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

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

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CLEAN TECHNOLOGIES

UTTARAKHAND OPEN UNIVERSITY

SCHOOL OF EARTH AND ENVIRONMENTAL SCIENCE

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Unit: 1 Technology for Development

Unit Structure

1.0 Learning Objectives

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

- Discuss about Environmental Problem and Technology
- Explain about Technology and Environment
- Describe about appropriate Technology for Sustainable Development
- Understand about the Transfer of Technology

1.1 Introduction

In a globalized society, state borders are less obvious, and political, economical, cultural, and social developments are more interrelated and have a wider impact. The impacts of globalization vary for every one of us. Accessibility to innovation and technology is now quick and simple. Globalization's enormous relevance is not absent from discussions on environmentalism. Globalization is a primary concern of environmental campaigners. The harm done to the ecosystem by the British Petroleum oil that leaked from one of its containers in 2010 is only one illustration of the danger that globalization provides to the environment. Since we have entered the era of resource wars, terms like climate change, deforestation, and pollution are only a few of the numerous, frequently used ones in international relations. Natural resources and the environment have a close connection to security, which has always been and always will be among the most divisive ideas in world politics. While some nations consume too much energy, others do not. The world's consumption levels have gotten so high that Earth is having trouble keeping up also with regeneration needed to sustain our high levels of consumption. Therefore, the international organizations that were established to safeguard the environment would need to reexamine their concerns and demonstrate a strong commitment to carrying out the decisions made in this direction.

1.2 Environmental Problem

In the global system, the environment is without a doubt the subject that is the most global and complex. The impact of climate change on the economy, the environment, and the environment itself is a major reason for concern for humanity. This necessitates taking action right away. The fact that we frequently experience disasters is well known. Disasters caused by climate change are occurring more frequently and with greater intensity. Several recent examples of disasters include hurricanes like Katrina in the United States, tsunamis in South Asia, earthquakes in Afghanistan and India, and typhoon Tokage in Japan.

Environmental pollution was not as bad as it is now, therefore worries were also minimal. Environmental movements have just recently, or one could say after World War II, become particularly active. We might also consider the possibility that the phenomenon of globalization, which has altered the architecture of the international system, is directly related to the growth of the environmental movement. Governments and citizens have become aware of the global and transnational implications of environmental challenges as a result of globalization.

There has been an increasing push for the use of international instruments as means for environmental preservation since the UN Conference on the Environment, which was held in Stockholm, Sweden in 1972. The protection of the world's climate system, which is a "common resource" due to the catastrophic effects of climate change brought on by global warming, is everyone's responsibility. A multinational agreement like the Montreal Protocol, which was implemented in 1987 to safeguard the ozone layer, is the only way to control this. There are two significant accomplishments in this area that the UN may be proud of. Both the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) fall under this category.

a) **UNFCCC:** In order to protect the climate system through the passage of a treaty, UN started negotiations in 1991. An international environmental pact known as the UNFCCC was established on May 9, 1992. On June 3–14, 1992, during the Earth Summit in Rio de Janeiro, it was made available for signing. After that, it became effective on March 21, 1994, when a significant number of nations ratified it. The goal of the UNFCCC is to stabilize atmospheric greenhouse gas (GHG) emissions at a level that would guard against harmful human intervention with the climate system. The concept of shared but distinct accountability has been adopted by the convention. For each nation, this framework has established non-binding caps on greenhouse gas emissions. The framework doesn't mention any enforcement practices. However, the framework defines how specific international treaties, often known as conventions or agreements, may be established to determine and specify additional action toward the primary goal of the UNFCCC. As of November 2019, there are 196 Parties (States) to the UNFCCC, including the European Union. The convention has broad legitimacy because membership is almost universal. Conferences of the Parties (COP) are yearly gatherings of the parties to the convention where they review the status of the fight against climate change and, if necessary, establish new policies. The Convention's top decision-making body is the COP. There have been 24 COPs to date; the most recent took place in Katowice, Poland, in December 2018. The North-South division was promoted by the UN's pursuit of an international agreement on this topic. These nations, which include affluent nations and transitional economies like Russia and Ukraine, are now collectively referred to as Annex I countries. Non-Annex I countries are a category of developing nations. The signatory nations were tasked by UNFCCC with compiling national-level assessments of GHG emissions.

b) **Kyoto Protocol:** In Kyoto, Japan during the third round in December 1997, the specifics of protocol were agreed. The Kyoto Protocol was made available for signature in 1998, but it wasn't until February 16th, 2005 that it actually went into effect. 2012 saw the end of the initial commitment period. The ratification of this protocol was rejected by the USA and Australia. The protocol had been ratified by thirty-eight industrialized nations, or Annex I countries. They were required by law to reduce their GHG emissions by 5.2 percent of their total base-level emissions by 2012, the conclusion of the first commitment period. The developing nations who are not parties to Annex I of the Protocol have also ratified it, but they are not subject to any emissions restrictions. In order to cut back on GHG emissions, they were supposed to work together. There were three set forth in the Kyoto Protocol to the UNFCCC. The mechanisms of flexibility to improve collaboration and help parties achieve their emission reduction goals within a certain time frame.

(I) Emissions Trading (ET): In accordance with Article 17 of the treaty, Annex-I nations are permitted to exchange emissions reductions or sell credits toward their commitments.

(II) Joint Implementation (JI): The Protocol's Article 6 permits cooperation between Annex I countries on initiatives that would lower carbon emissions. Such initiatives give the participating countries emission reduction credits.

(III) The Clean Development Mechanisms (CDM): Furthermore, Article 12 offers incentives to businesses planning to invest in programmes that aim to lower emissions in developing nations. Certified Emissions Reductions are the name given to the credits generated by such initiatives (CERs). The host nation and the company that made the investment in the project split these credits. The agreement prefers "Market-based Instruments" above the Command- and-Control intervention regime to handle the emission levels climate change challenge.

c) The first two mechanisms concentrated on Annex I developed countries. Both emission trade and program of action are anticipated to be economically and effectively successful in achieving the specified level of GHG emissions in a specific timeframe. The CDM focuses on partnership and cooperation between developing and developed countries. This mechanism anticipates that in addition to governments in developed nations, multinational corporations will also be encouraged to support the efforts of developing nations by supporting third world countries through appropriate projects, such as projects related to afforestation, technology transfer, and adaptation. The 1990 benchmark levels for Annex I country membership in the Kyoto Protocol and their commitment to GHG reductions were established using the levels of national GHG emissions identified by all UNFCCC signatory parties. The Annex I countries each year submit updated inventories of their GHG emissions. The Doha Amendment, which was added to the Protocol in 2012 to cover the years 2013 to 2020, had not yet come into effect as of December 2015 since only 31 nations had ratified it, less than the necessary 144.

d) **Paris Agreement:** The Paris Agreement was unanimously adopted on December 12, 2015, at the 21st Conference of the Parties of the UNFCCC, which was held in Le Bourget, close to Paris. The Paris Agreement became effective on November 4th, 2016. The agreement had been ratified by 195 UNFCCC members as of March 2019, and 187 more had joined as parties.

The major goal of this agreement is really to improve the international response to the risk posed by climate change by limiting the rise in global temperature this century to no more than 1.5 degrees Celsius and continuing efforts to keep it below 2 degrees Celsius. The accord also seeks to improve nations' capacity to deal with the effects of climate change. According to UNFCCC, in order to encourage action by developing nations along with the most vulnerable countries, viable investment flows, a new technological framework, and an improved capability building framework would be put in place.

Each nation is required by the Paris Agreement to decide, plan, and periodically report on the contribution that it contributes to reducing global warming. Each aim should surpass prior established targets, but no mechanism should compel a nation to set one by a particular deadline. US President Donald Trump declared his country's intention to leave the accord in June 2017.

According to the deal, the US can quit as early as November 2020, just before President Trump's current term as president comes to a conclusion. In reality, the United States has already implemented policy measures that are in conflict with the Paris Agreement.

Since trade is a crucial component of globalization, it directly affects the environment. Only via multilateral discussions, which were carried out with the assistance of the World Trade Organization, has globalization been made possible (WTO). Although it is not a major component of the WTO's mission, environmental protection has nevertheless sparked some interest among its member nations in sustainable development and environmentally friendly trading practices. When reading about the WTO, it is clear that many of its trade-related policies are in line with the preservation of the environment and the wise use of natural resources.

The WTO requires nations to protect people, animals, and plants and to conserve their finite natural resources as part of its green provisions. A further aspect of globalization that supports ecologically sustainable policy is regional trade agreements, which are distinct from the WTO. Environmental cooperation agreements are concurrently forced upon the nations who wish to join such regional agreements. Environmental impact studies must be conducted before signing any trade agreements, according to national rules that have been created by many EU member states.

1.3 A Technological Concept

The definition of technology is knowledge, which includes methods for creating, using, or manufacturing things. It is frequently associated with expertise in machinery and procedures, and is characterized as the capability to convert concepts into products and services that satisfy clients. Occasionally, it only alludes to a specific piece of equipment or method of production. The idea that technology solely exists in machines would be incorrect, despite the fact that machines are the apparent manifestation of technology.

There is "human ware," or the human abilities required to use that technology, as well as "techno ware," or the visible reality, such as machines. Technology also implies a "organ ware" or organizing structure. Additionally, there is "info ware," or the information that goes along with technology. A better way to define technology is as the systematic knowledge used in the production of a good, the implementation of a process, or the provision of a service. It can also be defined as the develop partnerships and professional know-how used to improve the performance or safety of a product, as well as to increase production or quality and lower costs.

1.4 Technology and Environment

Since the early 1970s, the following connection has represented the struggle for a sustainable future:

$$\text{Environmental impact (negative)} = \text{Population} \times \text{Standard of living} \times \text{Technology}$$

The environmental impact equation shown above is not complete. Technology doesn't have to be detrimental. In actuality, it can pave the way for a sustainable future. Three different sorts of technologies are widely acknowledged as having an impact on economic growth.

- Technologies that degrade the environment and consume a substantial amount of natural resources (T1).
- Environmentally friendly technologies that have minimal to no impact (T2).
- Environmentally friendly or environmentally beneficial technologies that use natural resources without causing severe long-term depletion (T3).

How can we increase the economic and social well-being of more people on the planet without harming the environment or exhausting the resources that new generations will require to ensure survival?

$$\text{Environmental impact} = \text{Population} \times \text{Affluence} \times \text{Technology}$$

Therefore, our task is to discuss the what, how, and underlying sciences of T2 and T3 technologies as well as the foundational science for which such technologies are based.

What

- What technologies do we wish to promote and advance?
- What technological advancements can truly assist society while still addressing human needs?
- What sort of study do we wish to support?
- What technologies are available for local development?

- Which technologies are most easily transferable to the areas of the job where they can be most effectively used?
- Which science do we want to investigate?
- **What technology will be helpful in the future?**

How

- How can the benefits of these technologies be delivered?
- How can we utilize technology to its fullest potential?
- How can local technology be improved and distributed?
- How can we remove the obstacles to such a technological transfer?

Perspectives

The following list includes some approaches for resolving the aforementioned problems:

- Industry must take the lead and innovate in order to transform sustainable development a reality. The industry plays an important role in ensuring sustainable growth because it is society's primary producer. It cannot see business and the environment as two distinct fields or as problems that must be balanced. The industry has the ability to make technological opportunities and solutions a reality.
- To achieve sustainable development, we must gradually alter how we conduct our business, and these adjustments must be made from the ground up. It takes a variety of distinct acts to create sustainable development because it is not a direct process. As an example of achieving gradual improvements toward the objective of sustainable development, the instance of DuPont may be cited here. Practically all industrial processes and products had to be rethought as a result. Every new product and process development process, as well as every manner it combined commercial expansion with environmental goals, needed to undergo a gradual adjustment in how it approached every facet of environmental preservation.
- Additionally, it forced the management to question the attitudes, ways of thinking, and deeds of every DuPont employee. The goal was to reduce all accidents, diseases, incidents, pollutants, and waste of resources—natural, human, or

financial—to zero in each and every action that was conducted. Over time, it has discovered that only one family, one manufacturing facility, one chemical process, one industrial product, one community, and one region can experience sustainable growth simultaneously.

- Sustainable development and long-term environmental conservation depend on a thriving economy. Only in the context of sustained economic growth and vitality will long-term environmental protection be possible. Local sustainability includes economic vitality. For a community to draw investments that create employment and revenue, it must be competitive in the areas of education, economy, and other factors. In order to achieve sustainability, economic development, environmental preservation, and robust social institutions must all be taken into consideration.
- There are numerous science and technology solutions that can promote economic growth and be in line with sustainable development, but pursuing them will require commitment from the business community and understanding from society. Some of these options include energy produced from renewable resources, sustainable agriculture using herbicides with low use rates or biotechnology, advanced materials that make communications quicker and easier based on recyclable resources, naturally secure and non-polluting manufacturing processes (zero waste), and others.
- Knowledge will soon replace labour, raw commodities, and money as the most valuable resource. Knowledge becomes the ultimate alternative, the main and perpetually renewable resource of an advanced economy, in an economy committed to sustainable development as it decreases the need for raw materials, labour, space, capital, and other inputs. An outstanding illustration is the Indian software sector. The most effective means of knowledge transmission become a significant challenge. Here, materials like fused silica optical fibers, optical switches, and wave-guides will play an increasingly important role in communications tools, increasing the simplicity, power, portability, and capability of information storage and manipulation while reducing the weight, mass, and total resources used.

- The amount spent on technologies related to the environment will alter. Cleaning up target sites will be the focus of short-term spending in cleanup and restoration. Increased investments in technology to prevent environmental harm will pay off. By 2024, many companies will be close to achieving the objective of zero discharges, but residual discharges may still necessitate the use of some control systems. We will have transitioned well into the twenty-first century from a paradigm of cleanup and control to one based on anticipating, avoidance, and assessment.
- Transferring ecologically suitable techniques and technologies that support sustainable technologies, which in turn support sustainable development, has a wide range of choices. To spread the advantages of these technologies throughout the world, public policy and a few innovative business models will be needed. Donations (such as nylon for water purification to fight the guinea worm disease, intellectual property to academic institutions or government-based research), exchanges (such as using natural products or microbes as the basis for pharmaceuticals), low-royalty or joint venture technology transfers, and exchanges (such as using nylon for water treatment to overcome the hookworm disease) are a few options.

To advance sustainable development, it is important to address these and other challenging problems relating to the "what" and "how" of science and technology.

1.5 Appropriate Technology for Sustainable Development

The idea of sustainable development was either created by humans or was rediscovered in the 20th century. Nature has always been self-regulatory and balance-focused, which means that it has always been sustainable. Increasingly, humans have interfered with this self-regulation, largely as a result of the technical advancements that we associate with progress. The outcome is an utterly abnormal, exponential rise in the human population (exponential growth, longer lifespan, etc,). Future efforts at sustainable development are anticipated to focus on minimizing human influence on natural interactions and systems while also attempting to provide people with access to the western standard of living. The viability and wisdom of this strategy must be considered.

Natural sciences, the foundation of specialist knowledge and revelations that have contributed to the environment's progressive decline, are typically brought up while discussing environmental technology.

Through the industrial revolution, the natural sciences have led us to where we are today, with an economy that rules us all and no clear sense of purpose. Now, in order to repair the harm, we still rely on this route—the natural sciences. In order to meet the requirements of a population focused on expansion, we believe in using contemporary, ecologically responsible technologies and sustainable standards of living. The transition to a supposedly sustainable, human equilibrium necessitates the use of environmental technology that is based on science and engineering. Our current way of life, which is characterized by intricate material and economic ties, would be irreparably altered by questioning the conditions of our technological advancement.

A key question that must be answered is whether continuing along this unadaptive path and being so closed-minded is necessary. Even if we applied the best financial incentives to the currently available resource- and environmental-saving strategies, it would only be sufficient to moderate growth. We would remain at the status quo as a result of the endeavor, which means we would continue to rely on our capital rather than our interest. Given that our way of life currently depends on material flow, technological possibilities have limitations, even with factors of 3, 4, or 10 in, say, the energy sector. The question that concerns the social preparedness to devote all of the resources and resources accessible to a technological revolution, however, is the most crucial in this context. Looking at our everyday political and economic events demonstrates our inability to act, rather than merely react, to what environmentalists currently know and are able to do. So how trustworthy is it to put our faith in science and technology to solve our problems?

When we talk about using these strategies to raise our own standards of living while simultaneously saying that everyone would be taken care of in the future and share in the defined prosperity out of an underlying unease, is that not just an illusion? Are there any conceivable alternate routes to the technological revolution, or is there just one? Where do the sociology fit into this conversation about the future? When a sustainable society is being planned, where are the perspectives of philosophy, ethics, and theology? These regions, which in fact served as the higher authority over the scientific method and life in general—were they not those that shaped human evolution over the course of centuries? How do you balance rationalism with emotive elements and technocracy with democracy? How do the principles of liberty, independence, prosperity, and joy fit in with the fast growing dependence on technology systems and limitations? The argument over whether developing nations should choose cutting-edge western technologies or more appropriate, low-level technology that fits their needs has persisted for a long time, albeit it is occasionally misperceived.

It is not necessary for appropriate technology to be basic and unsophisticated. Even cutting-edge technology can be used appropriately. Making a "acceptable option out of wide variety of technologies" rather than selecting just one suitable technology is what is expected of decision-makers in emerging nations. Review their resource capacities, development priorities, and potential effects on the environment, unemployment, and income distribution.

In light of these factors, the nation should make the right decisions. The need for prudence cannot be overstated. Instead of technologies requiring significant investments and high-quality materials, low level, inferior technologies are occasionally needed. The best course of action would be to pick a wide range of relevant technology, taking into account each industry, area, and product separately. There are, however, some restrictions. For example, they might not have the money to utilize this option of choice and might be forced to accept the technologies that are being provided to them. In most cases, technologies come in a box, and opening that package may not be simple.

Therefore, any development plan used by a developing nation must take into account factors such as satiating basic human needs, fostering endogenous self-reliance through social involvement and control, and maintaining harmony with the environment. They must establish priorities and conduct in-depth study into the required technology. Different nations have different capacities for absorbing new technologies due to varying levels of scientific advancement.

It must be recognized that not all current technologies and not all emerging technologies will necessarily be compatible with development. The type of development sought and the associated societal costs must be considered. Aspirations for third-world technology should focus on the following: Access to the full spectrum of available and potential technologies; 2) a just price structure on the global technology market; 3) the purchase of technology in a way that maximizes the use of local resources rather than buying packages that are forced upon the buyers as "all or nothing" by the outside technology supplier; and 4) a reduction in their reliance on outside technological innovations that enjoy a near monopoly in R&D.

These goals, however, are incompatible with one another. High levels of technological autonomy might prevent them from using all available technologies. Utilizing local resources, talent, capital, and limiting technology to "core" technologies can reduce the negotiation leverage that underdeveloped nations have over the pricing structure. Many TNCs forbid sales to customers who "break the box." Due to the technology controllers' disapproval, plans for the establishment of a "Technology Bank" that would allow developing nations to choose relevant technologies at a fair price and without any restrictions hardly ever gained traction.

1.6 Transfer of Technology

Technology transfer is the process through which technology is made available for use in the commercial sector. It could entail communication by giving the recipient access to pertinent knowledge and be a legally enforceable contract.

Any of the following sorts of technology transfer deals is possible:

1) All types of industrial property may be assigned, sold, or licensed, with the exception of trade names, service marks, and trademarks that are not included in a technology transfer (TOT) transaction.
2) Giving knowledge and technical experience in the form of feasibility analysis, plans, diagrams, models, procedures, guidelines, equations, basic or comprehensive engineering designs, specifications, equipment for training, and services including technical advising, managerial staff, and personnel training
3) The provision of technological expertise required for the installation, use, and operation of machinery, equipment, and turnkey projects.

4) Providing the technological expertise required purchasing, install, and use raw materials, intermediate goods, machinery, and other items that have been obtained through other ways than purchase or leasing.

5) Technology-related provisions made in agreements for industrial and technical cooperation.

The Draft TOT Code by UNCTAD includes a list of the aforementioned categories of technology transfers (TT). Non-commercial transfers, such as those covered by agreements for international co-operation between industrialized and third-world nations, are not included in the list.

There is a clear difference between "Externalized" and "Internalized" variants of TT. Investment related to TT is referred to as the internalized form of TT. Control in such a transfer belongs to the party transferring the technology, who often owns the majority or all of the shares. All other kinds of TT, such as joint ventures, strategic alliances, and global subcontracting, are considered externalized versions of TT. It is also possible to distinguish between the operational, duplicative, adaptive, and innovative levels of technology transfer. The following situational compulsions serve as the basis for technological transfer:

i) Technology typically has to be moved to business enterprises for commercial usage because innovators often lack the requisite competences and insufficient resources.

ii) The scientist or engineer who develops the breakthrough technology typically lacks the entrepreneurial know-how to take the lead.

iii) Commercializing technology requires significant upfront expenses for patenting and regulatory compliance, as well as risky investments in constructing plant and equipment and unpredictable product demand. Thus, the majority of the time, a technology user is a business initiative promoter.

iv) In order to ensure quicker industrial expansion and/or increase production efficiency, developing countries that are technologically behind industrialized countries must purchase the necessary technologies from them.

v) Market competition and the rapid rate of technical advancement also drive the transfer of technology.

vi) Universities, research organizations, and other institutions engage in technical research projects with the goal of selling modern technology to the potential buyer.

