are redundant protecting liners.

Secured landfills, which have numerous leachate barriers and dual liner systems, provide better protection than sanitary landfills, which are utilized for common municipal trash.

Direct landfilling is only used for waste that doesn't release harmful metals. It is necessary to treat waste that contains leachable toxins in order to stop it from leaking dangerous materials that could contaminate groundwater through leachate.

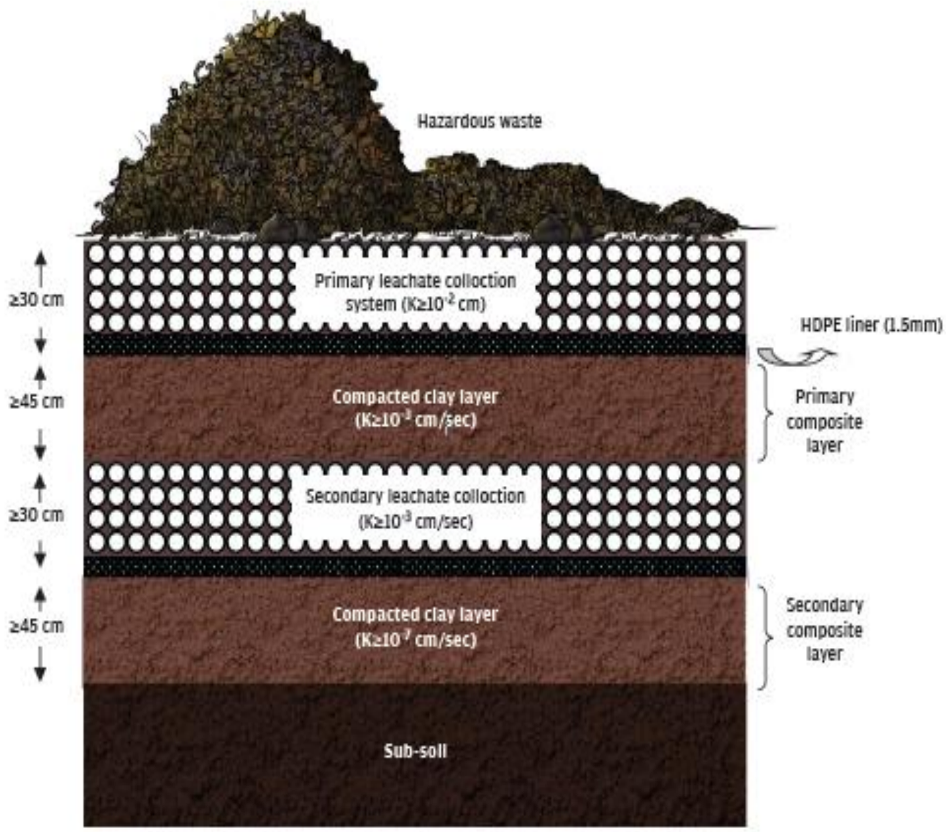


Figure 6: Double-liner composite system cross-section in a secured landfill system

Important Features of Secured Double-Liner Landfills

- In accordance with regulatory body directives (Figure 6), the design comprises:
- At least 30 cm deep and having a permeability of more than 10^{-7} cm/sec is the primary leachate collection layer.
- HDPE geomembrane primary liner, at least 1.5 mm thick
- At least 150 cm of compacted clay or modified soil, with a permeability of ≤ 10^{-7} cm/sec

- The permeability of the secondary leachate (leak detection) layer should be greater than 10^{-3} cm/sec and at least 30 cm thick.
- HDPE geomembrane secondary liner, at least 1.5 mm thick
- An extra layer of compacted clay that is at least 45 cm thick and has a permeability of less than 10^{-7} cm/sec

Waste Pretreatment Prior to Disposal

Pre-treating hazardous trash that contains leachable toxins is necessary to reduce dangers to the environment and human health. Typical methods of treatment consist of:

- **Decanting** is the process of emptying containers of any remaining liquid.
- **Solidification** is the process of combining trash with stabilizing agents to create a solid block, which enhances physical characteristics like permeability and strength and is appropriate for low-metal, high-moisture waste.
- In order to bind harmful metals (such as lead, chromium, mercury, and nickel) and reduce their likelihood of leaking, **stabilization** involves solidification and chemical treatment.
- **Encapsulation:** To stop waste from escaping, it is physically wrapped in materials like plastic.

These methods are not limited to heavy metals; they are also applied to asbestos, glass trash, and other waste materials that are challenging to handle.

7.6.2 Thermal processes

One of the tried-and-true methods for eliminating hazardous waste in all of its forms—solid, semi-solid, liquid, and gaseous, depending on the feeding system—is thermal oxidation via incineration, which leaves behind harmless residue that is neither toxic nor dangerous. Waste materials including paints, pesticides, insecticides, and expired medications can be handled with this technique.

The ability to assess the compatibility of different waste kinds for the purpose of homogenization prior to feeding them into the incinerator is necessary for the destruction of complicated hazardous waste. In order to operate and maintain the incinerator's thermal operations and pollution control systems in accordance with established environmental laws, expertise and experience are required.

7.7 First Aid Procedures Related to Hazardous Wastes

Chemical cleansers, batteries, solvents, pesticides, contaminated sharps, and other toxic or corrosive materials are just a few examples of the wide spectrum of items that are frequently produced in homes, labs, and businesses and are classified as hazardous wastes. Serious health hazards, such as skin burns, respiratory distress, poisoning, or even long-term organ damage, can arise from exposure to these compounds. Accidental exposures still happen, even though prevention through appropriate handling and protective measures is desirable. Therefore, lowering health risks and stabilizing the afflicted person until expert medical assistance is available require a thorough understanding of first aid practices.

Table 2: First Aid Procedures Related to Hazardous Wastes

Exposure Type	Overview	First Aid Protocol
Skin Contact	One of the most frequent exposure routes is the skin. Numerous dangerous chemicals have corrosive or irritating properties and can enter the bloodstream through the skin.	Remove any contaminated PPE or clothing at away. Spend at least 15 to 20 minutes rinsing the afflicted area under running, clean water. If safety showers are available, use them. Do not scrape the area. If it's okay to use mild soap, refer to the Safety Data Sheet (SDS). If you continue to experience redness, burns, or irritation, get medical help.
Eye Contact	Eyes are extremely sensitive and susceptible to particles, fumes, and splashes of chemicals. In order to prevent visual loss, immediate care is essential.	For at least 15 to 20 minutes, keep the eyelids open and rinse the eye with saline solution or lukewarm running water. Only take out contact lenses that are readily removed while rinsing. Apply no ointments unless a medical professional instructs you to do so.

		Seek emergency medical attention, particularly for unknown chemicals, acids, or alkalis.
Inhaling Vapors or Fumes	Exposure to harmful gases, fumes, or aerosols can result in long-term lung damage, asphyxia, dizziness, or respiratory irritation.	Get the person outside right away. Take off tight clothing and make sure the person is warm and calm. Call emergency services and perform cardiopulmonary resuscitation (CPR) if the person is not breathing or unresponsive. Only qualified individuals should deliver oxygen. Always get checked out by a doctor, even if your symptoms become better.
Consuming Dangerous Substances	Ingesting dangerous substances can cause internal burns, poisoning, or damage to many organs.	Unless instructed to do so by a medical professional or poison control, do not induce vomiting. Use water to gently rinse your mouth. Maintain the person's consciousness and composure. Give information about the chemical (from the label or SDS) and contact poison control or emergency services right away. Don't give anything by mouth if the person is unconscious; instead, put them in the recovery position and keep an eye on their respiration.
Burns from Chemicals	Deep tissue damage and a delayed onset are two characteristics of chemical burns that might be misleading.	Remove any contaminated apparel or accessories with care. Spend at least twenty minutes rinsing the afflicted region with cool, clean water. Applying lotions or ointments without a prescription is not advised. Put a sterile, non-stick bandage over it.

		Seek immediate medical attention, particularly if you have facial, deep, or severe burns.

Terminal Questions

6. What is the first step in managing Household Hazardous Waste (HHW) properly?

A. Burning waste materials

B. Mixing with municipal waste

C. Differentiating waste at its beginning

D. Flushing down the drain

7. Assertion (A): Household Hazardous Waste can pose significant health and environmental risks.

Reason (R): Many people are unaware that common household items like paints, batteries, and cleaning supplies are hazardous.

A. Both A and R are true, and R is the correct explanation of A.

B. Both A and R are true, but R is not the correct explanation of A.

C. A is true, but R is false.

D. A is false, but R is true.

8. True or False: HHW accounts for nearly 50% of municipal solid waste generated by households.

9. Improper disposal of HHW can lead to the creation of ________, a toxic liquid that can contaminate ________.

10. Match the Following

Column A (Waste Type)	Column B (Example)
1. Automotive items	A. Oven cleaner
2. Painting supplies	B. Paint thinner

Column A (Waste Type)	Column B (Example)
3. Home cleaners	C. Transmission fluid
4. Miscellaneous hazardous items	D. Mercury thermometer

11. Why is it dangerous to dispose of HHW with regular household waste?

12. Based on the cross-section of a secured landfill, name two components that prevent hazardous material from contaminating the environment.

13. Under the Solid Waste Management Rules, 2016 in India, what are the three categories' households must segregate their waste into?

14. What is the first aid procedure if someone inhales toxic fumes from HHW?

Summary

- Hazardous Waste Management: Materials that pose a risk to human health or the environment are classified as hazardous waste. Such waste was traditionally burned or disposed of in the open, which resulted in serious contamination. Safe, controlled handling is the main goal of modern management in order to avoid contaminating the air, water, and land.
- **Disposal Methods:**
  - **Secure Landfills**: Designed to safely hold hazardous wastes using leachate systems and several liners.
  - **Deep Well Injection**: To keep liquid waste away from water sources, it is pushed deep into rock layers.
  - **Bedrock Disposal**: Several protective barriers are used to bury solid or radioactive waste deep below in stable rock formations.
- Batteries, cleansers, insecticides, and outdated prescriptions are examples of household hazardous waste (HHW). Despite making up just around 1% of household trash by weight, HHW can lead to harmful leaks, air pollution, and health problems for humans, pets, and sanitation workers if it is improperly disposed of (in landfills, sewers, or by burning).

- Improved HHW Management Consists of: Sorting at the Source: Keep dangerous materials apart from ordinary garbage.
    - Recycling and Reuse: It's usually safe to recycle or repurpose used paint, batteries, and oil. Community Collection: Pollution can be avoided by
    - donating or appropriately disposing of extra materials.
- The Regulatory Structure of India:
    - SWM Rules, 2016: Demand that hazardous, non-hazardous, and biodegradable waste be separated.
    - Hazardous Waste Regulations & EPR Guidelines: Require manufacturers to take accountability for batteries and e-waste.
    - Treatment Facilities: CHW-TSDFs use thermal incineration and engineered landfills to manage HHW, frequently following pretreatment procedures including stabilization or solidification.
- First Aid for Hazardous Exposure: Before medical assistance arrives, serious harm can be avoided by acting quickly to neutralize, ventilate, or wash the affected area.

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Answer

1. **B. Deep well injection**
2. **A. Both A and R are true, and R is the correct explanation of A.**
3. **False**, *Explanation: This method is cost-effective but poses risks if the well or surrounding rock layers fail.*
4. **Solid**, **corrosion-resistant**
5. 1 → B, 2 → A, 3 → C, 4 → D
6. C. Differentiating waste at its beginning
7. A. Both A and R are true, and R is the correct explanation of A
8. False, Explanation: HHW accounts for only about 1% of household waste by weight.
9. leachate, groundwater
10. 1 → C, 2 → B, 3 → A, 4 → D

11. Because hazardous substances can leak, burn, or emit toxic gases when mixed with other garbage, leading to soil, air, and water contamination, and endangering human health.

12. HDPE geomembrane liners, Leachate collection systems

13. Biodegradable, Non-biodegradable, Hazardous household waste

14. Move the person to fresh air immediately,

Remove tight clothing,

Call emergency services,

Provide CPR, if necessary,

Get medical help even if symptoms subside.

Unit 08: Handling of Hazardous Wastes

Unit Structure

8.0 Learning Objectives

After going through this unit, you will be able to:

- Understand the key definitions for hazardous waste handling and management
- Understand the Evolution of 1989 Rules.
- Discuss the applications and implementation of hazardous waste and management.

8.1 Introduction

Hazardous wastes are wastes that, due to their physical, chemical, toxic, or reactive properties, pose a substantial or potential threat to public health and the environment. These wastes can be liquids, solids, gases, or sludges and may be discarded commercial products, like cleaning fluids or pesticides, or the by-products of manufacturing processes. These wastes are typically generated by industrial activities, such as manufacturing of chemicals, petroleum refining, pharmaceuticals, and metal processing. Improper handling or disposal of hazardous waste can lead to contamination of air, water, and soil, potentially resulting in long-term ecological damage and serious health risks.

In India, the issue of hazardous waste management (HWM) has become a significant environmental concern due to rapid industrialization, urbanization, population growth and changing lifestyles. Rapid industrialization in the late 20th century led to increased hazardous waste generation. Recognizing the risks associated with unregulated handling and disposal of such wastes, the Government of India enacted the Hazardous Wastes (Management and Handling) Rules in 1989, under the Environment (Protection) Act, 1986 with aimed to ensure safe management of hazardous wastes throughout their life cycle, from generation to final disposal.

According to the Central Pollution Control Board (CPCB), as of 2022–2023, India generated approximately 15.66 million metric tons of hazardous waste annually, with about 83,682 industrial units classified as hazardous waste generators (CPCB, 2023). These wastes are primarily generated by the petrochemical, pharmaceutical, metal processing, pesticide, dye, and electroplating industries. If not properly managed, hazardous wastes can contaminate soil, water, and air, leading to serious health and ecological problems.

In response to this growing issue, the Indian government has enacted a series of legislations and rules aimed at the proper handling, storage, transportation, and disposal of hazardous wastes. Among these, the Hazardous Wastes (Management and Handling) Rules, 1989, were the first comprehensive regulations addressing this issue.

8.2 Hazardous waste (Management and Handling) Rule 1989

The Hazardous Wastes Management and Handling Rules, 1989 were notified under the Environment (Protection) Act, 1986. These rules were a landmark step in establishing a legal framework for the safe management of hazardous wastes in India. The 1989 Rules laid down procedures for the authorization, storage, transport, and disposal of hazardous waste and assigned responsibilities to both waste generators and regulatory authorities.

Key Provisions

1. **Authorization Requirement**: Industries generating hazardous waste were required to obtain authorization from their respective State Pollution Control Boards (SPCBs). This authorization ensured that only competent facilities handled hazardous waste.
2. **Responsibilities of Occupiers and Operators**: Waste generators (referred as "occupiers") and operators of disposal facilities were held responsible for the safe handling, storage, and disposal of hazardous waste.

3. **Record Maintenance and Reporting**: According to this rules it is mandatory for industries to maintain records of the quantity and nature of hazardous wastes generated and disposed of. Annual returns were to be submitted to the SPCBs.
4. **Packaging and Labeling**: Hazardous wastes had to be appropriately packaged and labeled according to international standards to ensure safety during transportation and storage.
5. **Transportation Regulations**: The rules specified requirements for transportation, including the use of manifest systems, to track hazardous waste from its point of generation to its final disposal site.
6. **Emergency Procedures**: In case of accidental releases or spills, immediate reporting to concerned authorities and the execution of contingency plans were mandated.

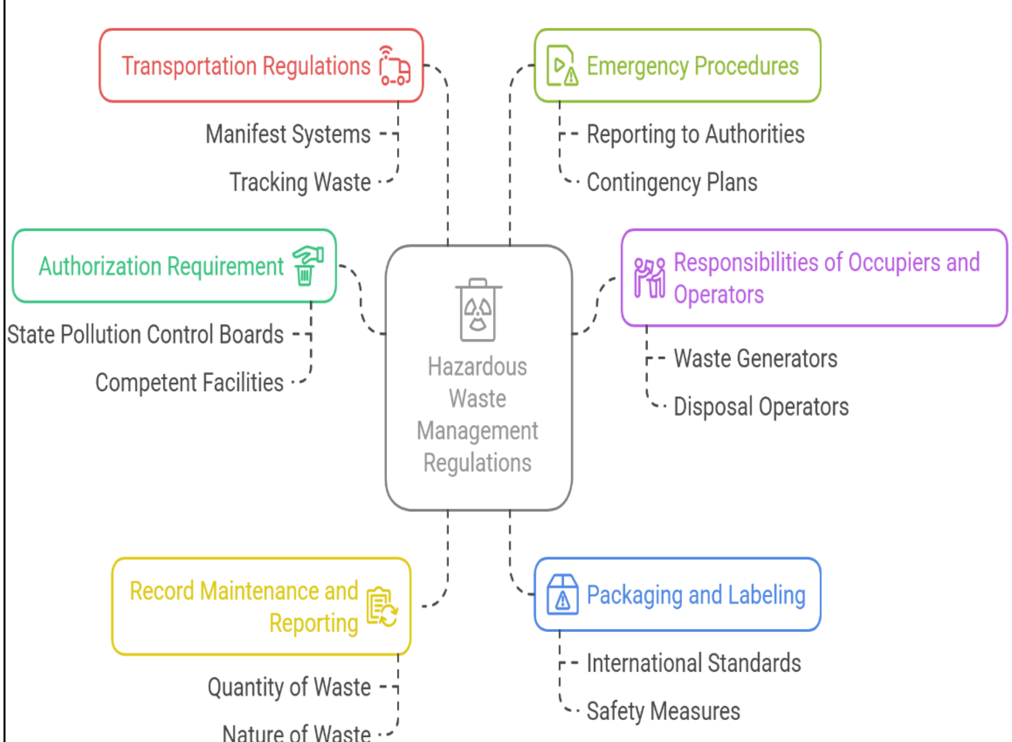

Figure 1. Hazardous Waste Management Regulations

The 1989 Rules were subsequently amended in 2000, 2003, and later replaced by the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016, to bring them in line with international practices, especially those under the Basel Convention.

8.3 Evolution and Amendments to the 1989 Rules

While the 1989 Rules laid the foundation, several issues in implementation prompted further revisions. The key amendments and updates include:

- **Hazardous Wastes (Management and Handling) Amendment Rules, 2000 & 2003**: These amendments expanded the list of hazardous wastes, introduced the concept of Common Treatment, Storage, and Disposal Facilities (TSDFs), and emphasized waste minimization through cleaner production technologies.
- **Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2008**: These rules aligned Indian legislation with the Basel Convention, regulating the import and export of hazardous waste.

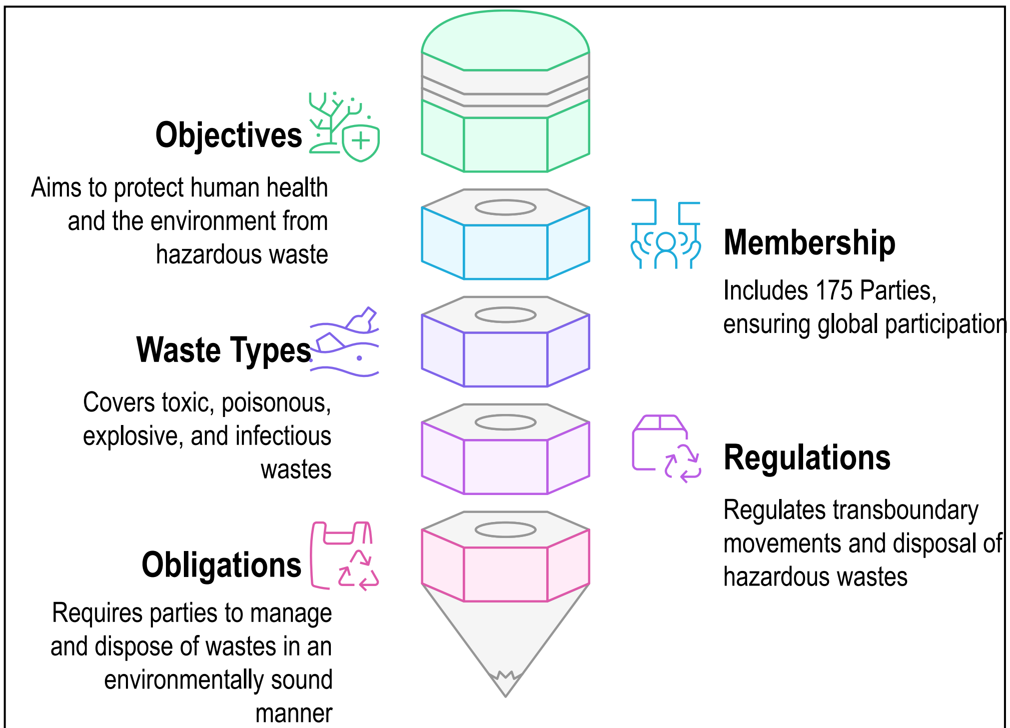

Figure 2. Overview of the Basel Convention

(Source: https://www.unep.org/resources/report/basel-convention-control-transboundary-movements-hazardous-wastes)

- **Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016**: These rules replaced the earlier versions and introduced clearer definitions, extended producer responsibilities, and laid down stringent norms for hazardous waste import/export. They also included other waste types such as electronic waste, lithium batteries, and used oils.

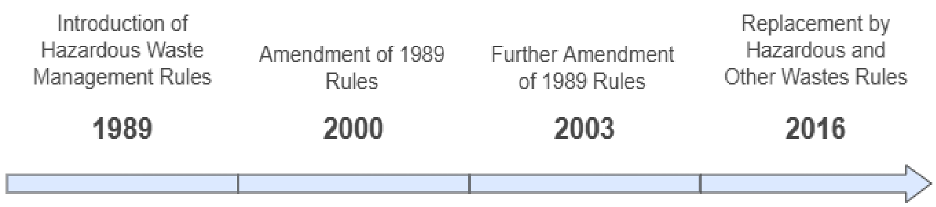

Figure 3. Evolution of Hazardous Waste Management Regulations

Self-Assessment 1

Very short answer type questions

1. What are hazardous wastes?
2. Mention two industries that generate hazardous waste.
3. In which year were the Hazardous Wastes (Management and Handling) Rules first enacted in India?
4. Under which Act were the 1989 Rules notified?
5. How much hazardous waste did India generate annually as per CPCB 2022–2023?
6. What is the purpose of the authorization requirement under the 1989 Rules?
7. What must industries submit annually to the SPCBs?
8. Which international agreement influenced the 2008 Rules?
9. What additional waste type was included in the 2016 Rules?

8.4 Key Definitions

a. **Hazardous Waste:** Defined under Rule 3(1)(17) of the 2016 Rules as “Any waste which by reason of characteristics such as physical, chemical, biological, reactive, toxic, flammable, explosive, or corrosive causes danger or is likely to cause danger to health or environment.”

b. **Occupier:** As per Rule 3(1)(20): "A person who has control over the premises of a factory or an institution and includes the person in possession of hazardous waste."

c. **Authorization:** The official permission granted by the SPCB or PCC to an occupier for the handling of hazardous wastes.

d. **Management:** means the collection, transport and disposal of hazardous wastes or other wastes, including after-care of disposal sites;

e. **Disposal:** Defined as any process that leads to final placement or destruction of hazardous waste, including landfilling, incineration, or other forms of treatment that render the waste non-hazardous.

f. **Transboundary movement:** means any movement of hazardous wastes or other wastes from an area under the national jurisdiction of one state to or through an area under the national jurisdiction of another State or to or through an area not under the national jurisdiction of any State, provided at least two States are involved in the movement.

g. **Treatment, Storage and Disposal Facility (TSDF):** A site authorized for the secure treatment, storage, and final disposal of hazardous wastes. This includes incinerators, landfills, and recycling units.

h. **Approved site or facility:** means a site or facility for the disposal of hazardous wastes or other wastes which is authorized or permitted to operate for this purpose by a relevant authority of the State where the site or facility is located.

i. **Environmentally sound management of hazardous wastes or other wastes** means taking all practicable steps to ensure that hazardous waste or other wastes are managed in a manner which will protect human health and the environment against the adverse effects which may result from such wastes.

j. **Area under the national jurisdiction of a State** means any land, marine area or airspace within which a state exercises administrative and regulatory responsibility in accordance with international law in regard to the protection of human health or the environment.

k. **State of export** means a Party from which a transboundary movement of hazardous wastes or other wastes is planned to be initiated or is initiated,

l. **State of import** means a Party to which a transboundary movement of hazardous wastes or other wastes is planned or takes place for the purpose of disposal therein or for the purpose of loading prior to disposal in an area not under the national jurisdiction of any State.

m. **State of transit** means any State, other than the State of export or import, through which a movement of hazardous wastes or other wastes is planned or takes place.

n. **States concerned** means Parties which are States of export or import, or transit States, whether or not Parties.

o. **Person** means any natural or legal person.

p. **Exporter** means any person under the jurisdiction of the State of export who arranges for hazardous wastes or other wastes to be exported.

q. **Importer** means any person under the jurisdiction of the State of import who arranges for hazardous wastes or other wastes to be imported.

r. **Carrier** means any person who carries out the transport of hazardous wastes or other wastes.

s. **Generator** means any person whose activity produces hazardous wastes or other wastes if that person is not known, the person who is in possession and/or control of those wastes.

t. **Disposer** means any person to whom hazardous wastes or other wastes are shipped and who carries out the disposal of such wastes.

u. **Political and/or economic integration organization** means an organization constituted by sovereign states to which its member States have competence in respect of matters governed by this Convention and which has been duly authorized, in accordance with its internal procedures to sign, ratify, accept, approve, formally confirm or accede to it.

8.5 Applications and Implementation of HWM

The operationalization of HWM requires concerted actions among industries, regulatory bodies, and waste management service providers.