Important aspects of technology transfer

The distinct benefits of technology transfer include:

i) The most reliable way to close the technological divide between commercial enterprises and nation-states is through technology transfer.

ii) It entails sharing technical expertise, such as drawings, designs, documentation, and technical staffing services.

iii) For developing nations, the transfer of technology may speed up the process of increasing production and cost effectiveness

iv) The transfer of suitable technique could improve a product's quality and add new features.

v) Developing nations can successfully compete in the global market by transferring technology that takes advantage of economies of scale and changing the location of corporate operations.

1.6.1 Mechanism

Depending on the type of transfer, a different mechanism is engaged in technology transfer, are as follows:

i) **Licensing Agreement:** The method by which the technological know-how of the owner is used by the licensee in accordance with terms and conditions outlined in an agreement between the parties is referred to as a licensing agreement mechanism.

ii) **Contract for the delivery of equipment and machinery:** Because the technology is not particularly sophisticated, the contract calls for the transfer of operational technology related to equipment that is suitable for manufacture.

iii) **Technical expert training or employment:** This method entails the transfer of small and unmanaged production operations, which can be run by either hiring foreign technical experts or educating qualified workers.

iv) **Turnkey agreement:** This is a thorough transfer of complicated technology through the provision of plans and services for the construction, commissioning, or management of a facility in the client's favor.

v) **Subcontracting:** A lot of foreign businesses hire local producers from the host nation to buy their inputs while offering a wide range of technical assistance, knowledge, and information. The motor industry, television, etc., all use this type of setup.

vi) The corporation or business that owns the technology is acquired.

vii) Contracts for joint ventures or partnership with the owners of the technology.

It should be mentioned that the technology industry is essentially a seller's market. A small number of powerful TNCs dominate the global technology sales, while the majority of purchasers come from developing nations. Trade in capital goods is a crucial method of technology transfer. The majority of developing nations import capital goods, which have recently increased significantly with a very large percentage of TNCs, including technology. When a TNC has certain competitive advantages in terms of technology or other economic factors, it typically makes foreign direct investments (FDI). Additionally, TNC benefits from maintaining ownership of its technologies. When TNCs build production facilities in high- and medium-research-intensive industries, this can indicate technology transfer not just through the product composition but also through the training of local workforce members in new skills and a new method of production process organization. In sectors where the host nation and its businesses are powerful and the market is competitive, FDI could help boost local innovation capacity.

1.6.2 Essential Components of Contract

A technology transfer agreement often includes a few essential elements, including:

i) Patent rights are available both with and without trademarks or brand names that are registered under the transferor's name.

ii) Industrial property that is relevant is sold, leased, assigned, or given a license.

iii) Knowledge-based and technical services, such as feasibility studies, plans, schematics, engineering designs, training specifications, as well as management, advisory, and technical services.

iv) For the installation, use, and operation of machinery and equipment, technical support and training are required.

v) Technical assistance in the purchase and usage of intermediate items and/or raw materials

vi) Royalty, management, and technical fees must be paid.

vii) The length of time the arrangement will last.

viii) Restrictive terms, including prohibitions on exports and imports from particular sources, etc.

1.6.3 Modern Trends

The way businesses employ technology has recently undergone significant changes as a result of technology transfer. Henery C. Lucas, Jr. identifies the following significant patterns as noteworthy:

i) Utilizing technology to structurally restructure the business and give rise to the T-form firm, a potent management tool

ii) Information processing technology use as a corporate strategy component. It is anticipated that business leaders who can create innovative, strategic applications of information processing technology will run the successful companies of the future.

iii) Technology use permeates every aspect of the workplace. Businesses of all sizes are now utilizing technology to transform the way they operate, reduce the amount of human labour required, increase quality, and deliver better customer service. With the use of modern technologies, companies can now control production and develop parts.

iv) Managerial workstation using a personal computer (PCS). When connected to both an internal network within the company and an external network like the Internet, PCs give managers a pervasive tool.

v) Evolution of computers from computational tools to communication tools. Today, it is acknowledged that computers are more helpful as a communication tool than as a computing tool.

The development of information technology and IT enabling services is another aspect of the recent trend, which has had a significant impact on business processes and made them extremely dynamic. Using computers, IT, and ITes has produced:

- innovative approaches of structuring organizations and changing their design
- greater efficiency in the production and service sectors through electronic data exchange to support just-in-time manufacturing and supply
- changes to the competition's character and the structure of the industry
- creating a knowledge foundation of organizational intelligence by providing a method for coordinating activities via groupware
- Establishment of new connections between electronically connected customers and suppliers
- Greater adaptability to face-to-face communication and supervision and increased productivity
- Managers who have access to electronic alternatives to in-person oversight and communication

The spread of technology has drastically altered the global trading system, which has resulted in another change. Technology, formerly seen as strategically important to a country's growth, is now recognized as being just as essential to gaining influence over global markets. In addition, technology is seen as the key element in developing competitiveness and comparative advantage in global markets.

1.6.4 Problems and Prospects

UN experts have called attention to a number of issues related to the transfer of foreign technology. Let's study them.

1) It is claimed that less developed nations have a significant challenge because of the expense of foreign technology transfer. Technology transfer and the additional capital outflow via royalties, dividend interest, and technical fees are linked to foreign direct investment.

2) The transfer of technology transfer should be reasonable given the physical, economic, and social circumstances of the host nation. There have reportedly been instances where transfer of technology has been ineffective, inappropriate for the socioeconomic interests of the recipient country, and at odds with the national culture. Furthermore, long-term national interests may not be served by complete reliance on foreign technology. This is due to the possibility that continued dependence will hinder and deter indigenous scientists and technologists from applying their skills to fundamental development issues.

3) It is well recognized that multinational corporations (MNCs) play a deterrent role in the promotion of domestic technological skills when they introduce new goods and processes in host countries. Industrial units are unable to launch even small-scale adaptive research efforts or to adopt locally developed processes if they are subservient to and dependent upon foreign technology.

4) In many instances, foreign businesses with better technological advantages and competitive strength have suppressed indigenous entrepreneurship, with small and medium-sized businesses suffering the most.

5) In addition to the expenses entailed and net capital outflow resulting from the transfer of technology transfer, the host country does not always reap the rewards of technological diffusion and adaption, neither are there any catalytic effects of MNCs in the promotion of R & D. The economy of many host nations has instead been forced to conform to oligopoly market structure conditions as a result of the use of MNCs' unacceptable activities, such as bid-rigging, pricing discrimination, and market intervention through media advertising.

6) In addition, it has become apparent that some multinational corporations tend to transfer outmoded technology to underdeveloped nations. According to one analyst, "Most countries frequently do not have the opportunity to acquire the most recent technology and as a result continue to lag behind, whereas

theowners of modern technology use the developing countries as a means to salvage technology that is obsolete in developed countries, despite the fact that they have more advanced technology."

Therefore, developing nations must implement policies that would enable them to utilize MNC skills while defending the legitimate interests of all stakeholders. Development strategies should be created to channel foreign investment in accordance with the national priorities, goals, and policies.

It must be acknowledged that there is a lot of room for technological collaborative efforts between businesses in developed and developing countries if there is effective regulation and advancement of such collaboration, even though the transfer of foreign technology raises a number of issues and there are drawbacks to total reliance on foreign technology.

Regarding the following components, it may be suggested that less developed countries' technological collaborations and knowledge transfer be regulated:

(a) The parties' level of equity ownership involvement and the terms of that participation The nature, kind, and supply circumstances of the technology, as well as the priority ranking of the related industry, are some variables that may control this aspect;

(b) The technology being examined suitability. This factor should be taken into account in light of how well the technology fits into the social, economic, and ecological contexts as well as the importance of the sector that has been recognized as the technology's primary user. Alternative technological sources may also need to be taken into account. From a techno-economic standpoint, they may need to be compared and evaluated.

(c) Phased adoption, adaption, and advancement of technology for household use through the supply of appropriate research and development, engineering design, and technical staff training. This feature actually refers to the insistence on gradual indigenization.

(d) Reasonable terms for payment and a mechanism for reimbursement. To ensure that payment of royalties, interest, dividends, and technological service charges are reasonable and ideally associated with effectiveness into arms of the sales value or export and transfers is linked with the availability of foreign currency or export earnings, it is important to keep this aspect of technology transfer in mind.

(e) Avoiding restrictive language in the technology transfer agreement. It is not anticipated that the import of technology will impose obligations on the host nation that limit the sources of imports or the destinations of exports to certain nations, or that result in binding agreements about pricing practices, sales contracts, or the acquisition of inputs.

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Terminal Questions

1) Explain the appropriate Technologies for Sustainable Development.
2) Give a brief outline of the policy relating to foreign technical collaboration and foreign investment pursued by the Government of India since independence.
3) Explain the mechanism involved in transfer of technology, and the vital components of the contract of such transfer.
4) Describe the recent trend of changes in the way that organizations use technology.
5) What are the problems faced by developing countries in respect of transfer of foreign technology?
6) "There is wide scope for foreign technical collaboration in developing countries subject to proper regulation and promotion," Elucidate the statement.

Unit 2: Cleaner Production and Sustainable Sanitation

Unit Structure

2.0 Learning Objectives

After completing this unit, you will be able to:

- Explain the concept of cleaner production
- Describe sustainable sanitation

2.1 Cleaner Production

2.1.1 What is Cleaner Production?

Over the years, industrialized nations have progressively taken different approaches to dealing with environmental degradation and pollution problems, by:

- ignoring the problem;
- diluting or dispersing the pollution so that its effects are less harmful or apparent;
- controlling pollution using 'end-of-pipe' treatment;

- Preventing pollution and waste at the source through a 'Cleaner Production' approach.
- The gradual progression from 'ignore' through to 'prevent' has culminated in the realization that it is possible to achieve economic savings for industry as well as an improved environment for society.
- For production processes, Cleaner Production involves the conservation of raw materials and energy, the elimination of toxic raw materials, and the reduction in the quantities and toxicity of wastes and emissions.
- For product development and design, Cleaner Production involves the reduction of negative impacts throughout the life cycle of the product: from raw material extraction to ultimate disposal.
- For service industries, Cleaner Production involves the incorporation of environmental considerations into the design and delivery of services.

This, essentially, is the goal of Cleaner Production. Cleaner Production is defined as the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to humans and the environment.

The key difference between pollution control and Cleaner Production is one of timing. Pollution control is an after-the-event, 'react and treat' approach, whereas Cleaner Production reflects a proactive, 'anticipate and prevent' philosophy. Prevention is always better than cure.

This does not mean, however, that 'end-of-pipe' technologies will never be required. By using a Cleaner Production philosophy to tackle pollution and waste problems, the dependence on 'end-of-pipe' solutions may be reduced or in some cases, eliminated altogether. Cleaner Production can be and has already been applied to raw material extraction, manufacturing, agriculture, fisheries, transportation, tourism, hospitals, energy generation and information systems.

It is important to stress that Cleaner Production is about attitudinal as well as technological change. In many cases, the most significant Cleaner Production benefits can be gained through lateral thinking, without adopting technological solutions. A change in attitude on the part of company directors, managers and employees is crucial to gaining the most from Cleaner Production.

Applying know-how means improving efficiency, adopting better management techniques, improving housekeeping practices, and refining company policies and procedures. Typically, the application of technical know-how results in the optimization of existing processes.

Technological improvements can occur in a number of ways:

- Changing manufacturing processes and technology;
- Changing the nature of process inputs (ingredients, energy sources, recycled water etc.);
- changing the final product or developing alternative products;
- On-site reuse of wastes and by-products.

2.1.2 Types of Cleaner Production options

Housekeeping: Improvements to work practices and proper maintenance can produce significant benefits. These options are typically low cost.

Process optimization: Resource consumption can be reduced by optimizing existing processes. These options are typically low to medium cost.

Raw material substitution: Environmental problems can be avoided by replacing hazardous materials with more environmentally benign materials. These options may require changes to process equipment.

New technology: Adopting new technologies can reduce resource consumption and minimize waste generation through improved operating efficiencies. These options are often highly capital intensive, but payback periods can be quite short.

New product design: Changing product design can result in benefits throughout the life cycle of the product, including reduced use of hazardous substances, reduced waste disposal, reduced energy consumption and more efficient production processes. New product design is a long-term strategy and may require new production equipment and marketing efforts, but paybacks can ultimately be very rewarding.

2.1.3 Why invest in Cleaner Production?

Investing in Cleaner Production, to prevent pollution and reduce resource consumption is more cost effective than continuing to rely on increasingly expensive 'end-of-pipe' solutions.

When Cleaner Production and pollution control options are carefully evaluated and compared, the Cleaner Production options are often more cost effective overall. The initial investment for Cleaner Production options and for installing pollution control technologies may be similar, but the ongoing costs of pollution control will generally be greater than for Cleaner Production. Furthermore, the Cleaner Production option will generate savings through reduced costs for raw materials, energy, waste treatment and regulatory compliance.

The environmental benefits of Cleaner Production can be translated into market opportunities for 'greener' products. Companies that factor environmental considerations into the design stage of a product will be well placed to benefit from the marketing advantages of any future eco-labeling schemes.

Some reasons to invest in Cleaner Production:

- improvements to product and processes;
- savings on raw materials and energy, thus reducing production costs;
- increased competitiveness through the use of new and improved technologies;
- reduced concerns over environmental legislation;
- reduced liability associated with the treatment, storage and disposal of hazardous wastes;
- improved health, safety and morale of employees;
- improved company image;
- Reduced costs of end-of-pipe solutions.

2.1.4. Cleaner Production can be practiced now

It is often claimed that Cleaner Production techniques do not yet exist or that, if they do, they are already patented and can be obtained only through expensive licenses. Neither statement is true, nor does this belief wrongly associate Cleaner Production with 'clean technology'.

Firstly, Cleaner Production depends only partly on new or alternative technologies. It can also be achieved through improved management techniques, different work practices and many other 'soft' approaches.

Cleaner Production is as much about attitudes, approaches and management as it is about technology.

Secondly, Cleaner Production approaches are widely and readily available, and methodologies exist for its application. While it is true that Cleaner Production technologies do not yet exist for all industrial processes and products, it is estimated that 70% of all current wastes and emissions from industrial processes can be prevented at source by the use of technically sound and economically profitable procedures (Baas et al., 1992).

2.1.5. Cleaner Production and sustainable development

In the past, companies have often introduced processes without considering their environmental impact. They have argued that a tradeoff is required between economic growth and the environment, and that some level of pollution must be accepted if reasonable rates of economic growth are to be achieved. This argument is no longer valid, and the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992, established new goals for the world community that advocate environmentally sustainable development.

Cleaner Production can contribute to sustainable development, as endorsed by Agenda 21. Cleaner Production can reduce or eliminate the need to trade off environmental protection against economic growth, occupational safety against productivity, and consumer safety against competition in international markets. Setting goals across a range of sustainability issues leads to 'win–win' situations that benefit everyone.

Cleaner Production is such a ‘win–win’ strategy: it protects the environment, the consumer and the worker while also improving industrial efficiency, profitability and competitiveness.

Cleaner Production can be especially beneficial to developing countries and those undergoing economic transition. It provides industries in these countries with an opportunity to ‘leapfrog’ those more established industries elsewhere that are saddled with costly pollution control.

2.1.6. Cleaner Production and quality and safety

Food safety and food quality are very important aspects of the food industry. While food safety has always been an important concern for the industry, it has received even greater attention over the past decade due to larger scales of production, more automated production processes and more stringent consumer expectations. A stronger emphasis is also being placed on quality due to the need for companies to be more efficient in an increasingly competitive industry.

In relation to food safety, Hazard Analysis Critical Control Point (HACCP) has become a widely use tool for managing food safety throughout the world. It is an approach based on preventing microbiological, chemical and physical hazards in food production processes by anticipating and preventing problems, rather than relying on inspection of the finished product. Similarly, quality systems such as Total Quality Management (TQM) are based on a systematic and holistic approach to production processes and aim to improve product quality while lowering costs.

Cleaner Production should operate in partnership with quality and safety systems and should never be allowed to compromise them. As well, quality, safety and Cleaner Production systems can work synergistically to identify areas for improvement in all three areas.

2.1.7 Cleaner Production and environmental management systems

Environmental issues are complex, numerous and continually evolving, and an ad hoc approach to solving environmental problems is no longer appropriate. Companies are therefore adopting a more systematic approach to environmental management, sometimes through a formalized environmental management system (EMS).

An EMS provides a company with a decision-making structure and action programme to bring Cleaner Production into the company's strategy, management and day-to-day operations.

As EMSs have evolved, a need has arisen to standardize their application. An evolving series of generic standards has been initiated by the International Organization for Standardization (ISO), to provide company management with the structure for managing environmental impacts. The UNEP/ICC/FIDIC Environmental Management System Training Resource Kit, mentioned above, is compatible with the ISO 14001 standard.

UNEP DTIE, together with the International Chamber of Commerce (ICC) and the International Federation of Engineers (FIDIC), has published an Environmental Management System Training Resource Kit, which functions as a training manual to help industry adopt EMSs.

2.2 Sustainable Sanitation[1]

For many years, the international focus has been to provide safe drinking water supply. The Millennium Development Goals (MDGs) however represent a clear commitment to address sanitation with the same priority as water supply.

An analysis of existing data on global sanitation coverage from most recent international reports (e.g. Rosemarin et al. 2008) however reveals that of all the MDG targets movement on sanitation provision has been the slowest. In his address to the high-level segment of 16th meeting of the UN-Commission for Sustainable Development (CSD) in May 2008 the UN Secretary General Ban Ki Moon therefore urged governments and stakeholders to move the sanitation crisis to the top of the international agenda (http://www.un.org/esa/sustdev/csd/review.htm).

How best to achieve the Millennium Development Goals had already been discussed in the report "Health, dignity, and development: what will it take?" (UN Millennium Project 2005). Hans Olaf Ibrek, Member of the "MDG Task Force on Water and Sanitation" points out during the launching of the report: “Efforts to reach Target 10 must focus on sustainable service delivery, rather than construction of facilities alone”.

The world-wide endorsement of the Millennium Development Goals calls for a radical re-thinking of the conventional, accepted approaches to urban infrastructure in general and sanitation in particular. Only a change in the basic paradigm from linear flow streams and disposal towards a cycle oriented management of renewable resources has the potential to deliver the kind and degree of change which the millennium development goals demand. Just how difficult it is to change from conventional approaches to better alternatives is demonstrated by the fact that visionary engineers proposed to move from the linear to circular systems of managing water and wastewater (including excreta, and rainwater) back in the 1970s (Schaeffer and Stevens 1983). Today, 35 odd years later, the circular approach remains the exception.

2.2.1 The modern concept of sustainable sanitation

The basic concept of collecting domestic liquid waste in water-borne sewer systems, treating the wastewater in centralized treatment plants and discharging the effluent to surface water bodies became the accepted, conventional approach to sanitation in urban areas in Europe in the last century. Although these conventional sewer systems have significantly improved the public health situation in those countries that can afford to install and operate them properly, the large number of people, particularly in fast developing countries like India, who still do not have sufficient access to adequate sanitation is a clear indication that the conventional approach to sanitation is likely to be unable to meet the needs universally.

The conventional sewer system was developed at a time, in regions, and under environmental conditions that made it in many cases an appropriate solution for removing liquid wastes from cities. Today with increased population pressure, changes in consumer habits and increasing pressure on freshwater and other resources, this human waste disposal system is no longer able to meet the pressing global needs alone.

A few decades ago it thus became a priority to:

- Identify appropriate simple, affordable decentralised sanitation systems and promote their adoption
- Implement appropriate technologies with the participation of the communities to be served, and

Focus on health and hygiene education so that physical facilities would be properly used and maintained, and that hygienic behaviour would support the improvements brought about by the infrastructure.

Over the years, it became clear however that this health and hygiene driven paradigm shift was still incomplete: In practice,fecal sludge management problems where often overlooked, as were negative downstream effects of effluents from sewer systems. Protection of the environment, resource conservation and waste reuse remained secondary concerns at best, or were neglected entirely, and operational problems reduced the health improvements expected of the technologies. The Sustainable Sanitation Alliance has, therefore, called for a paradigm shift from disposal towards reuse oriented sanitation systems, which take all dimensions of sustainability into account (SuSanA 2008). In addition to paying particular attention to the health aspects at household level, a holistic and reuse-oriented sanitation approach also emphasizes:

- The destruction of pathogens through flow stream separation, containment and specific treatment.
- Resource conservation through a reduced use of potable water as a transport medium for human waste and by recovering wastewater for irrigation
- The elimination or minimization of wastewater discharges to the environment
- The need to close the resource loops through the productive use of the nutrients and energy (biogas) contained in excreta

Thus, ideas of recycling have been developed. This modern concept represents the paradigm shift initiated in response to satisfying the health needs of unserved, mostly poor population groups.

2.2.2 What is sustainable sanitation?

Sustainable sanitation has recently been characterized by the Sustainable Sanitation Alliance (SuSanA). “The main objective of a sanitation system is to protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to be sustainable, a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources” - SuSanA (2008).

When improving an existing and/or designing a new sanitation system, sustainability criteria related to the following aspects should be considered:

(1) Health and hygiene: includes the risk of exposure to pathogens and hazardous substances that could affect public health at all points of the sanitation system from the toilet via the collection and treatment system to the point of reuse or disposal and downstream populations. This topic also covers aspects such as hygiene, nutrition and improvement of livelihood achieved by the application of a certain sanitation system, as well as downstream effects.

(2) Environment and natural resources: involves the required energy, water and other natural resources for construction, operation and maintenance of the system, as well as the potential emissions to the environment resulting from use. It also includes the degree of recycling and reuse practiced and the effects of these (e.g. reusing wastewater; returning nutrients and organic material to agriculture), and the protecting of other non-renewable resources, for example through the production of renewable energies (e.g. biogas).

(3) Technology and operation: incorporates the functionality and the ease with which the entire system including the collection, transport, treatment and reuse and/or final disposal can be constructed, operated and monitored by the local community and/or the technical teams of the local utilities. Furthermore, the robustness of the system, its vulnerability towards power cuts, water shortages, floods, etc. and the flexibility and adaptability of its technical elements to the existing infrastructure and to demographic and socio-economic developments are important aspects to be evaluated.

(4) **Financial and economic issues:** relate to the capacity of households and communities to pay for sanitation, including the construction, operation, maintenance and necessary reinvestments in the system. Besides the evaluation of these direct costs, also direct benefits e.g. from recycled products (soil conditioner, fertilizer, energy and reclaimed water) and, external costs and benefits have to be taken into account. Such external costs are e.g. environmental pollution and health hazards, while benefits include increased agricultural productivity and subsistence economy, employment creation, improved health and reduced environmental risks.

(5) **Socio-cultural and institutional aspects:** the criteria in this category evaluate the socio-cultural acceptance and appropriateness of the system, convenience, system perceptions, gender issues and impacts on human dignity, the contribution to food security, compliance with the legal framework and stable and efficient institutional settings.

Most sanitation systems have been designed with these aspects in mind, but in practice they are failing far too often because some of the criteria are not met. In fact, there is probably no system which is absolutely sustainable. The concept of sustainability is more of a direction rather than a stage to reach. Nevertheless, it is crucial, that sanitation systems are evaluated carefully with regard to all dimensions of sustainability. Since there is no one-for-all sanitation solution which fulfils the sustainability criteria in different circumstances to the same extent, this system evaluation will depend on the local framework and has to take into consideration existing environmental, technical, socio-cultural and economic conditions.

Taking into consideration the entire range of sustainability criteria, it is important to observe some basic principles when planning and implementing a sanitation system. These were already developed some years ago by a group of experts and were endorsed by the members of the Water Supply and Sanitation Collaborative Council as the “Bellagio Principles for Sustainable Sanitation” during its 5th Global Forum in November 2000:

a) Human dignity, quality of life and environmental security at household level should be at the center of any sanitation approach.

b) In line with good governance principles, decision making should involve participation of all stakeholders, especially the consumers and providers of services.

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1 This chapter has been adapted from a UNEP publication, Government Strategies and Policies for Cleaner Production, 1994.

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Adapted from "Sustainable Sanitation in India: Examples from Indo-German Development Cooperation" editors with text contribution from Arne Panesar, Jürgen Bischoff, Regina Dube, Dayanand Panse, Pedro Kraemer, Jens Götzenberger, Thomas Henke, Patrick Bracken, Sreevidya Satish, Rahul Ingle. Published by GTZ, Deutsche Gesellschaft für Technische, Zusammenarbeit (GTZ) GmbH, Dag Hammarskjöld Weg 1-5, Dr. J. Bischoff, 65760 Eschborn, Germany.

Unit 3: In Situ Remediation Technologies

Unit Structure

3.0. Learning Objectives

After going through this unit you will be able to:

- Classify *in-situ* and *ex-situ* remediation technologies
- Discuss in detail about the various kinds of *in-situ* remediation technologies

3.1. Introduction

Large numbers of contaminated soils are a result of accidental spills from petroleum hydrocarbon products ranging from light refined products to heavy crude, tank bottoms and used oil. Many of the problems related to contaminated sites have been caused by leakages from underground and above ground storage tanks as well as other facilities for storing and transferring petroleum fuel products at service stations and power generating plants.' There are also contaminated soils with a wide range of industrial chemicals including pesticides, industrial solvents, inorganic acids and bases and liquid wastes containing heavy metals.

The remediation technologies can be classified into two categories:

- *In-situ* technologies which remediate soil in its original location without any action taken to remove or excavate;
- *Ex-situ* technologies which allow for the treatment after the soil is excavated and removed from the ground.

In-situ technologies may involve any one or more of the following treatments:

- volatilization
- steam/heat stripping
- bioremediation
- soil leaching
- isolation/containment
- vitrification

Ex-situ technologies may involve any one or more of the following treatments:

- surface bioremediation
- enhanced bioremediation
- soil slurry bioreactor
- low temperature stripping
- high temperature thermal destruction
- beneficial reuse
- chemical extraction (soil washing)
- solidification/stabilization

Bioremediation is a waste management technique that involves the use of organisms to remove or neutralize pollutants from a contaminated site. According to the EPA, bioremediation is a "treatment that uses naturally occurring organisms to break down hazardous substances into less toxic or nontoxic substances".

3.2. Classification of *In-situ* Technologies

The in-situ remediation technologies can be broadly categorized into three main groups as follows:

a) In Situ Biological Treatment: It includes volatilization, bioventing, enhanced Bioremediation and Phyto-remediation

b) In Situ Physical/Chemical Treatment: it includes chemical Oxidation, Electro-kinetic Separation, Fracturing, Soil Flushing, Soil Vapor Extraction, Solidification/ Stabilization

c) In Situ Thermal Treatment: It includes thermal treatments

3.3 In-situ technologies

As discussed, the *in-situ* technologies mainly involve physical, chemical or biological treatment of the contaminated soil. These technologies are described in detail as follows:

3.3.1 Volatilization or Air Sparging

It is a simple evaporation process which removes the contaminant by forcing air through the pores of the affected soil. The process is usually referred to as **air stripping or air sparging**. **Steam/heat stripping** is another method of volatilization where heat is used to enhance the removal of less volatile contaminants with air stripping.

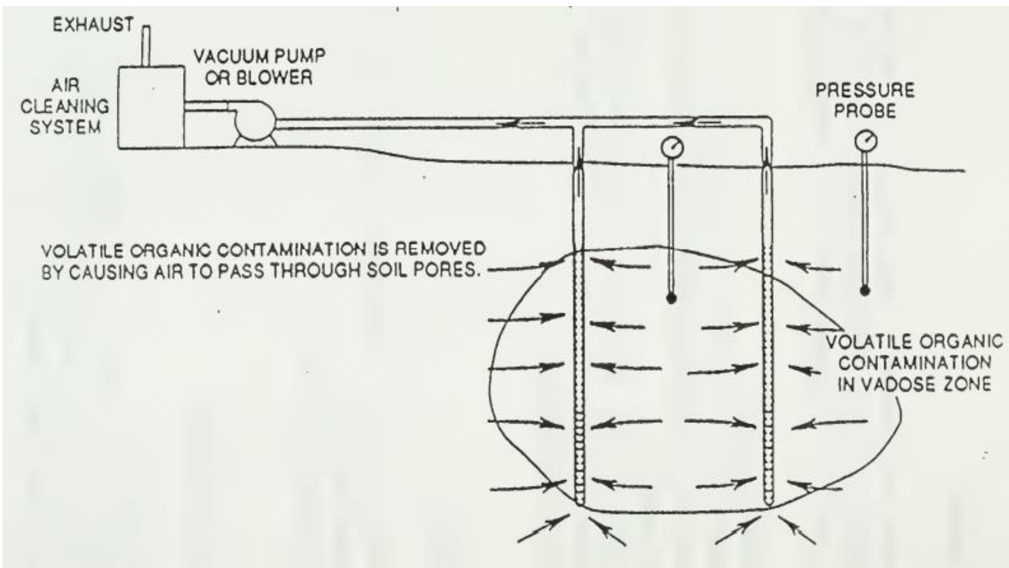
This technology involves the removal of volatile organic contaminants from the subsurface soils by forcing air through the soil matrix. The basic components of the system include:

- extraction well
- induced air draft fan or vacuum pump
- screened perforated pipes to direct air flow through the soil matrix;
- treatment unit such as an activated carbon filter to remove contaminants from the air emissions;
- monitoring system.

This technology is used in following areas:

- gasoline, jet and diesel fuels from unsaturated subsurface area;
- degreasing solvents.

The main advantages of this method is its low cost, its capability in removing hydrocarbon fuels from beneath the buildings and paved areas without serious disruptions and it demand low labour requirements.



In situ volatilization process

The limitations with this method include- it removes only volatile organic compounds and is not effective for soils below water table. Further; performance may be affected by soil conditions and removal efficiency depends on the spacing and depth of vents.

3.3.2 Steam/ Heat Stripping

This technology involves the removal of volatile contaminants by passing steam through the contaminated soil. Volatile organic carbons are transferred to the gaseous phase by steam distillation or vaporization. The contaminants may have to be removed from the air stream before venting to the atmosphere by appropriate air emission control devices such as condensers, carbon adsorption filters and/or thermal destruction systems;

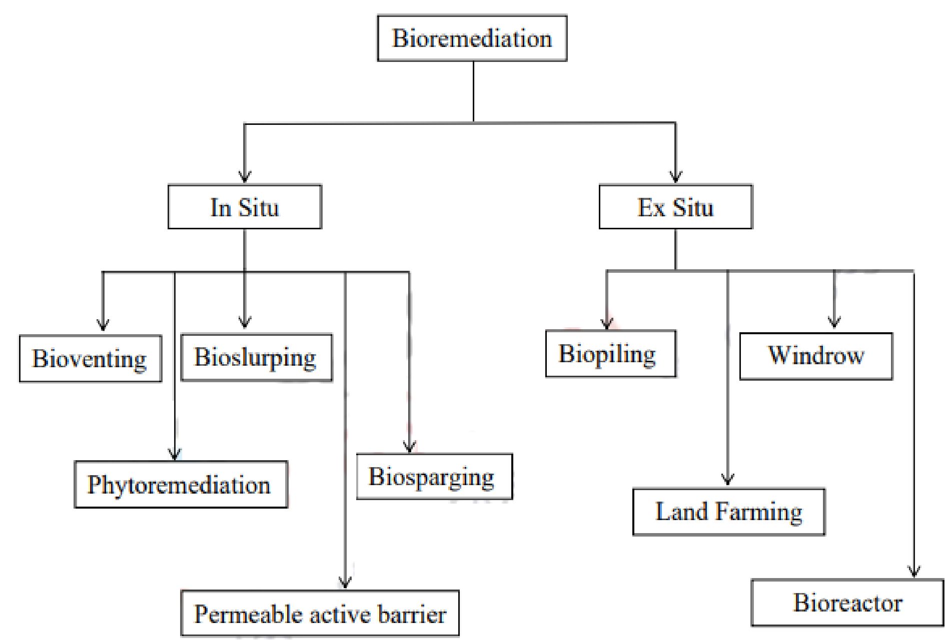
It is applicable for volatile organic compounds such as phenol, vinyl chloride, chlorinated hydrocarbons, ammonia and hydrogen sulphide etc.

The main advantage of this method is that it is very effective towards certain chlorinated solvents such as methylene chloride. However, involvement of high capital costs for steam generating and heat transfer equipment and condensers becomes a limiting factor for its wider applicability.

3.3.3 *In situ* Bioremediation

Bioremediation is a part of environmental technology, which uses living organisms particularly microbes such as bacteria, algae, yeast, fungi etc. to clean our environment. Amongst various microbes, bacteria play an important role in this process. They can digest or break down various toxins such as organic or inorganic, released from various natural/anthropogenic activities. This process of breakage is a usual part of their metabolic activity. Microbes can utilize different grouping of electron donors and acceptors to initiate their metabolism. Additional to these oxidation/reduction reactions, they are certain other strategies for detoxification of their surroundings. Thus an appropriate combination of active microbial community, electron donor / acceptor / pollutant and various additional physical and useful parameters are applied under bioremediation for remediation of polluted site (Cassidy et al. 2015; Garcia-Delgado et al. 2015; Martı´nez-Pascual et al. 2015). The pollutants break down into organic matter and nutrients. Heavy metals are non-biodegradable in nature thus can't be destroyed by bioremediation technology.

However, bacteria can assist in cleaning up of chlorinated pesticides and oil spills. In addition to it, wastewater can also be treated using algae which can take up most of nitrogen and phosphors present in wastewater and helps in cleaning of water. Microorganism used for such process should be healthy and active i.e. must be present in their active or exponential phase so that they can perform their work efficiently. Different microorganisms have different capability of detoxifying contaminants and toxins. Bioremediation can be achieved in both aerobic and anaerobic environment. In aerobic condition, microbes need oxygen to perform their activity. Oxygen quantity will decide the efficiency of microbes; if sufficient amount of oxygen is present then contaminants and toxins can easily be converted into water and carbon. Some microbes have capacity to perform in anaerobic conditions i.e. in the absence of oxygen. For example, soil contaminated with different types of chemical compounds can be efficiently decomposed by bacteria under anaerobic conditions, which liberate sufficient amount of energy for the survival of microbes. Bioremediation has been effectively evaluated and used for cleaning up of surface water, soil, groundwater, and sediments etc. It has been evidently established xenobiotic such as nitroglycerine which is an explosive, can also be cleaned up through bioremediation. Bioremediation is a natural attenuation with no or little human efforts. Furthermore, adding of natural or engineered microorganisms can enhance the ideal catalytic abilities (Paul et al. 2005).



Bioremediation and its type

Different types of bioremediation (Fig. 1) are described in following section:

This involves treatment of polluted substances at polluted site itself. This technique does not disturb soil structure as does not require excavation. Further these procedures seems to be less costly in comparison to ex situ, because no additional cost is involved in excavation procedures but cost of designing and installation of sophisticated instruments on-site for improvement in efficiency increases cost. In situ bioremediation techniques are successfully used for treatment of heavy metals, dyes, hydrocarbons and chlorinated solvents at polluted sites (Folch et al. 2013; Kim et al. 2014; Frascariet al. 2015; Roy et al.). There are certain parameters which affect the performance such as electron acceptor, nutrient availability, moisture content, soil porosity, temperature and pH (Philp and Atlas 2005).

3.3.3.1 Bioventing

Bioventing helps with in situ bioremediation of pollutants present in soil by providing enough supply of oxygen to microorganisms involved in converting pollutants into a harmless product (Philp and Atlas 2005; Hohener and Ponsin 2014). Further additional nutrients and moisture help in increased activities of indigenous microbes to enhance bioremediation. Although rate of airflow and air interval are the most important factors of bioventing, still accomplishment depend on number of air injection points for uniform distribution of air.

3.3.3.2 Bioslurping

In this process, combination of vacuum enriched pumping, soil vapor extraction alongwith bioventing is used for remediation of soil and groundwater providing indirect oxygen supply and stimulating the biodegradation of contaminants (Gidarakos and Aivalioti 2007; Kim et al. 2014). This technique can also be used for remediation of semi volatile and volatile organic compounds from contaminated soils. This method is not appropriate for remediation of soil having little permeability but it is less costly due to less amount of groundwater generated from process minimizing cost involved in storage, treatment and disposal.

3.3.3.3 Biosparging

Like bioventing, in this technique also air is inoculated into earth subsurface for stimulation of microbial activities to remove pollutants from contaminated sites. But in this technique air is added at saturated zone to result in ascending movement of VOCs to the unsaturated zone to stimulate biodegradation. Main factors i.e. permeability of soil and contaminant biodegradability affects the efficiency of system. Similar to biosparging there is another method identified as in situ air sparging (IAS) leading to pollutant volatilization with high airflow rates, whereas biosparging supports biodegradation. Biosparging is commonly used for treatment of aquifers polluted through petroleum products, particularly kerosene and diesel.

3.3.3.4 Phyto-remediation

In this method, plants interact with pollutants for mitigation of noxious effects. Mechanism of remediation is dependent on characteristics of contaminant i.e. elemental or organic. Elemental contaminants include lethal heavy metals and radio-nuclides which are typically displaced through transformation, sequestration and extraction mechanisms. Organic pollutants such as hydrocarbons and chlorinated mixtures are mainly removed by the process of degradation, stabilization, rhizo-remediation and volatilization. Plants should have some important characteristics to act as phyto-remediator i.e. rate of pollutant removal, growth rate of plant, tolerance and survival of plant, fibrous or tap root system on basis of pollutant depth, minimum above ground biomass to be accessible for animal ingestion, plant resistance to diseases and pests etc (Meagher 2000; Kuiper et al. 2004; Lee 2013; Miguel et al. 2013). Plants growing in contaminated site/environment are usually found to be good phyto-remediators. Their efficiency can further by enhanced by either bio-stimulation or bio-augmentation with endogenous or exogenous plant rhizo-bacteria. Simultaneously some precious metals can also bio-accumulate during remediation which can be recovered afterwards. This process is known as phytomining. Some of advantages of phyto-remediation are environmentally friendly, little installation and maintenance expenses, large-scale operation, preservation of soil structure, better soil fertility due to addition of plant organic matter, inhibition of erosion and metal leaching etc.

3.3.3.5 Permeable reactive barrier (PRB)

In this method, role of microorganisms is to enhance the process rather than to act as independent technology. Other terms viz. biological PRB, passive bio-reactive barrier, bio-enhanced PRB are also proposed for this technique. This is an in situ technique mainly uses a semi-permanent or permanent reactive barrier immersed in the path of groundwater polluted with heavy metals and chlorinated compounds. As contaminated water pours via barrier pollutants get stuck and experience sequence of reactions subsequently cleaning this. These barriers are typically responsive adequate to capture contaminants, penetrable to only water not contaminants, passive with slight energy involvement, cost effective, and easily available (De Pourcq et al. 2015). Efficiency of PBR depends typically on biogeochemical and hydro geological conditions, mechanical stability, characteristics of used media, which further is dependent on type of pollutants, environmental conditions etc. (Obiri-Nyarko et al. 2014; Liu et al. 2015).

3.3.3.5 Intrinsic bioremediation

This is also acknowledged as natural attenuation in which polluted sites are remediated with the help of aerobic and anaerobic microbial activities without any outside force or human involvement. The absence of exterior power makes this method less costly in comparison to additional in situ methods. To maintain the sustainability and continuity, the process need to be monitored frequently also known as monitored natural attenuation. Intrinsic bioremediation sometimes takes lengthier time to reach the marked pollutant level as there is no exterior power combined to accelerate remediation practice. Thus, it has been recommended to carry out risk assessment to confirm that less time for remediation is required.

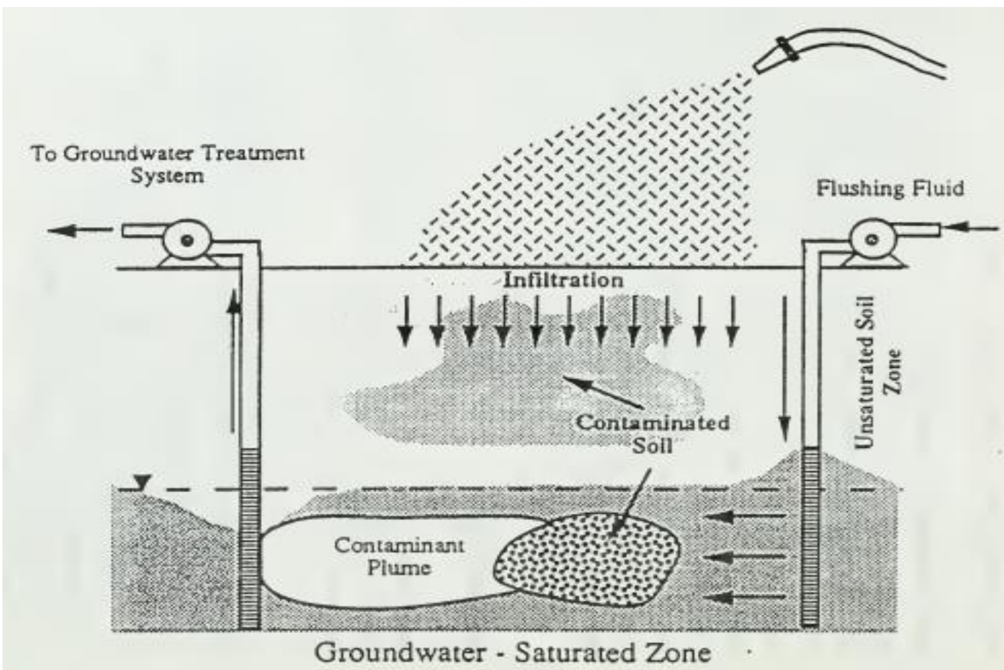
3.3.4 Soil leaching (flushing)

It involves spraying in-place contaminated soil with a mixture of water and additives. As the mixture percolates through the soil, the additives help to release the contaminants adsorbed on the soil surface. This technology involves injecting or flushing the soil with water to leach out contaminants in the soil. For petroleum hydrocarbons, non-toxic or biodegradable surfactants are added to the water to improve solubility and possible recovery. For heavy metals and inorganic contaminants, chemical reagents are added to the water to modify its pH or to enhance the solubility of contaminant. After the leaching, the water laden with the contaminants is sent to an on-site treatment plant for the removal of the contaminant. The purified water can be reused.

Depending on the type of leaching additives and soil characteristics, the method may result in the leaching out of chemicals like halogenated solvents, aromatics (benzene, cresols, toluene, phenols, xylenes), gasoline, fuel oils, diesel, crude oil; hydraulic and other viscous oils; PCBs and chlorinated phenols; and oily sledges from *in-situ* soils.

The main advantage of this method is its low costs and requirement of minimum labour. Further, there is no need for excavation.