Role of Regulatory Bodies

1. **Central Pollution Control Board (CPCB):** CPCB provides guidelines, oversees implementation, and coordinates with State Boards.
2. **State Pollution Control Boards (SPCBs):** SPCBs issue authorizations, oversee compliance, and keep a list of hazardous waste generators within their territory.
3. **MoEFCC:** The Ministry of Environment, Forest and Climate Change develops national policy and oversees international treaties like the Basel Convention.

Industry Responsibilities

Industries that produce hazardous waste must:

- Identify and classify the nature of the waste.
- Obtain permission for handling hazardous waste.
- Ensure packaging, labeling, and transit are done safely.
- Keep records and submit annual returns to SPCBs.
- Transfer waste to authorized TSDFs.

Treatment, Storage, and Disposal Facilities (TSDFs)

India has established a chain of TSDFs managed by public and private agencies. These have the capabilities to treat various kinds of hazardous waste, such as incinerable and land-disposable wastes. In 2023, 45 functional TSDFs existed in India, catering to several states and industrial clusters (CPCB, 2023).

Case Studies and Examples

Lead Acid Battery Recycling: Telangana's lead battery recycling industry suffered a setback when one such factory was recently closed down by the Telangana SPCB because of illegal operations and incorrect handling of lead slag, which polluted surrounding soil as well as water resources (Times of India, 2023).

There are several TSDF Network in Gujarat: Gujarat, which is one of India's most industrialized states, boasts the maximum number of TSDFs and has followed a cluster-based approach to deal with hazardous waste effectively (TERI, 2020).

Challenges in Hazardous Waste Management

Although there is a strong legal framework, India encounters the following challenges:

1. Lack of Infrastructure: Several states do not have proper TSDFs, which results in illegal dumping.

2. Enforcement Problems: SPCBs seldom have the personnel and infrastructure to ensure compliance on a regular basis.

3. Informal Sector Involvement: Informal disposal and recycling practices cause unsafe treatment, particularly in the case of e-waste and used oils.

4. Lack of Data: Inadequate or incorrect data on waste generation and disposal interfere with policymaking.

5. Low Awareness: Small and medium enterprises (SMEs) lack adequate awareness of hazardous waste regulations and enforcement mechanisms.

Policy Initiatives and the Way Forward

To combat the above issues, a number of initiatives have been undertaken:

Waste Management Frameworks: National Action Plans on hazardous waste have been drawn up to facilitate implementation.

Technology Promotion: Cleaner production technologies and co-processing in cement kilns are promoted to reduce hazardous waste.

Capacity Building: Training programs for industries and regulators on a regular basis are conducted by CPCB and MoEFCC.

Public-Private Partnerships: Promotion of PPP models for developing and running TSDFs.

Extended Producer Responsibility (EPR): While originally targeted at e-waste, EPR is being extended to include other hazardous waste streams.

Summary

- Hazardous waste is toxic, flammable, or reactive, mainly generated by industries like chemicals, metals, and pharmaceuticals. It poses serious risks to human health and the environment.

- India introduced the Hazardous Waste Rules in 1989, updated in 2000, 2003, 2008, and replaced by the 2016 rules. These align with the Basel Convention and provide a structured waste management process.

- The rules mandate authorization, proper packaging, labeling, transportation, and record-keeping. Terms like occupier, generator, and TSDFs are clearly defined for regulation.

- CPCB, SPCBs, and MoEFCC oversee enforcement. Industries must follow safety norms, and as of 2023, India had 45 functional Treatment, Storage, and Disposal Facilities (TSDFs).

- India faces issues like weak enforcement, inadequate facilities, and informal waste handling. Solutions include cleaner technologies, public-private partnerships, and extended producer responsibility.

Terminal Questions

1. Define various terminology used in Hazardous waste management.
2. Discuss the in detail the role of regulatory bodies in HWM monitoring and operation.
3. Discuss the challenges in Hazardous Waste Management.
4. What is Hazardous waste Rule 1989? Discuss the amendments to the 1989 rule.

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Answer Keys

Self -Assessment 1

1. Wastes that pose a threat to public health and the environment due to their harmful properties.
2. Petrochemical and pharmaceutical industries.
3. 1989.
4. Environment (Protection) Act, 1986.
5. Approximately 15.66 million metric tons.
6. To ensure only competent facilities handle hazardous waste.
7. Annual returns on hazardous waste.
8. Basel Convention.
9. Electronic waste.

Unit 09: Hazardous Wastes Management

Unit Structure

9.0 Learning Objectives

After going through this unit you will be able to:

- Understand the concept of Hazardous Wastes Management
- Explain the Basel Convention
- Understanding the provisions of the Basel Convention
- Describe the Hazardous Wastes Management plan in India

9.1 Introduction

Since the past few decades, garbage management has been one of the most important issues for the environment. Waste increases with increasing population, industrialization, and urbanization. Hazardous waste is waste that poses significant or potential threats to public health and the environment, but non-hazardous waste does not pose a threat to the environment. Rapidly growing industrial sector has led to the production of a significant amount of harmful waste. Hazardous waste cannot be disposed as off in the environment, so proper care is required during its storage, segregation, transportation, and disposal in order to reduce environmental hazard. Burning or incineration of hazardous and other waste causes toxic fumes to escape into the environment, which leads to air pollution and related health issue. Hazardous waste disposal in water-bodies or municipal dumps causes toxic releases due to leaching in land and water, which deteriorates soil and water quality. Additionally, those who are employed in these unscientific practices face a variety of health issues, including neurological disorders, skin diseases, genetic defects, cancer, etc. Thus, prevention, minimization, re-use, recycling, recovery, utilization, and co-processing of hazardous and other waste were necessary for environmentally safe waste management.

Hazardous waste management means the processes of handling, treatment, storage, and disposal of waste materials that are toxic, flammable, corrosive, or reactive and pose a significant risk to human health or the environment.

Effective hazardous waste management includes identifying hazardous waste, safely collecting and transporting it, treating or neutralizing harmful properties, and disposing of it in accordance with regulatory standards to minimize negative effects. Hazardous waste management consists of several steps as shown in figure1.

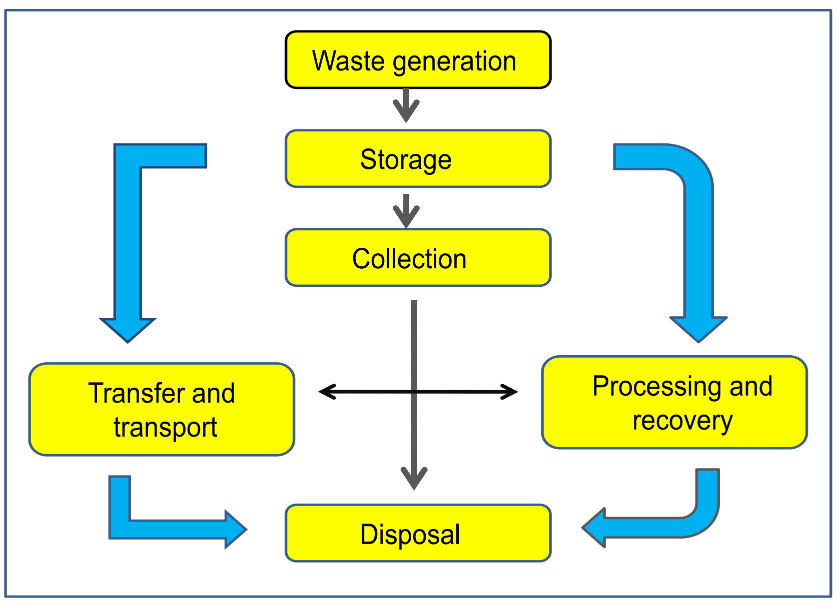


Figure 1: Steps involved in hazardous waste disposal

9.1.1 Waste generation

Hazardous wastes are generated in limited amounts in a community, and very little information is available about the amounts of hazardous waste generated in different industries and communities. Hazardous waste generation outside the industry is unpredictable and significantly less in quantity, so the waste generation parameter is useless. A thorough inventory and measurement study at each potential source in a community is the only practical way to overcome these limitations. Potential sources of hazardous waste are to be identified as a first step in developing a community inventory. Onsite data inventory must be done to determine the total annual amount of hazardous waste at any given source in a community. List of type of hazardous waste and their sources are given in table 1:

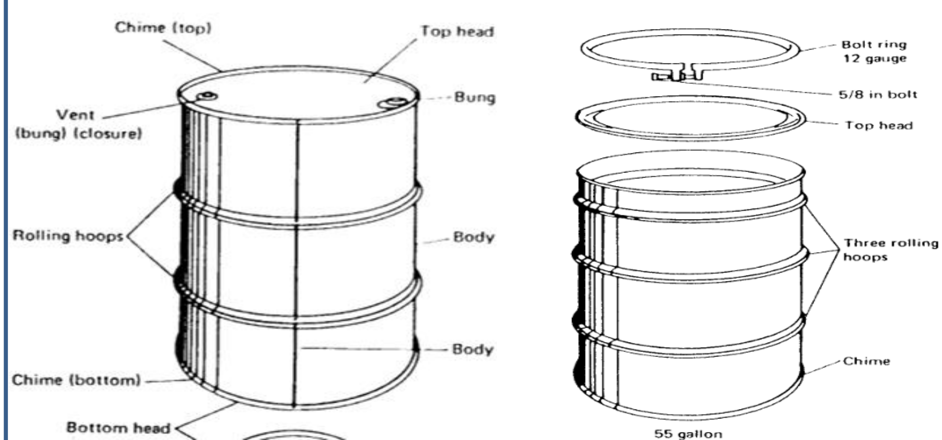
Table 1: Common hazardous wastes and their sources (Source: Tchobanoglous, et al., 1977)

Hazardous Waste Category	Sources
Radioactive substances	Nuclear power plants, offices, hospitals, colleges and university laboratories, biomedical research facilities, etc.
Toxic chemicals	Agriculture chemical companies, battery shops, car washes, chemicals, toxic chemicals and university laboratories, construction companies, electric utilities, hospitals and clinics, industrial cooling towers, newspapers and photographic solutions, nuclear power plants, pest control agencies, photographic processing facilities, plating shops, service stations, etc.
Biological wastes	Biomedical research facilities, drug companies, hospitals, medical clinics, etc.
Flammable wastes	Petroleum reclamation plants, refining and processing facilities, service stations, tanker truck cleaning stations, dry cleaners, etc.
Explosives	Construction companies, dry cleaners, ammunition production facilities, etc.

Containerized hazardous waste spillage is another important source that needs to be taken into consideration in addition to the above listed sources. Normally, no one knows how much hazardous waste is involved in spillage. The consequences of spillage are often remarkable and apparent to the community. Accidental spillage poses a greater risk to the environment and human health because its occurrence is unpredictable.

9.1.2 Storage and collection

Persons handling hazardous wastes are advised to have defending precautions to save themselves from health effects. Exposure of hazardous waste can cause dermatitis in the skin, eye irritation, asthma on long exposure and contraction of the chest. The kinds and quantities of hazardous waste produced, as well as the time span during which generation takes place, influence onsite storage procedures. When considerable amounts are produced, dedicated facilities are typically required, which have the space to store garbage that has collected over a number of days. Waste can be containerized and stored in tiny quantities when it is produced in small quantities. Facilities and containers used for managing and storing hazardous waste are chosen based on the properties of the garbage. For instance, to keep metals from deteriorating, caustic solutions or corrosive acids are kept in containers walled with glass or made of fiber-glass. Additionally, extreme caution must be used to prevent incompatible wastes from being stored in the same container or in the same areas. Typical drum containers used to store hazardous waste are depicted in Figures 9.2(a):



(a) (b)

Figure 9.2 (a) Light-gauge closed head drum, **(b)** Light-gauge open head drum

Hazardous trash is often collected by the waste generator or a specialized hauler and sent to disposal site. One of the following methods is used to load collection vehicles:

1. Wastes stored in large-capacity tanks are either drained or pumped into collection vehicles;
2. Wastes stored in sealed drums or sealed containers are loaded by hand or by mechanical equipment onto flatbed trucks.

Keep in mind that drums are frequently stored and collected using a flatbed truck for short-distance transportation. Larger tank trucks, trailers and railway tank wagons are utilized for longer hauls.

9.1.3 Transfer and transport

Hazardous waste generated frequently requires transport to a particular site for a permitted treatment, storage, or disposal facility (TSDF). Due to possible threats to public safety and the environment, transport is given extraordinary attention by governmental agencies to avoid any occasional accidental spill out. Sludge or solids are often reloaded into collecting containers without being removed in order to be transported to processing and disposal facilities, while liquid hazardous wastes are typically pumped from collection vehicles.

9.1.4 Processing

Hazardous waste is processed in order to recover valuable materials and get the waste ready for disposal. Either on-site or off-site processing is possible. The characteristics of the wastes, their quantity, the technical, financial, and environmental aspects of the available on-site treatment processes, and the accessibility of the closest off-site treatment facility (including haul distance, fees, and exclusions) are the factors that influence the choice of processing site. Hazardous waste can be treated using thermal, chemical, biological, or physical methods.

9.1.5 Disposal

Disposal is considered as the final stage of a hazardous waste management system. Bedrock disposal, secure landfill and deep well are some waste disposal methods. Regardless of its form (solid, liquid, or gas), most hazardous waste is disposed of either at the surface or by deep burial. Although controlled landfill methods have been demonstrated to be adequate for the disposal of municipal solid waste and small amounts of hazardous waste, they are not appropriate for the disposal of large amounts of hazardous waste due to the following factors: the possibility of dangerous liquid waste leaching and percolation into groundwater; the potential for hazardous waste to volatilize and release toxic or explosive vapors into the atmosphere; the potential for unexpected reactions in the landfill that could produce toxic or explosive gases; the rusting of containers holding hazardous wastes. As a result, we must exercise caution both when developing and when selecting a location for the disposal of hazardous material.

Self-assessment 1

1. What is the primary reason hazardous waste cannot be disposed of like regular waste?

A. It is biodegradable

B. It is too expensive to handle

C. It poses threats to human health and the environment

D. It cannot be transported

2. What is the major risk associated with burning or incinerating hazardous waste?

A. It delays waste decomposition

B. It creates non-biodegradable ash

C. It releases toxic fumes, causing air pollution

D. It is too expensive to operate

3. What factor does not influence the choice between on-site and off-site processing of hazardous waste?

A. Quantity of waste

B. Color of waste

C. Financial cost

D. Technical feasibility

4. What health effects can long-term exposure to hazardous waste cause for workers?

A. High blood pressure and diabetes

B. Neurological disorders, genetic defects, and cancer

C. Cold and flu symptoms

D. Vitamin deficiency

5. How are flammable hazardous wastes commonly stored?

A. In open containers

B. In containers made of wood

C. In sealed drums or sealed containers

D. In biodegradable bags

Answer key: 1.C; 2.C; 3.B; 4.B; 5.C

9.2 Basel convention

Beginning environmental awareness and subsequent tightening of environmental regulations in the 1970s and 1980s (industrialized world) led to growing public resistance to the disposal of hazardous wastes. This led to some operators to seek inexpensive disposal options for hazardous wastes in Eastern Europe and the developing world, where environmental consciousness was much less developed and regulations and enforcement mechanisms were missing.

Basel convention was adopted in 1989 by the conference of plenipotentiaries in Basel, Switzerland, in reaction to a public protest in the 1980s, in Africa and other parts of the developing world of deposits of toxic wastes imported from a foreign country. It is a comprehensive treaty, mainly concerned to the control of trans-boundary movements of hazardous wastes and their disposal. It has 188 member countries (Parties) and aims to protect the human and environment from the adverse effects of hazardous waste. India ratified it on 24th June 1992 and it came into force in India on 22nd September 1992. India has implemented the Hazardous and Other Wastes (Management and Trans-boundary Movement) Rules of 2016 (HOWM rules), which align with the Basel Convention's principles. These rules are notified under the Environment Protection Act, 1986, which aims to ensure the safe and environmentally sound management of hazardous and other wastes including their trans-boundary movement. The HOWM Rules were a supersession of the earlier Hazardous Wastes (Management, Handling and Trans-boundary Movement) Rules, 2008.

The Indian Ministry of Environment, Forest and Climate Change (MOEF&CC) plays a key role in implementing and enforcing the Basel Convention in India. India's Ministry of Consumer Affairs Food and Public Distribution has announced a ban on all types of single-use plastic products in all its Public Sector Undertaking (PSUs) including Food Corporation in India in September 2019.

Salient Points of Basel Convention:

1. Came into force in 1992.
2. The Basel Convention secretariat is situated in Geneva, Switzerland.
3. It requires "Prior Consent Approval" practice to regulate the trans-boundary movement of the hazardous wastes.
4. To protect human health and environment against adverse effects of Hazardous wastes.
5. Decrease of hazardous waste generation and the encouragement of environmentally friendly management of hazardous wastes, at the disposal sites.
6. Helping developing countries to develop environmentally sound management of the hazardous waste generation.
7. A regulatory system is mandatory for trans-boundary movements.
8. Special agreement needed for non-parties, otherwise they cannot transport hazardous.
9. The member nations are required to have domestic legislation for both prevention and the punishment of the illegal trafficking of such hazardous wastes.
10. The member nations ensures that they control the generation, storage, transportation, treatment, reuse, recycling, recovery and final disposal of hazardous wastes.
11. Conference of Parties (COP) meets biennially to make decisions about the operations of the convention.

9.2.1 What is Environmentally Sound Management (ESM)?

There is currently no universally accepted definition for environmentally sound management. Nonetheless, the Basel and Stockholm conventions' provisions on ESM as it relates to hazardous wastes, as well as those of the Organization for Economic Co-operation and Development (OECD), offer global guidance that supports ESM initiatives being undertaken in different nations and across industrial sectors.

There are some provisions on ESM under the Basel Convention, which are as follows:

(i) In paragraph 8 of Article 2, the Basel Convention defines Environmentally Sound Management of hazardous or other wastes as “taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner which will protect human health and the environment against adverse effects which may result from such wastes”.

(ii) Paragraph 2(b) of Article 4, The Convention requires that each party must "ensure the availability of adequate disposal facilities for the environmentally sound management of hazardous or other wastes that shall be located to the extent possible, within it, whatever the place of their disposal". Additionally, paragraph 2 (c) requires each party must "ensure that persons involved in the management of hazardous wastes or other wastes within it take such steps as are necessary to prevent pollution due to hazardous wastes and other wastes arising from such management and, if such pollution occurs, to minimize the consequences thereof for human health and the environment.

(iii) According to Article 4 paragraph 8, “hazardous wastes or other wastes, to be exported, are managed in an environmentally sound manner in the State of import or elsewhere," At their first meeting, the Parties will decide on technical recommendations for the environmentally appropriate handling of wastes covered by this Convention. In the context of co-processing hazardous wastes in cement kilns, the current guidelines aim to provide a more accurate definition of ESM along with suitable treatment and disposal techniques for these waste streams.

Numerous key principles were articulated in the 1994 framework as technical guidelines for the environmentally sound management of wastes subject to the Basel Convention. Aiming to achieve ESM through prevention, minimization, recycling, recovery, and disposal of hazardous and other wastes subject to the Convention while taking into account social, technological, and economic concerns, as well as by further reducing trans-boundary movements of hazardous and other wastes subject to the Convention, the 1999 Basel Declaration on Environmentally Sound Management was adopted by the Conference of the Parties to the Basel Convention at its fifth meeting.

9.2.2 The “Blue Lady” Issue

The "Blue Lady" issue is one of the most notable examples of Basel convention. A ship called the "Blue Lady" carrying dangerous wastes has been sitting in a Gujrat port for more than a year as legal disputes about who should be responsible for its dismantling and eventual disposal have persisted. After considering the evidence in September 2007, the Indian Supreme Court established the following rules:

(i) The Supreme Court gave the government the authority to return any contaminated ships that arrive in India for breaking at Alang or any other ship-breaking yard in the country. The court has ordered that the government formulate a comprehensive code and immediately incorporate these recommendations until the laws are modified and aligned with the court orders.

(ii) The order leaves little space for the authorities to permit ship-breaking even if ship owners do not provide details of contaminants on board.

(iii) The court has reaffirmed that India should take part in relevant international conventions with the clear mandate for decontamination of ships for hazardous substances like asbestos, waste oil, and PCBS before being exported to India for destruction.

(iv) The court has requested that the National Institute of Occupational Health, the Atomic Energy Regulatory Board, the state pollution control boards, and the customs department supervise the entire arrangement at the shipyards until further orders are given.

However, it is impossible to eliminate waste entirely because some processes will predictably result in hazardous by-products; instead of this reducing waste is good economic and environmental sense.

9.2.3 How the Basel Convention works

First, the "Prior Informed Consent" process is used by the Basel Convention to govern the trans-boundary movements of hazardous and other wastes (shipments done without consent is unlawful). Since illegal trafficking of hazardous and other wastes is a crime, each party must enact the necessary domestic or national laws to stop and punish it.

Second, the Convention requires its Parties to have environmentally sound management and disposal practices for hazardous and other wastes. In order to do this, Parties are expected to reduce the amount of trash that is transported across borders, treat and dispose of waste as close to its source as feasible, and reduce waste generation at its source. From the time a hazardous waste is generated until it is stored, transported, treated, reused, recycled, recovered, and finally disposed of, strict controls must be implemented.

However, the Convention works enthusiastically with governments and private entities to minimize trade in waste, but the Basel Convention lacks effective measures for enforcement and for assigning liabilities. The Convention has also invested greatly in generating awareness on the problem.

Self-assessment 2

1. What was the primary reason for the adoption of the Basel Convention in 1989?

A. To promote international trade of waste

B. To control trans-boundary movement of hazardous waste

C. To encourage landfill, use in developed countries

D. To ban all industrial activity in developing nations

2. When did the Basel Convention come into force in India?

A. 1st January 1990

B. 24th June 1992

C. 22nd September 1992

D. 15th August 1995

3. Which Indian ministry is responsible for implementing the Basel Convention?

A. Ministry of Shipping

B. Ministry of Environment, Forest and Climate Change

C. Ministry of External Affairs

D. Ministry of Power

4. What was the "Blue Lady" issue related to?

A. A ship carrying hazardous waste meant for dismantling in India

B. Illegal dumping of plastic waste

C. A nuclear power plant leakage

D. Oil spill in Gujarat

5. Which of the following is not a provision under the Basel Convention's Environmentally Sound Management (ESM) guidelines?

A. Waste must be treated and disposed near its source

B. Waste should be stored permanently in exporting countries

C. Waste handlers must prevent and minimize pollution

D. Safe disposal methods must be used for all waste

Answer key: 1.B; 2.C; 3.B; 4.A; 5.B

9.3 Hazardous Wastes Management plan in India

India is converting into the industrial and services-oriented country instead of an agricultural-based. The population of urban area is increasing day by day due to shifting of rural area population to urban area. According to the 2011 census, 7,935 towns and cities are home to 377 million people. 43 cities have a population of one million or more, 415 have a population of 100,000 or more, and the three megacities-Greater Mumbai, Delhi, and Kolkata have a population of over ten million. Large amounts of municipal solid trash are produced mostly by densely populated cities with numerous industrial operations. According to the Comptroller and Auditor General's (CAG) study, over 48 million tons of trash were generated by India's cities in 2009. Additionally, the Department of Economic Affairs (DEA) calculated that around 58 million tons of garbage were produced annually during that same year. The Central Pollution Control Board (CPCB) then announced in 2012 that around 47 million tons of trash were generated in urban India between 2011 and 2012. In 2014, there is the production of 62 million tons of municipal solid garbage, according to the Planning Commission Committee's 2014 report. A recent CPCB estimate states that 52 million tons of trash were created annually in India in 2016.

The government's emphasis on cleanliness and sanitation has led to a notable expansion in India's solid waste management industry in recent years. The demand for effective and sustainable waste management techniques stems from the significant rise in trash generated as a result of population growth and fast urbanization. The industry has benefited from the government's Swachh Bharat Abhiyan (Clean India Mission), which has increased demand for waste management solutions. During the forecast period (2021–2026), the solid waste management market in India is anticipated to expand at a compound annual growth rate (CAGR) of 7.5% due to factors including expanding urbanization, increased waste management awareness, and rising expenditures in waste management infrastructure.

India is one of the top 10 countries in the world for the generation of municipal solid waste (MSW) because of its fast urbanization, economic expansion, and higher rates of urban consumption. The Energy and Resources Institute (TERI) said that India produces more than 62 million tons (MT) of trash annually. Of the whole amount of garbage produced, only 43 MT are collected; 12 MT are processed before being disposed of, and the remaining 31 MT are just dumped in waste yards. The majority of the garbage produced is left unprocessed and even unrecorded. The nation's environmental and public health issues are mostly caused by inadequate trash collection, transportation, treatment, and disposal.

According to a recent prediction by the Central Pollution Control Board (CPCB), India's yearly trash production is expected to reach 165 MT by 2030. The amount of hazardous, plastic, e-waste, and biomedical waste produced is also anticipated to rise accordingly. Projects like the Swachh Bharat initiative in 2014 and the creation of 100 smart cities nationwide in 2015 were started by the Indian government ten years ago in cooperation with state governments and union territories (UTs). The Ministry of Environment, Forests, and Climate Change also modified India's SWM regulations in 2016 with the three fundamental circular economy tenets- reduce, reuse, and recycle-in mind. Every ULB in India is encouraged to create integrated waste management systems, wet and dry segregation, source-specific collection, home composting/bio-methanation, and material and energy recovery from waste as a result of these programs and the CPCB's rigorous implementation of the new SWM regulations.

9.3.1 Waste Management and Policies

According to the 2013 CPCB data, no Indian city can claim 100% garbage segregation. Only 70% of waste is typically collected in cities, with the remaining 30% being lost to the urban environment. Additionally, only 12.45% of the waste that is collected is handled scientifically; the remainder is dumped in open spaces. The following describes the current state of waste management practices in India.