However, the limitation of the method is that it is difficult to ascertain as how well the objectives have been met. Soil conditions must be ideal (e.g. low permeability clay type soils do not lend themselves to this technology). Further, injection of some chemicals into the subsurface may not be acceptable. There are chances for contaminant migration beyond the affected area. It demands large volumes of water and chemicals.



In situ soil flushing

3.3.5 Isolation / Containment

This technology involves the isolation of the contaminated soils from the surrounding area by installing an impervious surface cap (e.g. synthetic cover) and a barrier wall. This procedure does not destroy nor reduce the total amount of contaminants but it prevents their migration to the groundwater or escape into the atmosphere.

Usually applied to sites with petroleum hydrocarbons but could be used for all sites. The potential advantages include:

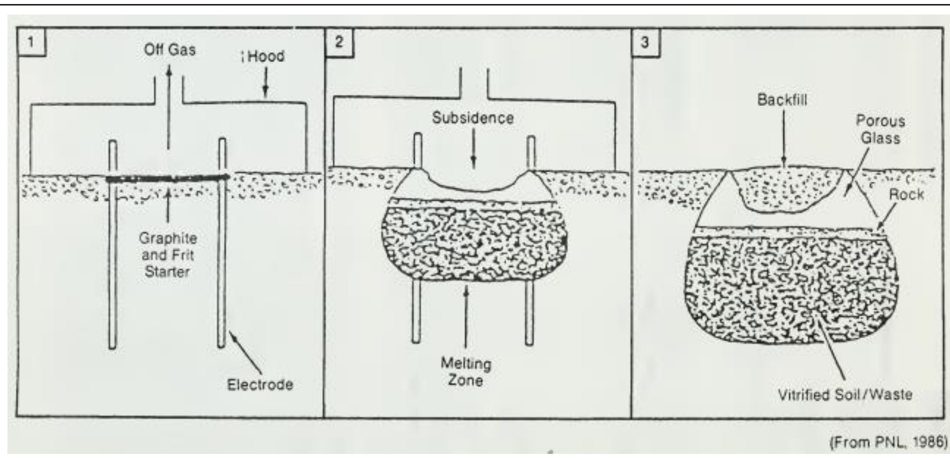
- its relatively low cost

- Process has been proven and commercially available.
- It controls contaminant migration

However, the method does not reduce the contaminants from the soil and further, the operation is limited to a depth of 3 to 5 meters. It is not suitable for large area. Further, long term monitoring may be required.

3.3.6 *In situ* Vitrification

In-situ vitrification is a process by which the in-place contaminated soils are converted into a chemically inert stable glass and crystalline product through the use of electrical heat. Four electrodes are inserted into the contaminated soil in a square pattern and a small quantity of a mixture of graphite and glass frit is placed in an "X" pattern on the soil surface. This provides a conductive path for the initial electrical current. When the electrical current is applied, heat is generated with the temperatures in the soil matrix reaching over 1,700°C. This cause the silica and aluminum oxides in the soil to melt. Any organic in the soil will be pyrolysed and resulting gases may combust at the surface when they come into contact with air. At the end of the specified time, all of the organics are destroyed.



Adapted from Remedial Technologies for Underground Water

The electrodes are removed from molten mass which is allowed to cool into a vitrified mass entrapping remaining contaminants. It is applied for contaminated soils with a wide range of chemicals such as heavy metals and plating wastes; inorganic (fluorides, nitrates, chlorides and sulphates); PCBs, high boiling organics (PCBs, PAHs, tank bottoms, petroleum-based oils, heavy fuel oils, tank bottoms.

Advantage of the method is that the process can treat simultaneously soils contaminated with mixed classes of chemicals (both organics and inorganic) and the treated by-product is not likely to have any environment or health impact.

This method, however, has certain limitations like it:

- cannot treat soils with high permeability;
- is not suitable for soils located near groundwater and those with high organic content (over 10 percent)
- mercury will vaporize when exposed to vitrification temperatures
- metal drums buried between electrodes may cause electrical short-circuit;
- It cannot be used for soils with combustible liquids, low boiling liquids; depth up to 17m.
- It is an expensive method.

References

Ontario Ministry of the Environment, 1992. *Remediation Technologies for Contaminated Soils.* Report prepared by Technology & Site Assessment Section Waste Management Branch. Ontario Ministry of the Environment. Printer for Ontario, 1992. pp-56

Unit 4: Ex Situ Remediation Technologies

Unit Structure

4.0 Learning Objectives

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

- Explain the various kinds of *ex-situ* remediation
- Discuss the *ex-situ* remediation technologies

4.1 Introduction

In this excavated samples from polluted sites are transported to another site for treatment. Some of the factors, which influence efficiency are cost; intensity, type, degree and depth of pollution; geographical location and geology of the polluted site. Thus, *Ex situ* remediation technology involves the removal of the contaminated material away from the site and is treated elsewhere for making it less toxic or non-toxic.

4.2 Surface Bioremediation or Land farming

Surface bioremediation is also called land treatment or land farming and involves the tilling and the cultivating of the soils to enhance biological degradation of hydrocarbons. This method is the easiest one with very less expenses and equipment needs. In this method, contaminated soils are typically dug and/or tilled. This can be done in both *ex situ* or *in situ* manner depending on depth of pollutant. When treatment of excavated contaminated soil is done on-site it is known as in situ and in another case it is called as ex situ. Like other ex situ methods, land farming also has certain drawbacks such as large area requirement, effect of variable environmental conditions on microbial activities, high cost involved in excavation, and inefficiency in removal of inorganic pollutant (Silva-Castro et al. 2012; Cerqueira et al. 2014). Additionally, land farming is not appropriate for treatment of soil contaminated by harmful/toxic volatile compounds because of design and contaminant removal mechanism i.e. volatilization, mainly in tropical climate locations. Due to these drawbacks and many more make land farming assisted bioremediation more time consuming and less efficient in comparison to other ex situ methods (Khan et al. 2004; Maila and Colete 2004).Surface bioremediation is a process in which naturally occurring bacteria are utilized to degrade the contaminants in the soil. This technique can be used effectively for soils contaminated with petroleum hydrocarbon fuels.

Excavated contaminated soil is spread over a treatment area in a layer usually 15 to 30 cm thick. The treatment area is properly designed for positive drainage and is surrounded by a soil berm to prevent runoffs. Agricultural fertilizer, water and bacteria, lime is added, if required. The soil is cultivated with a tiller disc harrow or some other farm implement to mix with the soil bacteria, air and moisture. In some cases, a road grader is used.

4.2.1 Applicability

It may be applied in the treatment of:

- petroleum hydrocarbon fuels (gasoline, diesel and heating fuels)
- oil sludges and tank bottoms;
- soils contaminated with polycyclic aromatic hydrocarbons.

4.2.2 Potential Advantages

- low to moderate costs;
- low labor requirements;
- can be effective on some heavier crudes.

4.2.3 Potential Limitations

- It is temperature dependent;
- Presence of certain contaminants may be toxic to bacteria;
- air emissions control may be needed;
- may require large volumes of water to keep the soil moist;
- soil conditions may not be suitable (e.g. dense soils);
- may be difficult to attain required cleanup levels;
- large treatment area may be required;

4.3 Enhanced Bioremediation (Composting)

This is a process in which the bacterial action is accelerated by controlled treatment conditions with uniform distribution of water, oxygen and nutrients, chemicals for pH control, and temperature control. In some cases, a special culture of bacteria may be added along with soil amendments.

Contaminated soil is placed in a large pile over a number of perforated pipes laid out in parallel. The pile is sprinkled with a mixture of water surfactants and fertilizer. The air is drawn through the pile by a vacuum pump. In some cases, large wood chips are added as a bulking agent to facilitate the flow of air through the pile.

4.3.1 Applicability

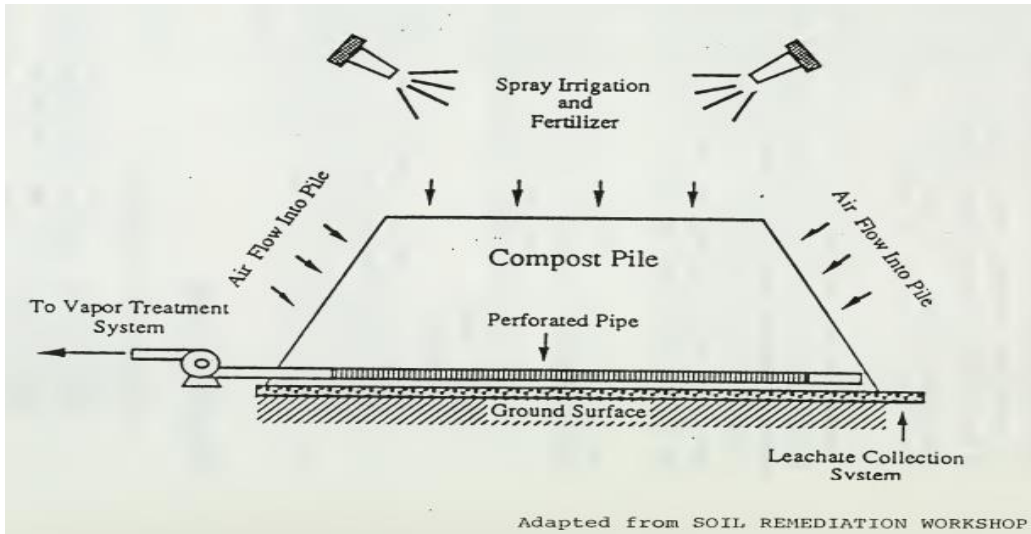
- soils contaminated with petroleum fuels (as gasoline, jet fuel, diesel) ; oil sludges;
- polycyclic aromatic hydrocarbons (PAHs including napthalene, anthracene, etc.); benzene, toluene, ethylbenzene, and xylene (BTEX) , some chlorinated solvents.

4.3.2 Potential Advantages

- minimum labour requirements;
- low costs;
- shorter time of treatment than land farming;
- more positive control of air emission;
- soils with high contaminant levels can be treated.

4.3.3 Potential Limitations

- presence of heavy metals, chlorinated organic, pesticides, etc. can be toxic to bacteria;
- variable composition of soil may lead to inconsistent results;
- low levels cannot always be achieved.



Composting

4.4 Soil Slurry Bioreactor

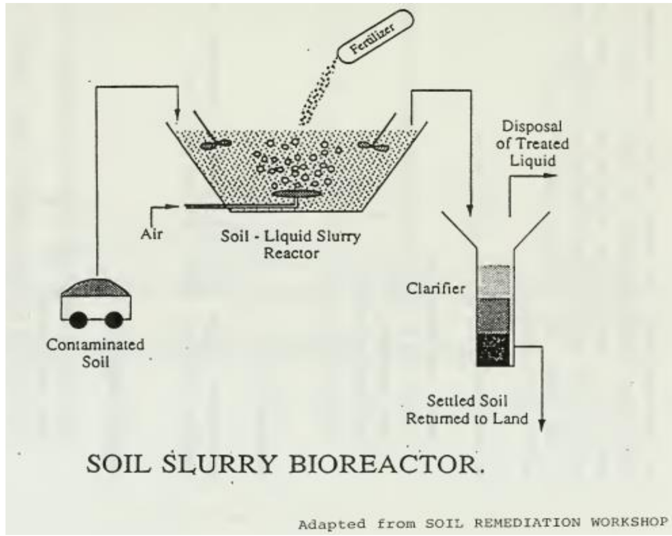
The first step in this process is to separate and remove the larger soil particles. The soil is then mixed with water to obtain slurry of proper consistency. Slurry is mechanically agitated in a bioreactor vessel to keep the solids suspended and to maintain an intimate contact with the bacteria. Suitable amounts of nutrients, water, surfactants and sugars are added to maintain proper levels of active biomass population in the bioreactor. Once the treatment is completed, the slurry is dewatered and the water is further treated and clarified and the clean soil is disposed of.

4.4.1 Applicability

- petroleum hydrocarbon fuels;
- chlorinated organic solvents;
- crude oil, oils and grease;
- PAHs
- some pesticides.

4.4.2 Potential Advantages

- minimum labour requirements;
- treats higher levels of contaminants;
- a wide range of organics can be treated;
- less space requirements;
- air emissions can be controlled.



4.4.3Potential Limitations

- presence of heavy metals, pesticides and chlorinated
- Organics may be toxic to the bacteria;
- capital costs for equipment may be expensive;
- contaminants with low solubility are more difficult to treat;
- low cleanup levels are not always achieved;
- operating temperature must be 20° to 30°

4.5 Low Temperature Thermal Stripping

The excavated soil is heated in a closed chamber to temperatures ranging from 200^{0}C to 260^{0}C to volatilize the contaminants. The off-gases from the soil are then passed through an air emission control system or a recovery system. In some cases, the gases are passed through to a second reactor and incinerated.

The basic components of the operation are:

- feeder with screening;
- rotary kiln with indirect infrared heating or indirect heat exchanger;

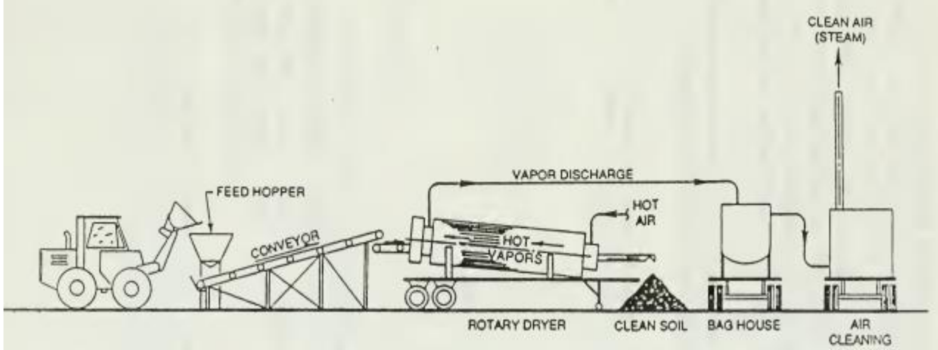
- air emission control;
- recovery system with activated carbon or an afterburner.

4.5.1 Applicability

Contaminated soils with low volatile petroleum fuels (gasoline, jet fuel, diesel fuel) and pesticides.

4.5.2Potential Advantages

- volatilize a wider range of petroleum products than *in-situ* technologies;
- treatment can be accomplished in a short period of time;
- treated soil can be returned to site;
- system is relatively compact and mobile.



LOW TEMPERATURE THERMAL PROCESS.

Adapted from ON-SITE TREATMENT OF SOILS 1989 MANUAL

4.5.3 Potential Limitations

- removes only volatile organic compounds;
- precautions must be taken to avoid explosions within the equipment;
- high levels of metals, fluorides, chlorides, and sulphur may cause problems in the air emission controls;
- high moisture content may reduce efficiency;

- may not be suitable for soils with high percentage of clay and silt;
- may not be capable of handling soils with greater than one percent petroleum hydrocarbon content for some design;
- Chlorinated organic require more elaborate air emission control system.

4.6 High Temperature Thermal Destruction

This technology utilizes high temperatures as the principal method of destroying organic contaminants. The treatment involves heating excavated soil in a closed chamber to volatilize and destroy organic compounds by converting them to carbon dioxide and water. The off gases are passed through a secondary chamber at higher temperatures to ensure complete destruction of all organic constituents and then through the air emission control system. The destruction and removal efficiency achieved in this treatment exceeds 99.9 percent.

The process temperatures during the operation are in the range of 850 to 1200°C.

Types of incineration equipment include:

- rotary kiln;
- fluidized bed;
- infrared thermal;
- pyrolytic.

4.6.1 Applicability

- practically any type of organic contaminant, however, not applicable for metals.

4.6.2 Potential Advantages

- all organics are completely destroyed;
- Destruction and removal efficiency (DRE) is greater than 99.99% with most organic compounds.

4.6.3 Potential Limitations

- presence of halogenated organics may require special air pollution control equipment;
- production of volatile metals, PCB and dioxins;
- feed size limitations for some equipment;
- high fuel requirements;
- high capital costs for incineration equipment;
- high operating costs;
- permits may be difficult to obtain;
- Treated soils may be sterile.

4.7 Beneficial Reuse

Soils contaminated with petroleum hydrocarbons are incorporated into hot asphalt mix as a partial substitute for stone aggregate. During the asphalt batching process, the contaminated soil is heated to 260°C to 427°C and passed through a dryer where the lighter petroleum hydrocarbons such as gasoline, kerosene, diesel and heating oil's are volatilized. The heavier hydrocarbon residual along with the soil are blended at less than 5 percent of the total feed with other aggregates into the hot asphalt mix. The resultant mixture is used as base material for road bed or parking lots. Dryer exhaust gases may require treatment such as thermal destruction of organic compounds

4.7.1 Applicability

- soils contaminated with heavier petroleum hydrocarbon fuels;
- not applicable for petroleum wastes because of unknown constituents

4.7.2 Potential Advantages

- costs are relatively low in comparison with other ex-situ technologies ;
- labour and maintenance requirements are low;
- Treatment time is short.

4.7.3 Potential Limitations

- asphalt plants are not operated during cold weather;
- not all soils may be suitable for asphalt incorporation;
- transportation is required as the treatment plant may not be located conveniently between on-site and point-of-use for asphalt;
- not widely practiced

4.8 Chemical Extraction

This is a soil washing process which is used to separate the contaminants into respective phase fractions: organics, water, inorganic and particulate soils. It involves mixing the soil with water or water containing a chemical extracting agent to release and remove the contaminant from the soil particles. The extracting reagent may be any one of a lixiviant such as a solvent, surfactant, chelating agent, an acid or a base. The reagent may dissolve, precipitate and separate the contaminant from the soil. The resulting mixture is mechanically aerated, centrifuged or filtered to separate the extracting reagent with the contaminant from soil. The soil may be washed or aerated to remove residual extracting reagent. The recovered extracting agent is then filtered to remove particulates and treated to remove contaminants. This technology may also be referred to as solvent extraction/soil washing and soil washing/volume reduction.

*Chemical reagent used to extract, a soluble component from a mixture by washing.

4.8.1 Applicability

- With the use of appropriate extracting agents this process can effectively remove any petroleum hydrocarbons and fuel residuals, heavy metals, pesticides, herbicides, PCB, cyanides, wood preservatives, and creosote.
- Can be used to treat any soils contaminated with acids, base and heavy metals and any soils with high moisture content.

4.8.2 Potential Advantages

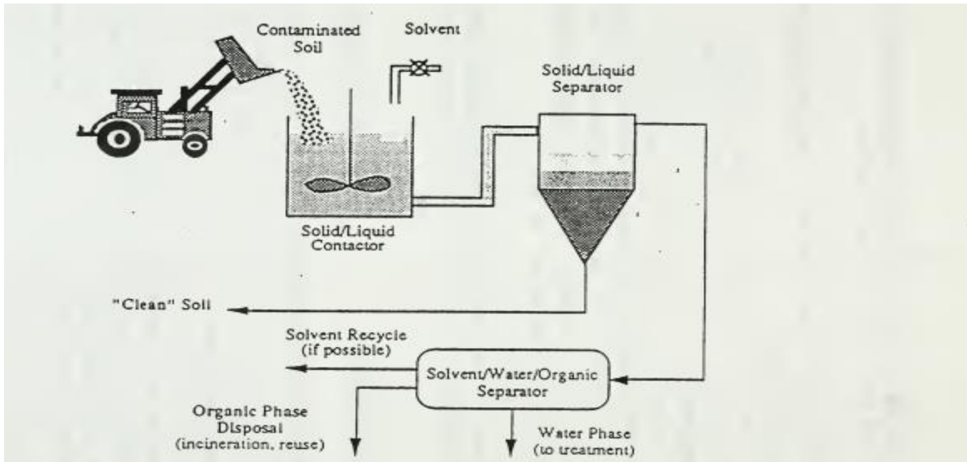
• wide range of applications.

4.8.3 Potential Limitations

• clay content greater than 20 to 30 percent;

• high level of volatile organic carbon may combine with the extracting agent;

• not all organic compounds can be removed effectively.



SOLVENT EXTRACTION / SOIL WASHING.

Adapted from ON-SITE TREATMENT OF SOILS 1989 MANUAL

4.9 Solidification/ Stabilization

The main purpose of this technology is to immobilize the contaminants in the soil for safe disposal or reuse. The process involves the addition of a sufficient quantity of materials that combine physically (solidification) and/or chemically (stabilization) to decrease the mobility of the contaminants in the soil. Other purposes include:

- limit the solubility of contaminants in the soil;
- detoxify contaminants;
- decrease the surface area through which the transfer and loss of contaminant can occur.

4.9.1 Applicability

- soils moderately contaminated with petroleum hydrocarbon fuels;
- soils moderately contaminated with refined petroleum products ;
- soils contaminated with heavy metals.

4.9.2 Potential Advantages

- raw materials are inexpensive;
- technology is well established and equipment is readily available;
- least expensive of the ex-situ technologies.

4.9.3 Potential Limitations

- restrictions may be imposed on future land use;
- long term integrity of solidified materials are not well established;
- no test protocols;
- presence of high levels of organics in the soil may interfere with process.