S. No	Waste Management Practices	Status
1.	Segregation	Currently, neither household-level nor community-level MSW segregation is systematic or scientifically planned. Waste sorting is primarily carried out by the unorganized sector.
2.	Collection	Household waste is often disposed of in common bins that are constructed of concrete, metal, or a combination of the two. Waste was collected from these containers by a street sweeper.
3.	Recycle and reuse	Unsegregated waste cannot be recycled to its full potential because it is disposed of in community bins. The only people that sorted, collected, and sold recyclable materials like glass, plastics, etc. were rag-pickers.
4.	Transportation	Hand rickshaws, compactors, vehicles, tractors, trailers and dumpers are the main modes of transportation. Trucks with a 5–9 tons capacity are utilized in smaller communities without proper cover systems.

9.3.2 Waste Disposal System in India

Open dumping, land filling, landfill gas-to-energy facilities, and biological treatment of organic waste (composting) are the current waste disposal methods used in India. The table provides the current state of these systems.

S. No.	Waste Disposal Practices	Status
1.	Open dumping	MSW produced in India is typically dumped in low-lying areas without any scientific consideration.
2.	Landfilling	There is a shortage of land for disposing of waste in major cities like Delhi, Mumbai, Kolkata, and Chennai, and the approved landfill sites are overflowing.
3.	Landfill gas-to-energy plants	An estimated 16 million metric CO_2 equivalents of methane are released annually from landfills in India (International Energy Agency, 2008).
4.	Composting	A MSW composting center installed at Indore City (Madhya Pradesh) is one of the best maintained facilities. In Bengaluru, Vadodara, Mumbai, Delhi, and Kanpur, mechanical composting units of 150 to 300 tons/day capacities were also installed. Maharashtra and Gujarat are the top states in the composting of the trash.

9.3.3 Biomedical Waste Management in India

The majority of healthcare facilities disregard the rules. Due to carelessness or poor sorting, biomedical waste is frequently disposed of in landfills or the ocean, where it finally washes up on shore. Therefore, in order to regulate the management of biomedical waste, the Biomedical Waste (Management and Handling) Rules, 1998, together with other revisions, were passed. The Central Government announced the Biomedical Waste Management Rules 2016 on March 28, 2016. The new legislation will be implemented by the Pollution Control Board or Pollution Control Committee of each state. The following color coding is advised by the most recent guidelines for the segregation of biomedical waste.

Red Bag: Needles-free syringes, soiled gloves, IV tubing, catheters, and other items should all be disposed of in a red bag that will be burned after use.

Yellow Bag: Yellow bags should be used to dispose of any bandages, dressings, cotton swabs containing bodily fluids, blood bags, human anatomical waste, and body parts.

Blue-marked cardboard box: Glass vials, ampules, and other glassware should be disposed of in a cardboard box that has a blue sticker or marking on it.

White Puncture Proof Container (PPC): Needles, knives, and sharp objects are disposed away in a white, translucent puncture-proof container (PPC).

Black Bags: Non-biomedical garbage should go in these. Stationery, vegetable and fruit peels, leftovers, packaging, including medication packaging, disposable caps, disposable masks, disposable shoe covers, disposable tea cups, cartons, dust sweeping, kitchen waste, etc. are all examples of this in a hospital setting.

9.3.4 Policies for hazardous waste management

The Environment (Protection) Act of 1986 established the Hazardous Wastes (Management and Handling) Rules, 1989, often known as the HWM Rules 1989. The 1989 HWM Rules regulate the production, gathering, processing, transportation, importation, storage, and disposal of wastes specified in the schedule that is appended to these regulations. In the states and union territories, the SPCBs and pollution control committees carry out the regulations. The Basel Convention, 1989, on the Control of Trans-boundary Movement of Hazardous Wastes and Their Disposal, is another agreement that India has ratified.

Since the HWM Rules, 1989 had certain inherent restrictions, they were amended in 2000 and 2002 to broaden the definition of hazardous waste and bring the list of hazardous wastes into compliance with the Basel Convention. In addition to these regulations, the MoEF published Guidelines for Management and Handling of Hazardous Wastes in 1991 for (a) waste producers, (b) hazardous waste transportation, and (c) owners/operators of facilities for the storage, treatment, and disposal of hazardous waste. Along with establishing processes for landfill closure and post-closure criteria for the first time, these guidelines also provided mechanisms for the creation of a manifest system, a reporting system for the transfer of hazardous waste.

These were followed in 1995 by the release of Guidelines for Safe Road Transport of Hazardous Chemicals, which set down fundamental regulations for the transportation of hazardous materials, as well as requirements for the identification and assessment of hazards and the creation of a transport emergency plan. The government has taken steps to pass legislation and provide extra incentives for industries to adhere to environmental regulations and bring market forces into the environmental industry, in addition to these direct regulations addressing hazardous waste management. In keeping with this, the Public Liability Act of 1991 was passed, requiring enterprises that deal with dangers to provide insurance against mishaps or losses brought on by the discharge of pollutants. Parties harmed by the National Environmental Tribunal Act of 1995 are entitled to prompt redress.

9.3.5 Initiatives taken for hazardous waste management

The need for scientific waste disposal and policies that promote waste reduction and the use of cleaner technologies are highlighted by emerging policy directions in the field of hazardous waste management. The following is a list of the various initiatives the Indian government has launched to achieve these goals: Based on the EIA of the possible locations, state governments are currently in the process of identifying disposal sites for hazardous waste. In 1998, the CPCB created technical details about the origins of hazardous wastes, their properties, and recycling and disposal techniques. To familiarize employees with the testing procedures and preventive measures for hazardous waste elements, training programs have been arranged for concerned port, customs, and pollution control board workers.

Based on the recommendations of a national expert committee that was established to provide advice on hazardous waste-related issues, it has been decided to prohibit the import of hazardous wastes that contain beryllium, selenium, chromium (hexavalent), thallium, pesticides, herbicides, and their intermediates or residues. The export and import of cyanide wastes and wastes containing mercury and arsenic has been prohibited since December 1996 in order to regulate the flow of Basel Wastes.

The MoEF will regulate the import of waste oil and metal-bearing wastes, such as zinc ash, skimming's, brass dross, and lead acid batteries, for processing to recover resources. Only ecologically acceptable technologies will be permitted. Alongside these efforts, the nation has started a number of projects to control the handling, disposal, and storage of hazardous waste.

Summary

In recent decades, hazardous waste management has become a pressing environmental issue, driven by population growth, industrialization, and urbanization. Hazardous waste, unlike non-hazardous waste, poses serious risks to human health and the environment, requiring careful handling during storage, transport, treatment, and disposal. Improper practices, such as incineration or dumping in water bodies, lead to pollution and health hazards like respiratory problems, cancer, and genetic disorders.

Hazardous waste management involves several steps: waste generation, storage, collection, transport, processing, and final disposal. Waste is produced by industries, healthcare facilities, and even households. Proper identification, onsite inventory, and safe containment are critical to minimize risk. Processing may include thermal, chemical, biological, or physical methods, while disposal often involves secure landfills, deep wells, or bedrock disposal.

Internationally, the Basel Convention (1989) governs the trans-boundary movement of hazardous waste. Ratified by 188 countries, including India in 1992, it enforces environmentally sound management (ESM) and prohibits illegal waste trade. India implements these rules under the Hazardous and Other Wastes (Management and Trans-boundary Movement) Rules, 2016**.** Key principles include waste minimization, consent-based transport, and ensuring safe disposal.

India's growing urbanization and industrialization have resulted in rapidly increasing municipal solid waste (MSW) and hazardous waste. Despite programs like Swachh Bharat Abhiyan and the Smart Cities Mission, challenges remain in waste segregation, collection, and treatment. Biomedical waste is a specific concern, addressed by the Biomedical Waste Management Rules, 2016, with color-coded disposal methods to ensure safe handling.

The Hazardous Waste Management Rules (1989, amended in 2000, 2002, and 2016) regulate waste lifecycle management. The government has introduced several initiatives such as import bans on specific hazardous substances, training for enforcement agencies, and identification of secure disposal sites. Policies are increasingly aligned with circular economy principles-reduce, reuse, and recycle-to create a cleaner and safer environment.

Terminal questions

Short answer type questions

1. Why is incineration of hazardous waste harmful to the environment?
2. What types of containers are typically used to store flammable hazardous waste?
3. Define the "Blue Lady" Issue?
4. Name one method used for the final disposal of hazardous waste.

Long answer type questions

1. Discuss the steps involved in the proper disposal of hazardous waste, from generation to final disposal?
2. What is basal convention, explain in details?

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Unit 10: Hazardous Wastes Management Strategy

Unit Structure

10.0 Objectives

After reading this unit students should be able to:

- Identify and classify hazardous wastes;
- Explain the techniques of hazardous waste management, treatment and minimization;
- Describe the physical, chemical, thermal and biological methods of treating hazardous waste;
- Understand the waste minimization and pollution prevention techniques.

10.1 Introduction

In the previous units we have discussed about the general introduction to hazardous wastes, its types, sources, composition, characteristics, and classification: ISIC system, hazardous wastes and environment, hazardous wastes sampling and transportation. In view of the substantial threat – present and potential – hazardous wastes pose to human health, or living organisms in general, they ought to be handled, treated and managed differently, and this issue is discussed in the present unit. In this unit, we will first identify and classify hazardous wastes, and then discuss their functional elements namely generation, storage and collection, transfer and transport, processing and disposal. Subsequently, we will discuss the various physical, chemical, thermal and biological treatments to reduce the impact of hazardous wastes on public health and the environment. The current unit will also explain some of the techniques for hazardous waste minimization and pollution prevention and touching upon the prevailing hazardous waste management practices in India.

10.2 Hazardous Waste: Identification and Classification

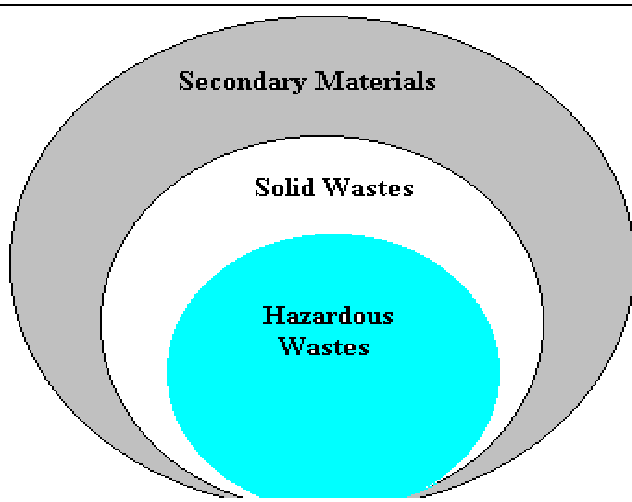

Figure 10.1 Secondary Materials, Solid and Hazardous Wastes: Relationship

Hazardous wastes refer to wastes that may, or tend to, or cause adverse health effects on the ecosystem and human beings. These wastes pose present or potential risks to human health or living organisms, due to the fact that they: are non-degradable or persistent in nature; can be biologically magnified; Are highly toxic and even lethal at very low concentrations.

The above list relates only to the intrinsic hazard of the waste, under uncontrolled release, to the environment, regardless of quantity or pathways to humans or other critical organisms (i.e., plants and animals). The criteria used to determine the nature of hazard include toxicity, phytotoxicity, genetic activity and bio- concentration. The threat to public health and the environment of a given hazardous waste is dependent on the quantity and characteristics of the waste involved. Wastes are secondary materials, which are generally classified into six categories as inherently waste: like materials, spent materials, sludges, by- products, commercial chemical products and scrap metals. Solid wastes form a subset of all secondary materials and hazardous wastes form a subset of solid waste. However, note that certain secondary materials are not regulated as wastes, as they are recycled and reused. Figure 10.1 illustrates the relationship among secondary materials, solid wastes and hazardous wastes (http://www.dep.state.pa.us/dep/deputate/airwaste/):Note that for a material to be classified as a hazardous waste, it must also meet the criteria specified in the regulatory definition of solid waste.

10.2.1 Identification

By using either or both of the following criteria, we can identify as to whether or not a waste is hazardous:

(i) The list provided by government agencies declaring that substance as hazardous.

(ii) Characteristics such as ignitibility, corrosively, reactivity and toxicity of the substance.

Let us now explain these two criteria.

A specific list showing certain materials as hazardous wastes minimizes the need to test wastes as well as simplifies waste determination. In other words, any waste that fits the definition of a listed waste is considered a hazardous waste. Four separate lists cover wastes from generic industrial processes, specific industrial sectors, unused pure chemical products and formulations that are either acutely toxic or toxic, and all hazardous waste regulations apply to these lists of wastes. We will describe these wastes, classified in the F, K, P, and U industrial waste codes, respectively, below

(http://www2.kumc.edu/safety/kdhehw/hwg1_10.html#SectionIV):

- **F-list:** The F-list contains hazardous wastes from non-specific sources, that is, various industrial processes that may have generated the waste. The list consists of solvents commonly used in degreasing, metal treatment baths and sludges, wastewaters from metal plating operations and dioxin containing chemicals or their precursors. Examples of solvents that are F-listed hazardous wastes, along with their code numbers, include benzene (F005), carbon tetrachloride (F001), cresylic acid (F004), methyl ethyl ketone (F005), methylene chloride (F001), 1,1,1, trichloroethane (F001), toluene (F005) and trichloroethylene (F001). Solvent mixtures or blends, which contain greater than 10% of one or more of the solvents listed in F001, F002, F003, F004 and F005 are also considered F-listed wastes.

- **K-list:** The K-list contains hazardous wastes generated by specific industrial processes. Examples of industries, which generate K-listed wastes include wood preservation, pigment production, chemical production, petroleum refining, iron and steel production, explosive manufacturing and pesticide production.
- **P and U lists:** The P and U lists contain discarded commercial chemical products, off-specification chemicals, container residues and residues from the spillage of materials. These two lists include commercial pure grades of the chemical, any technical grades of the chemical that are produced or marketed, and all formulations in which the chemical is the sole active ingredient. An example of a P or U listed hazardous waste is a pesticide, which is not used during its shelf-life and requires to be disposed in bulk. The primary distinction between the two lists is the quantity at which the chemical is regulated. The P-list consists of acutely toxic wastes that are regulated when the quantity generated per month, or accumulated at any time, exceeds one kilogram (2.2 pounds), while U-listed hazardous wastes are regulated when the quantity generated per month exceeds 25 kilograms (55 pounds). Examples of businesses that typically generate P or U listed wastes include pesticide applicators, laboratories and chemical formulators.

10.2.2 Characteristics of Hazardous Wastes

The regulations define characteristic hazardous wastes as wastes that exhibit measurable properties posing sufficient threats to warrant regulation. For a waste to be deemed a characteristic hazardous waste, it must cause, or significantly contribute to, an increased mortality or an increase in serious irreversible or incapacitating reversible illness, or pose a substantial hazard or threat of a hazard to human health or the environment, when it is improperly treated, stored, transported, disposed of, or otherwise mismanaged.

In other words, if the wastes generated at a facility are not listed in the F, K, P, or U lists, the final step to determine whether a waste is hazardous is to evaluate it against the following 4 hazardous characteristics:

(i) Ignitability (EPA Waste Identification Number D001): A waste is an ignitable hazardous waste, if it has a flash point of less than 60 C; readily catches fire and burns so vigorously as to create a hazard; or is an ignitable compressed gas or an oxidizer. A simple method of determining the flash point of a waste is to review the material safety data sheet, which can be obtained from the manufacturer or distributor of the material. Naphtha, lacquer thinner, epoxy resins, adhesives and oil-based paints are all examples of ignitable hazardous wastes.

(ii) Corrosively (EPA Waste Identification Number D002): A liquid waste which has a pH of less than or equal to 2 or greater than or equal to 12.5 is considered to be a corrosive hazardous waste. Sodium hydroxide, a caustic solution with a high pH, is often used by many industries to clean or degrease metal parts. Hydrochloric acid, a solution with a low pH, is used by many industries to clean metal parts prior to painting. When these caustic or acid solutions are disposed of, the waste is a corrosive hazardous waste.

(iii) Reactivity (EPA Waste Identification Number D003): A material is considered a reactive hazardous waste, if it is unstable, reacts violently with water, generates toxic gases when exposed to water or corrosive materials, or if it is capable of detonation or explosion when exposed to heat or a flame. Examples of reactive wastes would be waste gunpowder, sodium metal or wastes containing cyanides or sulphide.

(iv) Toxicity (EPA Waste Identification Number D004): To determine if a waste is a toxic hazardous waste, a representative sample of the material must be subjected to a test conducted in a certified laboratory. The toxic characteristic identifies wastes that are likely to leach dangerous concentrations of toxic chemicals into ground water.

10.2.3 Classification

There are far too many compounds, products and product combinations that fit within the broad definition of hazardous waste. For this reason, groups of waste are considered in the following five general categories:

(i) Radioactive substance: Substances that emit ionizing radiation are radioactive. Such substances are hazardous because prolonged exposure to radiation often results in damage to living organisms. Radioactive substances are of special concern because they persist for a long period. The period in which radiation occurs is commonly measured and expressed as half-life, i.e., the time required for the radioactivity of a given amount of the substance to decay to half its initial value. For example, uranium compounds have half-lives that range from 72 years for U232 to 23,420,000 years for U236. The management of radioactive wastes is highly controlled by national and state regulatory agencies. Disposal sites that are used for the long-term storage of radioactive wastes are not used for the disposal of any other solid waste.

(ii) Chemicals: Most hazardous chemical wastes can be classified into four groups: synthetic organics, inorganic metals, salts, acids and bases, and flammables and explosives. Some of the chemicals are hazardous because they are highly toxic to most life forms. When such hazardous compounds are present in a waste stream at levels equal to, or greater than, their threshold levels, the entire waste stream is identified as hazardous.

(iii) Biomedical wastes: The principal sources of hazardous biological wastes are hospitals and biological research facilities. The ability to infect other living organisms and the ability to produce toxins are the most significant characteristics of hazardous biological wastes. This group mainly includes malignant tissues discarded during surgical procedures and contaminated materials, such as hypodermic needles, bandages and outdated drugs. This waste can also be generated as a by-product of industrial biological conversion processes.

(iv) Flammable wastes: Most flammable wastes are also identified as hazardous chemical wastes. This dual grouping is necessary because of the high potential hazard in storing, collecting and disposing of flammable wastes. These wastes may be liquid, gaseous or solid, but most often they are liquids. Typical examples include organic solvents, oils, plasticizers and organic sludges.

(v) Explosives: Explosive hazardous wastes are mainly ordnance (artillery) materials, i.e., the wastes resulting from ordnance manufacturing and some industrial gases. Similar to flammables, these wastes also have a high potential for hazard in storage, collection and disposal, and therefore, they should be considered separately in addition to being listed as hazardous chemicals. These wastes may exist in solid, liquid or gaseous form.

(vi) Household hazardous wastes: Household wastes such as cleaning chemicals, batteries, nail polish etc., in MSW constitute hazardous waste. Especially batteries contain mercury which are alkaline which is dangerous enough to kill people. Generic household hazardous material includes non-chlorinated organic, chlorinated organic, pesticides, latex paint, oil-based paints, waste oil, automobile battery and household battery.

10.3 Hazardous Waste Management

10.3.1 Hazardous Waste Generation

Hazardous wastes are generated in limited amounts in a community and very little information is available on the quantities of hazardous waste generated within a community and in various industries. Hazardous waste generation outside the industry is irregular and very less in amount, rendering the waste generation parameter meaningless. The only practical means to overcome these limitations is to conduct a detailed inventory and measurement studies at each potential source in a community. As a first step in developing a community inventory, potential sources of hazardous waste are to be identified. The total annual quantity of hazardous waste at any given source in a community must be established through data inventory completed during onsite visits.

Table 10.1 Common Hazardous Wastes: Community Source (Tchobanoglous, et al., (1977 and 1993)

Waste Category	Sources
Radioactive substances	Biomedical research facilities, colleges and university laboratories, offices, hospitals, nuclear power plants, etc.

Toxic chemicals	Agricultural chemical companies, battery shops, car washes, chemical shops, college and university laboratories, construction companies, electric utilities, hospitals and clinics, industrial cooling towers, newspaper and photographic solutions, nuclear power plants, pest control agencies, photographic processing facilities, plating shops, service stations, etc.
Biological wastes	Biomedical research facilities, drug companies, hospitals, medical clinics, etc.
Flammable wastes	Dry cleaners, petroleum reclamation plants, petroleum refining and processing facilities, service stations, tanker truck cleaning stations, etc.
Explosives	Construction companies, dry cleaners, ammunition production facilities, etc.

In addition to the sources listed, the spillage of containerized hazardous waste must also be considered an important source. The quantities of hazardous wastes that are involved in spillage are usually not known. The effects of spillage are often spectacular and visible to the community. Because the occurrence of spillage cannot be predicted, the potential threat to human health and environment is greater than that from routinely generated hazardous wastes.

10.3.2 Storage and Collection

Onsite storage practices are a function of the types and amounts of hazardous wastes generated and the period over which generation occurs. Usually, when large quantities are generated, special facilities are used that have sufficient capacity to hold wastes accumulated over a period of several days. When only a small amount is generated, the waste can be containerized, and limited quantity may be stored. Containers and facilities used in hazardous waste storage and handling are selected on the basis of waste characteristics. For example, corrosive acids or caustic solutions are stored in fiberglass or glass-lined containers to prevent deterioration of metals in the container. Great care must also be exercised to avoid storing incompatible wastes in the same container or locations. Figures 10.2 and 10.3 show typical drum containers used for the storage of hazardous waste:

The waste generator, or a specialized hauler, generally collects the hazardous waste for delivery to a treatment or disposal site. The loading of collection vehicles is completed in either of the following ways:

(i) Wastes stored in large-capacity tanks are either drained or pumped into collection vehicles;

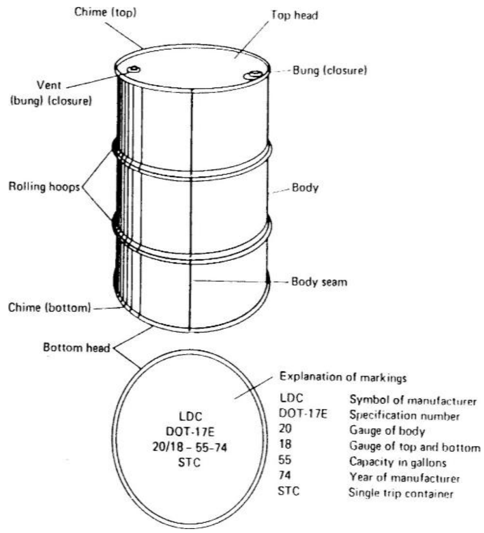

Figure 10.2 Light-Gauge Closed Head Drum

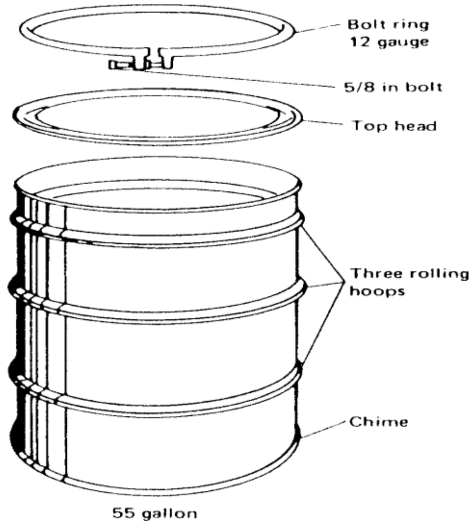

Figure 10.3 Light-Gauge Open Head Drum

(ii) Wastes stored in sealed drums or sealed containers are loaded by hand or by mechanical equipment onto flatbed trucks.

(iii) The stored containers are transported unopened to the treatment and disposal facility. To avoid accidents and the possible loss of life, two collectors should be assigned when hazardous wastes are to be collected. The equipment used for collection vary with the waste characteristics, and the typical collection equipment are listed in Table 10.2 below

Table 10.2: Equipment for Collection of Hazardous Waste (Source: Tchobanoglous, et al., (1977 and 1993)

Waste Category	Collection equipment and accessories
Radioactive substances	Various types of trucks and railroad equipment depending on characteristics of wastes; special marking to show safety hazard; heavy loading equipment to handle concrete-encased lead containers.
Toxic chemicals	Flatbed trucks for wastes stored in drums; tractor-trailer tank truck combination for large volumes of wastes; railroad tank cars; special interior linings such as glass, fiberglass or rubber.
Biological wastes	Standard packers' collection truck with some special precautions to prevent contact between wastes and the collector; flatbed trucks for wastes stored in drums.
Flammable wastes	Same as those for toxic chemicals, with special colorings and safety warning printed on vehicles.
Explosives	Same as those for toxic chemicals with some restriction on transport routes, especially through residential areas.

10.3.3 Transfer and Transport

The economic benefits derived by transferring smaller vehicle loads to larger vehicles, as discussed earlier for non-hazardous solid waste are equally applicable to hazardous wastes. However, the facilities of a hazardous waste transfer station are quite different from solid waste transfer station. Typically, hazardous wastes are not compacted (i.e., mechanical volume reduction) or delivered by numerous community residents. Instead, liquid hazardous wastes are generally pumped from collection vehicles and sludge or solids are reloaded without removal from the collection containers for transport to processing and disposal facilities.

It is unusual to find a hazardous waste transfer facility, where wastes are simply transferred to larger transport vehicles. Some processing and storage facilities are often part of the material handling sequence at a transfer station. For example, neutralization of corrosive wastes might result in the use of a lower-cost holding tank on transport vehicles. As in the case of storage great care must be exercised to avoid the danger of mixing incompatible wastes.