4.10 Biopile

This is a complete treatment technology in which excavated soils are mixed with nutrients to enhance microbial activities and placed on a treatment bed with main components as irrigation, aeration, leachate and nutrient collection systems. Various environmental and physico-chemical parameters viz. heat, moisture, nutrients, pH and oxygen can be controlled for further enhancement of biodegradation (Whelan et al. 2015). Filtering and ventilation of polluted soil, addition of bulking agents like saw dust, straw, wood chips or any other organic materials can further help in enhancement of efficiency. Biopiling can be effectively used to control volatilization of low molecular weight pollutants and can work even under extreme cold environments (Dias et al. 2015; Gomez and Sartaj 2014; Whelan et al. 2015). Additionally, biopile can be used for treatment of huge quantity of contaminated soil in less space in comparison to different ex situ bioremediation methods comprising land farming. Some of major limitations of biofiling are maintenance and operation cost, robust engineering, power fluctuations and unavailability at remote sites which is an essential requirement for even supply of air in heaped soil etc. Excessive air heating can result in drying of soil which will promote volatilization rather than biodegradation due to inhibition of microbial activities.

4.11 Windrows

The efficiency of windrows depends on periodic rotating of heaped contaminated earth with growing degradation activities of native or transient hydro-carbonoclastic bacteria. This periodic rotating of contaminated soil along with water addition results in increased ventilation and even delivery of contaminants with speedy bioremediation through the mechanism of assimilation, biotransformation and mineralization (Barr 2002). However, this technique may not be the best option for remediation of soil polluted with toxic volatiles.

4.12Bioreactor

Bioreactor is a container used for conversion of raw materials to specific products through a chain of biological reactions. Different modes of operation are fed-batch, batch, sequencing batch, continuous and multistage bioreactors. Various process parameters viz. pH, temperature, mixing, rate of aeration, substrate and inoculums concentrations can be controlled effectively in bioreactors which is one of the key benefits of this bioremediation over other ex situ bioremediation techniques. Contaminated samples can be fed into bioreactor either as dry matter or slurry. Optimum growth conditions provided in a bioreactor are needed to maintain natural growth environment. Bioremediation time can be reduced with manipulation of process parameters. Various factors affecting the efficiency of bioremediation are nutrients concentration, bio-augmentation, pollutant availability, contact between microbes and pollutants etc. Water or soil contaminated with VOCs such as BTEX (benzene, toluene, ethylbenzene and xylenes) can also be treated through this technique (Mohan et al. 2007).

References

Ontario Ministry of the Environment, 1992. *Remediation Technologies for Contaminated Soils.* Report prepared by Technology & Site Assessment Section Waste Management Branch. Ontario Ministry of the Environment. Printer for Ontario, 1992. pp-56

Unit 5: Contaminated Site Remediation

Unit Structure

5.0 Learning Objectives

After reading this Unit you will be able to:

- Discuss contaminated site characterization
- Discuss selection and planning of remediation methods
- Assess the risk involved in contaminated sites
- Discuss the various remediation methods for soil and ground water

5.1 Introduction

Soil contamination by organic or inorganic pollutants is caused by a number of industries such as chemical, pharmaceuticals, plastics, automobile, nuclear industries, biomedical wastes, mining industries and municipal solid waste. At times it becomes essential to decontaminate soil. Broadly the soil decontamination is done in two ways: (a) pump and treat in which the pollutant is pumped out using external energy source, treated using methods such as incineration, radiation, oxidation etc (b) removal of contaminated soil, treat it and then returning back to its original place. This module is meant to briefly introduce various soil/ water decontamination processes.

5.2 Contaminated site characterization/ assessment

Broadly, site characterization or contaminated site assessment (CSA) is important for:

a) Determining concentration and spatial distribution of harmful pollutants under consideration.

b) Determining the extent of site remediation (zonation) based on which the suitable remediation technique is selected.

c) For assessing environmental and human health risk due to contamination. More specifically, CSA is required to answer the following questions:

i) What is the source of contaminants?

ii) What is the type and physical form of contaminants?

iii) Spatial and depth wise extent of contamination

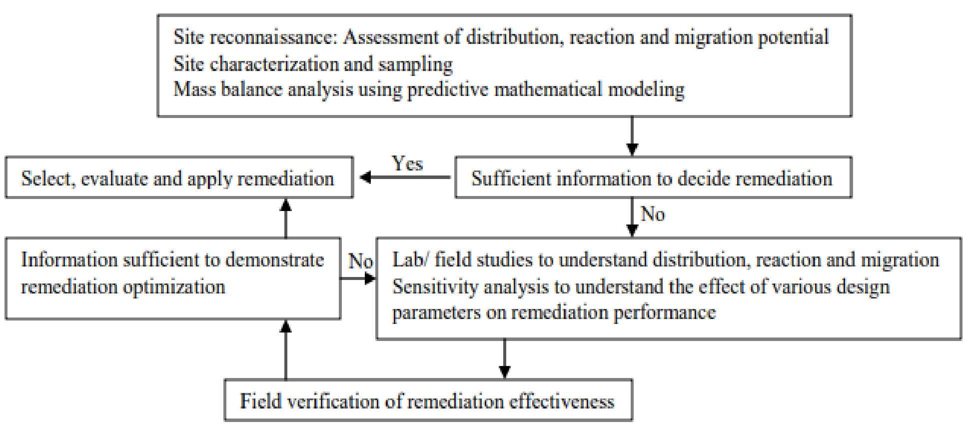
iv) Whether the contaminants are stationery or movable?

v) If they are movable, then identify the significant pathways.

vi) Identify the potential receptors of contaminants

5.3 Selection and planning of remediation methods

Figure below (USEPA 1991) presents a flowchart on various processes involved in the planning of site remediation.



Processes involved in deciding contaminated site remediation

It can be noted from Figure above that the most important step for making a decision on site remediation is collection of data. Table below summarizes the essential data to be collected as part of site reconnaissance and site characterization.

Summary of data required for planning contaminated site remediation

Data	Details	Method of acquisition
1) Site history and land use pattern	a) Population density within 3 km from the contaminated site b) Proximity to important geographical features like airport, railways, river etc. c) Ownership of the land d) Extent of contamination	Field
2) Geologic and hydrologic	a) Topography b) Soil profile up to bed rock c) Information on aquifer d) Groundwater depth and flow direction	Field
3) Geotechnical	a) Soil sampling and classification b) Permeability of soil c) Chemical characteristics of soil d) Soil strength	Field Field Lab Lab
4) Waste	a) Water quality b) Identifying the type of contamination c) Concentration of contaminants d) Spatial extent of contamination e) Depth of contamination f) Contaminant retention characteristics g) Contaminant transport characteristics h) Hazard assessment and zonation	Field/ Lab Field/ Lab Lab Field/ Lab Field/ Lab Lab Lab Lab

5.4 Risk assessment of contaminated site

Risk assessment or hazard assessment is required to decide the extent of contaminant remediation required for a particular site. The factors influencing risk assessment are: **Toxicity:** A material is deemed toxic when it produces detrimental effects on biological tissues or associated process when organisms are exposed to concentration above some prescribed level. Acute toxicity is the effect that occurs immediately after exposure whereas chronic toxicity deals with long term effects. It is expressed as mass unit of toxicant dose per unit mass of receiving organism. It must be noted that concentration is an important factor while deciding toxicity. Only when a contaminant crosses a particular concentration, it becomes toxic. If the concentration is within the prescribed limit then no remediation need to be performed. Only those site which have toxic level of contaminant concentration needs remediation. For example, toxic contamination level leading to cancer becomes the basis for some of the site clean-up programs. Test protocols such as toxicity characteristics leaching procedure (TCLP) (Method 1311, EPA) have been developed for extraction of chemicals from wastes to verify whether the concentration is within the prescribed toxicity limit. TCLP is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphase wastes. Several regulatoryagencies such as central pollution control board (CPCB), India, United States Environmental Protection Agency (USEPA) have prescribed toxic concentration levels for various chemicals that get leached from the waste samples by conducting TCLP. In some cases, multiple extractions from the wastes become necessary. For performing TCLP appropriate extraction fluid need to be used. Glacial acetic acid mixed with water is used as the extraction fluid. In some cases sodium hydroxide is also added. For detailed procedure, readers are advised to refer to Method 1311, EPA.

Reactivity: It is the tendency to interact chemically with other substances. These interactions become hazardous when it results in explosive reaction with water and/or other substances and generate toxic gases.

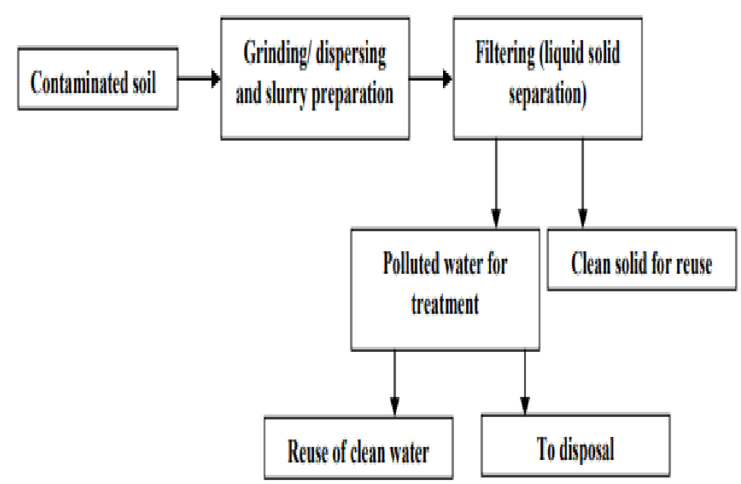
Corrosivity: Corrosive contaminants degrade materials such as cells and tissues and remove matter. It is defined as the ability of contaminant to deteriorate the biological matter. Strong acids, bases, oxidants, dehydrating agents are corrosive. $pH < 2$ or $pH > 12.5$ is considered as highly corrosive. Substances that corrode steel at a rate of 6.35 mm/year is also considered hazardous.

Ignitability: It is the ease with which substance can burn. The temperature at which the mixture of chemicals, vapour and air ignite is called the flash point of chemical substances. Contaminants are classified as hazardous if it is easily ignitable or its flash point is low.

Based on the above four factors the risk associated with a particular site is determined by specifying maximum acceptable risk using risk estimation equations (Reddi and Inyang 2000). Risk assessment provides a numerical quantification of the probability of harm from hazardous or toxic contamination. Risk management uses this input of risk assessment in deciding how much regulation and corrective measure need to be taken. The corrective action is mostly the practice of remediation of the contaminated site. The maximum possible concentration that could lead to the maximum acceptable risk is backcalculated. If the level of concentration at a particular site is greater than the maximum possible concentration, then it requires remediation. This approach would clearly indicate the extent of remediation required for the contaminated site. Appropriate remediation scheme is then selected to bring the concentration level much less than the maximum possible concentration. Since risk assessment and risk management is a very broad topic, it is difficult to discuss the mathematical formulation in this course. Interested readers are requested to go through additional literature (USEPA 1989; Asante-Duah 1996; Mohamed and Antia 1998).

5.5 Remediation methods for soil and groundwater

Based on the toxic level of contaminants and the risk it pose to the environment, a suitable remediation method is selected. It must be noted that the remediation does not aim for entire decontamination. The major focus is to bring the contamination level well below the regulatory toxic limit. This is done by removing the toxic contaminants and/or immobilizing the contaminant that prevents its movement through subsurface geo environment. The remediation methods are broadly classified as physico-chemical, biological, electrical, thermal and combination of these methods.

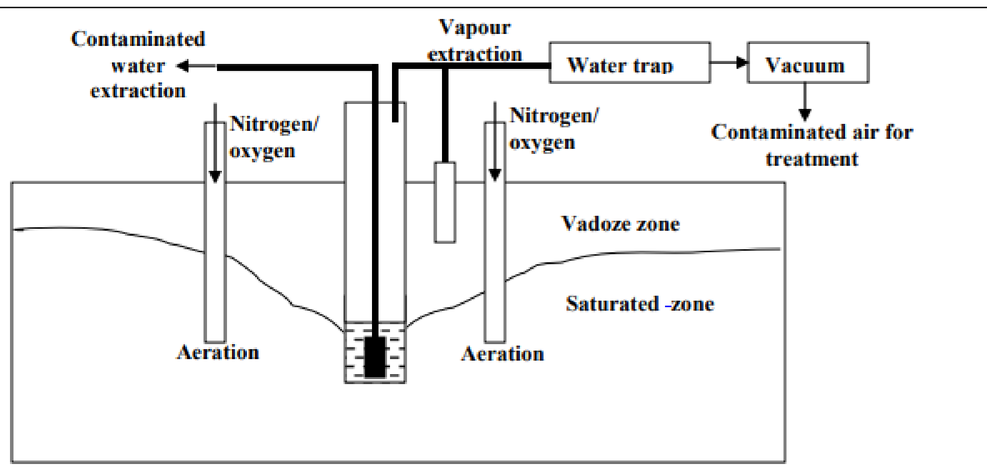


Soil washing for granular soils contaminated with inorganic pollutant

5.5.1 Physico-chemical methods

a) Removal and treatment of contaminated soil: One of the simplest physical methods for remediation is by removing the contaminated soil and replacing it with clean soil. Essentially it is a dig, dump and replace procedure. Such a method is practically possible only if the spatial extent and depth of the contaminated region is small. The dug out contaminated soil can be either disposed off in an engineered landfill or subjected to simple washing as shown in Figure. However, washing procedure is mostly suitable for granular soils with less clay content and contaminated with inorganic pollutants. For clay dominated soils, a chemical dispersion agent need to be added to deflocculated and then chemical washing is employed to break the retention of contaminants with the clay surface. Incineration is suggested for soils contaminated with organic pollutants. In case, it is necessary to remove organic pollutants then certain solvents or surfactants are used as washing agents. The method is directly applied in situ where solvent, surfactant solution or water mixed with additives is used to wash the contaminants from the saturated zone by injection and recovery system. The additives are used to enhance contaminant release and mobility resulting in increased recovery and hence decreased soil contamination.

b) Vacuum extraction: This method is one of the most widely used in situ treatment technologies. The method is cost-effective but time consuming and ineffective in water saturated soil. The technique, as depicted in Fig. 4.3, is useful for extracting contaminated



A schematic diagram for vacuum extraction procedure (Reddi and Inyang,

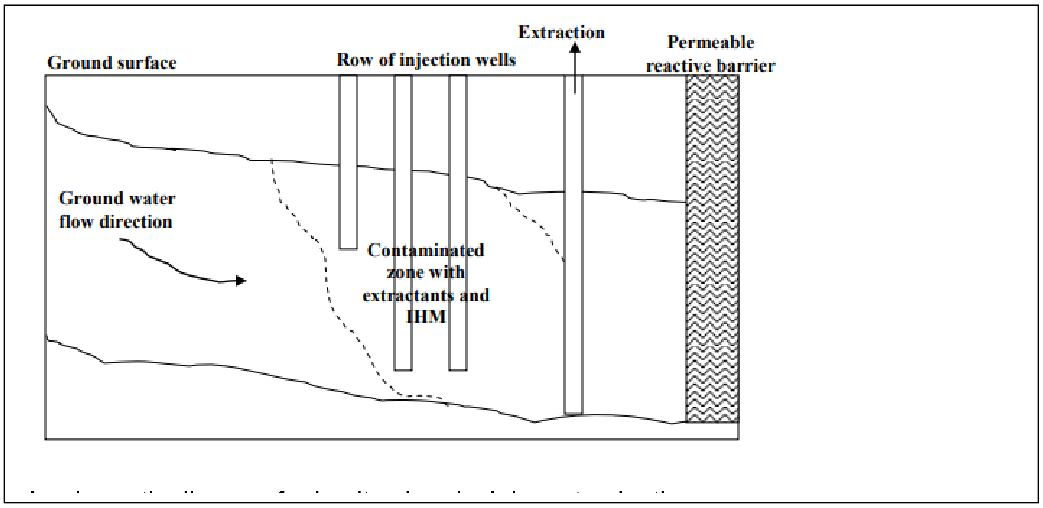
groundwater and soil vapour from a limited subsurface depth. The contaminated water is then subjected to standard chemical and biological treatment techniques. Vacuum technique is also useful when soil-water is contaminated with volatile organic compound (VOC). The method is then termedas “air sparging”. Sometimes biodegradation is clubbed with air sparging for enhanced removal of VOC. Such a technique is then termed as biosparging.

The vacuum extraction probe is always placed in the vadoze zone. The success of the method depends on the volatilization of VOC from water into air present in voids. An injecting medium is used to extract soil-water and/ or soil-air. When oxygen is used instead of nitrogen as the injecting medium, it enhances aerobic biodegradation.

Soil structure influences a lot on the passage of extracted water and vapour and hence on the success of vacuum extraction technique. It is not only important that the injecting medium is delivered efficiently but also the extracted product reaches the exit with less hindrance. Granular soils provide better passage where as the presence of clay and organic matter impedes the transmission of both fluid and vapour. Organic matter provides high retention leading to less volatilization. High density and water content also minimize transmissivity. Apart from soil, the VOC properties such as solubility, sorption, vapour pressure, concentration etc. also influence the extraction process.

c) Solidification and stabilization: This is the process of immobilizing toxic contaminants so that it does not have any effect temporally and spatially. Stabilization-solidification (SS) isperformed in single step or in two steps. In single step, the polluted soil is mixed with a special binder so that polluted soil is fixed and rendered insoluble. In two step process, the polluted soil is first made insoluble and non-reactive and in the second step it is solidified. SS process is mostly justified for highly toxic pollutants. In-situ SS process is mostly influenced by the transmissivity characteristics of the soil, viscosity and setting time of the binder. Well compacted soil, high clay and organic content do not favour in-situ SS. In ex-situ methods, polluted soil is first grinded, dispersed, and then mixed with binder material. The resultant SS material need to be disposed in a well contained landfill. It is essential that the resultant SS product does not undergo leaching. The common binders used in practice include cement, lime, fly ash, clays, zeolites, pozzolonic products etc. Organic binders include bitumen, polyethylene, epoxy and resins. These organic binders are used for soil contaminated with organic pollutants.

d) Chemical decontamination: This method is mostly applicable for those soils which have high sorbed concentration of inorganic heavy metals (IHM).



The first process in this method is to understand the nature of bonding between the pollutant and the soil surface. A suitable extractant need to be selected for selective sequential extraction (SSE) of IHM from the soil mass. The extractants include electrolytes, weak acids, complexing agents, oxidizing and reducing agents, strong acids etc. The use of these extractants in single or in combination will depend upon the concentration of IHM and nature of the soil mass. In-situ application (as depicted in Fig. 4.4) of extractants would remove IHM from the soil surface and enter into the pore water. The pore water is pumped and treated (pump and treat method) on the ground. While treating the pumped water, both extractants and IHM are removed.

Another method is to allow the contaminated pore water to flow through a permeable reactive barrier (PRB). Hence the placement of the barrier is determined by the direction of flow of ground water. The material packed in the barrier will retain IHM by exchange (sorption), complexation or precipitation reaction. The transmission and the reaction time determine the thickness of the reactive barrier to be provided. The material to be provided in the barrier is influenced by the knowledge of IHM to be removed. This is mainly due to the fact that the above mentioned reaction occurs differently when IHM is present as single or as multiple species. The successful use of PRB or treatment wall (TW) depends upon its location such that majority of the contaminated groundwater flows through it. It is essential to have a good knowledge on the hydro geological conditions where such barriers need to be placed. In some cases, sheet pile walls are used to confine the flow towards the permeable barrier. Some of the materials used in PRBs are exchange resins, activated carbon, zeolites, various biota, ferric oxides, ferrous hydroxide etc. Hydraulic conductivity of the PRB should be greater than or equal to the surrounding soil for proper permeation to occur. The knowledge on reaction kinetics and permeability of the barrier would determine the thickness of the wall to be provided such that enough residence time is achieved for the removal reaction to occur.

5.5.2 Biological methods

Remediation by biological treatment is mostly applicable for soil contaminated with organic pollutants and the process is termed as bioremediation. In this method, certain soil microorganisms are used to metabolize organic chemical compounds. In the process these microorganisms degrade the contaminant. If naturally occurring microorganisms such as bacteria, virus or fungi is not capable of producing enzymes required for bioremediation, then genetically engineered microorganisms would be required. At the same time, it should be ensured that such microorganisms do not produce any undesirable effect on the geo-environment (such as toxins). The process of bioremediation is dependent on reactions such as microbial degradation, hydrolysis, aerobic and anaerobic transformation, redox reaction, volatilization etc. An example of bioremediation is discussed in the next section where in the process is used for the remediation of oil spill land.

5.5.3 Electro-kinetic methods

Electro-kinetic methods are popular field method for decontaminating a particular site by using electrical principles. The procedure is more effective for granular type of soils. Two metal electrodes are inserted into the soil mass which acts as anode and cathode. An electric field is established across these electrodes that produces electronic conduction as well as charge transfer between electrodes and solids in the soil-water system. This is achieved by applying a low intensity direct current across electrode pairs which are positioned on each side of the contaminated soil. The electric current results in electro-osmosis and ion migration resulting in the movement of contaminants from one electrode to the other. Contaminants in the soil water or those which are desorbed from the soil surface are transported to the electrodes depending upon their charges. Contaminants are then collected by a recovery system or deposited at the electrodes. Sometimes, surfactants and complexing agents are used to facilitate the process of contaminant movement. This method is commercially used for the removal of heavy metals such as uranium, mercury etc from the soil.