10.3.4 Processing

Processing of hazardous waste is done for purposes of recovering useful materials and preparing the wastes for disposal. Processing can be accomplished on-site or off-site. The variables affecting the selection of processing site include the characteristics of wastes, the quantity of wastes, the technical, economic and environmental aspects of available on-site treatment processes and the availability of the nearest off-site treatment facility (e.g., haul distance, fees, and exclusions). The treatment of hazardous waste can be accomplished by physical, chemical, thermal or biological means. Table 10.3 below gives the various individual processes in each category:

Note that in practice, the physical, chemical and thermal treatment operations are the most commonly used. (Biological treatment processes are used less often because of their sensitivity.) Depending on the type of wastes being treated, one or more of these methods may be used.

Table 10.3 Hazardous Waste Treatment Operations and Processes (Source: Tchobanoglous, et al., (1977, 1993)

Operation/Processes	Functions performed$	Types of wastes*	Forms of waste#
Physical Treatment			
Aeration	Se	1, 2, 3, 4	L
Ammonia stripping	VR, Se	1, 2, 3, 4	L
Carbon sorption	VR, Se	1, 3, 4, 5	L,G
Centrifugation	VR, Se	1, 2, 3, 4, 5	L
Dialysis	VR, Se	1, 2, 3, 4	L
Distillation	VR, Se	1, 2, 3, 4, 5	L
Electro dialysis	VR, Se	1, 2, 3, 4, 6	L
Encapsulation	St	1, 2, 3, 4, 6	L,S
Evaporation	VR, Se	1, 2, 5	L
Filtration	VR, Se	1, 2, 3, 4, 5	L,G
Flocculation/Settling	VR, Se	1, 2, 3, 4, 5	L
Flotation	Se	1, 2, 3, 4	L
Reverse osmosis	VR, Se	1, 2, 4, 6	L
Sedimentation	VR, Se	1, 2, 3, 4, 5	L
Thickening	Se	1, 2, 3, 4	L
Vapour scrubbing	VR, Se	1, 2, 3, 4	L
Chemical Treatment			
Calcination	VR	1, 2, 5	L
Ion exchange	VR, Se, De	1, 2, 3, 4, 5	L
Neutralisation	De	1, 2, 3, 4	L
Oxidation	De	1, 2, 3, 4	L
Precipitation	VR, Se	1, 2, 3, 4, 5	L
Reduction	De	1, 2	L
Solvent extraction	Se	1, 2, 3, 4, 5	L
Sorption	De	1, 2, 3, 4	L
Thermal treatment			
Incineration	VR, De	3, 5, 6, 7, 8	S, L, G
Pyrolysis	VR, De	3, 4, 6	S, L, G
Biological Treatment			
Activated sludges	De	3	L
Aerated lagoons	De	3	L
Anaerobic digestion	De	3	L
Anaerobic filters	De	3	L
Trickling filters	De	3	L
Waste stabilisation pond	De	3	L

*$ Functions: VR= volume reduction; Se = separation; De = detoxification; St = storage; * Waste types: 1= inorganic chemical without heavy metals; 2 = inorganic chemical with heavy metal; 3 = organic chemical without heavy metal; 4 = organic chemical with heavy metal; 5= radiological; 6 = biological; 7= flammable and 8= explosive; # Waste forms: S=solid; L= liquid and G= gas*

10.3.5 Disposal

Regardless of their form (i.e., solid, liquid, or gas), most hazardous waste is disposed-off either near the surface or by deep burial. Table 10.4 shows the various hazardous waste disposal methods:

Although, controlled landfill methods have been proved adequate for disposing of municipal solid waste and limited amounts of hazardous waste, they are not suitable enough for the disposal of a large quantity of hazardous waste, due to the following reasons:

- possible percolation of toxic liquid waste to the ground water;

Table 10.4 Hazardous Wastes Disposal and Storage Methods Source: Tchobanoglous, et al., (1977 and 1993)

Operation/Process	Functions performed$	Types of wastes*	Forms of waste#
Deep well injection	Di	1, 2, 3, 4,5,6,7	L
Detonation	Di	6, 8	S, L, G
Engineered storage	St	1, 2, 3, 4, 5,6,7,8	S, L, G
Land burial	Di	1, 2, 3, 4, 5,6,7,8	S, L
Ocean dumping	Di	1, 2, 3, 4, 7, 8	S, L, G

*$ Functions: Di= disposal; St = storage; * Waste types: 1= inorganic chemical without heavy metals; 2 = inorganic chemical with heavy metal; 3 = organic chemical without heavy metal; 4 = organic chemical with heavy metal; 5= radiological; 6 = biological; 7= flammable and 8= explosive. # Waste form: S=solid; L= liquid and G= gas*

- dissolution of solids followed by leaching and percolation to the ground water;
- dissolution of solid hazardous wastes by acid leachate from solid waste,
- followed by leaching and percolation to the ground water;
- potential for undesirable reactions in the landfill that may lead to the development of explosive or toxic gases;
- volatilization of hazardous waste leading to the release of toxic or explosive vapors to the atmosphere;
- corrosion of containers with hazardous wastes.

We must, therefore, take care both in the selection of a hazardous waste disposal site and its design. In general, disposal sites for hazardous wastes should be separate from those for municipal solid wastes. As hazardous wastes can exist in the form of liquids, sludges, solids and dusts, a correct approach for co-disposal for each of the hazardous wastes should be determined. To avoid the co-disposal of incompatible wastes, separate storage areas within the total landfill site should be designated for various classes of compatible wastes (Phelps, et al., 1995).

Liquid wastes are usually stored in a tank near the site and can be introduced into the landfill by means of trenches or lagoons, injection or irrigation. Sludges are also placed in trenches. During disposal of lightweight wastes, the disposal area must be kept wet to prevent dust emissions. Hazardous solid waste characterized by a high degree of impermeability as such must not be disposed of over large areas. When containerized wastes are to be disposed of, precautions must be taken to avoid the rupturing of containers during the unloading operation and the placement of incompatible waste in the same location. To avoid rupturing, the containers are unloaded and placed in position individually. The covering of the containers with earth should be monitored and controlled carefully to ensure that a soil layer exists between each container and the equipment placing the soil does not crush or deform the container.

While designing a landfill site for hazardous waste, provision should be made to prevent any leachate escaping from landfill site. This requires a clay liner, and in some cases, both clay and impermeable membrane liners are used. A layer of limestone is placed at the bottom of the landfill to neutralize the pH of leachate. A final soil cover of 25 cm or more should be placed over the liner. The completed site should be monitored continuously, both visually and with sample wells.

10.3.6 Hazardous waste options

A three-stage hierarchy of options for handling hazardous wastes are:

1) The top tier includes in plant options such as process manipulation, recycle and reuse options that reduce the production of hazardous waste in the first place. It also contains most desirable options.
2) Middle stage highlights processes that convert hazardous waste to less hazardous or non-hazardous substances that include
    a) Incineration
    b) Land treatment
    c) Ocean and atmospheric assimilation
    d) Chemical, physical and biological treatments
    e) Thermal treatments
3) Last stage which is least preferred or desirable tier that is perpetual storage cheapest alternative. Few processes include landfill, underground injection, arid region unsaturated zone, surface impoundments, salt formations and waste piles.

10.4 Hazardous Waste Treatment

In Section 10.2, we discussed the various elements of hazardous waste management such as generation, storage and transport, transfer and transport, processing and disposal. Processing is mainly done to recover useful products and to prepare waste for disposal. But prior to disposal, hazardous wastes need appropriate treatment, depending on the type of waste. The various options for hazardous waste treatment can be categorized under physical, chemical, thermal and biological treatments. We will discuss these options, in Subsections 10.3.1 to 10.3.3.

10.4.1 Physical and chemical treatment

Physical and chemical treatments are an essential part of most hazardous waste treatment operations, and the treatments include the following (Freeman, 1988):

- **Filtration and separation:** Filtration is a method for separating solid particles from a liquid using a porous medium. The driving force in filtration is a pressure gradient, caused by gravity, centrifugal force, vacuum, or pressure greater than atmospheric pressure. The application of filtration for treatment of hazardous waste fall into the following categories:
- **Clarification,** in which suspended solid particles less than 100 ppm (parts per million) concentration are removed from an aqueous stream. This is usually accomplished by depth filtration and cross-flow filtration and the primary aim is to produce a clear aqueous effluent, which can either be discharged directly, or further processed. The suspended solids are concentrated in a reject stream.
- **Dewatering** of slurries of typically 1% to 30 % solids by weight. Here, the aim is to concentrate the solids into a phase or solid form for disposal or further treatment. This is usually accomplished by cake filtration. The filtration treatment, for example, can be used for neutralization of strong acid with lime or limestone, or precipitation of dissolved heavy metals as carbonates or sulphide followed by settling and thickening of the resulting precipitated solids as slurry. The slurry can be dewatered by cake filtration and the effluent from the settling step can be filtered by depth filtration prior to discharge.

- **Chemical precipitation:** This is a process by which the soluble substance is converted to an insoluble form either by a chemical reaction or by change in the composition of the solvent to diminish the solubility of the substance in it. Settling and/or filtration can then remove the precipitated solids. In the treatment of hazardous waste, the process has a wide applicability in the removal of toxic metal from aqueous wastes by converting them to an insoluble form. This includes wastes containing arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium and zinc. The sources of wastes containing metals are metal plating and polishing, inorganic pigment, mining and the electronic industries. Hazardous wastes containing metals are also generated from cleanup of uncontrolled hazardous waste sites, e.g., leachate or contaminated ground water.
- **Chemical oxidation and reduction (redox):** In these reactions, the oxidation state of one reactant is raised, while that of the other reactant is lowered. When electrons are removed from an ion, atom, or molecule, the substance is oxidized and when electrons are added to a substance, it is reduced. Such reactions are used in treatment of metal-bearing wastes, sulphide, cyanides and chromium and in the treatment of many organic wastes such as phenols, pesticides and sulphur containing compounds. Since these treatment processes involve chemical reactions, both reactants are generally in solution. However, in some cases, a solution reacts with a slightly soluble solid or gas. There are many chemicals, which are oxidizing agents; but relatively few of them are used for waste treatment. Some of the commonly used oxidizing agents are sodium hypochlorite, hydrogen peroxide, calcium hypochlorite, potassium permanganate and ozone. Reducing agents are used to treat wastes containing hexavalent chromium, mercury, organometallic compounds and chelated metals. Some of the compounds used as reducing agents are sulphur dioxide, sodium borohydride, etc. In general, chemical treatment costs are highly influenced by the chemical cost. This oxidation and reduction treatment tends to be more suitable for low concentration (i.e., less than 1%) in wastes.
- **Solidification and stabilization:** In hazardous waste management, solidification and stabilization (S/S) is a term normally used to designate a technology employing activities to reduce the mobility of pollutants, thereby making the waste acceptable under current land disposal requirements. Solidification and stabilization are treatment processes

designed to improve waste handling and physical characteristics, decrease surface area across which pollutants can transfer or leach, limit the solubility or detoxify the hazardous constituent. To understand this technology, it is important for us to understand the following terms:

- **Solidification:** This refers to a process in which materials are added to the waste to produce a solid. It may or may not involve a chemical bonding between the toxic contaminant and the additive.
- **Stabilization:** This refers to a process by which a waste is converted to a more chemically stable form. Subsuming solidification, stabilization represents the use of a chemical reaction to transform the toxic component to a new, non-toxic compound or substance.
- **Chemical fixation:** This implies the transformation of toxic contaminants to a new non-toxic compound. The term has been misused to describe processes, which do not involve chemical bonding of the contaminant to the binder.
- **Encapsulation:** This is a process involving the complete coating or enclosure of a toxic particle or waste agglomerate with a new substance (e.g., S/S additive or binder). The encapsulation of the individual particles is known as micro-encapsulation, while that of an agglomeration of waste particles or micro-encapsulated materials is known as macro-encapsulation.
- In S/S method, some wastes can be mixed with filling and binding agents to obtain a dischargeable product. This rather simple treatment can only be used for waste with chemical properties suitable for landfilling. With regard to wastes with physical properties, it changes only the physical properties, but is unsuitable for landfilling. The most important application of this technology, however, is the solidification of metal-containing waste. S/S technology could potentially be an important alternative technology with a major use being to treat wastes in order to make them acceptable for land disposal. Lower permeability, lower contaminant leaching rate and such similar characteristics may make hazardous wastes acceptable for land disposal after stabilization.

- **Evaporation:** Evaporation is defined as the conversion of a liquid from a solution or slurry into vapor. All evaporation systems require the transfer of sufficient heat from a heating medium to the process fluid to vaporize the volatile solvent. Evaporation is used in the treatment of hazardous waste and the process equipment is quite flexible and can handle waste in various forms – aqueous, slurries, sludges and tars. Evaporation is commonly used as a pre-treatment method to decrease quantities of material for final treatment. It is also used in cases where no other treatment method was found to be practical, such as in the concentration of trinitrotoluene (TNT) for subsequent incineration.
- **Ozonation:** Ozone is a relatively unstable gas consisting of three oxygen atoms per molecule (O_3) and is one of the strongest oxidizing agents known. It can be substituted for conventional oxidants such as chlorine, hydrogen peroxide and potassium permanganate. Ozone and UV radiations have been used to detoxify industrial organic wastes, containing aromatic and aliphatic polychlorinated compounds, ketones and alcohols.

10.4.2 Thermal treatment

The two main thermal treatments used with regard to hazardous wastes are:

- **Incineration:** Incineration can be regarded as either a pre-treatment of hazardous waste, prior to final disposal or as a means of valorizing waste by recovering energy. It includes both the burning of mixed solid waste or burning of selected parts of the waste stream as a fuel. The concept of treating hazardous waste is similar to that of municipal solid waste.
- **Pyrolysis:** This is defined as the chemical decomposition or change brought about by heating in the absence of oxygen. This is a thermal process for transformation of solid and liquid carbonaceous materials into gaseous components and the solid residue containing fixed carbon and ash. The application of pyrolysis to hazardous waste treatment leads to a two-step process for disposal. In the first step, wastes are heated separating the volatile contents (e.g., combustible gases, water vapor, etc.) from non-volatile char and ash. In the second step volatile components are burned under proper

conditions to assure incineration of all hazardous components (Freeman, M. H. et al., 1988).

To elaborate, pyrolysis is applicable to hazardous waste treatment, as it provides a precise control of the combustion process. The first step of pyrolysis treatment is endothermic and generally done at 425 to 760 °C. The heating chamber is called the pyrolizer. Hazardous organic compounds can be volatilized at this low temperature, leaving a clean residue. In the second step, the volatiles are burned in a fume incinerator to achieve destruction efficiency of more than 99%. Separating the process into two very controllable steps allows precise temperature control and makes it possible to build simpler equipment. The pyrolysis process can be applied to solids, sludges and liquid wastes. Wastes with the following characteristics are especially amenable to pyrolysis:

(i) Sludge material that is either too viscous, too abrasive or varies too much in consistency to be atomized in an incinerator.

(ii) Wastes such as plastic, which undergo partial or complete phase changes during thermal processing.

(iii) High-residue materials such as high-ash liquid and sludges, with light, easily entrained solids that will generally require substantial stack gas clean up.

(iv) Materials containing salts and metals, which melt and volatilize at normal incineration temperatures. Materials like sodium chloride (NaCl), zinc (Zn) and lead (Pb), when incinerated may cause refractory spalling and fouling of the heat-exchanger surface.

10.4.3 Biological Treatment

On the basis of the fact that hazardous materials are toxic to living beings, it is not uncommon for some to assume that biological treatment is not possible for hazardous wastes. This assumption is untenable, and, in fact, we must aggressively seek biological treatment in order to exploit the full potential of hazardous wastes in terms of removal efficiency and cost (Freeman, et al., 1988). Against this background, let us now list some of the techniques used for biological treatment of hazardous waste:

- **Land treatment:** This is a waste treatment and disposal process, where a waste is mixed with or incorporated into the surface soil and is degraded, transformed or immobilized through proper management. The other terminologies used commonly include land cultivation, land farming, land application and sludge spreading. Compared to other land disposal options (e.g., landfill and surface impoundments), land treatment has lower long-term monitoring, maintenance and potential clean up liabilities and because of this, it has received considerable attention as an ultimate disposal method. It is a dynamic, management-intensive process involving waste, site, soil, climate and biological activity as a system to degrade and immobilize waste constituents.

- In land treatment, the organic fraction must be biodegradable at reasonable rates to minimize environmental problems associated with migration of hazardous waste constituents. The various factors involved in the operation of the system are as follows:
- **Waste characteristics:** Biodegradable wastes are suitable for land treatment. Radioactive wastes, highly volatile, reactive, flammable liquids and inorganic wastes such as heavy metals, acids and bases, cyanides and ammonia are not considered for land treatment. Land treatability of organic compound often follows a predictable pattern for similar type of compounds. Chemical structure, molecular weight, water solubility and vapor pressure are few of the characteristics that determine the ease of biodegradation.
- **Soil characteristics:** The rate of biodegradation and leaching of waste applied, the availability of nutrients and toxicants to microorganisms and the fate of hazardous waste constituents are determined largely by application rate as well as the soil's chemical and physical characteristics or reaction. Principal soil characteristics affecting land treatment processes are pH, salinity, aeration, moisture holding capacity, soil temperature, etc. Some of the characteristics can be improved through soil amendments (e.g., nutrients, lime, etc.), tillage or through adjustments of loading rate, frequency, etc., at the time of waste application.
- **Microorganisms:** Soil normally contains a large number of diverse microorganisms, consisting of several groups that are predominantly aerobic in well-drained soil. The types and population of microorganisms present in the waste-amended soil depend on the soil moisture content, available oxygen, nutrient composition and other characteristics. The key groups of the microorganisms present in the surface soil are bacteria,

actinomycetes, fungi, algae and protozoa. In addition to these groups, other micro and macro fauna, such as nematodes and insects are often present.

- **Waste Degradation:** Conditions favorable for plant growth are also favorable for the activity of soil microorganisms. The factors affecting waste degradation that (may be adjusted in the design and operation of a land treatment facility) are soil pH (near 7), soil moisture content (usually between 30 to 90 %), soil temperature (activity decreases below 10° C) and nutrients.
- **Enzymatic Systems:** Enzymes are complex proteins ubiquitous in nature. These proteins, composed of amino acids, are linked together via peptide bonds. Enzymes capable of transforming hazardous waste chemicals to non-toxic products can be harvested from microorganisms grown in mass culture. Such crude enzyme extracts derived from microorganisms have been shown to convert pesticides into less toxic and persistent products. The reaction of detoxifying enzymes are not limited to intracellular conditions but have been demonstrated through the use of immobilized enzyme extracts on several liquid waste streams. The factors of moisture, temperature, aeration, soil structure, organic matter content, seasonal variation and the availability of soil nutrients influence the presence and abundance of enzymes.
- **Composting:** The principals involved in composting organic hazardous wastes are the same as those in the composting of all organic materials, though with moderate modifications. The microbiology of hazardous wastes differs from that of composting in the use of inoculums. The reaction is that certain types of hazardous waste molecules can be degraded by only one or a very few microbial species, which may not be widely distributed or abundant in nature. The factors important in composting of hazardous wastes are those that govern all biological reactions. The principal physical parameters are the shape and dimensions of the particles of the material to be composted and the environmental factors of interest in an operation are temperature, pH, available oxygen, moisture, and nutrient availability.

  As we know the compost technology can be divided into two broad classes – windrow (open pile) and in-vessel (enclosed), and the former may be further subdivided into turned and forced aeration (static pile). Composting, by no means, is a panacea for the hazardous waste problem. When considering the future of hazardous waste composting needs, attention must be paid to the advantages and disadvantages inherent in composting as compared to those inherent in physical, chemical and thermal method of waste treatment.

- **Aerobic and anaerobic treatment:** Hazardous materials are present in low to high concentration in wastewaters, leachate and soil. These wastes are characterized by high organic content (e.g., up to 40,000 mg/l total organic carbon), low and high pH (2 to 12), elevated salt levels (sometimes, over 5%), and presence of heavy metals and hazardous organics. Hazardous wastes can be treated using either aerobic or anaerobic treatment methods.

  In aerobic treatment, under proper conditions, microorganisms grow. They need a carbon and energy source, which many hazardous wastes satisfy, nutrients such as nitrogen, phosphorus and trace metals and a source of oxygen. Some organisms can use oxidized inorganic compounds (e.g. nitrate) as a substitute for oxygen. Care is to be taken such that all the required nutrients and substances are supplied in sufficient quantities. Temperature and pH must be controlled as needed and the substances that are toxic to the organisms (e.g., heavy metals) must be removed.

  Anaerobic treatment is a sequential biologically destructive process in which hydrocarbons are converted, in the absence of free oxygen, from complex to simpler molecules, and ultimately to carbon dioxide and methane. The process is mediated through enzyme catalysis and depends on maintaining a balance of population within a specific set of environmental conditions. Hazardous waste streams often consist of hydrocarbons leading to higher concentrations of chemical oxygen demand (COD). Depending upon the nature of waste, the organic constituents may be derived from a single process stream or from a mixture of streams.

  The treatability of the waste depends upon the susceptibility of the hydrocarbon content to anaerobic biological degradation, and on the ability of the organisms to resist detrimental effect of biologically recalcitrant and toxic organic and inorganic chemicals. The metabolic interactions among the various groups of organisms are essential for the successful and complete mineralization of the organic molecules. Various parameters such as the influent quality, the biological activity of the reactor and the quality of the reactor environment are monitored to maintain efficient operating conditions within the reactor.

10.5 Pollution Prevention and Waste Minimization

Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the generation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous and non-hazardous materials, energy, water or other resources as well as those that protect natural resources through conservation or more efficient use. Pollution prevention is the maximum feasible reduction of all wastes generated at production sites. It involves the judicious use of resources through source reduction, energy efficiency, and reuse of input materials and reduces water consumption.

Waste minimization means the feasible reduction of hazardous waste that is generated prior to treatment, storage and disposal. It is defined as any source reduction or recycling activity that results in the reduction of the total volume of hazardous waste, or toxicity of hazardous waste, or both. Practices that are considered in waste minimization include recycling, source separation, product substitution, manufacturing process changes and the use of less toxic raw materials.

Pollution prevention and waste minimization provides us with an opportunity to be environmentally responsible (http://www.ehs.umaryland.edu/waste/pollutio.htm). While pollution prevention reduces waste at its source, waste minimization, including recycling and other methods, reduces the amount of waste. In what follows, we will look at some of the factors that can contribute to pollution prevention and waste minimization.

(i) **Management support and employee participation:** A clear commitment by management (through policy, communications and resources) for waste minimization and pollution prevention is essential to earn the dedication of all employees. For this to happen, a formal policy statement must be drafted and adopted. The purpose of this statement is to reflect commitment and attitude towards protecting the environment, minimizing or eliminating waste and reusing or recycling materials by the laboratories, departments and industries. Creative, progressive and responsible leadership will serve to develop an environmental policy. However, the total employee workforce will need to be involved to realize the fruits of the planning.

(ii) **Training:** As with any activity, it is important for management to train employees so that they will have an understanding of what is expected of them and why they are being asked to change the way things are done. Employees must be provided with formal and on-the-job training to increase awareness of operating practices that reduce both solid and hazardous waste generation. The training programme should include the industries' compliance requirements, which may be found in the waste management policies, occupational health and safety requirements. Additionally, training on waste minimization and pollution prevention is necessary.

(iii) **Waste audits:** A programme of waste audits at the departmental level will provide a systematic and periodic survey of the industries designed to identify areas of potential waste reduction. The audit programme includes the identification of hazardous wastes and their sources, prioritization of various waste reduction actions to be undertaken, evaluation of some technically, economically and ecologically feasible approaches to waste minimization and pollution prevention, development of an economic comparison of waste minimization and pollution prevention options and evaluation of their results.

(iv) **Good operating practices:** These practices involve the procedural or organizational aspects of industry, research or teaching activities and, in some areas, changes in operating practices, in order to reduce the amount of waste generated. These practices would include, at a minimum, material handling improvements, scheduling improvements, spill and leak prevention, preventive maintenance, corrective maintenance, material/waste tracking or inventory control and waste stream segregation, according to the toxicity, type of contaminant and physical state.

(v) **Material substitution practices:** The purpose of these practices is to find substitute materials, which are less hazardous than those currently utilized and which result in the generation of waste in smaller quantities and/or of less toxicity.

(vi) **Technological modification practices:** These practices should be oriented towards process and equipment modifications to reduce waste generation. These can range from changes that can be implemented in a matter of days at low cost to the replacement of process equipment involving large capital expenditures.

(vii) **Recycling options:** These options are characterized as use/reuse and resource recovery techniques. Use and reuse practices involve the return of a waste material either to the originating process or to another process as a substitute for an input material. Reclamation practices tender a waste to another company.

(viii) **Surplus chemical waste exchange options:** Inter- and intra-department chemical exchange is to be implemented and encouraged by employers/employees. Material exchanges not only reduce wastes but also save money – both are important considerations, during times of fiscal crisis.

In addition, by auditing each department or section, a knowledge base of chemical purchase and usage can be developed, allowing each department to develop and implement controls on the purchase of chemicals, institute intra- departmental chemical sharing/swapping programmes and eliminate excessive purchase and usage.

Research protocols should also be examined and modified in a manner similar to the above. Facility operations need to be examined to determine whether changes in practices and procedures will result in the generation of non- hazardous or less hazardous waste, or waste reduced in toxicity or volume. The specifics to be considered in this context include the substitution of non-toxic materials for toxic ones, distillation or evaporation of water-based chemical end- products, reclamation and reuse of common solvents, use of non-chromate cleaners as a standard part of doing business to generate non-hazardous end products. By implementing and adhering to the guidelines for handling and storing wastes at the point of generation, the costs associated with hazardous waste disposal will also be minimized.

10.6 Hazardous Wastes Management Strategies in India

In the USA, more than 70% of the hazardous waste generated was produced from chemical and petrochemical industries of the remaining waste produced, 22% was generated by metal related industries. As industrialization proceeds, the management of hazardous wastes is increasingly becoming a serious problem in India as well. The Indian chemical industry, which accounts for about 13% of the total industrial production and about 10% of the GNP valued at US \$ 2.64 X 1011 (NNP is US \$ 2.345 X 1011) per annum, employs about 6% of the nation's industrial workforce and is one of the major generators of toxic and hazardous wastes. There are 13,011 industrial units located in 340 districts, out of which 11,038 units have been granted authorization for multiple disposal practices encompassing incineration, storage land disposal and other disposal options. However, small and medium sized enterprises (SMEs) are the major sources of hazardous wastes. And, the States of Andhra Pradesh, Assam, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan and Tamil Nadu generate the majority of all hazardous wastes. The total estimate of hazardous waste generated in India is 4,434,257 tons per annum.

India is the first country that has made provisions for the protection and improvement of environment in its Constitution. The Directive Principles of State Policy of the Constitution, Article 48-A of Chapter IV enjoins the State to make endeavor for protection and improvement of the environment and for safeguarding the forest and wild life of the country. In Article 51 A (g) of the Constitution, one of the Fundamental Duties of every citizen of India is to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures. India has enacted the following laws, regulations and standards governing the country's environmental protection:

- **(i)** The Water (Prevention and Control of Pollution) Act, 1974 as amended in 1988.
- **(ii)** Water (Prevention and Control of Pollution) Rules, 1975.
- **(iii)** The Water (Prevention and Control of Pollution) Cess Act, 1977, as amended by Amendment Act, 1991.
- **(iv)** The Water (Prevention and Control of Pollution) Cess Rules, 1978.
- **(v)** The Air (Prevention and Control of Pollution) Act, 1984, as amended by Amendment Act, 1987.
- **(vi)** The Air (Prevention and Control of Pollution) Rules 1982 and 1983.
- **(vii)** The Environment (Protection) Act, 1986.
- **(viii)** Hazardous Waste (Management and Handling) Rules, 1989 as amended in 2000.
- **(ix)** Management, Storage and Import of Hazardous Chemical Rules, 1989.
- **(x)** Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms, Genetically Engineered Microorganisms or Cells Rules, 1989.
- **(xi)** The Public Liability Insurance Act, 1991.
- **(xii)** The Public Liability Insurance Rules, 1991.

(xiii) The Biomedical Wastes (Management and Handling) Rules, 1995.

(xiv) Municipal Wastes (Management and Handling) Draft Rules, 1999.

(xv) Hazardous Waste (Management and Handling) Amendment Rules 2000.

Because of these amendments, the legal management of hazardous substances in India will now apply to 44 industrial processes, as specified in Schedule I of the Rules. The penal provisions for non-compliance under Hazardous Waste (Management and Handling) Amended Rules 2000 and Environment (Protection) Act, 1986 are:

- The State Pollution Control Board may cancel an authorization issued under these rules or suspend it for such period as it thinks fit, if, in its opinion, the authorized person has failed to comply with any of the conditions of the authorization or with any provisions of the Act of these rules, after giving the authorized person an opportunity to show cause and after recording reasons therefore.
- The occupier, transporter and operator of a facility shall be liable for damages caused to the environment resulting due to improper disposal of hazardous waste listed in Schedule 1, 2 and 3 of The Hazardous Waste (Management and Handling) Amendment Rules, 2000. The occupier and operator of a facility shall also be liable to reinstate or restore damaged or destroyed elements of the environment. The occupier and operator of a facility shall be liable to pay a fine as levied by the SPCB with the approval of the Central Pollution Control Board (CPCB) for any violation of the provisions under these rules. An appeal shall lie against any order of grantor refusal of an authorization by the Member Secretary, SPCB, etc., to the Secretary, Department of Environment of the State.
- Besides the aforementioned provisions for non-compliance(s), the Penalty Provisions, delineated under Sections 15 (1,2) and 16 of the Environmental (Protection) Act, 1986 are also applicable.
- Furthermore, the Union Ministry of Environment and Forests, through the Gazette Notification of March 24, 1992, introduced Public Liability Insurance Act Policy, which is specially designed to protect any person, firm, association, or company who owns or has control over handling any hazardous substance at the time of accident. These include 179 hazardous substances along with three categories of

inflammable substances. The term handling means manufacturing, processing, treatment, packaging, storing, and transportation by vehicle, use, collection, destruction, conversion, offering for sale, transfer or any other similar form of dealing with hazardous substances. Hazardous waste (Management, Handling and transboundary movement) rules 2007.

Summary

In this Unit, our focus was on the management of hazardous wastes. We began the Unit with a discussion on the identification and classification of hazardous wastes, and in that context, explained the major identification lists (i.e., F, K, P and U), the characteristics (i.e., corrosively, ignitability, toxicity and reactivity) and classifications (i.e., radioactive substances, chemicals, biological wastes, flammable wastes and explosives.) We then discussed the functional elements involved in hazardous waste management (i.e., generation, storage and collection, transfer and transport, processing and disposal.) Subsequently, we explained how hazardous wastes could be treated through the physical, chemical, thermal and biological means to reduce their impact on public health and the environment. We then discussed some of the techniques for hazardous waste minimization and pollution prevention. We closed the Unit by touching upon some aspects of hazardous waste management in India.

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Unit 11: Hazardous Waste Treatment Practices I

Unit Structure

11.0 Learning Objectives

After completion of this unit, the leaner would be able to:

- Classify the various hazardous waste treatment methods
- Explain the various physical methods of hazardous waste treatments
- Explain the advantages and disadvantages of the various physical treatment methods

11.1 Introduction

Hazardous waste treatment technologies are broadly grouped into physical, chemical, biological, fixation/encapsulation, and thermal processes. Each has distinct mechanisms. Some concentrate or separate hazardous components; others chemically transform them into less harmful forms, while thermal processes may completely destroy toxic substances. Fixation and encapsulation techniques immobilize contaminants to prevent environmental release.

The physical methods usually involve phase separation, sedimentation, filtration, evaporation, or adsorption, but they do not change the chemical nature of the waste. Whereas the chemical methods which include oxidation, reduction, neutralization, and precipitation, alter the hazardous nature of the waste. Biological methods mainly applied to organic hazardous wastes (e.g., bioremediation, composting, anaerobic digestion). Fixation/encapsulation (stabilization/solidification) immobilizes hazardous constituents, often using binders like cement, lime, or polymers, reducing leachability. Thermal methods include incineration, pyrolysis, and plasma arc treatment, aimed at destroying or detoxifying wastes through high temperatures. Because no single technology can address all objectives (separation, detoxification, volume reduction, destruction, storage, and resource recovery), integrated treatment systems combining multiple methods are generally required.

11.2 Classification of Hazardous Waste Treatment Methods

Hazardous waste treatment technologies play a vital role in minimizing the environmental and health risks posed by hazardous materials. Their primary objectives are to reduce the toxicity, volume, and mobility of waste, thereby making it safer for disposal, storage, or potential reuse. A range of treatment methods are available, broadly classified as physical, chemical, biological, fixation/encapsulation, and thermal processes. Depending on the characteristics of the waste, these technologies may be applied individually or in combination to achieve effective treatment outcomes. Collectively, they serve multiple purposes, such as detoxification, volume reduction, immobilization, destruction of harmful constituents, and recovery of useful materials. The major hazardous waste treatment technologies are as follows:

11.2.1 Physical Treatment Methods

Physical treatment processes for hazardous waste are primarily aimed at separating different phases or components without changing their chemical nature. These methods help concentrate hazardous constituents and recover valuable materials, thereby improving the efficiency and cost-effectiveness of subsequent treatment steps. Commonly used physical treatment techniques include sedimentation, filtration, reverse osmosis, evaporation, magnetic separation, centrifugation, and adsorption etc.

11.2.2 Chemical Treatment Methods

Chemical treatment processes for hazardous waste involve the use of chemical reactions to modify the composition of the waste. These reactions may facilitate separation and filtration, neutralize or detoxify hazardous constituents, or convert them into less harmful and more manageable forms suitable for further treatment, reuse, or safe disposal. Despite their effectiveness, these methods have certain limitations, such as the low solubility of specific metals, interference from impurities, and the possibility of generating secondary hazardous byproducts.

Common chemical treatment methods include the following:

i) **Neutralization** – balancing acidic and alkaline wastes.
ii) **Precipitation** – converting dissolved metals into insoluble forms for removal.
iii) **Oxidation** – destroying or transforming toxic organics (e.g., cyanides, phenols).
iv) **Reduction** – converting hazardous compounds (e.g., Cr^{6+} to Cr^{3+}) into safer forms.
v) **Ozonation** – advanced oxidation for refractory organic pollutants.
vi) **Ion exchange** – removing dissolved contaminants, especially heavy metals.

vii) **Electrolysis** – recovering metals or decomposing hazardous ions.

viii) **Calcination –** thermal decomposition of certain wastes, often overlapping with thermal treatment.

11.2.3 Biological Treatment Methods

Biological treatment of hazardous waste relies on the ability of microorganisms such as bacteria, fungi, and algae to degrade, transform, or immobilize toxic compounds. These processes are especially effective for treating organic pollutants, including petroleum hydrocarbons, chlorinated solvents, and pesticides. In some cases, microorganisms can also transform metals into less toxic or less mobile forms, or sequester them in biomass. However, the success of biological treatment depends on maintaining suitable environmental conditions, as microorganisms are sensitive to changes in waste concentration, pH, temperature, and the presence of inhibitory substances such as salts and heavy metals. Despite their advantages, biological methods also have certain limitations. They may produce large volumes of sludge that require further treatment, cause the accumulation of metals in sludge and biomass, and generate unpleasant odors.

Some of the common biological treatment methods include:

i) **Aerobic digestion –** breakdown of organic matter in the presence of oxygen.

ii) **Anaerobic digestion –** microbial decomposition of organic waste in oxygen-free conditions, producing biogas.

iii) **Bioremediation –** use of microorganisms (sometimes enhanced by nutrients or oxygen) to detoxify or degrade pollutants in soil, water, or sediments.

iv) **Composting –** aerobic microbial degradation of organic waste with stabilization.

v) **Phytoremediation –** use of plants and associated microbes to remove or stabilize contaminants.

11.2.4 Thermal Treatment Methods

Thermal treatment processes involve the application of high temperatures to decompose, destroy, or transform hazardous wastes, particularly those containing organic compounds. These methods are highly effective in reducing waste volume, recovering energy, and destroying toxic constituents. However, they are often capital- and energy-intensive, and they require advanced air pollution control systems to prevent the release of harmful byproducts such as dioxins, furans, and acid gases.

Despite these limitations, thermal treatment remains one of the most comprehensive approaches for managing hazardous wastes, especially when other treatment methods are ineffective. Common thermal treatment methods include:

i) **Incineration –** controlled combustion of hazardous waste at high temperatures with energy recovery and destruction of toxic organics.

ii) **Pyrolysis –** thermal decomposition of wastes in the absence of oxygen, producing char, oil, and syngas.

iii) **Gasification –** partial oxidation of carbonaceous waste at high temperatures to produce a usable synthesis gas (syngas).

iv) **Plasma arc treatment –** extremely high-temperature process (up to 10,000 °C) using plasma torches to achieve nearly complete destruction of hazardous materials.

v) **Cement kiln co-processing –** use of cement kilns to treat compatible hazardous wastes while simultaneously recovering energy.

11.2.5 Other Treatment Methods

In addition to physical, chemical, biological, and thermal methods, several other treatment approaches are employed for hazardous waste management. These methods mainly focus on immobilizing, extracting, or stabilizing contaminants rather than destroying them. They include:

i) **Phytoremediation** – the use of plants (sometimes aided by microbes) to absorb, degrade, stabilize, or accumulate hazardous contaminants from soil and water.

ii) **Soil washing** – a mechanical/chemical process that removes hazardous contaminants from soils and sediments using water, surfactants, or chelating agents.

iii) **Stabilization/Solidification (S/S)** – treatment of waste with binding agents such as cement, lime, or polymers to reduce solubility and leachability of hazardous constituents.

iv) **Fixation and Encapsulation** – immobilization of wastes by physically enclosing them in an inert material or chemically binding contaminants to minimize their release into the environment.

Other specialized methods may also be used in certain cases, such as vitrification (trapping wastes in a stable glassy matrix), landfilling with engineered liners and leachate controls, or soil vapor extraction for volatile organic contaminants.

A summary of various treatment processes and their usefulness is given below:

Hazardous waste treatment technologies			
Treatment Categories	**Main Function(s)**	**Typical Waste Treated**	**Waste Form**
A) Physical Treatment			
1. Sedimentation	Solid-liquid separation	Inorganics, slurries	Liquids, sludge
2. Filtration (sand, membrane, reverse osmosis)	Separation / Concentration	Organics, inorganics	Liquids
3. Centrifugation	Separation / Dewatering	Sludge, slurry	Liquids, sludge
4. Magnetic Separation	Metal removal	Ferrous metals	Solids, sludge
5. Adsorption (activated carbon, zeolite)	Concentration / Detoxification	VOCs, organics, metals	Liquids, gases
6. Air Stripping (aeration)	Volatile removal	VOCs, hydrocarbons	Liquids
7. Evaporation	Volume reduction	Salts, inorganics	Liquids
8. Flocculation / Coagulation	Phase separation (with chemicals)	Metals, suspended solids	Liquids
B) Chemical Treatment			
9. Neutralization	Detoxification / pH adjustment	Acids, bases	Liquids
10. Precipitation	Immobilization	Metals, inorganics	Liquids, sludge
11. Oxidation (ozone, chlorine, Fenton's reagent, permanganate)	Detoxification / Destruction	Organics, cyanides	Liquids, sludge
12. Reduction	Detoxification	Cr(VI), nitro-compounds	Liquids
13. Ion Exchange	Separation / Detoxification	Metals, radionuclides	Liquids
14. Electrochemical (electrolysis, electrocoagulation)	Separation / Detoxification	Metals, organics	Liquids, sludge
15. Calcination	Detoxification / Stabilization	Inorganic salts	Solids
C) Thermal Treatment			
16. Incineration	Destruction / Detoxification / Volume reduction	Organics, biologicals, flammables	Solids, liquids, gases
17. Pyrolysis	Destruction / Energy recovery	Organics, plastics, oils	Solids, liquids

18. Gasification	Destruction / Energy recovery	Organics, biomass	Solids, sludges
19. Plasma Arc Treatment	High-temp destruction	Hazardous organics, mixed waste	Solids, liquids
20. Supercritical Water Oxidation (SCWO)	Destruction / Detoxification	Aqueous organics	Liquids
21. Microwave Treatment	Detoxification (thermal)	Soils, sludges	Solids
D) Biological Treatment			
22. Aerobic Digestion	Biodegradation	Organic waste, oils	Liquids, sludge
23. Anaerobic Digestion	Biodegradation / Energy recovery	Organics	Sludges, wastewater
24. Composting	Biodegradation	Organic waste (low hazard)	Solids
25. Bioremediation (in situ/ex situ: landfarming, bio piles, bio slurry)	Detoxification via microbes	Hydrocarbons, pesticides	Soils, groundwater
26. Biofiltration / Biosorption	VOC/odor removal, biosorption of metals	Organics, metals	Gas, liquids
E) Stabilization & Disposal Methods			
27. Solidification / Stabilization (S/S)	Immobilization	Metals, radionuclides	Solids, sludges
28. Encapsulation	Immobilization (barrier method)	Metals, mixed waste	Solids
29. Vitrification / Glassification	Immobilization (glass matrix)	Metals, radionuclides	Solids
30. Deep Well Injection	Long-term disposal	Non-reactive liquids	Liquids
31. Landfilling (engineered)	Secure disposal	Inorganics, residuals	Solids
F) Other / Emerging Methods			
32. Phytoremediation	Uptake/degradation via plants	Metals, organics	Soil, water
33. Soil Washing	Contaminant removal by washing agents	Metals, organics	Soil
34. Thermal Desorption	Separation of organics by heating	Hydrocarbons, pesticides	Soils, sludges

11.3 Physical Methods of HW Treatment

Physical methods of hazardous waste treatment involve the separation of waste components, such as solids and liquids, without altering their chemical composition. These methods are primarily used to concentrate or isolate hazardous materials, thereby enhancing the efficiency and cost-effectiveness of subsequent treatment or disposal processes. Common physical treatment techniques include filtration, sedimentation, evaporation, and osmosis, among others. Each of these processes is discussed in detail below.

11.3.1 Filtration

Filtration is an important physical method in hazardous waste treatment, as it enables the removal of suspended solids, contaminants, and pollutants from wastewater and other liquid streams. The primary objective is to separate harmful substances such as heavy metals, organic chemicals, and toxic particulates from the liquid phase, making it safer for either discharge or reuse. A range of filtration technologies are applied in hazardous waste management, including granular media filtration, cartridge filtration, and advanced membrane filtration systems.

Granular media filtration employs a bed of materials such as sand, gravel, or activated carbon to trap suspended solids and adsorb certain contaminants. Cartridge filtration relies on replaceable cartridges containing porous elements that physically screen out particles and impurities. Membrane filtration methods such as ultrafiltration, nan filtration, and reverse osmosis, uses semipermeable membranes to separate contaminants from liquid streams based on particle size or molecular weight. The choice of filtration technology in hazardous waste treatment depends on several factors, including the type and concentration of contaminants, the required effluent quality, flow rate, and overall treatment objectives. When properly applied, filtration can substantially reduce both environmental and health risks by enabling the safe reuse or discharge of treated liquids.

Granular media filtration is commonly used for treating aqueous hazardous waste streams. It employs a bed of granular particles, typically sand or a sand–anthracite combination, to trap suspended solids. As liquid passes through the filter bed, particles accumulate both on the surface and within the media, gradually reducing flow rates at constant pressure or requiring higher pressure to maintain flow. To prevent clogging, filters are periodically backwashed with high-velocity water, which dislodges the trapped solids. The resulting backwash water, however, contains concentrated contaminants and requires further treatment. This method is most economical for streams with suspended solids concentrations below 100–200 mg/L, though it can be applied to higher concentrations with more frequent backwashing.

For a filter bed to operate effectively, a reliable backwashing system is essential. Several backwashing methods are commonly employed:

- Water backwash only
- Water backwash with surface wash
- Air scour followed by water wash
- Simultaneous air and water wash

In hazardous waste treatment, filtration serves two primary purposes:

(1) removal of suspended solids to improve water clarity and protect downstream treatment processes, and

(2) volume reduction by dewatering of sludge and partial removal of hazardous contaminants, thereby reducing volume of waste, and also reduction in environmental and health risks.

While filtration can also be applied to non-aqueous liquids, it is generally unsuitable for highly viscous materials such as tars. It is a reliable and efficient method for removing small amounts of solids from waste streams, provided the solid content remains relatively consistent and regular backwashing is carried out. Filtration equipment is simple, widely available in different sizes, and easy to operate and control. It can also be effectively integrated with other treatment steps.

A key maintenance issue is the management of backwash water, which contains concentrated contaminants and requires further treatment. Filtration is energy-intensive, relying on gravity, pumps, or vacuums to remove suspended solids. As filters or media become clogged, energy demands increase accordingly.

11.3.2 Sedimentation

Sedimentation is a gravity-driven physical separation process in which suspended particles are removed from a liquid stream due to differences in density. It is extensively applied in water and wastewater treatment, mineral processing, and chemical industries. Under quiescent conditions, particles denser than the fluid migrate downward, producing a clarified supernatant.

The rate of settling is governed by factors such as the density gradient between particle and fluid, particle diameter, viscosity of the suspending medium, and temperature, which alters both fluid viscosity and density.

Sedimentation is particularly suited for aqueous waste streams containing significant suspended solids (e.g., surface runoff, leachates, and biological effluents). It also functions as a pretreatment stage for advanced processes such as filtration, ion exchange, carbon adsorption, stripping, and reverse osmosis. However, it is generally ineffective for oils, greases, and hydrophobic solids, which require complementary treatment.

Sedimentation has certain advantages like its simplicity, low operational cost, and moderate efficiency. However, it has also certain l**imitations** which include its long retention time for fine particles, relatively slow kinetics, and substantial capital costs for large installations, and periodic maintenance demands.

Common equipment includes clarifiers, thickeners, centrifuges, and hydro cyclones, each designed to enhance particle-liquid separation by gravity or centrifugal forces.

Settling phenomena are categorized as:

- ***Discrete settling –*** individual particles settle independently.
- ***Flocculent settling –*** aggregation of particles into flocs enhances settling.
- ***Zone settling –*** a collective particle blanket forms with a distinct liquid-solid interface.
- ***Compression settling –*** consolidation occurs due to overlying particle weight.

11.3.3. Gravity Separation

Gravity separation is a widely applied physical process for treating two-phase aqueous wastes, particularly oil–water mixtures. The principle relies on the density difference between the immiscible phases: water (heavier) and oil (lighter). Under quiescent conditions, oil droplets rise to the surface while solids (if present) may settle at the bottom.

For effective separation, the oil phase must be non-emulsified and present as droplets of sufficient size to rise within the available residence time. Since oil–water emulsions are common in industrial effluents, emulsion-breaking chemicals (demulsifiers) are often required before treatment. Separation efficiency is governed not only by density difference but also by droplet size, fluid viscosity, and flow regime (ideally laminar).

Gravity separators are built in various shapes and arrangements, with a trend toward compact, cost-effective designs. Common configurations include:

- **Horizontal cylindrical decanters** – maximize surface area for oil rise.

- **Vertical cylindrical decanters** – useful where space is limited.
- **Cone-bottom settlers** – allow simultaneous oil separation (at the top) and solids removal (at the bottom).

Baffles are often installed to reduce turbulence, promote laminar flow, and provide surface area for **droplet coalescence**. Advanced units such as **coalescing plate separators** and **corrugated plate separators** further improve performance by greatly increasing the effective surface area for droplet interaction and coalescence.

Gravity separation is straightforward and requires minimal operational control. Simple, readily available equipment can achieve effective separation provided sufficient residence time is allowed. Where emulsifiers are used, laboratory jar tests should be conducted periodically to optimize dosage and ensure reliable performance.

The primary waste generated consists of the separated oil phase, often accompanied by settled sludge or scum, depending on the feed characteristics. Proper collection, handling, and disposal (or recovery) of these residuals are essential for environmental compliance.

11.3.4 Centrifugation

Centrifugation is an extension of gravity settling, in which centrifugal forces are generated by high rotational speeds to accelerate the separation of solids and liquids. Unlike sedimentation, where separation is governed solely by gravity, centrifugation produces forces many times greater than gravity, thereby achieving faster and more efficient separation.

From a treatment perspective, centrifugation is more effective than gravity settling. However, from an energy standpoint, it is less favorable, as the power requirements are high unless the waste stream contains a significant concentration of solids. For this reason, centrifuges are most commonly employed in the final thickening or dewatering of sludge rather than bulk liquid clarification.

A typical centrifuge consists of three major components:

- a rotating solid bowl,
- an internal screw conveyor (which conveys separated solids toward the discharge end), and

- a planetary gear system (to control relative motion between bowl and conveyor).

Machine variables include bowl speed, internal bowl volume, and conveyor speed, while **process variables** include solids feed rate, settling characteristics of the solids, and temperature of the suspension.

Centrifugation is **technically and economically competitive** with other sludge dewatering methods, such as **vacuum filtration** and **filter presses**. A distinct advantage is its ability to dewater **sticky or gelatinous sludges** that are difficult to process by other means.

Limitations include:

- it is non-selective separation (it separates phases but cannot fractionate or refine components),
- it requires high maintenance costs when handling **abrasive materials**, and
- it is unable to destroy or chemically modify hazardous constituents, since centrifugation is strictly a **physical separation process**.

11.3.5 Flotation

Flotation is a separation process in which air bubbles are introduced into a wastewater stream to attach to suspended solids, oils, or other hydrophobic particles, causing them to rise to the surface. The floating layer of scum or froth is then mechanically removed, while the clarified effluent is withdrawn from near the bottom of the unit.

Two principal methods are used:

- **Air injection flotation** – air is directly injected into the liquid, producing relatively larger bubbles.
- **Dissolved air flotation (DAF)** – water is saturated with air under pressure and then released at atmospheric pressure, producing **microscopic bubbles**. These small bubbles are more effective, as their higher surface area improves particle attachment and flotation efficiency.

The **effectiveness of flotation** depends primarily on the **air-to-solids ratio (A/S)**, i.e., the volume of air released relative to the mass of solids present. An adequate A/S ratio ensures sufficient bubble coverage for particle attachment and flotation.

Flotation is widely applied as a **solids separation process following biological treatment** of organic wastes. It is also effective for:

- removing **inorganic flocks** formed after chemical precipitation/coagulation–flocculation,
- treating **oily or greasy wastewaters**,
- separating **algae** from surface waters.

In many cases, **dissolved air flotation units** can replace conventional sedimentation basins or clarifiers, especially where fine particles, low-density solids, or oil and grease must be removed.

11.3.6 Equalization

Equalization is a preliminary wastewater treatment process designed to balance variations in flow rate, composition, and pollutant concentration before the waste stream enters subsequent treatment units. Industrial effluents often exhibit wide fluctuations in pH, organic load, solids content, or flow volume due to batch operations, production cycles, or cleaning processes. Equalization serves to dampen these variations and provide a uniform, consistent influent for downstream treatment.

Objectives of Equalization

- **Flow stabilization** – reduces hydraulic surges and prevents overloading of downstream units.
- **Load balancing** – evens out variations in organic or toxic load, improving the performance of biological and chemical processes.
- **pH adjustment through blending** – mixing acidic and alkaline streams can result in partial or complete neutralization without additional chemical input.
- **Improved efficiency of treatment** – downstream processes such as coagulation–flocculation, biological treatment, and disinfection perform better when influent conditions are stable.

Equalization is typically achieved using **tanks, basins, or lagoons** equipped with:

- **Mixing systems** (mechanical or air) to prevent settling and to promote blending.