5.5.4 Thermal methods

Thermal methods include both high temperature (>5000C) and low temperature (<5000C) methods and are mostly useful for contaminants with high volatilization potential (Evangelou 1998). High temperature processes include incineration, electric pyrolysis, and in-situ vitrification. Low temperature treatments include low temperature incineration, thermal aeration, infrared furnace treatment, thermal stripping. High temperature treatment involves complete destruction of contaminants through oxidation. Low temperature treatment increases the rate of phase transfer of contaminants from liquid to gaseous phase there by causing contaminant separation from the soil. Radio frequency (RF) heating is used for in situ thermal decontamination of soil having volatile and semi-volatile organic contaminants. Steam stripping or thermal stripping is another process useful for soils contaminated with volatile and semi-volatile organic contaminants. It is an in situ process in which hot air, water or steam is injected into the ground resulting in increased volatilization of contaminants. Sometimes vacuum is applied to extract air or steam back to the surface for further treatment. The effectiveness of this method is increased by the use of chemical agents that are capable of increasing the volatility of the contaminants. High cost and its ineffectiveness with some contaminants (with low volatilization potential) make thermal method less attractive. Also, in some cases incineration process produces more toxic gases.

5.6 Some examples of *in-situ* remediation

Harbottle et al. (2006) have compared the technical and environmental impacts of taking no remedial action with those of two remediation technologies.The main objective of this study is to verify the sustainability of remediation technologies. The two remediation technologies evaluated in this study are solidification/ stabilization (S/S) and landfilling. In both these methods contaminants are contained rather than destroyed. Therefore, it is extremely important to analyze the long-term effect to avoid any potential problems in future. In this study, sustainable remediation project is defined as the one that satisfies the five criteria listed as follows:

Criterion 1: Future benefits outweigh the cost of remediation.

Criterion 2: Overall environmental impact of the remediation method is less than the impact of leaving the land untreated.

Criterion 3: Environmental impact of remediation process is minimal and measurable.
Criterion 4: The time-scale over which the environmental consequences occur is part of the decision-making process.

Criterion 5: The decision making process

The site selected in this study was an industrial location polluted by BTEX (benzene, toluene, ethylbenzene and xylene) and TPH (total petroleum hydrocarbon). About 4400 m3 of contaminated soil has been remediated. The stabilization mix used was cement: bentonite of 2.5:1 and water: dry grout of 3.8:1. It was found that due to S/S, groundwater pollution reduced by 98 percent and the leachate from S/S sample was well within the limit. S/S process resulted in the increase in strength, reduction in permeability and increase in pH of the soil. The same quantity of contaminated soil has been landfilled at a distance of 96 km from the source. In long term, S/S has been found to perform better than landfill and no action taken for remediation. Other advantages of S/S are low material usage, low off-site waste disposal, potential ground improvement for immediate re-use, and lesser impact on the local community. However, the contaminants remain on the site which increases the level of uncertainty in long term. In the case of landfilling, long term impacts are less due to the fact that contaminated soil is removed from the site. The resources that need to be mobilized for landfill are more than S/S.

Ludwig et al. (2011) have explained the use of permeable reactive barrier (PRB) for the treatment of Cr6 in groundwater. PRB in the form of trench and fill system, chemical redox curtain or organic carbon based biotic treatment zone induce reduction condition for converting Cr6 to relatively immobile and non-toxic Cr3. The most efficient trench and fill application is granular zero valent Iron (ZVI) fillings, which rapidly converts Cr6 to Cr3. Alternatively, organic mulch and compost has been used to initiate microbially active Cr6 reduction. However, the use of organic matter as well as organic carbon does not have the longevity of ZVI. The study quotes an example of ZVI based PRB installed at North Carolina in 1996. This PRB is of 10 m depth, 0.6 m wide and 46 m long. This PRB is found to treat groundwater containing Cr6 (approximately 15 mg/l concentration) for more than 15 years. This study also quotes the use of chemical reducing agent such as sodium dithionite at US department of energy, Hanford, site for treating large Cr6 containing groundwater plume. Asquith and Geary (2011) have compared bioremediation of petroleum contaminated soil by three methods, namely, biostimulation, bioaugmentation and surfactant addition. Bioremediation process depends on microbial activity for biodegrading petroleum hydrocarbons. Since it is a natural process, it is a slow reaction. The above mentioned three methods are used for increasing the rate of bioremediation reaction. Biostimulation enhances the growth and activity of microorganisms by the addition of nutrients and/or additives. Bioaugmentation is the addition of hydrocarbon degrading microbial cultures. Surfactant addition would enhance solubility, emulsify and disperse hydrophobic contaminants to overcome the problem of low contaminant bioavailability. Sandy loam soil with total petroleum hydrocarbon (TPH) > 30000mg/kg has been used to evaluate the three methods. It was noted from this study that biostimulation with nutrients enhanced bioremediation process. Organic amendments provided a better bioremediation than inorganic amendments. Surfactant addition was found to increase bioavailability of hydrocarbon and hence enhance bioremediation. Ascenco (2009) has discussed about contaminated site characterization and clean up based on two case studies. The first case study pertains to the excavation and washing of soil in an industrial estate site of 0.12 km2 . Preliminary investigation of the site revealed contamination upto a depth of 6m with TPH, volatile aromatics such as toluene, ethylbenzene and xylene. Soil was found to be free of heavy metals. A quantitative risk assessment indicated the need for remediation. 40000 tonnes of soil was excavated from the affected site and subjected to soil washing. Washing has been performed in a unit with a capacity of 70 tonnes/ hour. Washed soil has been declared safe after adequate laboratory testing and the clean soil reused in the site. The soil has been first homogenized and sieved. The required surfactant and extracting agents were mixed with water and used for soil washing. The waste water which comes out after washing has been treated and reused. Contaminated sludge and fines after waste water treatment and oversized soil mass rejected during sieving was transferred to landfills. The second case study is another industrial area of 3 km2 near Lisbon. The industrial site comprised mainly of organic and inorganic chemistry industries producing pesticides, acid, copper, lead, zinc, iron pyrites etc. The site consists of 52000 tonnes of hazardous sludge from zinc metallurgy and iron pyrite ashes. The site required investigation and remediation due to the placement of an airport in the vicinity of this site. The groundwater exhibited high levels of arsenic, lead, mercury, cadmium, copper, zinc, cobalt. In some areas the pH was as low as 1, which increased metal mobility. The investigations were mainly focused on developing a conceptual site model and environmental risk analysis for defining remediation options. The efforts are still on for this particular site.

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Unit 6: Waste Water Treatment Technology

Unit Structure

6.0 Learning Objectives

After reading this Unit you will be able to:

- discuss the various waste water treatment methods
- explain the various processes involved in the physical, chemical and biological treatment of waste water
- explain the functioning of waste water treatment plant

6.1. Introduction

In the previous units, you have learnt about various kinds of remediation technologies. In this unit we will learn about various processes for waste water treatment. You will be surprised to know that ninety nine (99%) percent constituents of wastewater is just water whereas only one (01%) percent is solid wastes. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage in the natural environment. Thus, Water treatment is a process of making water suitable for its application or, conversion of used water into environmentally acceptable water or even drinking water or to its natural state.

Water treatment may include mechanical, physical, biological, and chemical methods and is an integrated system comprising of the conventional series of primary and secondary treatment processes, but also includes tertiary treatment (Figure 1) and individual treatment of certain streams.All water treatments involve the removal of solids, bacteria, algae, plants, inorganic and organic compounds.

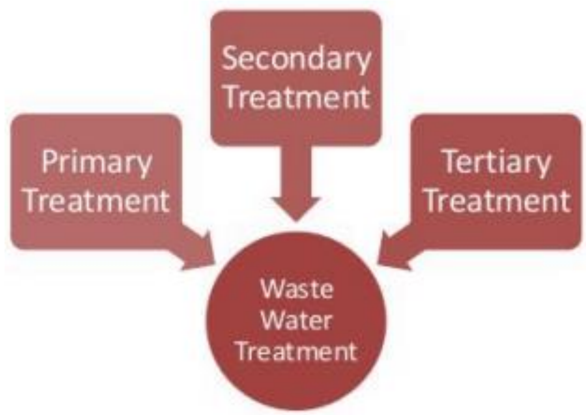


Figure: 1 Different phases of waste water treatment

A typical waste water treatment plant is the conventional series of primary and secondary treatment processes, but may also include tertiary treatment. The primary and secondary treatment processes handle most of the nontoxic waste waters; while some pre-treatment of the waste water before being added to this flow is necessary to prevent the damage to the downstream equipment. The schematic diagram in Figure 2 and 3 illustrates the outline of waste water treatment system treating the sewage and industrial effluents.

Table1: Major classes of municipal wastewater contaminants, their significance & origin

Contaminant	Significance	Origin
Settleable solids (sand,	Settleable solids may create sludge deposits and anaerobic conditions in sewers, treatment facilities or open	Domestic, runoff

grit)	water	
Organic matter (BOD);Kjeldahl nitrogen	Biological degradation consumes oxygen and may disturb the oxygen balance of surface water; if the oxygen in the water is exhausted anaerobic conditions, odour formation, fish kills and ecological imbalance will occur	Domestic, industrial
Pathogenic microorganisms	Severe public health risks through transmission of communicable water borne diseases such as cholera	Domestic
Nutrients (N and P)	High levels of nitrogen and phosphorus in surface water will create excessive algal growth(eutrophication). Dying algae contribute to organic matter	Domestic, rural runoff, industrial
Micro-pollutants (heavy metals, organic compounds)	Non-biodegradable compounds may be toxic, carcinogenic or mutagenic at very low concentrations (to plants, animals, humans). Some maybioaccumulate in food chains, e.g. chromium (VI), cadmium, lead, most pesticides and herbicides, and PCBs	Industrial, rural runoff (pesticides)
Total dissolved solids (salts)	High levels may restrict wastewater use for agricultural irrigation or aquaculture	Industrial, (salt water intrusion)

Source: Metcalf and Eddy Inc., 1991

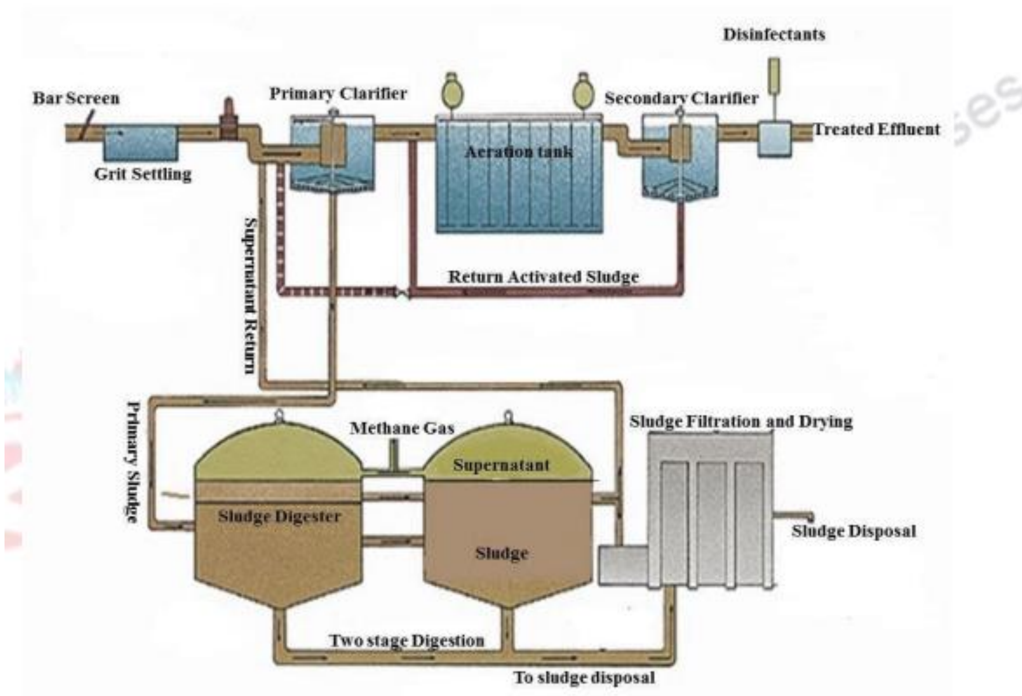


Figure 2: Outline of Sewage Treatment Plant

(Image: http://www.dec.ny.gov/chemical/97463.html)

6.2 Waste Water Treatment Process

After the wastewater has been collected and transported to the plant, the treatment of waste water can be initiated. The various steps involved in a typical waste water treatment are as mentioned in the table below:

Table 3.1 Wastewater treatment process

A) Preliminary Treatment	
Screening	Removes rags, sticks, and other debris; protects pumping equipment
Degritting	Removes settleable inorganic grit
Pre-Aeration	Adds oxygen to the wastewater to reduce odors
Flow Metering and Sampling	Measures and records flows; sample wastewater for analyses of components
B) Primary Treatment	
Sedimentation and Flotation	Removes settleable organic and inorganic particles and floating debris such as fats, oils, and greases
C) Secondary Treatment	
Biological Treatment	Removes dissolved and remaining colloidal (also known as nonsettleable) organic matter; can convert ammonia-nitrogen to nitrate-nitrogen
Sedimentation	Separates biomass and chemical precipitates from treated wastewater
D) Tertiary (Advanced) Treatment	
Chemical Phosphorus Removal	Adds chemical to form precipitate with phosphorus for removal in the secondary clarifiers
Biological Nutrient Removal	Removes nitrogen and phosphorus using specialized microorganisms
Multimedia Filtration	Removes additional suspended solids (beyond that obtained by simple settling) using gravity or pressure filters
E) Disinfection	
Disinfection	Kills pathogenic organisms
F) Solids Treatment	
Digestion	Stabilizes remaining organic matter; reduces pathogen levels; results in overall net reduction in solids
Disposal	Moves stabilized solids from plant to farmland for recycling or to landfill

6.3 Preliminary treatment

In many waste water treatment plants the preliminary treatment is the part of the primary treatment, which includes only the mechanical processes. The pretreatment of the influent involves one or all the following steps depending upon the kind of the waste water to be treated.

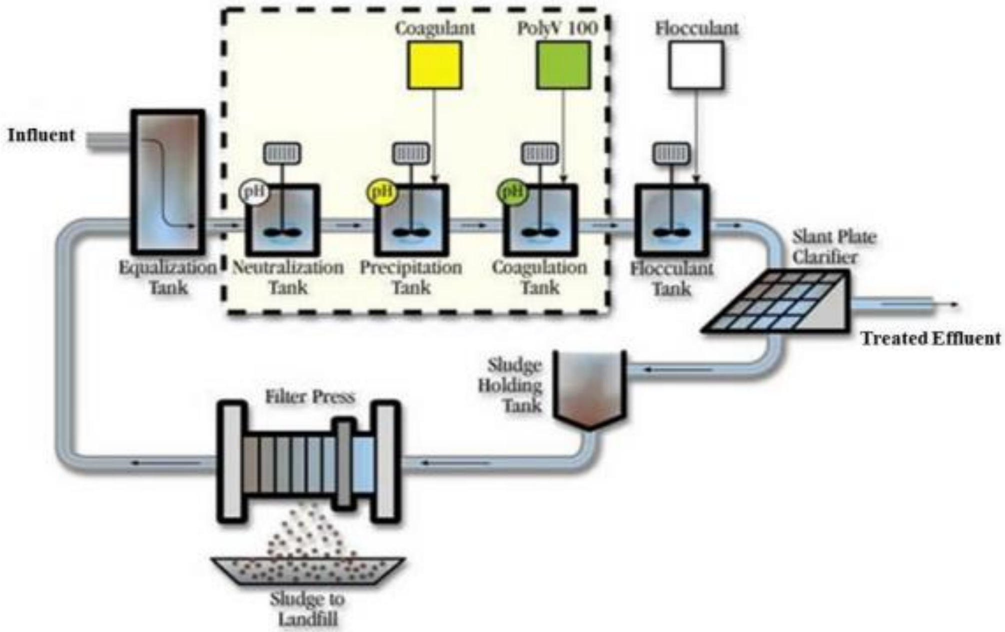


Figure 3: Outline of Industrial wastewater Treatment Plant
(Image: http://www.water-technology.net/projects/metal_beckart/)

6.3.1 Screening

Screening is the first unit operation used at wastewater treatment plants. It removes large solid chunks and objects such as rags, paper, plastics, and metals to prevent damage and clogging of downstream equipment, piping and accessories. Some modern wastewater treatment plants use both

Table 2: Types of Screens used in Preliminary treatment of Waste water

Screen Type	Description
Trash Rack	Designed to prevent large debris from entering treatment processes. Opening size: 38 to 150 mm.
Manually Cleaned Bar Screen	Designed to remove large solids, rags, and debris. Opening size: 30 to 50 mm. Bars set at 30 to 45 degrees from vertical to facilitate cleaning. Primarily used in older or smaller treatment facilities, or in bypass channels.
Mechanically Cleaned Bar Screen	Designed to remove large solids, rags, and debris. Opening size: 6 to 38 mm. Bars set at 0 to 30 degrees from vertical. Always used in new installations because of large number of advantages relative to other screens.

Source: Design of Municipal Wastewater Treatment Plants, WEF MOP 8, Fourth Edition, 1998 coarse screen and fine screen filters as a part of the pretreatment process.

Coarse screens remove large solids, rags, and debris from wastewater, and the types of coarse screens include mechanically and manually cleaned bar screens, including trash racks.

Fine Screens are typically used to remove material that may create operation and maintenance problems in downstream processes, particularly in systems that lack primary treatment. Typical opening sizes for fine screens are 1.5 to 6 mm (0.06 to 0.25 inches). Very fine screens with openings of 0.2 to 1.5 mm (0.01 to 0.06 inches) placed after coarse or fine screens that can further reduce suspended solids to levels near those achieved by primary clarification. Various screen types are shown in table 2.

6.3.2 Comminuting and Grinding

The processing of coarse solids using comminutors and grinders reduces the size of coarser particles so that they can be removed during downstream treatment operations, such as primary clarification, where both floating and settle able solids are removed. Comminuting and grinding devices are installed in the wastewater flow channel to grind and shred material in the size range of 20 mm (0.75 inches). **Comminutors** consist of a rotating slotted cylinder through which wastewater flow passes. Solids that are too large to pass through the slots are cut by blades as the cylinder rotates, reducing their size until they pass through the slot openings. **Grinders** consist of two sets of counter rotating, intermeshing cutters that trap and shear wastewater solids into a consistent typically 6 mm particle size.

6.3.3 Grit Removal

Grit includes sand, gravel or other heavy solid materials that are "heavier" (higher specific gravity) than the organic biodegradable solids in the wastewater. The removal of grit prevents unnecessary abrasion and wear of mechanical equipment, grit deposition in pipelines and channels, as well as the accumulation of grit in anaerobic digesters and aeration basins. Grit removal facilities typically precede primary clarification and follow screening and comminution. Many types of grit removal systems exist, including aerated grit chambers, vortex-type (paddle or jet induced vortex) grit removal systems, detritus tanks (short term sedimentation basins), horizontal flow grit chambers (velocity-controlled channel), and hydro cyclones (cyclonic inertial separation). The collected grit must be removed from the chamber, dewatered, washed, and conveyed to a disposal site. Some smaller plants use manual methods to remove grit, but grit removal is usually accomplished by an automatic method. The four methods of automatic grit removal include inclined screw or tubular conveyors, chain and bucket elevators, clamshell buckets, and pumping.

6.3.4 Flow Equalization

The influent before the actual treatment is subjected to flow equalization in a mixing tank to level out the hour-to-hour variations in flows and concentrations. There are spill pond to retain slugs of concentrated wastes that could interfere with the downstream processes.

6.3.5 Fat and grease removal

In some larger waste water treatment plants, fat and grease are removed by passing the wastewater through a small tank where mechanical skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help the recovery of the fat as froth. Many plants, however, use primary clarifiers with surface skimmers for fat and grease removal.

6.4 Primary Treatment

Primary Treatment is a physical (non-biological) treatment process that takes place in tank andallows substances to settle or float, and be separated from the water being treated. It prepares the wastewater for the next secondary (biological) treatment. This involves the separation of suspended organic matter (or human waste) from the wastewater through **sedimentation**. Sedimentation is the process of gravitational settling, where in the solid suspended particles that are heavier than water are allowed to settle by the gravitational force. This is done by putting the wastewater into large settlement tanks for the solids to sink or settle down to the bottom of the tank. The settled solids are called 'sludge'. At the bottom of these circular tanks, large scrappers continuously scrape the floor of the tank and push the sludge towards the pump away for further treatment. The rest of the water is then moved to the secondary treatment.

6.5 Secondary Treatment

The secondary treatment is the **biological degradation** of soluble organic compounds that escapes primary treatment. This process is usually done aerobically in an open, aerated vessel or lagoon where the microorganisms degrade this organic matter, which serve as "food" for them. Microorganisms combine this matter with oxygen from the water to yield the energy they need to thrive and multiply. Unfortunately, this oxygen is also needed by fish and other organisms in the river. So, the heavy organic pollution in the river or water bodies can lead to "dead zones" where no fish can be found and sudden releases of heavy organic loads can lead to dramatic "fish kills".

The water, at this stage, is put into large rectangular tanks. These are called aeration lanes. Air is pumped into the water to encourage bacteria to break down the organic contaminants of sludge that escaped the sludge scrapping process. The biological process is then followed by additional settling tanks (**secondary sedimentation**) to remove more of the suspended solids and microorganisms called as **activated sludge**. A fraction of this sludge is recycled in certain processes, but ultimately the excess sludge along with the sediment solids has to be disposed-off. Next, the 'almost' treated wastewater is passed through a **settlement tank**, where, more sludge is formed at the bottom of the tank from the settling of the bacterial action. Again, the sludge is scraped and collected for treatment. The water at this stage is almost free from harmful substances and chemicals. The water is allowed to flow over a wall where it is filtered through a bed of sand to remove any additional particles. The filtered water is then discharged into the water bodies.

About 85% of the suspended solids can be removed by a well running plant with secondary treatment. Secondary treatment technologies include the basic activated sludge process, the variants of pond and constructed wetland systems, **trickling filters**, **rotating biological contactors** and **other forms of treatment which use biological activity to break down organic matter**. The existing treatment systems can also be modified so as to broaden the capabilities and performance. One example is the addition of powdered activated carbon (PAC) to the biological treatment process, to adsorb organics that the microorganisms cannot degrade. Another example is to add coagulants at the end of the biological treatment to remove phosphorus and residual suspended solids and nutrients like N and P.

In **Trickling Filter (TF), w**ater trickles downward over media made of stone or plastic which comes in a variety of shapes and sizes. The media offers a place for aerobic bacteria to attach, multiply, and feed on the passing wastewater.

Rotating Biological Contactor (RBC) has a rotating shaft surrounded by plastic disks (media) that allows microorganisms to grow. In this, Media is rotated in and out of the wastewater to provide oxygen for organisms, which feed on the wastewater.

6.6 Disinfection

The disinfection typically with chlorine can be the final step before discharge of the effluent. However, some environmental authorities are concerned that chlorine residuals in the effluent can be a problem in their own right, and have moved away from this process.

Disinfection is frequently built into treatment plant design, but not effectively practiced, because of the high cost of chlorine, or the reduced effectiveness of ultraviolet radiation where the water is not sufficiently clear or free of particles.

6.7 Tertiary treatment (Advanced treatments)

Many existing wastewater-treatment systems were built for primary and secondary treatment only, but now tertiary treatment processes are added on beyond secondary treatment in order to remove specific type of residuals. The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality to the desired level by removing more than 99 per cent of all the impurities from wastewater, producing an effluent of almost **drinking-water quality**. This advanced treatment can be accomplished by a variety of methods such as **coagulation sedimentation**, **filtration**, **reverse osmosis**, and **extending secondary biological treatment** to further stabilize oxygen-demanding substances or remove nutrients. In various combinations, these processes can achieve any degree of desired pollution control. As wastewater is purified to higher and higher degrees by such advanced treatment processes, the treated effluent can then be reused for urban, landscape, and agricultural irrigation, industrial cooling and processing, recreational uses and water recharge, and even indirect and direct augmentation of drinking water supplies. The related technology can be very expensive, requiring a high level of technical know-how and well trained treatment plant operators, a steady energy supply, and chemicals and specific equipment which may not be readily available.

6.7.1 Coagulation- Sedimentation

Chemical coagulation sedimentation is used to increase the removal of solids from effluent after primary and secondary treatment. The solids heavier than water settle out of wastewater by gravity in the primary and secondary sedimentation tanks but the lighter particles are made to settle down with the addition of specific chemicals, like alum $Al_2(SO_4)_3$, lime (CaO), or ferric salts of iron (Fe^{3+}). With the addition of these chemicals, the smaller particles clump or 'floc' together into large masses. The larger masses of particles will settle out in the sedimentation tank reducing their concentration in the final effluent.

6.7.2 Filtration

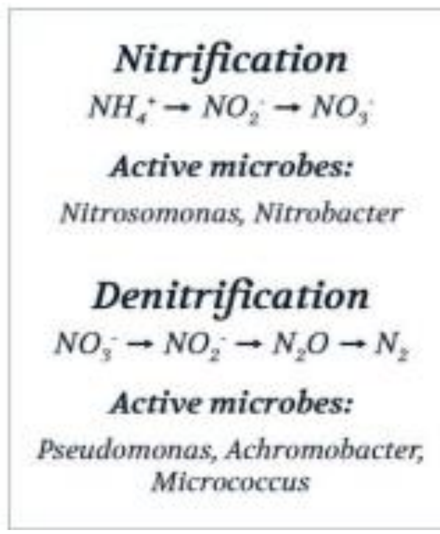
A variety of filtration methods are available to ensure high quality water. Sand filtration, which consists of simply directing the flow of water through a sand bed, is used to remove residual suspended matter. Filtration over activated carbon results in the removal of: non-biodegradable organic compounds, absorbable organic halogens, toxins, color compounds and dyestuffs, aromatic compounds. Although there are a number of different methods of filtration are practiced, but in tertiary treatment the most mature is pressure driven membrane filtration. This relies on a liquid being forced through a filter membrane with a high surface area and small pore size (0.02-0.2µm) to remove bacteria, viruses, pathogens, metals, and suspended solids.

6.7.3 Reverse osmosis

In the reverse osmosis process, pressure is used to force effluent through a membrane that retains contaminants on one side and allows the clean water to pass to the other side. Reverse osmosis is actually a type of membrane filtration called microfiltration because it is capable of removing much smaller particles including dissolved solids such as salt.

6.7.4 Nutrient Removal

The nutrients in the form of **Nitrogen and Phosphorus** present in the treated water are also needed to be removed to prevent "**Eutrophication**" of the water bodies where the water is discharged.



Nitrogen control: Nitrogen present in the waste water as ammonia can be toxic to aquatic life in certain instances and can be removed by additional biological treatment beyond the secondary stage. **The nitrifying bacteria** are employed for removal of ammonia present in wastewater. These bacteria can biologically convert ammonia to the non-toxic nitrate through a process known as **nitrification**. The nitrification process is normally sufficient to remove the toxicity associated with ammonia

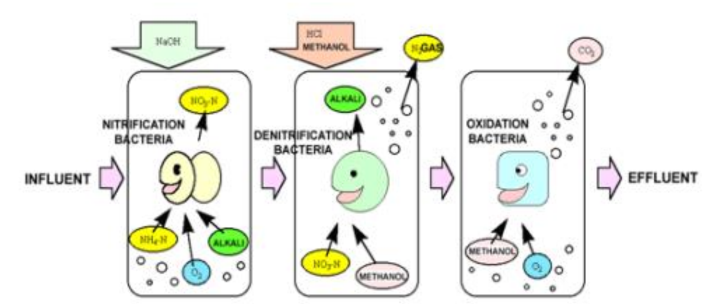


Fig.4: The process of nitrification and denitrification in nutrient removal process

in the effluent but the product formed, the nitrate is a nutrient and in excess amounts can contribute to eutrophication in the receiving waters. In such situations where nitrogen must be completely removed from effluent, an additional biological process can be added to the system to convert the nitrate to nitrogen gas. The conversion of nitrate to nitrogen gas is accomplished by **denitrifying bacteria** in a process known as **denitrification**. In this process, the effluent with nitrogen in the form of nitrate is placed into a tank devoid of oxygen, where carbon-containing chemicals, such as methanol, are added. In this oxygen-free environment, bacteria use the oxygen attached to the nitrogen in the nitrate form releasing nitrogen gas. Because nitrogen comprises almost 80% of the air in the earth's atmosphere, the release of nitrogen into the atmosphere does not cause any environmental harm.

Phosphorus control: Like nitrogen, phosphorus is a necessary nutrient for the growth of algae. Phosphorus reduction is often needed to prevent eutrophication before discharging effluent into lakes, reservoirs, and estuaries. Phosphorus can be removed either through chemical or biological processes. In biological process, specific bacteria, called **polyphosphate accumulating organisms (PAOs)**, are selectively enriched in sludge. They can accumulate large quantities of phosphorus within their cells (up to 20% of their mass) and these bio-solids after their separation from the treated water have a high fertilizer value.

Phosphorus removal can also be achieved by chemical precipitation, usually with salts or iron, alum, or lime. This may lead to excessive sludge productions as hydroxides precipitates and the added chemicals can be expensive. Despite this, chemical phosphorus removal requires a significantly smaller equipment footprint than biological removal, is easier to operate, and is often more reliable than biological phosphorus removal.

The existing treatment systems can also be modified so as to improve the performance and broaden the possibilities of waste water treatment.

6.7.5 Coagulation- Flocculation

The treatment of wastewater treatment is a matter of solids separation, since most of the contaminants in wastewater are present in particulate or colloidal form, or are transformed into such forms during the treatment. The separation of particulate matter from the liquid phase is one of the important steps in most wastewater treatment processes. The waters contain both dissolved and suspended particles and the suspended particles vary considerably depending upon the source of water. The larger particulate matter can be easily separated using the conventional filtration, sedimentation techniques while, the colloidal particles are difficult to separate from water because they do not settle by gravity and due to their small size they can easily pass through the pores of filtration media. The colloidal particles are very fine particles having the size over a range of 1nm to 0.1 nm and electrostatic charge on their surface. For the removal of these particles, these individual colloidal particles must aggregate and grow in size. The aggregation of colloidal particles involves the following separate and distinct steps:

1. Destabilization of the colloidal particles to promote the attachment after they come in contact with each other
2. The transport of colloidal particles to promote their inter-particle collision.

The bringing together of the destabilized particles to form a larger agglomeration is **flocculation** whereas the overall process involving destabilization, transport and floc formation is called **coagulation**.

In general, most colloidal material has a negative surface charge and like charges tend to repel each other preventing the phenomenon of coagulation. These characteristics cause the colloidal particles to remain in solution. The destabilization of colloidal particles to promote coagulation and settlement is achieved by adding chemicals that coat the colloids by opposite charges. The addition of positively charged ions in the solution will destabilize the colloidal matter and allow their settlement. The measurable quantity used to predict the potential of coagulation is **Zeta potential** and effective coagulation has been found to occur experimentally at zeta potential values ranging from ± 0.5 mV.

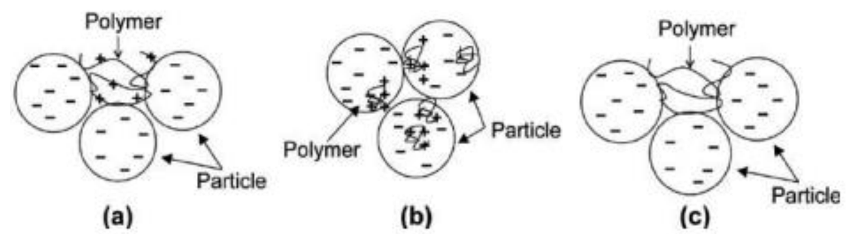


Fig. 5:A schematic representation of coagulation-flocculation mechanism; a) Charged neutralization b) Charge patch formation c) Polymer bridging

(Image adapted from Gerhard, 2005 (in E-PGPathshala)

In the process of water treatment, clarification of water with coagulating agents has been practiced since ancient times, using a variety of substances. The alum was used as a coagulant in water treatment and more formally for the treatment of public water suppliessince seventeenth century (Bratby, 2006). In modern water treatment process, coagulation and flocculation are still essential steps.

Coagulant chemicals are of two main types

- Primary coagulants
- Coagulant aids

1. Primary coagulants are the coagulants that neutralize the electrical charge of particles present in the water leading the particles to clump together (Schulz and Okun, 1984). Chemical coagulation has been in practice for several decades to precipitate the soluble heavy metals present in the waste water as hydroxides, thus facilitating their removal by physical separations through the sedimentation process.

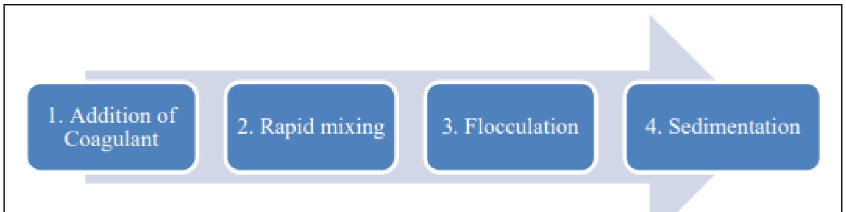


Figure 6: Various steps of Coagulation

Chemically, the coagulants are either metallic salts (such as alum, ferric salts) or polymers. Polymers are man-made organic compounds which are made up of a long chain of smaller molecules. Polymers can be cationic, anionic, or nonionic. The process of coagulation consists of the following four steps:

The first and the initial step is simply addition of the chemical to be used as coagulant to wastewater. This is followed by the second step, where the solution is mixed rapidly to ensure even and homogeneous distribution of the coagulant throughout the wastewater. In the third step, the solution is mixed again, but this time in a slow speed to encourage the formation of insoluble solid precipitates, the process known as "coagulation." The final step is the removal of the coagulated particles by way of filtration or decantation.

Mechanism of coagulation

The process of coagulation results from the two basic mechanisms namely Electro kinetic and Orthokinetic. In the electro kinetic coagulation, the zeta potential is reduced by ions or colloids of opposite charge to a level below the Vander Waals attractive forces while in orthokinetic coagulation the micelles aggregate and form clumps which agglomerate the colloidal particles (Yılmaz et al., 2007). The addition of high valence cations accompanying the dissolution of the coagulant neutralizes the negative charge present on the colloids before the visible floc formation. The rapid mixing coats the colloidal particles resulting in the formation of microflocs. The microflocs, thus, formed retain a positive charge in the acidic range because of the adsorption of H+ ions. These microflocs are also serves to further neutralize and coat the colloidal particles while Flocculation agglomerates the colloids with a hydrous oxide floc. In this phase surface adsorption is also active, so the colloids not initially adsorbed are removed by entrapment in the floc.

The outline of operation for effective coagulation as shown in Figure6 was given by Riddick in 1964. The alkalinity should be added in the form of Bicarbonate without raising the pH of the water before the addition of Alum or Ferric salts. A rapid mixing of 1-3 minutes is needed to allow the Al3+ and Fe3+ cations to coat the colloids resulting in the formation of microflocs. The coagulant aids such as activated silica or polyelectrolyte are added followed by mixing of 20-30 minutes to build up the floc and control the zeta potential.

Commonly used Coagulants: The most common type of coagulants used are metal salts like Aluminium coagulants (Aluminium sulphate, Aluminium chloride, Poly-aluminium chloride and Sodium aluminates), Iron coagulants (Ferric sulphate, Ferrous sulphate, Ferric chloride) and other chemicals as Hydrated lime Ca(OH)2 and Magnesium carbonate MgCO3.

Alum: The most popular and economical coagulant in water treatment application is alum ($Al_2(SO_4)_3.18H_2O$). When alum is added to water, the reaction is $Al_2(SO_4)_3.18H2O + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 18H_2O$

The formation of an aluminium hydroxide floc is the outcome of the reaction between the coagulant and the alkalinity of the water present as hydroxides of calcium and magnesium. If the water to be treated has insufficient alkalinity or `buffering' capacity, additional alkali such as hydrated lime, sodium hydroxide or sodium carbonate must be provided for the reaction. With the addition of sodium carbonate commonly known as soda ash, the reaction is as following:

$$Al_2(SO_4)_3 + 3NaCO_3 + 3H_2O \rightarrow 2Al(OH)_3 + 3Na_2SO_4 + 3CO_2$$

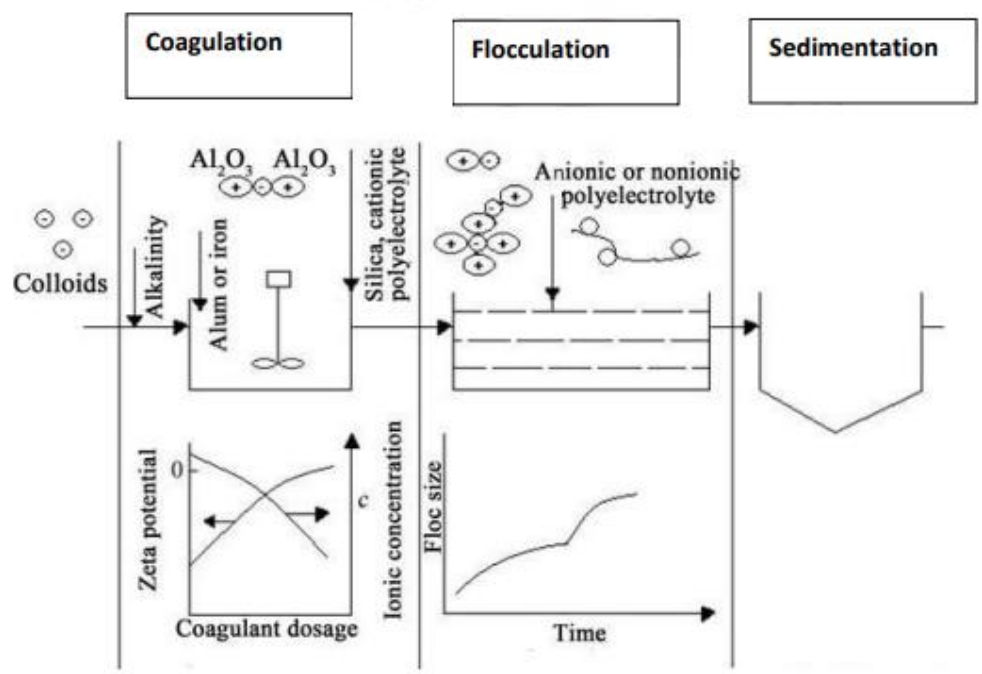


Figure 7: The mechanism of Coagulation

Image: http://web.deu.edu.tr/atiksu/ana52/ychem07.html

The aluminium hydroxide actually exists in the chemical form $Al_2O_3.xH_2O$ and is amphoteric in nature means that it can act as either an acid or a base. The alum floc is least soluble at pH 7.0. The pH control is important in coagulation process, not only in the removal of turbidity and colour but also to maintain satisfactory minimum levels of dissolved residual aluminium in the clarified water. The optimum coagulation pH value should be attained by adding sulphuric or similar strong acid rather than excess coagulant.

The coagulation process with alum as the coagulant is capable of achieving significant removal of organic contaminants, but the pH of the water during coagulation process has profound influences on effectiveness of coagulation and the best results are achieved in slightly acidic condition. Simultaneously, the optimum pH for alum coagulation is influenced by the concentration of organic matter in the water. For water with higher organic matter content, the optimum pH is displaced to be slightly more acidic values

(AWWA, 1979). Thus, conventional coagulation practices may provide excellent organic removal if the coagulant dose and pH conditions are adjusted into the optimum range.

Iron salts: The iron salts most commonly used as coagulants include ferric sulfate, ferric chloride and ferrous sulfate. These compounds often produce good coagulation when conditions are too acidic for use of alum but have the disadvantage of being more difficult to handle.

Ferric Sulphate available in the form of red-brown powder or as granules. The formation of a ferric hydroxide floc is the result of the reaction between the acidic coagulant and the alkalinity of the water, which usually consists of calcium bicarbonate.

$$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Fe(OH)_3 + 3CaSO_4 + 6CO_2$$

Ferric Chloride is available in anhydrous form as a green-black powder, and also as a dark brown syrupy liquid or as crystal ferric chloride.

$$2FeCl_3 + 3Ca(HCO_3)_2 \rightarrow 2Fe(OH)_3 + 3\,CaCl_2 + 6\,CO_2$$

An insoluble hydrous ferric oxide is produced over a pH range of 3.0 to13.0.The floc charge is positive in the acidic range and negative in the basic range with mixed charges over the pH range 6.5 to 8.0.

2. Coagulant Aids

Coagulant aid is an inorganic material and is used along with main coagulant. Coagulant aids when added increase the density and provide toughness to the flocs so that they will not break up during the mixing and settling processes. The common coagulant aids used are **Bentonite**, **Calcium carbonate, Sodium silicate and polyelectrolytes**. Polyelectrolytes are high molecular weight polymers have absorbable groups and form bridges between particles or charged flocs. There are three types of polyelectrolytes: a cationic (adsorbed on negative colloids), anionic (adsorbed on positive colloids) and nonionic. These polyelectrolytes replaces ionic group on the colloid and permits hydrogen bonding between the colloid and the polymer.

Coagulation Control Test

The quality of water changes with season and weather so, the coagulant dosages have to be adjusted accordingly for variations in water turbidity and organic material. An under dose of coagulant may cause the sample to appear cloudy with no floc and settling and an overdose of coagulant may form dense floc that may be fragile and fluffy which will not settle well when the mixing is turned off. However, coagulant dosages cannot be calculated, they have to be determined experimentally by jar test. The jar test is a simple effective method that simulates the coagulation/flocculation process of the existing or proposed water treatment plant. It is a widely used laboratory test for coagulation and flocculation control in water treatment plant operations and design. The purpose of a jar test is to select the type of coagulant used and dosage selection, coagulant aid and dosage selection, determination of optimal pH, determination of the point of chemical addition, optimization of mixing time and intensity for rapid and slow mixings (Amirtharajah and O'Melia, 1990).

Jar Test Procedure

The jar test procedure involves the following steps:

1. Fill the jar testing apparatus containers with sample water and keep it on the magnetic stirrer. Add the coagulant to each container in small increments at a pH of 6.0. After each addition stir rapidly for 1 minute followed by a 3-5 minute slow mix. The rapid mix stage helps to disperse the coagulant throughout each container. Continue the addition until a visible floc is formed.

2. Using this dosage, place 1000 ml of sample in each of six beakers and adjust the pH of each beaker in the range of 4.0-9.0 with standard alkali.

3. Rapid mix each sample for 3 minutes followed by gentle mixing for 15 to 20 minutes to allow flocculation.

4. Measure the effluent concentration of each settled sample.

5. Plot the percentage removal versus pH and select the optimum pH. Using this pH optimize the coagulant dosage and plot percentage removal versus coagulant dosage and select the optimum dosage.

6. If coagulation aid is to be used, repeat the procedure adding the same towards the end of a rapid mix. The values that are obtained through the experiment are correlated and adjusted in order to account for the actual treatment system.