- **Flow control devices** to regulate discharge and maintain uniform flow to subsequent units.
- **Level control systems** to buffer peak flows and prevent overflows.

Retention time is determined based on the degree of variation in the waste stream, ranging from several hours to a full day. Aeration may be provided in some equalization basins to prevent septic conditions, reduce odors, and maintain solids in suspension.

The advantages include:

- Reduces shock loading on downstream processes.
- Minimizes the need for extensive chemical dosing for pH control.
- Improves overall system stability and treatment efficiency.
- Provides flexibility for handling variable industrial discharges.

Limitations include:

- Requires significant **tank volume and capital investment**, especially for large flow variations.
- Mixing and aeration increase **operating costs**.

11.3.7 Precipitation, Coagulation, Flocculation

Precipitation, coagulation, and flocculation are commonly used in the treatment of wastewater streams containing soluble heavy metals and colloidal hazardous substances. Precipitation metals such as salts of copper, nickel, cadmium, and chromium, are accomplished as hydrated oxides using lime. Chromium, present as chromate or dichromate must first be reduced to trivalent chromium.

11.3.7.1 Precipitation

Precipitation is a physicochemical process in which dissolved substances in wastewater are transformed into insoluble solid compounds. This treatment method relies on altering the chemical equilibrium that controls the solubility of inorganic constituents. In practice, precipitation is most commonly applied for the removal of heavy metals, which are converted into either hydroxides or sulfides. For this purpose, chemicals such as lime Ca $(OH)_2$, Ca $(OH)_2$) or sodium sulfide (Na_2S) are added in a rapid-mixing tank, frequently along with flocculating agents to promote particle aggregation. The mixture then enters a flocculation chamber, where controlled mixing and adequate retention time allow the fine precipitates to agglomerate into larger, settleable flocs. These solids are subsequently removed from the liquid stream by sedimentation or, where needed, by filtration.

For example, chromium in wastewater is often present in the hexavalent form (Cr^{6+}), which is highly toxic and soluble. Before precipitation, it must first be reduced to the trivalent state (Cr^{3+}), usually by using reducing agents such as sulfur dioxide or ferrous sulfate. Once reduced, trivalent chromium can be effectively precipitated as chromium hydroxide $Cr(OH)_3$) at an alkaline pH. Similarly, metals like cadmium or lead can be precipitated more effectively as sulfides due to the very low solubility of their sulfide salts.

Although the precipitation of metals is theoretically governed by the solubility product of the ionic species involved, in practice effluent concentrations rarely approach these theoretical limits. To achieve effective precipitation, lime is typically added in amounts up to three times the stoichiometric requirement, partly to compensate for the common ion effect and process inefficiencies. In comparison to hydroxides, metal sulfides exhibit significantly lower solubility, resulting in more complete precipitation and greater stability across a wide pH range. Metal hydroxides, by contrast, are stable only within a relatively narrow pH window: each metal exhibits a minimum solubility at a specific pH, but excess lime beyond this point can lead to redissolution due to amphoteric behavior. Consequently, lime dosage must be carefully controlled. This requirement is particularly challenging when treating aqueous wastes from disposal sites, where both flow rates and metal concentrations may fluctuate widely. Similarly, the precipitation of metals as carbonates is also strongly influenced by pH, and stability varies accordingly.

11.3.7.2 Flocculation

Flocculation refers to the process by which fine, non-settleable particles suspended in a liquid are induced to aggregate into larger, settleable masses. The underlying mechanisms involve interactions of surface chemistry and particle charge, leading to destabilization of colloids. Flocculants may be inorganic salts, such as alum, lime, ferric chloride, or ferrous sulfate, or organic compounds, typically long-chain, water-soluble polymers known as polyelectrolytes. Several thousand synthetic polymers are available, varying in charge type and molecular weight, to suit specific applications. Inorganic flocculants act primarily through precipitation reactions. For example, alum (hydrated aluminum sulfate), when added to wastewater, undergoes hydrolysis under near-neutral pH conditions to form a voluminous, gelatinous precipitate of aluminum hydroxide. This hydroxide floc possesses a high surface area, enabling it to adsorb and enmesh fine suspended solids into larger aggregates. Similarly, lime and iron salts hydrolyze to form bulky precipitates that enhance particle agglomeration. However, not all precipitation reactions yield settleable flocs. Metal sulfides, for instance, often precipitate as very fine and stable colloidal particles. In such cases, additional flocculating agents such as alum or synthetic polyelectrolytes are required to induce aggregation and facilitate their removal by sedimentation or filtration.

Once suspended particles have been flocculated into larger aggregates, they can usually be separated from the liquid by sedimentation, provided there is an adequate density difference between the solid and liquid phases. Precipitation is one of the most widely applied methods for removing metals from wastewater, and is effective for contaminants such as zinc, cadmium, chromium, copper, lead, manganese, mercury, and fluoride. In addition, several anionic species, including phosphate, sulfate, and fluoride, can also be removed through precipitation reactions. Because of its versatility, precipitation is applicable to most aqueous hazardous waste streams. However, treatment efficiency may be limited by certain wastewater characteristics. The presence of organic matter can result in the formation of stable organometallic complexes that resist precipitation, while ligands such as cyanide or other chelating ions can form strong metal complexes that reduce removal efficiency. Flocculation, on the other hand, is applicable to nearly any aqueous waste stream in which fine suspended solids must be agglomerated into larger, more settleable particles prior to sedimentation or further treatment. It should be noted that neither precipitation nor flocculation have a strict concentration limit; however, highly viscous waste streams may significantly reduce settling efficiency. In addition to conventional treatment systems, precipitation may also be applied in situ, for example in surface impoundments or lagoons. In such cases, lime and flocculants are introduced directly, and mixing, flocculation, and sedimentation occur within the lagoon itself, with energy provided by wind action or mechanical pumping. The choice of the most effective precipitant or flocculant, along with the determination of optimum dosages, is typically established through laboratory jar test studies.

In addition to selecting suitable chemicals and determining their optimum dosages, several other design parameters must be considered for effective precipitation and flocculation. These include the optimum pH range for each target contaminant, mixing intensity and duration, the quantity of sludge produced, and appropriate methods for sludge handling and disposal. Both precipitation and flocculation are well-established treatment technologies with clearly defined operating requirements. The processes typically require only basic equipment such as chemical feed pumps, metering devices, and mixing or settling tanks, all of which are widely available and straightforward to operate. Furthermore, precipitation and flocculation can be readily incorporated into more complex treatment systems as either primary or supporting processes. However, their performance and overall reliability are strongly influenced by the variability of the wastewater being treated, particularly fluctuations in flow and contaminant concentration.

The selection and dosage of chemicals for precipitation and flocculation must be established through laboratory testing and adjusted continuously to account for variations in waste composition. Precipitation is a nonselective process, meaning that compounds other than the intended targets may also be removed. Both precipitation and flocculation are nondestructive methods that transfer contaminants from the liquid to the solid phase, generating large volumes of sludge that must be properly managed and disposed of. From an operational standpoint, these processes pose minimal safety and health risks to workers. They are conducted under near-ambient conditions, avoiding the hazards associated with high-pressure or high-temperature systems. Although many of the chemical reagents, such as lime or alum, can cause skin or eye irritation, they are generally straightforward to handle safely with appropriate protective measures. An additional advantage of precipitation is its ability to remove many substances that can inhibit biological treatment, provided they form insoluble compounds in water. Heavy metals, for instance, are typically precipitated as oxides or hydroxides, which are largely insoluble. This behavior is explained by the common ion effect and the solubility product constant (K_{sp}). The smaller the value of the solubility product, the lower the solubility of the compound in the aqueous phase.

The contaminant must be converted into an insoluble compound for precipitation to be effective. It requires selecting an economical chemical source of the appropriate counter-ion. However, in some cases, the precipitant itself may present greater hazards than the material being removed. Common chemicals employed as precipitants in wastewater treatment include aluminum sulfate (alum), ferrous sulfate, lime, ferric chloride, ferrous chloride, sulfur dioxide, and sulfuric acid. Many of these reagents also interact with the natural alkalinity of water—primarily carbonate and bicarbonate ions—leading to the formation of additional precipitates.

As an example, wastewater containing oxalic acid can be treated with calcium chloride to form calcium oxalate, an insoluble compound that may be removed through sedimentation or filtration. Despite such effectiveness, precipitation has certain drawbacks. In particular, excessive dosing of some precipitants may result in the formation of compounds more toxic than the original contaminant. For instance, cadmium sulfide precipitation in the presence of organic compounds can generate dimethyl cadmium, an extremely toxic byproduct. Furthermore, precipitation reactions are highly dependent on pH, with solubility minima occurring within specific ranges for each metal.

A related process is **chelation**, which also targets dissolved metals but employs more specialized and costly reagents. Chelating agents form stable complexes with metal ions, thereby neutralizing and facilitating their removal. For example, polystyrene sulfonate has been successfully applied to recover cadmium from wastewater streams.

11.3.7.3 Coagulation

Coagulation is one of the most widely applied processes in wastewater treatment, particularly for the removal of fine colloidal particles that do not readily settle by gravity. The process works by destabilizing colloids and reducing the electrostatic repulsive forces that normally keep them suspended, thereby enhancing particle collisions and promoting aggregation. Coagulants may include inorganic salts, such as aluminum or iron compounds, as well as organic formulations such as polyelectrolytes and synthetic polymers, which may be cationic, anionic, or nonionic. The use of a coagulant provides an economical and efficient means of removing submicron particles from wastewater. In practice, more than a thousand chemical agents and formulations are available for use as coagulants, each selected based on wastewater composition and treatment objectives.

11.3.8 Polymerization of Pollutants

Research conducted at the Massachusetts Institute of Technology by Alexander Klibanov and coworkers demonstrated an innovative biochemical method for removing phenols and aromatic amines from industrial wastewater. The process employs the enzyme horseradish peroxidase (HRP) together with hydrogen peroxide to catalyze the oxidative polymerization of these toxic organics. Through enzymatic action, phenolic and aminic compounds are converted into high-molecular-weight polymers, which are insoluble and can be precipitated from solution. Under laboratory conditions, this technique was shown to remove more than 99% of phenols and aromatic amines within three hours. Compared with conventional treatment methods such as activated carbon adsorption or chemical oxidation, the enzymatic approach has the potential to be both more efficient and more cost-effective.

11.3.9 Centrifugation

Centrifugation is considered both technically and economically competitive with other sludge dewatering methods, such as vacuum filtration and filter presses. A key advantage of centrifugation is its superior ability to dewater sticky or gelatinous sludges, which are often problematic for other processes. However, the method also has limitations. It is inherently non-selective, meaning it cannot effectively separate different components from one another. In addition, processing abrasive materials can result in relatively high maintenance costs. Since centrifugation is strictly a physical separation technique, it does not destroy or chemically modify hazardous constituents present in the sludge.

C. SURFACE PHENOMENON

A distinct category of physical treatment involves the adsorptive capture of selected chemicals on the surfaces of specially designed porous materials. This process relies on complex surface bonding mechanisms rather than simple phase changes. Since the adsorbed chemicals can often be recovered and reused, this method is classified under physical treatment technologies rather than chemical destruction processes.

11.3.10 Adsorption

Adsorption is the process by which one substance adheres to the surface of another through physical (van der Waals forces, hydrogen bonding) or chemical (chemisorption) interactions**.** In waste treatment, adsorption is widely applied to transfer and concentrate contaminants—known as the *adsorbate*—from a liquid or gaseous medium onto a solid surface, referred to as the *adsorbent*. The most commonly used adsorbent is activated carbon, owing to its extremely high surface area and porous structure. Other specialized adsorbents include synthetic resins, zeolites, and silica gels, which can be tailored for specific contaminants. Adsorption occurs primarily along the walls of the pores within the adsorbent, where unsatisfied surface forces attract and retain contaminant molecules. Typical gas-phase adsorption systems consist of packed beds of adsorbent housed in containers. The large, highly permeable void spaces between pellets (several millimeters in diameter) allow contaminated air or liquid streams to flow through, ensuring intimate contact between the fluid and adsorbent surface for efficient pollutant removal.

Once an adsorbent reaches its saturation capacity, little or no additional adsorption occurs. In some cases, previously adsorbed contaminants may even be released back into the medium through desorption, leading to an increase in contaminant concentrations. To prevent this, exhausted adsorbents must be properly managed. Depending on the material and contaminants, spent adsorbents may be disposed of in engineered landfills, incinerated, or regenerated for reuse**.**

Regeneration restores the adsorbent's capacity. For example, synthetic resins are typically regenerated by washing with suitable solvents, allowing them to be reused multiple times. Resins are highly effective in removing most organic contaminants from water and can also be applied to the removal of organic pollutants from gaseous streams.

Adsorption is extensively used in industrial applications, particularly for air pollution control, odor abatement, and solvent recovery. The method is especially effective for the removal of organic compounds, and to some extent, certain inorganic contaminants from gas streams.

Adsorption depends on:

- the strength of the molecular attraction between adsorbent and the adsorbate,
- molecular weight,

- type and characteristic of adsorbent
- electro-kinetic charge
- surface area
- pH

The substance that is accumulated or concentrated at the surface is termed the adsorbate**,** while the material providing the surface is known as the adsorbent**.** The rate and efficiency of adsorption are influenced by several factors, including the chemical nature of the adsorbate, the properties of the adsorbent, the temperature of the system, the pH of the solution, and the surface tension of the waste stream.

In specialized cases, such as foam fractionation, surface-active agents are used to lower the surface tension and promote foam formation. This enhances the ability of bubbles to capture and concentrate certain contaminants, thereby increasing removal efficiency. Such techniques are particularly useful when targeting trace organic compounds or surfactants from aqueous systems.

11.3.11 Activated Carbon

Carbon adsorption is a widely used method for treating hazardous waste streams, based on the transfer of contaminants from liquid or gas phases onto the porous surface of activated carbon. Activated carbon, produced from materials such as coal, wood, nut shells, or petroleum residues and activated at 300–1000 °C, has a very high surface area (600–800 m^2/g), making it highly effective for adsorbing hydrophobic organic compounds and certain inorganic pollutants like arsenic, mercury, and chromium. The process is typically carried out in granular activated carbon (GAC) fixed-bed columns, usually operated in series for higher removal efficiency or in parallel to increase hydraulic capacity. Pretreatment is required to remove oil, grease, and suspended solids, as these reduce adsorption performance. Activated carbon adsorption is effective for volatile organics, halogenated compounds, hydrogen sulfide, heavy metals, and even radioactive gases. Once saturated, the carbon must be replaced or thermally regenerated, though regeneration requires complete destruction of sorbed chemicals to prevent secondary pollution. The technology is compact, reliable, and easily integrated into complex treatment systems, but its main drawbacks are high costs and sensitivity to influent quality.

11.3.12 Clay Treatment

A study was conducted to treat textile wastewater on a sandy site in a warm climate using locally available clay as an economical treatment medium, with the objective of reusing the effluent for irrigation. Experiments showed that the clay could adsorb trace and refractory organic matter as well as color due to its fine particle size (<0.002 mm), porous structure, and large surface area (up to 800 m^2/g), which provide significant adsorption capacity. Clay suspends easily as colloids because of its negative surface charge arising from lattice imperfections and isomorphic substitution. This charge allows interaction with cationic polyelectrolytes, which act as flocculation aids by binding colloids and promoting particle agglomeration through chemical bridging. The treatment process involved countercurrent clay washing of gravels, followed by sedimentation, coagulation, and flocculation, producing effluent that met environmental standards and was suitable for irrigating salt-tolerant plants.

11.3.13 Resin Adsorption

Resin adsorption is primarily used for removing organic chemicals from wastewater, while inorganic contaminants are generally removed using ion-exchange resins. Regeneration of the resins can be carried out with basic, acidic, or saline solutions, as well as with hot water or steam. The process can tolerate variations in feed pH and temperature; however, performance issues arise when suspended solids exceed about 50 ppm, as clogging may occur. In addition, strong oxidizing agents must be excluded from the waste stream to prevent resin degradation.

11.3.14 Glass Surfaces

Gold, platinum, and palladium can be selectively recovered from oilfield brine by passing the effluent through glass wool or beads, where the metals are deposited. The process is believed to operate through adsorption of metal ions complexed with sulfur, while other metals are largely unaffected. In practice, the metal-laden glass material is replaced approximately once a month and treated with aqua regia to dissolve and recover the precious metals. The economic evaluation indicates that the value of the recovered metals is typically 2.5 to 5 times greater than the processing cost, making the method economically attractive.

An additional advantage of this technique is its operational simplicity, since it requires minimal on-site handling and can be readily integrated with existing brine treatment facilities. Furthermore, by targeting high-value metals in dilute concentrations, the process provides a sustainable route for resource recovery from waste streams, reducing the reliance on conventional mining. This approach not only generates economic benefits but also contributes to environmental protection by lowering the metal content in discharged brines.

11.3.15 Reverse Osmosis

Reverse osmosis is the movement of solvent across a semipermeable membrane from a dilute to a concentrated solution, but under applied pressure greater than the osmotic pressure, the net flow is reversed. This forces water from the concentrated side to the dilute side, leaving behind impurities and allowing relatively pure water to be collected. While some solute molecules may permeate the membrane, the rate is much slower compared to water. RO systems are particularly effective for separating ions and small molecules from water.

Reverse osmosis is widely applied to reduce dissolved solids, both organic and inorganic. In hazardous waste treatment, its use is generally limited to polishing low-flow streams containing highly toxic contaminants. The technique is highly effective for removing high molecular weight organics, multivalent ions, and charged species, while univalent ions are less effectively removed. Advances in membrane technology now allow partial removal of low molecular weight organics such as alcohols, ketones, aldehydes, and amines.

RO membranes are susceptible to chemical attack, fouling, and plugging. Extensive pretreatment is often required, including removal of oxidizing agents (e.g., iron and manganese salts), filtration of suspended solids, adjustment of pH (4.0–7.5), and elimination of oil, grease, and other film-forming materials. Organic fouling from biomass growth is common but can be controlled by prechlorination, addition of biocides, or activated carbon pretreatment. On-line monitoring of pH, suspended solids, and organics is often necessary for reliable operation.

The semipermeable membrane is the most critical element in RO design. A well-designed system must ensure:

a) Minimum concentration polarization (low buildup of solutes at the membrane surface).

b) High packing density (large membrane area per unit volume of pressure module).

c) Tolerance to particulates and ease of cleaning or replacement.

d) Adequate mechanical support, effective seals, and operational durability.

RO systems are highly sensitive to feedwater quality. High concentrations of organics can dissolve or damage the membrane, while even moderate levels may promote biological growth. Harsh operating conditions, such as high pressure (400–600 psi), elevated temperatures from pumping friction, and high osmotic pressures, significantly reduce membrane life. The reject stream typically accounts for 10–25% of the feed volume and requires safe handling as a potentially hazardous waste.

Although reverse osmosis is effective for dissolved solids removal, its costs are dominated by membrane modules and antifouling measures. More than 85% of equipment costs and nearly 75% of operation and maintenance costs are attributed to antifouling chemicals. RO units can be operated in series or parallel to handle variations in flow and contaminant concentration, providing flexibility, but their long-term reliability remains a concern in hazardous waste applications.

11.3.16 Soil Scrubbing

Solvent extraction is a basic separation method that relies on the selective removal of chemicals using the ability of a specific solvent to dissolve and separate targeted compounds from a mixture. In environmental applications, soil scrubbing or solvent extraction is widely employed for the leaching of organic and inorganic pollutants from contaminated soils.

Studies on the extraction of organic pollutants from oil shale using water as the solvent indicate that internal diffusion is the most likely rate-limiting step. Since internal diffusion is a slow mass transfer process, organic contaminants may leach gradually, resulting in low but persistent pollutant levels in groundwater over extended periods.

Research by Chien on phosphate sorption and desorption demonstrated that desorption decreases with increasing temperature, highlighting the strong influence of thermal conditions on pollutant mobility. Other important factors include soil pH, particle size, pollutant mobility, and soil type. Lower pH values are known to enhance the extraction rate of heavy metals by increasing their solubility and mobility.

Soil column studies further reveal that the mobility of metals in soils generally follows the order: Cu > Zn > Ni > Cd**.** In addition, metal ions can be mobilized through complexation with inorganic anions, which facilitates their migration through soil systems.

11.3.17 Solvent Extraction

This process is particularly effective when one component of a mixture is insoluble in water while the others are water soluble. Repeated extraction is carried out by passing water through the mixture, allowing the soluble components to dissolve while leaving behind the insoluble fraction. The aqueous extract is then decanted and subjected to distillation to recover the solvent, thereby reducing the overall volume of the waste stream. However, this method is less applicable when water-soluble components are reactive, as unwanted side reactions may interfere with separation.

An important application of this technique is the removal of chlorinated hydrocarbons, including PCBs, from transformer oil**.** In this case, dimethylformamide (DMF) is used as the extraction solvent. In a subsequent step, water is employed to separate the PCBs from the solvent, after which the PCBs are destroyed by alternative treatment methods. This approach significantly reduces the need to transport large volumes of PCB-contaminated oil to specialized destruction facilities, thereby lowering costs and minimizing risk.

11.3.18 Air Stripping

Air stripping is a mass transfer process used to remove volatile contaminants from water or soil by transferring them into the gas phase. It is commonly carried out in four types of equipment:

- packed towers,
- cross-flow towers,
- coke tray aerators, and
- diffused or induced draft aeration basins

Packed towers use countercurrent flow of water and air to maximize contact, while cross-flow towers use fans to move air across the water path. Coke tray aerators allow water to trickle over trays, creating large surface area without the need for blowers, and aeration basins introduce air through diffusers, though with lower air-to-water ratios. Air stripping is effective for removing volatile organic compounds (VOCs) but requires pretreatment to remove suspended solids and may involve pH adjustment to enhance contaminant volatilization. Since it is often only partially effective, it is commonly combined with activated carbon adsorption, where the stripper removes volatile compounds and reduces the organic load on carbon, lowering regeneration costs and improving overall treatment efficiency.

11.3.18 Stripping with added Heat

Water contaminated with low-volatility compounds, such as methyl ethyl ketone, can be treated by air stripping after heating to about 140 °F (with higher temperatures required in colder conditions). Under these conditions, up to 99.995% of the contaminant can be removed. Pilot-scale tests on groundwater have demonstrated that a steam boiler with a steam–water heat exchanger, when coupled with a forced-draft stripping column, effectively facilitates this process. In operation, groundwater is pumped, heated, and then injected into the air-stripping column for treatment.

11.3.19 Water Decontamination by Air-Stripping / Carbon Adsorption

A packed system typically employs either a column or an induced-draft air stripper in combination with a conventional gravity-fed activated carbon adsorption unit. In this process, water enters at the top of the stripping column and flows downward while mixing with upward-moving air, resulting in volatilization of approximately 60–85% of the dissolved organic contaminants. The partially treated water then passes through an activated carbon bed, where residual contaminants are removed, providing final polishing. This method is widely applied for the treatment of process water, drinking water, and groundwater.

11.3.20 Evaporation / Distillation

Evaporation and distillation are the physical processes used for the treatment of hazardous liquid wastes, particularly those containing volatile organic compounds or high concentrations of dissolved solids. In evaporation, the waste stream is heated to vaporize water or other volatile components, thereby concentrating non-volatile contaminants into a reduced-volume residue. Distillation, on the other hand, involves controlled vaporization and subsequent condensation to separate and recover specific volatile constituents based on differences in boiling points. These processes are effective for reducing waste volume, recovering solvents, and producing cleaner effluents suitable for further treatment or reuse. However, they are energy-intensive and generate concentrated residues or still bottoms that require proper disposal. Applications include treating industrial process effluents, solvent recovery, and concentrating heavy metal or high-salt solutions.

11.3.21 Freeze-Crystallization

Freeze–crystallization is a separation process that relies on freezing water or other solvents in a waste stream to form nearly pure ice crystals, leaving contaminants concentrated in the unfrozen liquid phase. As water freezes, most dissolved salts, heavy metals, and organic pollutants are excluded from the crystal lattice, producing a purified solid phase (ice) that can be melted to recover clean water. This method is especially effective for treating high-salinity or high-strength industrial wastes where conventional evaporation or biological treatment is not feasible. It operates at low temperatures, avoiding the volatilization of hazardous organics and minimizing energy input compared to thermal evaporation, particularly in cold climates where ambient conditions assist the process. However, the technology faces challenges such as ice–contaminant entrapment, handling of concentrated brine, and the need for efficient separation of ice crystals from the waste liquor. Applications include treatment of industrial brines, radioactive wastewaters, and recovery of usable water from saline or toxic streams.

11.3.22 Foam Evaporation

Foam evaporation is a thermal treatment method that utilizes the large surface area generated by foaming to enhance the evaporation of water or volatile components from liquid hazardous wastes. In this process, air or steam is introduced into the waste stream to create a stable foam layer, which significantly increases the air–liquid contact area and accelerates evaporation under controlled heating. As the water evaporates, contaminants such as dissolved solids, heavy metals, and refractory organics become concentrated in the residual liquid or sludge. This method is particularly suited for wastes with high concentrations of dissolved or suspended solids, oily wastes, and certain chemical effluents where conventional evaporation is inefficient. Foam evaporation offers advantages such as reduced energy consumption compared to simple surface evaporation, the ability to handle viscous or surfactant-rich wastes, and compatibility with downstream treatment processes like incineration or solidification of the concentrate. Limitations include foam stability control, scaling or fouling of equipment, and the management of concentrated residues.

11.3.23 Evaporation

Evaporation is a process in which the aqueous phase of a waste stream is removed by heating the solution to dryness, leaving behind a concentrated slurry or solid cake. A related process, fractional distillation, applies the same principle but separates components based on differences in boiling points. This allows recovery of one or more liquid constituents from a mixture, and the technique is not limited to binary systems; it can be applied to multicomponent solutions. Common applications include waste oil separation, solvent recovery, and concentration of wastes for final disposal**.** Evaporation can also be used to recover dissolved solids in a more manageable form. The major limitation of this technology is its high energy demand, with as much as 90% of operating costs attributed to the steam source. However, both operating and capital costs benefit from economies of scale, as larger systems generally achieve lower unit costs and more efficient maintenance.

11.3.24 Magnetic Separation

Magnetic separation is a physical treatment process that uses magnetic fields to remove or recover ferromagnetic and paramagnetic materials from waste streams. The process is particularly useful for separating metallic contaminants such as iron, nickel, cobalt, and their alloys from soils, sludges, incinerator ash, or industrial effluents. In operation, waste is passed through magnetic separators—such as drum magnets, belt magnets, or high-gradient magnetic separators—that attract and retain magnetic particles while allowing non-magnetic materials to pass through. This technique can be applied either as a primary treatment step for bulk removal of metals or as a polishing step to enhance the quality of treated material.

The advantages of magnetic separation include simplicity of design, relatively low operating costs, and the ability to recover valuable metals for recycling. Limitations arise when dealing with very fine particles, weakly magnetic contaminants, or wastes with high moisture or organic content, which can reduce separation efficiency. Typical applications include treatment of incinerator residues, contaminated soils, foundry sands, and certain industrial process sludges.

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Unit 12: Hazardous Waste Treatment Practices II: Chemical Methods

Unit Structure

12.0 Learning Objectives

After completion of this unit, the leaner would be able to:

- Explain the various chemical methods for hazardous waste treatments
- Explain the advantages and disadvantages of the various physical treatment methods

12.1 Introduction

In the previous unit, you have studied the various physical processes conducted to treat hazardous waste. In this unit you will learn the kind of treatments which involve the use of chemicals and thus chemical reactions to alter the nature of hazardous wastes. Such methods are known as chemical treatment methods.

In the chemical treatment methods, the reactions may either enhance separation or filtration processes, or completely destroy the harmful components. However, sometimes the byproducts still remain hazardous, though they may be converted into a form that is easier to handle, process, or dispose of. Among the various chemical methods following are important:

- Neutralization
- Calcination
- Ion exchange
- Oxidation
- Reduction
- Ozonation,
- Electrolysis

Although chemical methods are very effective, there are certain limitations which include the poor solubility of certain metals, the presence of impurities in the waste that may hinder reactions, and the risk of producing equally harmful byproducts.

12.2 Neutralization

Neutralization is among the most basic and widely applied detoxification processes, involving the addition of acids or bases to adjust the pH of a waste stream. Typically, neutralization systems employ multi-compartment basins constructed from concrete and lined with acid-resistant brick or protective coatings. Mixers are installed in each compartment to optimize basin size, while stainless steel plates beneath the mixers minimize corrosion damage. Flow distribution is managed through inlet baffles, and effluent baffles are used to prevent foam carryover into receiving streams. This process is versatile and applicable to nearly all waste streams requiring pH adjustment. It is commonly implemented before biological treatment since microorganisms are highly sensitive to pH fluctuations and operate optimally within a 6–9 pH range. Neutralization is also mandatory before the discharge of treated wastewater into natural water bodies. Additionally, it serves as a pretreatment for advanced chemical processes, including carbon adsorption, ion exchange, air stripping, wet air oxidation, and chemical oxidation–reduction. Beyond these applications, neutralization is effective in breaking emulsions, precipitating certain inorganic and organic materials, and regulating reaction rates in processes such as chlorination.

The selection of an acidic reagent for neutralizing alkaline wastewater typically involves a choice between sulfuric acid and hydrochloric acid. Sulfuric acid is more commonly used owing to its relatively low cost, while hydrochloric acid, though more expensive, offers the advantage of producing soluble reaction products. For neutralizing acidic waste streams, the caustic reagents most often considered are sodium hydroxide and various lime compounds, with ammonium hydroxide occasionally employed.

Several factors govern the choice of the most appropriate reagent, including purchase cost, neutralization capacity, reaction rate, ease of storage and feeding, and the nature of the neutralization byproducts. Despite its higher cost, sodium hydroxide is frequently preferred due to its uniformity, ease of handling, rapid reaction with acids, and the solubility of its end products. Lime materials, although inexpensive, necessitate more complex handling and reaction systems and are associated with higher capital and operational costs. Furthermore, the neutralization of strong acids by sodium hydroxide occurs almost instantaneously, whereas lime-based reactions are considerably slower. This limitation may be reduced through strategies such as operating at a relatively high end-point pH, ensuring effective mixing, and employing slurry feeding rather than dry feeding. The process is reliable, particularly when integrated with pH monitoring systems that allow for automated control of reagent dosing, thereby ensuring effective neutralization while minimizing worker exposure to hazardous chemicals.

Fundamentally, neutralization is a chemical reaction between an acid and a base that typically produces harmless ions. A range of effective neutralizing agents are available, including carbon dioxide, sodium bicarbonate, calcium hydroxide, calcium carbonate, calcium oxide, and sodium hydroxide. However, certain neutralization reactions can be highly exothermic or violent, with the potential to release explosive gases, highlighting the importance of proper design, monitoring, and safety measures during operation. Thus, while neutralization is an essential and versatile treatment process, its implementation must account for both process efficiency and hazard prevention. Although it is quite effective yet it also carries certain risks that must be carefully managed. The process can produce air emissions, including toxic gases such as hydrogen sulfide, if sulfide salts are present in the waste. In order to minimize emissions, feed tanks should be fully enclosed to prevent the release of acid fumes, and adequate mixing must be provided to dissipate the heat of reaction, particularly when treating concentrated wastes. For safety, process controls should ideally be operated remotely. In some cases, specific reagents offer added benefits; for example, phosphoric acid, though not a strong acid, may be used in combination with stronger acids when subsequent biological treatment requires phosphorus supplementation. Likewise, ammonium hydroxide may be applied where nitrogen supplementation is needed.

12.3 Oxidation Reduction

12.3.1 Oxidation

Oxidation reactions involve electron transfer in which at least one reactant increases in oxidation state while another decreases. In chemical oxidation, the target contaminant is oxidized to a less harmful or more manageable form. For example, under alkaline conditions, potassium permanganate ($KMnO_4$) oxidizes cyanide (CN^-) to cyanate (CNO^-) while permanganate is reduced to manganese dioxide (MnO_2). A balanced molecular equation (using sodium cyanide and potassium permanganate) is:

$$3NACN+2KMnO_4+KOH \rightarrow 2MnO_2(s)+3NaCNO+2KOH$$

$$(\text{Ionic form } 3CN^-+2MnO_4^-+H_2O \rightarrow 3CNO^-+2MnO_2(s)+2OH^-)$$

Chemical oxidation is a widely used process for treating hazardous wastes, employing oxidizing agents such as potassium permanganate, hydrogen peroxide, hypochlorites, and chlorine gas. It is particularly effective for detoxifying cyanide, treating dilute organic waste streams, and serving as a pretreatment step to make refractory compounds more amenable to biological degradation. However, its limitations include incomplete oxidation—often due to oxidant concentration, pH, or the formation of stable intermediates—which can sometimes generate more toxic byproducts. Chemical oxidation is also less suitable for high-strength or complex wastes, as strong oxidants are non-selective and may require large dosages to treat target compounds, with some, like permanganate, decomposing in the presence of solvents. Despite these challenges, the process requires only simple equipment, such as contact vessels with agitation, storage tanks, metering systems, and basic monitoring instruments, making it a practical treatment option under appropriate conditions.

Oxidation processes are capable of converting toxic materials into less harmful forms, however, it also poses significant operational and safety challenges such as the strong oxidizing reagents can react violently with readily oxidizable substances, necessitating careful dosing in small quantities to avoid explosion. The use of oxidants also carries inherent risks, as many treatment chemicals are themselves hazardous and must be handled with strict adherence to safety guidelines. Additionally, oxidation can sometimes lead to the formation of undesirable byproducts; for instance, chlorine treatment may generate bio-resistant and odorous compounds that are more toxic than the original waste. Consequently, although oxidation offers an important means of detoxification, its application to hazardous waste treatment has been limited.

So far as the requirements of equipments are concerned, they are relatively simple consisting of storage tanks, measuring devices, and agitated contact vessels. The selection of an oxidant for hazardous waste treatment depends on its effectiveness, cost, ease of handling, and compatibility with the treatment process, with commonly used agents including ozone, hydrogen peroxide, potassium permanganate, chlorine or hypochlorites, and chlorine dioxide, while oxygen requires catalysts to be effective. Care must be taken, as chlorine can react with low molecular weight hydrocarbons to form potentially carcinogenic byproducts. Process conditions strongly influence performance: higher temperatures generally accelerate reaction rates, and pH is critical, as seen in the oxidation of cyanide to cyanate by permanganate, which is efficient at pH ≥ 12 but ineffective below pH 6. Residual oxidants must also be removable from the treated stream; for example, insoluble manganese dioxide formed from permanganate under alkaline conditions can be removed by sedimentation.

Ozone is one of the cleanest oxidizing agents since it quickly breaks down without leaving harmful residues. However, its poor solubility in water and short life make treatment design difficult, often requiring deep tanks and costly generation equipment. Other oxidants like hydrogen peroxide and concentrated perhydrol are also used. Photochemical oxidation, although slow, is applied when chemical reactions could be hazardous. In industries like electroplating, redox processes are mainly used to reduce toxic chromium. Strong oxidants such as chlorine dioxide and potassium permanganate are effective against certain pesticides, while sodium borohydride is used to reduce metals like mercury, lead, and silver.

12.3.2. Chemical Reduction

Chemical reduction involves adding a reducing agent that lowers a substance's oxidation state—making it less toxic, less soluble, or easier to handle. For instance, sulfur dioxide can convert harmful hexavalent chromium (Cr^{6+}) into the less dangerous trivalent form (Cr^{3+}); sulfur itself becomes oxidized in the process. Common reducing agents include sulfur-based compounds (such as sodium bisulfite, metabisulfite, and hydrosulfite), sulfur dioxide, and reactive metals like iron, aluminum, and zinc. This process is widely used to detoxify chromium, mercury, and lead. The equipment needed is straightforward: tanks for chemicals and waste, metering pumps, mixing vessels with agitators, and monitoring instruments (like pH or ORP meters) to ensure the reaction completes. Recent research has demonstrated even more efficient methods—such as sodium thiosulfate combined with lime and fly ash, which achieved 99% irreversible reduction of Cr^{6+} in contaminated soils at low doses and novel systems using two-component reducing agents like thiourea dioxide and monoethanolamine that work effectively under alkaline conditions and yield neutral, non-polluting byproducts. These findings showcase that chemical reduction remains a cost-effective, reliable, and increasingly refined way to treat heavy-metal contamination.

12.4 Hydrolysis

Hydrolysis is a highly effective and reliable method for breaking down organophosphorus and carbamate pesticides and can be driven by acids, enzymes, or microbes. Enzymatic hydrolysis—often using enzymes like organophosphorus hydrolase (OPH or phosphotriesterase) and organophosphorus acid anhydrolase (OPAA)—is the cleanest and often the most efficient option. These enzymes, many of which are metalloenzymes encoded by genes like *opdA*, rapidly degrade a wide range of pesticides and even some nerve agents. For instance, the OpdA enzyme, when boosted with cobalt, can hydrolyze chlorpyrifos, diazinon, malathion, and others. Another enzyme, highly effective against nerve toxins, is OPAA, which is durable under salt and heat and is being explored for detox applications. Beyond enzymes, soil hydrolysis of compounds like urea still follows classic kinetics: early work by Vlek and Carter found zero-order behavior under uniform conditions, with rates slowing linearly as temperature or moisture drop and stalling with extreme heat or waterlogging. More recent studies confirm that urea hydrolysis often fits first-order models better under varied conditions and have developed improved mathematical models that accurately forecast reaction rates by accounting for temperature and application rate. These findings—including enhanced enzyme variants and refined predictive models—highlight how hydrolysis remains a practical, safe, and continuously improving approach to detoxifying harmful organic chemicals.

12.5 De-chlorination

Substrate dechlorination has proven to be an effective method for treating polychlorinated pesticides and hazardous chlorinated hydrocarbon wastes. Laboratory studies have shown that reagents such as t-butyl alcohol, tetrahydrofuran, and alkali metals (lithium or sodium) can achieve dechlorination, although these reactions produce hydrogen gas and involve flammable solvents like tetrahydrofuran, creating significant fire hazards. Over time, several industrial processes have been developed to destroy persistent pollutants including PCBs, 2,3,7,8-TCDD, and related chlorinated organic compounds. One innovative approach has been the use of quaternary ammonium dichloroiodide salt surfactants for soil cleanup, with benzalkonium dichloroiodide and cetylpyridinium dichloroiodide showing the most promising results. Other conventional methods include catalytic reduction with iron chlorides, catalytic oxidation with ruthenium tetroxide, and chlorolysis. More recent advances focus on safer and more scalable technologies, such as nanoscale zero-valent iron and palladium- or nickel-doped catalysts, which significantly enhance dechlorination rates under mild conditions. In addition, combined approaches that pair zero-valent iron with activated carbon or other supports have been shown to improve pollutant adsorption and contact efficiency, offering a practical pathway for large-scale remediation of soils and sediments contaminated with chlorinated organic compounds.

12.6 Chlorinolysis

Certain chlorinated hydrocarbons can be chemically transformed into carbon tetrachloride (CCl_4) when heated to about 500 °C under pressures around 200 atm. After the reaction, distillation separates the CCl_4, but the process can also generate hazardous byproducts such as hydrochloric acid and phosgene gas. Neutralization of acidic effluents produces sodium hypochlorite, which itself requires treatment before disposal. Another approach is hydrolysis, where organic wastes are broken down in the presence of water at high temperature and pressure, sometimes with acid, alkali, or enzyme catalysts. Hydrolysis can treat liquids, slurries, sludges, and tars, but the resulting products are not always predictable, and in some cases may be equally or more toxic

12.7 Ion Exchange

Ion exchange is a process in which toxic ions in water are removed by swapping them with harmless ions held on a solid ion-exchange material. Modern ion-exchange resins are synthetic polymers with attached ionic functional groups that carry exchangeable ions. These resins are chemically and structurally stable and are able to withstand a wide range of temperatures and pH conditions. They can be engineered to selectively target specific ions. Cation exchange resins, which have negatively charged functional groups, remove positively charged ions (cations) whereas anion exchange resins having positively charged groups, can remove negatively charged ions (anions). The process is reversible and is dependent on concentration. This means that the resins can be regenerated and reused multiple times. Ion exchange is widely applied to remove contaminants such as hardness (calcium, magnesium), heavy metals (lead, mercury, cadmium), nitrates, fluorides, sulfates, and other undesirable ionic species from water.

Ion exchange is used to remove a broad range of ionic species from water including:

- all metallic elements when present in soluble form either as anion or cation
- inorganic anions such as halides, sulfates, nitrates, cyanides, etc.
- organic acids such as carboxylics, sulfonics,
- organic amines when in sufficiently acidic and thus forms the corresponding acid salt

Ion exchange is a well-established method for removing heavy metals, hazardous anions, and some organics from dilute aqueous waste streams. In practice, it works best when contaminant concentrations are below 2,500–4,000 mg/L, as higher concentrations lead to rapid exhaustion of resin and thus, enhances regeneration costs. Suspended solids should be kept under 50 mg/L to prevent clogging, and the feed must be free of oxidants to avoid resin damage. For streams containing both organics and inorganics, hybrid systems with sorptive resins in the lead beds and ion-exchange resins in the final beds can broaden the range of contaminants removed. Ion exchange units are compact, energy-efficient, and commercially available, making them practical for field applications. Start-up and shut-down are straightforward, and systems can be operated manually or automatically depending on waste variability. Manual operation is often preferred for hazardous waste sites where contaminants vary, while automatic operation suits consistent waste streams with proper monitoring equipment. Flexibility can be increased by arranging multiple columns in series, which extends resin life, or in parallel, which maximizes flow capacity. Overall, ion exchange is a reliable and versatile treatment technology, provided that feed water quality is controlled and resin exhaustion is carefully monitored.

In ion exchange treatment, careful attention must be given to the disposal of spent regenerant solutions, as they often contain concentrated toxic contaminants. Equally important is the proper selection of regeneration chemicals, since incompatibility can create hazardous by-products—for instance, using nitric acid to regenerate a resin containing ammonium ions produces ammonium nitrate, an explosive compound. The process itself is a specialized form of adsorption, in which ions are electrostatically bound to charged functional groups on synthetic resins. These resins are classified as cation exchangers (acidic) or anion exchangers (basic) and can be regenerated by flushing them with strong solutions of appropriate counter-ions, allowing reuse in subsequent treatment cycles.

12.8 Ozonation

Ozone is an extremely powerful oxidizing agent, but because it is unstable and cannot be shipped or stored, it must be generated on-site. It is considered economically competitive for the treatment of dilute waste streams, particularly aqueous solutions or gaseous waste streams with less than 1% oxidizable content that contain hazardous compounds. However, ozone treatment is generally unsuitable for slurries, tars, and sludges, or for highly concentrated oxidizable liquids. Since ozone itself is toxic, strict precautions must be taken during its production and application.

12.9 Photolysis

Photolysis is a photochemical process that degrades TCDD, PCD, and other polychlorinated organic compounds utilizing sunlight or ultraviolet rays. It has been established through experiments that the ultraviolet (UV) stability of TCDD is greatly reduced, and the natural degradation process is accelerated in the presence hydrogen donors. Olive oil has proven to be a suitable hydrogen donor.

12.10 Electrolytic Recovery of Zinc from Metal Finishing Rinse Waters

Electrolytic recovery is a method used to remove and recycle metals from wastewater. In this process, an electric current is passed through water containing dissolved metal ions. The metal ions, which carry a positive charge, are attracted to negatively charged cathodes, where they form a solid metal layer that can later be collected. This technique has been used for over a century to recover valuable metals such as gold and silver. Today, it is also being applied to recover fewer precious metals from industrial wastewater, especially dilute rinse waters, making it a useful tool for both resource recovery and pollution control.

Dilute rinse waters present challenges for electrolytic recovery due to cathode polarization. As metal plating progresses, ions near the cathode are rapidly consumed, forming a depleted boundary layer. This reduces ion diffusion and slows deposition, causing low recovery efficiency. To overcome these issues, strategies include lowering current density, modifying solution chemistry and temperature, or agitating the electrolyte. Walker and Holt studied zinc recovery from dilute zincate solutions and found that operating at lower current density with vigorous agitation was more efficient than using high current density. In further experiments, they showed that ultrasonic agitation improved mass transfer, reduced polarization, and allowed higher current densities with better efficiency, thereby increasing the overall metal deposition rate.

Weymearsch developed a polyacrylate cell to study the electrodeposition of zinc at high current densities. The cell was designed to produce turbulent flow between parallel electrodes. The results of this showed that zinc deposition could occur at current densities as high as 350 Amp/sqm. Cathode polarization can also be minimized by employing high cathode surface areas.

12.11 Electro-dialysis

Electro-dialysis combines membrane separation with an electric field to selectively transfer ions across ion-exchange membranes, producing two streams: a treated dilute stream and a concentrated brine. It is particularly suitable for aqueous waste streams containing 1,000–5,000 ppm inorganic salts, yielding a dilute stream of 100–500 ppm and a concentrated stream up to ~10,000 ppm. Applications include plating wastes, rinses, acid mine drainage, and sulfite liquor recovery, though small amounts of toxic or flammable gases may be generated and require treatment.

Liquid Ion Exchange (LIX) is effective for removing dissolved inorganic species, including both free and complexed metal ions, and can handle higher concentrations than conventional ion exchange resins. It has proven reliable for treating pickling liquors and electroplating wastes. However, its efficiency is reduced by oxidants, surfactants, and suspended solids, and improper recovery of extractants or regenerant solutions can result in secondary pollution.

12.12 Electrolysis

Electrolysis is an oxidation–reduction process that uses electrodes to drive chemical reactions. During electrolysis, gases such as hydrogen, oxygen, or chlorine may be generated and require appropriate treatment. The method is mainly used in three ways:

- Cathodic reduction – plating out dissolved metals from wastewater.
- Anodic oxidation – destruction of toxic species such as cyanides.
- Electroflotation – separating oil and suspended solids by generating fine gas bubbles.

Electrolysis is not effective for dissolved organics, viscous wastes, or tarry liquids. The most common application is the partial removal and recovery of metals from waste streams for recycling or reuse. For example, in spent copper pickling baths, dissolved copper accumulates while acidity decreases. Electrolysis can simultaneously remove copper by placing it on the cathode and regenerate the bath acidity, while producing hydrogen and oxygen at the electrodes.

12.13 Destruction of Polychlorinated Biphenyl's (PCB)

Polychlorinated biphenyls (PCBs) are highly chlorinated aromatic compounds that resist biological and thermal degradation. One effective chemical method for their destruction is alkali metal reduction, in which PCBs are treated with sodium or sodium-based reagents.

The sodium reacts with the chlorine atoms in the PCB molecule, producing sodium chloride and leaving behind less harmful hydrocarbons.

$$C_{12}H_{(10-n)}Cl_n + nNa = C_{12}H_{10} + nNaCl$$

(where *n* = number of chlorine atoms per molecule).

Other methods include base-catalyzed dechlorination, reductive dechlorination with metals, advanced oxidation, and electrochemical oxidation. Among these, sodium-based and base-catalyzed dechlorination are widely applied, while electrochemical techniques are promising for future large-scale cleanup.

12.14 Cadmium Removal from Phosphoric Acid

Phosphoric acid from phosphate rock often contains cadmium, which must be removed for both safety and fertilizer quality. Traditionally, cadmium is extracted using heavy amine solvents and recovered via sodium sulfate regeneration.

Recent advances include custom-designed organic extractants like $C_{11}H_{18}N_2O$, which have achieved nearly 99 % cadmium removal under optimized conditions. Other improved systems employ TOPO-based solvents or Cyanex series extractants. Modern extraction approaches leverage refined experimental designs to optimize performance. Additionally, co-crystallization methods now offer cadmium removal while increasing phosphoric acid purity and reducing energy demands. These advances are making cadmium removal methods cleaner, more efficient, and industrially scalable.

12.15 Heavy Metal Removal with Chelating Agents

Chelating agents attached to solid supports (like silica gel) have long been used to remove heavy metals from industrial wastewater. Thanks to recent breakthroughs, these materials are faster, more durable, and more selective. New designs—such as NTA-functionalized silica for quick adsorption, acid-resistant polymers like 25DTF, and resins with advanced functional groups-offer significant improvements. These advancements enable safer, more efficient purification, flexible regeneration, and effective performance across diverse conditions.

12.16 Phenol Removal in Calcium Hydroxide Slurry

Phenol is a toxic, water-soluble organic pollutant often present in industrial effluents (e.g., from petroleum refining, coal gasification, coking plants, resin production, and pharmaceuticals). Separation of phenol and phenolic heavy hydrocarbons is done by derivatives from reacting with an equimolar amount of calcium hydroxide slurry to form a thermally stable half-salt of calcium hydroxide. In this process, calcium hydroxide reacts with phenol to form calcium phenoxide ($Ca(C_6H_5O)_2$), an insoluble salt that precipitates out of solution. The reaction can be represented as:

$$2C_6H_5OH+Ca(OH)_2 \rightarrow Ca(C_6H_5O)_2+2H_2O$$

The precipitated calcium phenoxide can be separated by sedimentation or filtration, thereby removing phenol from the aqueous phase.

12.17 Odor Destruction by Catalytic Oxidation

Odorous compounds such as hydrogen sulfide (H_2S), mercaptans, volatile organic compounds (VOCs), aldehydes, and amines are common in wastewater treatment plants, food processing, tanneries, pulp and paper industries, and petrochemical facilities. Catalytic oxidation is a promising method to eliminate these odors.

In this process, odorous gases are passed over a catalyst at moderate temperatures (150–400 °C). The catalyst lowers the activation energy required for oxidation, allowing the odorous compounds to be converted into odorless products such as carbon dioxide, water vapor, and inorganic salts (e.g., sulfur dioxide or sulfates).

$$2H_2S+ O_2 \xrightarrow{\text{Catalyst}} 2H_2O+2S \text{ (elemental sulfur)}$$

or, under complete oxidation:

$$2H_2S+ 3O_2 \xrightarrow{\text{Catalyst}} 2SO_2+2H_2O$$

Volatile organic compounds (VOCs):

$$CxHyOz + 3O_2 \xrightarrow{\text{Catalyst}} CO_2+H_2O$$

Summary

The chapter covers a range of chemical and electrochemical treatment processes for hazardous waste and industrial effluents, including:

- Oxidation methods (ozone, chlorine, catalytic oxidation)
- Ion exchange & liquid ion exchange
- Electrolysis & electrodialysis
- Electrolytic metal recovery
- Special cases like cadmium removal from phosphoric acid, PCB destruction, phenol removal, odor control
- Heavy metal removal with chelating agents

Oxidation processes use agents like chlorine, chlorine dioxide, ozone, hydrogen peroxide, or potassium permanganate to degrade hazardous organics. Ozone is one of the strongest oxidants but must be generated on-site. These methods are effective for dilute aqueous or gaseous waste streams, but not suitable for slurries or tars. Catalytic oxidation (including metal-activated manganese oxides) improves efficiency, lowers operating temperatures, and is widely used for odor control and VOC destruction.

Hydrolysis involves breaking down organics in the presence of water at high temperatures and pressures, often with acids, alkalis, or catalysts. It can treat aqueous/non-aqueous solutions, slurries, and tars. However, product outcomes are unpredictable and may generate additional toxic substances. Cost is often dominated by chemicals like chlorine.

Ion exchange removes toxic ions by replacing them with harmless ones on a synthetic resin. Cation exchangers attract positive ions, while anion exchangers capture negatives. The process is reversible, and resins can be regenerated, though regeneration chemicals must be selected carefully (e.g., nitric acid with ammonium ions may create explosive ammonium nitrate). Liquid ion exchange extends this principle to higher inorganic concentrations and can treat pickling and electroplating wastes, though it is sensitive to oxidants and surfactants.

Electrodialysis combines selective membranes with an electric field to separate salts from water. It can concentrate waste streams while producing a purified dilute stream. Typical applications include plating rinses, acid mine drainage, and sulfite-liquor recovery. It is effective for waste streams with 1000–5000 ppm salts but may generate minor toxic gases requiring further treatment.

Electrolysis uses electrodes and electric current to drive oxidation-reduction reactions. Applications include (a) plating metals onto cathodes, (b) oxidizing species like cyanides at the anode, and (c) electroflotation for oil/water separation. It is most common in recovering metals from wastewaters (e.g., regenerating copper pickling baths). It is not effective for viscous or tarry wastes. Electrolysis may also produce gases such as hydrogen and oxygen, which require safe handling.

Electrolytic recovery deposits metals from dilute rinse waters onto cathodes. It was first applied to gold and silver and now extends to base metals. Challenges occur at low concentrations due to cathode polarization, which slows metal deposition. Agitation, temperature control, and low current density help, while ultrasonic agitation has been shown to significantly improve efficiency and deposition rates.

Chelating agents immobilize and selectively bind heavy metals from wastewater or groundwater. They can be fixed onto silica gels or resins in packed reactors and later regenerated with acids. Recent advances include nanomaterial-supported chelators, magnetic nanoparticles for easy recovery, and biodegradable chelating agents to reduce secondary pollution. This method is especially relevant for treating effluents from plating, mining, and electronics industries.

Phosphate rocks naturally contain cadmium, which ends up in phosphoric acid. Cadmium can be removed using countercurrent liquid-liquid extraction with heavy amine hydrochlorides. Regeneration is achieved with sodium sulfate solutions. Modern methods also explore solvent extraction with environmentally friendly extractants and membrane-based separation to improve efficiency and reduce chemical usage.

PCBs are persistent organic pollutants. A common method is chemical dechlorination, where sodium compounds react with chlorine atoms, producing hydrocarbons and sodium chloride. Additional techniques include base-catalyzed decomposition, supercritical water oxidation, and catalytic hydro-dechlorination. These methods aim to fully destroy PCBs without generating toxic byproducts like dioxins.

Phenol, a common toxic organic in industrial effluents, can be treated using lime ($Ca(OH)_2$) slurry. The process converts phenol into calcium phenoxide, reducing solubility and toxicity. It is simple and cost-effective but generates sludge. Recent studies suggest coupling this method with advanced oxidation or adsorption to enhance removal efficiency.

Industrial odors (e.g., from sulfides, VOCs, or ammonia) can be treated by catalytic oxidation. Metal-activated manganese oxides perform comparably to precious-metal catalysts, offering cost-effective and durable alternatives. Catalysts accelerate the oxidation of odor-causing compounds into harmless CO_2 and water at lower temperatures, making the process energy-efficient and widely applicable in wastewater treatment plants, refineries, and chemical industries.

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Unit 13: Hazardous Waste Treatment III: Biological Methods

Unit Structure

13.0 Learning Objectives

At completion of this unit, the learner should be able to:

- Understand the principles of biological treatment methods
- Identify the applications and limitations of biological treatment methods
- Discuss the various biological methods of hazardous waste treatment
- Recognize the importance of monitoring and control in biological treatment systems

13.1 Introductions

Hazardous substances are found in solids, concentrated liquids, and both industrial and household effluent that has been diluted. Almost all of the wastewater from homes and a lot of the wastewater from factories can be handled organically. Biological methods have also been employed to treat municipal wastewater. These methods involve bacteria, algae, fungi, and other microorganisms to stabilize, absorb, change, or get rid of dangerous organic chemicals. During treatment, things like oil, chlorinated hydrocarbons, and heavy metals can be reduced. If the hazardous levels don't stop progress, considerable cuts can be made. There are several problems with this method, though. For example, it is sensitive to changes in the concentration of metal salts, the concentration of waste stream, and the pH level. Biological approaches can also make sludges that are hard to handle, soak up metals into both the sludge and the cellular biomass, and smell bad. In most cases, the sludge needs to be processed more. Biological techniques utilizing free or immobilized enzymes and intact cells are useful for hazardous waste treatment.

13.2 Biological Treatment

The basic purpose of biological treatment is to get rid of organic pollutants in the waste stream by breaking them down using bacteria. The most common type of biological treatment is aerobic biological activity, which happens when there is oxygen. There are many approaches to biologically treat water waste, such as conventional activated sludge, pure oxygen activated sludge, extended aeration, and contact stabilization. There are also fixed film systems, such as spinning biological contactors and trickling filters. In the traditional activated sludge method, liquid waste is put into an aeration basin, where it is aerated for a few hours. A population of microorganisms that are not in a solid state breaks down the organic molecules in the stream and creates new cells throughout this time. This method can be shown more clearly like when you mix organic matter with oxygen, you get carbon dioxide, water, and new cells.

$$\text{Organics} + O2 = CO2 + H2O + \text{new cells}$$

During aeration, new cells grow and generate sludge that settles out in a clarifier. Some of this sludge that has settled is transported back to the aeration basin to keep the microbes alive, and the rest is thrown away. The remaining sludge is very less, and it can be thrown away. The water that was cleaned up during the process is either thrown away or allowed to be cleaned again.

In the pure oxygen activated sludge process, pure oxygen or air with more oxygen replaces the air around it. This makes it easier for oxygen to circulate. Extended aeration uses microorganisms to break down trash and keeps it for longer than other methods. Contact stabilization happens when microorganisms that are attached to an inert medium, like rock or specially made plastic, come into contact with a stream of water for a brief time. The earliest trickling filter had a bed of rocks on which unclean water was poured. This made it possible for bacteria to grow a slime layer on the rocks that would break down the organics. At the same time, air moved in the opposite direction of the water flow to give oxygen. A biological tower is a kind of trickling filter. The material used to make the towers, which are usually between 16 and 20 feet tall, could be polyvinyl chloride (PVC), polyethylene, polystyrene, or redwood. Dirty water is sprayed on top, and as it runs down, air is sucked up through the slime layer on the media. The rotating biological contactor (RBC) is a basin with discs that spin around a shaft. The dirty water travels into the basin, where microorganisms that are adhered to the discs break down the organic waste in the water. Biological treatment is quite versatile because there are so many various ways to do it and the microorganisms that are used might change. Many organic materials can break down on their own, but the way they do it can be very diverse. When it comes to how well aerobic biological treatment works on organic materials, there are a few general things that can be said:

1. Non-aromatic hydrocarbons, particularly unsubstituted or cyclic variants, are preferred above unsubstituted aromatic hydrocarbons.

2. Alkenes and other compounds with unsaturated bonds are better than those with saturated ones.

3. In general, organic chemicals that dissolve in water break down more easily than those that don't. Biological treatment is usually better at getting rid of dissolved or colloidal contaminants since enzymes can destroy them more quickly. This is not the case for fixed film treatment methods, which tend to focus on elements that are suspended.

4. Functional groups change how quickly something breaks down. In general, alcohols, aldehydes, acids, esters, amides, and amino acids are easier to break down than alkanes, olefins, ketones, dicarboxylic acids, nitriles, and chloroalkanes.

5. Compounds with halogens are the least likely to break down naturally. Chlorinated aliphatic compounds are usually more resistant than their aromatic counterparts, but the exact number of halogens and where they are located are also very important.

6. Compounds that include nitro groups are also hard to break down, but they are usually not as resistant as compounds that have halogen groups.

Industrial waste may not be able to be broken down by biological treatment, although microorganisms can help break down a lot of compounds that are hard to break down. Heavy metals can make biological therapy less effective, although the biomass can also be prepared to handle higher levels of metals. Several additional things, such the amount of suspended particles, oil, and grease, changes in the organic load, and temperature, can also affect how well a biological treatment system works. When it comes to cleaning up hazardous waste sites, biological treatment methods are not as frequent as physical or chemical treatment methods like activated carbon, filtration, precipitation, or flocculation.

Biological treatment can handle a wide range of organic materials well, but it has certain problems when it comes to dealing with hazardous wastes. Sudden loading of toxic compounds can slow down this process, and if the organisms need time to get used to the wastes, the process might take a long period. For complicated waste products, the detention time can be very long. But using cultures that are already used to hazardous wastes can cut down on both start-up and detention times by a lot.

The sludge produced by a biological wastewater treatment system could be dangerous because it can absorb and store poisonous and harmful elements that are already in the wastewater. If the sludge is dangerous, it must be thrown away according to the rules that are already in place.

When there is too much oxygen, bacteria turn organic molecules into carbon dioxide and water. This phase is very important for biological wastewater treatment because it lets microorganisms break down organic contaminants into less hazardous byproducts. Bacteria can grow well when there is too much oxygen, which helps break down organic substances quickly.

The treatment procedure is quite helpful since it reduces hazardous elements and high BOD compounds in the effluent by a lot, by 80–95%. Nonetheless, its implementation faces significant obstacles, including substantial capital and operational costs, extensive acreage needs, and susceptibility to sudden variations in water quality, pH, temperature, and oxygen levels.

13.3 Biological Treatment Methods

The following are the several biological ways to deal with hazardous waste:

- Biological Contactors That Are Activated and Rotating
- Activated Rotating Biological Contactors (RBCs)
- Getting Silver Back from Trash via Microbial Action
- Anaerobic Degradation for the Removal of Halogenated Aromatics
- Bacterial Action for Cleaning Up Groundwater
- Sludge that is active
- Lagoons with Air
- Activation of Soil
- Taking in plants
- Inoculation in the treatment of hazardous waste
- Method of composting
- Other Systems for Cleaning Up Groundwater

13.3.1 Activated Rotating Biological Contactors (RBCs)

Activated Rotating Biological Contactors (RBCs) are a kind of biological treatment device that is used to clean up wastewater. RBCs use both mechanical and biological mechanisms to break down organic materials in wastewater. The system has a series of disks or cylinders that spin around and are usually constructed of plastic or metal. Some of these elements are found submerged in wastewater. Recent research has employed waste formulations derived from pesticide manufacturing to evaluate the efficacy of activated rotating biological contactors in the treatment of hazardous wastewaters.

The first time the Activated Rotating Biological Contactor (RBC) device was used to treat formulation waste, it followed the usual acclimatization procedure. This meant slowly adding the microbes to the waste stream so they could get used to the toxins and grow. During the acclimatization period, the microbes were able to generate the enzymes and metabolic pathways they needed to break down the complex substances in the formulation waste. By using this traditional method, the Activated RBC system was able to build a strong and stable biological community, which in turn made it possible to treat the waste stream quickly and effectively. The essential point is that the current biomass will adapt the way its enzymes work so that they can use the more frequent carbon source. The ARBC systems were first powered by dog food waste. This helped to grow a microbial population and make the systems stable.

It is generally known that activated rotating biological contactors (ARBC) can be used to treat dangerous organic wastes. ARBC systems were better in getting rid of organic matter than activated sludge systems, and they usually got rid of more dangerous pollutants like copper and pesticides. Research on heptachlor, chlordane, and endrin shows that biological treatment systems can work well even when these chemicals are present in amounts greater than 100 mg/l. Also, the treatment process cuts down on these chemicals by a lot. Two ARBC systems linked together got rid of around 85% of the raw waste COD (2000 mg/l) and about 95% of the heptachlor, chlordane, and endrin.

The Activated Rotating Biological Contactor (ARBC) system was better at processing industrial waste with a lot of organic content than a normal activated sludge system. The ARBC system got rid of 91% of the BOD5 from wastewater that wasn't mixed with anything else and had 600 mg/l BOD5. This is a lot better than the activated sludge system's 42% removal rate.

13.3.2 Silver Recovery from Wastes by Microbial Action

Some types of bacteria and fungi may take silver out of rubbish and store it. This process is often called "bioremediation" or "bioaccumulation." The microorganisms have special enzymes and proteins that let them stick to silver ions in the trash. After that, the cells take in the silver ions and store them. Pseudomonas and Bacillus are two species of bacteria that can do this, and Aspergillus and Penicillium are two forms of fungi. People usually locate these bacteria in regions where heavy metals have gotten into the environment, like mine tailings or places where industrial waste is dumped. Some microorganisms can get rid of metals like silver from dangerous waste because of this property.

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13.3.3 Removal of Halogenated-Aromatics Through Anaerobic Degradation

Halogenated aromatics, such as polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins (PCDDs), are persistent organic pollutants (POPs) that pose significant environmental and health risks. Anaerobic degradation is a fantastic approach to clean up the environment by getting rid of dangerous chemicals. There is no oxygen present when anaerobic degradation happens. Microorganisms use alternative electron acceptors, such sulphate, nitrate, or carbon dioxide, to break down organic matter. For halogenated aromatics, anaerobic degradation involves getting rid of halogen atoms and producing compounds that are less hazardous. Dehalobacter and other anaerobic bacteria are known for their capacity to remove halogens from PCBs and other compounds that contain halogens. Desulfitobacterium may also break down PCDDs and other aromatic compounds that have halogens in them. Geobacter is another kind of bacteria that might be able to break down PCBs and other contaminants by making them smaller. Temperature, pH (most anaerobic microorganisms do best in neutral to slightly alkaline pH conditions), electron acceptors (the availability of alternative electron acceptors, such as sulphate or nitrate, can affect degradation rates), and contaminant concentration (higher contaminant concentrations can slow down anaerobic degradation) are all factors that affect the efficiency of anaerobic degradation. Microorganisms isolated from lake sediments and sewage sludge are known to completely degrade certain halogenated aromatic compounds. These bacteria might be great at cleaning up the environment by getting rid of herbicides and maybe even polychlorinated biphenyls.

13.3.4 Groundwater Decontamination by Bacterial Action

Pollutants including pesticides, heavy metals, and industrial solvents can hurt people and ecosystems; hence pollution of groundwater is a big environmental problem. Using bacteria to clean up groundwater is a good concept because microorganisms can break down and modify pollutants on their own. This approach works because some kinds of soil bacteria can break down organic or halogenated chemicals. There are numerous methods that bacteria break down contaminants in groundwater. Aerobic degradation, for instance, uses oxygen to break down organic contaminants like pesticides and solvents used in industry.

Anaerobic degradation works best in places where there is no oxygen. It breaks down contaminants including heavy metals and chlorinated solvents. Enzymes and cofactors are widely used in metabolism to turn contaminants into less toxic substances.

In this process, sludge from a landfill or contaminated site that is full with bacteria is poured into a tank to be activated. There, air and nutrition help the germs break down faster. After this, the water goes through more breakdown in a settling tank before being returned back to where it came from. Pseudomonas, Rhodococcus, and Geobacter are some of the bacteria that can clean up groundwater. Pseudomonas can break down polycyclic aromatic hydrocarbons (PAHs) and other organic pollutants. Rhodococcus can break down chlorinated solvents and other halogenated compounds. Geobacter can make heavy metals like uranium and chromium less harmful.

13.3.5 Activated Sludge

A common biological strategy to clean up wastewater is the activated sludge method, which employs microorganisms to break down organic matter. An aeration tank mixes dirty water with air. This offers bacteria the oxygen they need to grow and devour organic matter, which they then transform into carbon dioxide, water, and biomass. After that, the effluent passes to a settling tank, where the biomass settles to the bottom. After that, it is taken out as activated sludge and sent back to the tank where it is aerated. This method is useful for cleaning up wastewater from cities and businesses because it works effectively, is adaptable, and doesn't cost much to set up. But it takes a lot of energy to aerate and pump, it doesn't handle shock loads well, and it needs skilled individuals to watch over it and adjust the process. The activated sludge process is still a very important part of treating wastewater, even with these issues. It is utilized in preparing food and drinks, as well as in cities and businesses.

13.3.6 Aerobic Lagoons

Aerobic lagoons are a type of wastewater treatment system that uses natural processes to break down organic waste in a controlled environment. These lagoons work like lakes and rivers do when they clean themselves, except they do it much faster. Aerobic lagoons are usually not very deep, with depths of 1 to 4 meters. Mechanical aeration systems provide oxygen to the microorganisms that break down the organic matter. When wastewater pours into the lagoon, microorganisms including bacteria, algae, and protozoa devour the organic materials. This turns the organic materials into water, carbon dioxide, and biomass. The aeration system gives the microorganisms the oxygen they need to grow, which makes the wastewater treatment more effective. Aerobic lagoons are widely used to clean up wastewater from cities, factories, and farms. They are quite good at getting rid of organic matter, fertilizers, and diseases. They have a number of good things about them, such being cheap to establish and run, easy to use, and having flexible designs. Aerobic lagoons do take up a lot of space, and elements like temperature, pH, and hydraulic retention time can change how effectively they perform.

13.3.7. Soil Activation

Soil activation is a new method for dealing with hazardous waste that harnesses the natural processes that happen in soil to alter and break down toxic compounds. This innovative method makes the soil better at breaking down pollutants by improving its biological, chemical, and physical properties. Soil activation can break down a wide range of contaminants by supplying nutrients to speed up chemical processes, stimulating the growth and activity of natural microbes, and adding specialist bacteria.

The first step in activating soil is usually to carefully look at the area to find out what kind of soil and contaminants are there. Then, the soil is prepared, which may mean treating it first to improve its physical, chemical, and biological features. Then, fertilizers, microorganisms, or chemical activators are given to the soil to assist get rid of the toxins. To make sure that the ideal circumstances for contaminant degradation are always there and to limit rebound, it is very necessary to keep an eye on and take care of things constantly.

There are many excellent things about soil activation for cleaning up hazardous waste. For example, it is cheap, can be done on-site, lasts a long time, and is healthy for the environment. Compared to more typical techniques of cleaning up, this method can save money. It also lets you treat the area where it is, which means you don't have to dig up and move dirt as much. Soil activation can also aid the environment in the long run by creating an ecosystem that can keep breaking down contaminants on its own. Soil activation can also be very useful for the environment by making the soil healthier, reducing the number of pollutants that drain into the water, and promoting ecosystem services. There are a lot of good things regarding soil activation, but there are also some undesirable things and limits. Soil activation may not work as well if the soil isn't the same throughout. It could also be hard to break down complex mixes of contaminants. Soil activation could not operate well on big regions that are very polluted or on sites with geometries that are hard to understand.

13.3.8 Vegetation Uptake

One way to deal with hazardous waste is to employ plants to clean it up, which is called phytoremediation. It uses plants to get rid of, break down, or trap pollutants in the ground and water. This green technology has been quite popular in the last few years because it is cheap, lasts a long time, and doesn't affect the environment too much. Plants can take in and break down pollutants in a number of ways, such as phytoaccumulation, phytodegradation, Phyto stabilization, and phytovolatilization. It is natural for plants to take in nutrients to clean up dirt. This implies putting crops in the ground that can absorb harmful pollutants. After that, the crops need to be collected and transferred to a place where they may be thrown away, which is commonly by burning them. This method usually only works on pollutants that are at the surface of the soil.

Absorbing vegetation has several benefits, like being cheap, lasting a long time, and not hurting the environment too much. This technology is often less expensive than more traditional means of mending items and can last for many years. Vegetation absorption is another non-invasive method that doesn't require a lot of excavating or disturbing the soil. This makes it an excellent alternative for dealing with dangerous waste. You can also use vegetation absorption to create green spaces and bring ecosystems back to life. This is excellent for the environment and makes things look better. Vegetation uptake has some good things about it, but it also has some bad things and restrictions. Choosing the right plant species for a specific contaminant and place can be problematic because soil and climate can make it harder for plants to take up pollutants. Also, vegetation uptake might not work effectively for mixtures of pollutants that are particularly intricate or that have a lot of them. Future research should concentrate on genetic engineering and plant breeding to develop plant species that have enhanced capabilities for pollution uptake and degradation. Scientists are looking for new ways to make the soil better and help plants grow because plants can only take in so much.

This includes putting things in soil and using fertilizers to help pollutants go into the ground and break down. Scientists are also working on making plants take in more nutrients so that they can be used on a broad basis to deal with dangerous waste. If these problems and limits are fixed, vegetation absorption could become a more useful and frequently used method for dealing with hazardous waste.

13.3.9 Inoculation in hazardous waste treatment

The inoculation strategy sends microorganisms into polluted soil or groundwater to break down and get rid of the poisons. This is how hazardous waste is treated. This plan is based on the idea that microorganisms can change dangerous chemicals into less harmful ones. Choosing the right microorganisms that can break down the pollutants in the hazardous waste is usually the first step in the inoculation procedure. You can discover these tiny living things in nature, like in water, dirt, or sediments. You can also change their DNA to make them better at breaking things down.

There are many ways to use the inoculation process, including to inoculate soil, groundwater, or a bioreactor. When you inoculate soil, you mix the unclean soil with microorganisms. Microorganisms are added to polluted groundwater in a process called groundwater inoculation. Bioreactor-based inoculation uses a controlled setting, such a bioreactor, to assist microorganisms grow and accomplish their duties better. The inoculation method has been proved to work for a multitude of bad chemicals, like heavy metals, chlorinated solvents, and petroleum hydrocarbons. But how well this treatment works depends on a number of things, such as the kind and amount of contaminants, the existence of the right microorganisms, and the state of the environment. pH, nutrient availability, oxidation-reduction potential, moisture levels, and how easily chemicals dissolve are some of the most important things that affect this process. Rittmann has shown that bacteria can't break down chemicals that don't dissolve in water. Some pollutants still don't have any recognized microbes that can break them down. We need to perform more research to find a lot of different microbes that can completely break down different kinds of harmful substances. Aerobacter has demonstrated its capability to transform approximately 70% of DDT and DDD within a single night. There have been a lot more research on how microbial communities can break down hazardous substances. It is very crucial to improve the soil's natural ability to break down harmful pollutants utilizing chemical and biological processes in order to provide the best circumstances. The pH, the best temperature for the process, the amount of carbon, nitrogen, and oxygen in the soil, and how toxic the contaminants are all affect how well these activities work. To create effective in situ therapy procedures, we need to learn more about how these factors affect people. These methods are usually cheaper and healthier for the environment, but they don't work as quickly and don't get rid of all the toxins.

13.3.10 Composting method

Composting is a good way to deal with organic waste that is full of oils, tars, and industrial sludges. It is the only biological therapeutic process that metals and other dangerous compounds don't affect. Composting is a way to remediate hazardous waste by letting microorganisms break down organic hazardous waste in a regulated way, usually with oxygen. Putting the garbage in windrows and moving the piles often to let air in is part of the composting process. It can take almost a year for the body to digest food. Leachate can be a concern if the metals aren't absorbed, and unpleasant smells can come up during digestion. This process changes the dangerous waste into a stable, humus-like substance that is less harmful and easier to handle. Composting can be used to get rid of a wide range of dangerous pollutants, such as pesticides, industrial sludges, and soils that have been poisoned. To make the composting process better, people usually mix the dangerous waste with bulking agents like straw or wood chips. This helps with aeration and lowers the amount of moisture.

There are many techniques to compost, such as windrow composting, aerated static pile composting, and in-vessel composting. When you do windrow composting, you put the trash mixture into long, narrow rows and turn them every so often to keep the air flowing. Aerated static pile composting is putting the waste mixture in a pile and blowing air through it to keep the oxygen levels up. When you compost in a vessel, you put the waste combination in a container and control the temperature, moisture, and air flow. Composting can be a good way to get rid of hazardous waste that is good for the environment, but it needs to be watched and controlled closely to make sure it is safe and works well.

13.3.11 Other Groundwater Decontamination Systems

Polluted groundwater is cleaned up using a special hybrid approach. This approach uses a series of pumping wells to collect water from an aquifer that isn't clean. The water that is taken out is transferred to a biological treatment plant on the ground. This plant works like a typical activated sludge system, with an aeration tank and a settling tank for the sludge. The first tank gets air that has been cleaned and nutrients. Steam coils help maintain the temperature steady, which is good for microorganisms. This tank can also store microorganisms that have already changed to fit in. You can either toss away the settled biological solids or put them back in the treatment tank. The water that comes out of the settling tank still includes nutrients, dissolved oxygen, and bacteria in it. After that, injection wells or trenches put the cleaned water back into the polluted aquifer. Microorganisms begin to break down the pollutants as the oxygen in the wastewater is used up. There are air injection wells along the channel of the groundwater flow to make sure that the biological elimination process has enough oxygen to work. People have seen that hydrogen peroxide can swiftly clean up polluted groundwater right where it is. When air sparging alone didn't work, this approach got rid of remaining low-level gasoline contamination from an aquifer. Groundwater decontamination systems have worked well to clean up shallow aquifers that were polluted with dimethyl aniline, acetone, n-butyl alcohol, and methylene chloride.

Summary

This unit discusses about a lot of biological ways to clean up hazardous waste, like composting, inoculation, and plants taking up the material. Composting is a controlled approach for microorganisms to break down organic hazardous waste, usually with the use of oxygen. The inoculation method puts microorganisms into polluted soil or groundwater so they can break down and get rid of the poisons. Plants can get rid of, break down, or retain contaminants in soil and water through a process called phytoremediation, also known as vegetation uptake. These methods have several benefits, such as being cheap, lasting a long time, and not hurting the environment too much.

The section also looks at different ways to treat biological waste, like activated sludge, aerobic lagoons, and techniques for cleaning up groundwater. The activated sludge method uses microorganisms to break down organic materials in wastewater. Aerobic lagoons use natural mechanisms to break down organic materials in a regulated space. Air sparging and hydrogen peroxide treatment are two examples of groundwater decontamination methods that can clean up contaminated groundwater on site. These methods show promise for managing hazardous waste, but their success depends on a number of things, such as the type and amount of toxins, the existence of the right microbes, and the state of the ecosystem.

REFERENCE

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