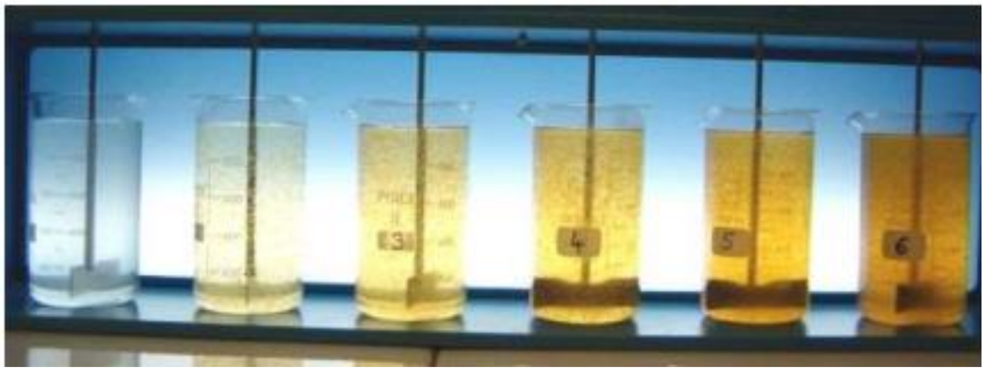


Figure 8: Coagulation Jar Test

6.7.6 Precipitation

Precipitation is a method for the removal of metallic suspended solids, fats, oils, greases, and other organic substances from wastewater that are either dissolved or suspended in solution. These dissolved or suspended particles can be made to settle out of solution as a solid precipitate, which can then be easily separated using sedimentation, filtration or centrifugation. The voluminous precipitate formed can capture ions and particles causing

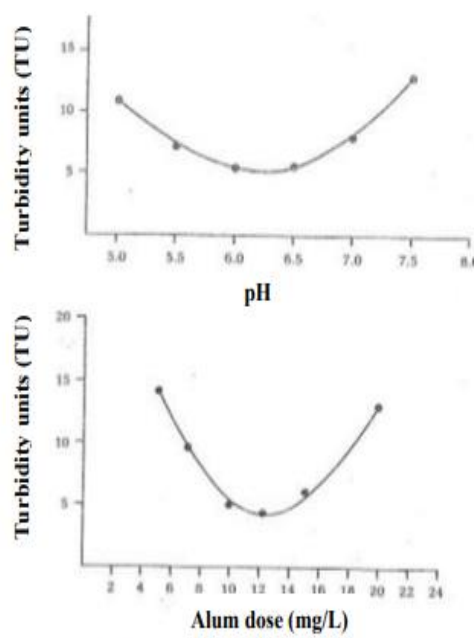


Figure 8: Optimization plots for pH and coagulant dosage in Jar test

sweeping of ions and particles from the wastewater (Tchobanoglous and Burton, 1991). The process of precipitation can also be assisted through the use of coagulants.

The method used for precipitation will depend upon the contaminants to be removed from the waste water. Different methods were adopted for precipitation and they are described as below.

6.7.6.1 Metals Removal

Heavy metals are generally precipitated as hydroxide through the addition of lime or caustic soda. The additions of these chemicals change the pH of the water to a pH of minimum solubility of metallic ions present in it. The pH of minimum solubility varies with the metal and shown in the graph below (Figure 9).

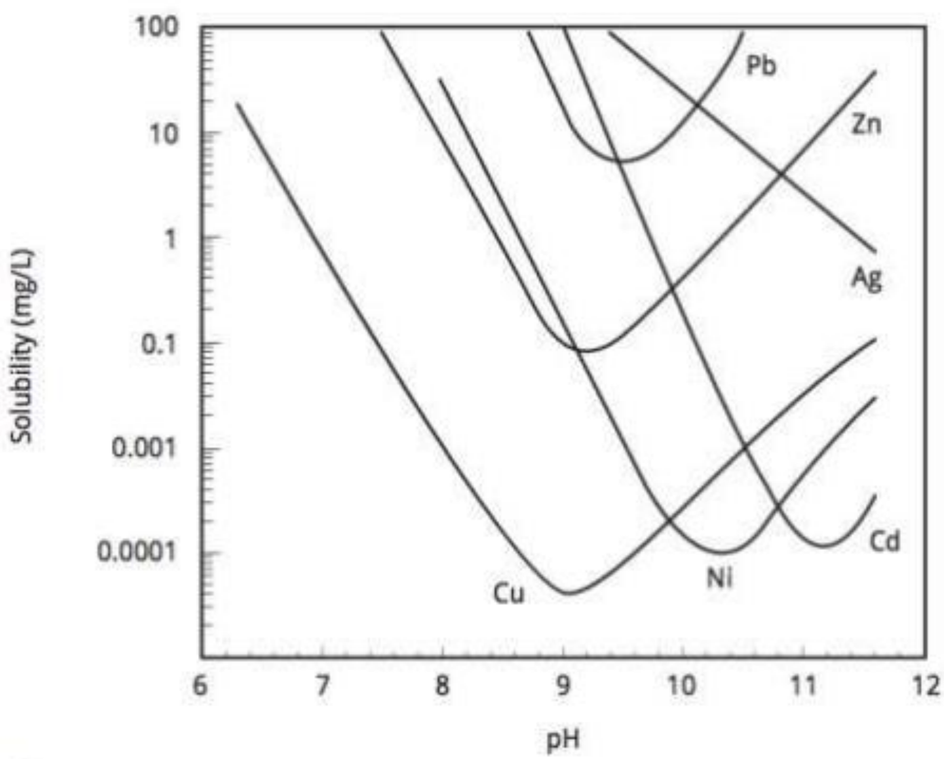


Figure 9: Metal hydroxides solubility curves at different pH.

(Source: US EPA; 1980)

When treating industrial waste water containing metallic ions as the contaminants, the pretreatment of the waste water is necessary to remove substances that may interfere with the precipitation of these metals specifically ammonia and cyanide. These interfering contaminants form complexes and limit the removal of metals by precipitation. Further, cyanide can be removed by alkaline chlorination, catalytic oxidation and ammonia can be removed by stripping or other suitable methods prior to the removal of metals. Once rendered insoluble, these compounds will tend to precipitate and settle.

Since the optimal pH for precipitation depends both on the metal to be removed and on the counter ion used (hydroxide, carbonate, or sulfide), the best treatment procedure must be determined on a case by- case basis. After the optimum pH for precipitation of various metallic contaminants is established, the settling process can be accelerated by addition of a coagulant, which gathers the insoluble metal compound particles into a coarse floc that can settle rapidly.

6.7.6.2Removal of Fats, Oils and Greases

Fats, oils, and greases are typically organic substances having density less than water. So, float on the surface forming the surface slicks rather than settling to the bottom of the water to be treated. They behave in this way because they are hydrophobic, nonpolar substances and are insoluble in water. These free floating slicks can be removed by skimming the surface of the solution. However, oils, fats, and greases can also be emulsified in aqueous solution by the addition of the surfactants. The addition of surfactants will disperse the oils and fats into small globules, which remain suspended in the aqueous solution. The substances like soaps and detergents act as surfactants and help in making hydrophobic substances soluble in water. These dispersed globules can be removed by destabilizing the electrical charge attractions that keep the localized globules of oil in solution. This can be done with the addition of a polymer which act as coagulant and leads to charge neutralization. In this way, the charge attraction of the oily particles is disrupted, allowing them to separate from the aqueous solution.

6.7.6.3 Phosphorus Removal

The treatment for phosphorus removal involves the addition of lime or metal salts (most commonly ferric chloride or aluminium sulfate, also called alum) to react with soluble phosphate to form solid precipitates that are removed by solids separation processes including clarification and filtration. Chemical treatment is the most common method used for phosphorus removal to meet effluent concentrations below 1.0 mg/L. When lime is used, a sufficient amount of lime must be added to increase the pH of the solution to at least 10, creating an environment in which excess calcium ions can react with the phosphate to produce an insoluble precipitate (hydroxylapatite). Lime is an effective phosphate removal agent, but results in a large sludge volume. When ferric chloride or alum is used, the iron or aluminium ions in solution will react with phosphate to produce insoluble metal phosphates. The degree of insolubility for these compounds is pH dependent (Details discussed in Module 22). Moreover, many competing chemical reactions can take place alongside these, meaning that the amount of metal salt to add to the solution cannot simply be calculated on the basis of the phosphate concentration, but must be determined in the laboratory for each case (Tchobanoglous and Burton, 1991).

6.7.6.4 Suspended Solids

The fine particles suspended in solution can escape the filtration, sedimentation and other similar removal processes. Their small size allows them to remain suspended over extended periods of time. These suspended particles in the wastewater are negatively charged and so the cationic polymers are generally used to reduce the surface charge of the suspended particles thus causing particle to get coagulated and settled (Tchobanoglous and Burton, 1991). Alternatively, lime can be used as a clarifying agent for removal of particulate matter. The calcium hydroxide reacts in the wastewater solution to form calcium carbonate, which itself acts as a coagulant, sweeping particles out of solution.

The amount of chemicals required for treatment depends on the physic-chemical parameters as pH, alkalinity, phosphates present of the wastewater. The interference of the co-contaminants actually makes it difficult to calculate the quantities of chemical needed for the precipitation. The accurate doses should be determined by jar tests and should be confirmed by field evaluations.

6.7.7 Ion exchange

Waste-water treatment is becoming very essential for the sustainability due to diminishing water resources, increasing waste-water disposal costs, and stringent discharge regulations that have lowered permissible contaminant levels in waste streams. Absolutely pure water is rarely found in nature and the impurities occur in three progressively finer states - suspended, colloidal and dissolved matter. Therefore different methods of treatment and new innovative technologies are adopted for the removal or reduction of the contaminants to acceptable limits.

Ion exchange is the process used for the removal of undesirable anions and cations from the waste water. It allows the separation of dissolved ionic species through their transfer from the liquid phase to a solid exchange material, where they replace other ions of the same charge that, in turn, pass to the liquid phase. In this reversible process, chemical transformations do not take place in the ionic species involved or in the exchanger material, enabling their recovery after the ion exchange. The soils and sands were the first known ion exchangers used and as the universality of ion exchangers grew from the last few years many synthetic exchangers have been evolved. Earlier ion exchangers used were natural zeolites, but now there are synthetic zeolites and polymeric ion exchangers are used. The interest for the applications of the ion exchange lies precisely in the possibility of reusing the exchanger material again and again. In order to do so, the material must previously undergo a regeneration process before recovering its initial conditions.

Ion exchange resins are typically presented in the form of spherical particles and consist of an organic or inorganic network structure with attached functional groups that contains soluble and mobile exchangeable ions. Most of the ion exchange resins are synthetic and made up by the polymerization of organic compounds into a three dimensional structure and the degree of cross linking between organic chains determines the pore size. In aqueous solution and depending on their selectivity towards the ions contained in the solution, resin functional groups carry out the exchange process by replacing their counter ions with the ions of interest to be removed from the solution. The exchange process between the resin and the aqueous solution comprises phases of diffusion, adsorption, electrostatic attraction and acid-base balance. The process is entirely reversible and under the appropriate acid or base conditions, the equilibrium can be moved in opposite direction, resulting in the original chemical form of the resin. This property allows ion exchange resins to be used through many load and regeneration cycles. The cost effectiveness of treatment processes based on ion exchange is due precisely to the number of regeneration cycles that can be obtained with a specific resin under certain operating conditions and constitutes a major design factor.

When the resin comes in contact with water, swelling of the resin results into the decrease of cross linking density and the functional groups are exposed. The exchangeable ion dissociates from the resin and becomes mobile, thus exchange of ions in the aqueous phase by the exchanger takes place and overall charge neutrality is maintained, otherwise the resin will attract or repel ions to maintain the charge balance.

Cations, such as calcium, magnesium, barium, strontium and radium, can be separated from an aqueous solution by using a cation-exchange resin and anions like fluoride, nitrate, arsenate, selenate, chromate, as well as humic and fulvic acids can be separated by means of an anion exchange resin. Cations are exchanged for hydrogen or sodium and anions for hydroxyl ions.

Exchange capacity is determined by the number of functional groups per unit mass of the resin.All ion exchange resins will establish ion selectivity based on the type of resin and resin structure, removing either cations or anions. Some resins have been traced to target removal of specific chemicals and some are designed to perform in particular conditions.

The selectivity of an ion exchange media can be described by the selectivity coefficient described by the following equation

$$K_j{}^i = C_j{}^n q^i \,/\, q_j{}^n C$$

Whereas, Cj = concentration of target ion in solution, eq/L

qi = concentration of counter-ion on resin, eq/L

Ci = concentration of counter-ion in solution, eq/L

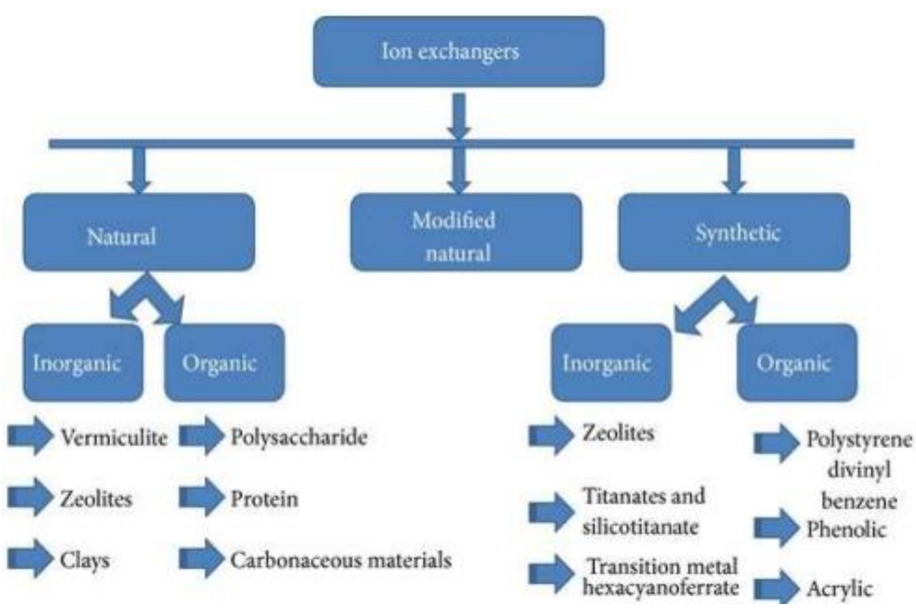
qj = concentration of target ion on resin, eq/L

n = valence of the exchanging ion.

6.7.7.1 Types of ion exchangers

Natural Ion Exchanger: Naturally occurring ion exchange material functions much the same as synthetic resin but with a different structural makeup. Some of the most popular and widely available natural ion exchangers are zeolites, which consist of an alumino-silicate molecular structure with weak cationic bonding sites (Guisnet and Gilson, 2002). Natural zeolites have been avoided in high purity processes or where consistency is vital because of irregularities and impurities of the material. However, zeolites have been used in many applications where uniformity is less critical, such as treating of waste streams and metals separation.

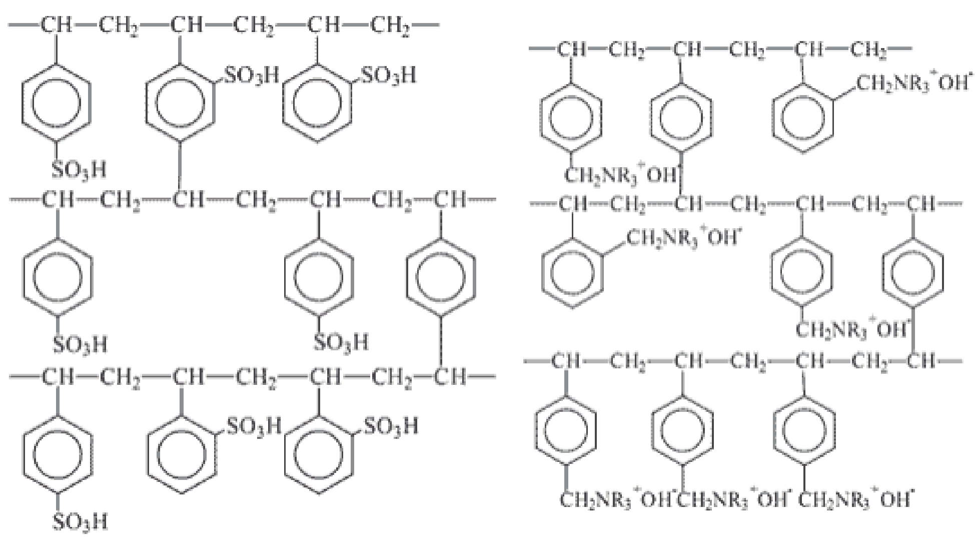
Synthetic Ion exchangers: The first synthetic ion exchangers were prepared in the mid 1930's based on coal and phenolic resins for industrial use. A few years' later resins consisting of polystyrene with sulphonate groups to form cation exchangers or amine groups to form anion exchangers were developed. There are many possible combinations of polymers, cross-linking, and functional groups. Most ion exchange materials currently used in industrial applications are synthetic compounds traditionally known as resins. Exchange resins are obtained by styrene and vinyl benzene copolymerization, or from acrylic materials. One of the most common polymers used for ion exchange resins is



Type of Ion Exchangers

polystyrene cross-linked with divinylbenzene.

On the basis of their porosity, the resins can be classified in gel-type or micro porous resins, and macro porous type resins, of less packed lattice. The porosity of gel-type resins is in the order of ionic sizes, whereas macro porous resins have a pipe network in their structural matrix, known as macro pores, supporting adsorption and desorption of the larger molecular size substances, such as organic compounds. The higher degree of cross-linking of gel-type resins confers them a higher resistance to chemical degradation and better mechanical properties. Ion exchange resins are further classified according to their chemical structure and the acidic and basic properties shown by their functional groups.



Polystyrene based ion exchange resins

Accordingly, four resin categories are defined:

Cation-exchange resins: They are characterized by sulphonic groups -SO3 -(strong) or –COO- (weak) as functional groups. Sulphonic groups behave like strong acids, entirely hydrolyzed in aqueous solution and attract positively charged ions exchanged for protons or sodium, depending on their presentation under acidic or sodium salt form. While as weak cation exchanger resins balance other weak acids in the solution, like bicarbonates, but they cannot exchange ions that are in balance with strong acid anions.

The reactions that occur depend upon chemical equilibrium situation in which one ion will selectively replace another on the ionized exchange site. Cation exchange on the sodium/hydrogen cycle can be illustrated by the following reaction:

$$Na_2.R + Ca^{2+} \leftrightarrow Ca.R + 2Na^+$$

$$H_2.R + Ca^{2+} \leftrightarrow Ca.R + 2H^+$$

Where, R represents the exchange resin.

When all the exchange sites have been substantially replaced with calcium, the resin can be regenerated by passing a concentrated solution of sodium ions (5-10% brine solution) in case of sodium and 2-10% sulphuric acid in case of hydrogen ions through the bed.

$$Ca.R + 2Na^+ \leftrightarrow Na_2.R + Ca^{2+}$$

$$Ca.R + 2H^+ \leftrightarrow H_2.R + Ca^{2+}$$

Anion-exchange resins: They contain quaternary ammonium ions $–R_3N^+OH^-$ or amino groups $–NH_2$ or –RNH in their structure as functional groups acting as strong and weak anion exchangers, respectively. They bound to the dissolved anions, releasing alkalinity to the solution.

Anion exchange resins work by replacing anions with hydroxyl group. The regeneration with 5-10% sodium hydroxide will renew the exchange sites.

$$R.(OH)_2 + SO_4^{2-} \leftrightarrow R.SO_4 + 2OH^-$$

6.7.7.2 Kinetics of the ion exchange process

The rate at which the ionic species exchange process takes place between the solid and liquid phases is regulated by both the differences of concentration between the two phases and the neutral electric balance that must be maintained between them.

One major factor controlling ion exchange rate is the diffusion time necessary in order to achieve the ionic balance between liquid and solid phases. Ion transfer between both phases is controlled by diffusion, under a 3-step classical scheme:

1. Transfer from the solution to the stationary boundary layer surrounding the resin sphere. This process is independent of the resin sphere size.

2. Transfer through the boundary layer to the sphere surface. The rate of this process is inversely proportional to the sphere radius.

3. Ion transfer into the resin sphere. The rate of this phase is inversely proportional to 1/r2. During operation phase, step one in the resin is faster than step two, which becomes limiting of the process. Use of smaller-sized resin spheres increases surface area, and thus, the transfer through the boundary layer. During resin regeneration phase, a high ion concentration in the liquid phase increases the rate of step two, and thus intra particle diffusion in step three becomes limiting. Smaller-sized spheres present the advantage of a smaller inside path, which is beneficial for step three. The result of choosing a smaller size of particle therefore favors the resin diffusion phases during the operation and regeneration periods.

6.7.7.3 Applications of ion exchange process

An ion exchange resin has a wide range of applications of the technology in water and wastewater treatment (Gu et al., 1999; Velizarov et al., 2008; Wang and Peng, 2010). Mostly the aim of ion exchange is to remove a particular ionic species from a liquid solution, resulting in their specific separation and concentration in the solid phase.

1. Industrial applications are recovery of metal cations in solution, separation of ion mixtures, purification of liquids, controlled release of a chemical species, salts recovery, etc.

2. In Water treatment, the most common uses of ion exchange are:

- Water softening
- Water demineralization
- Alkalinity removal
- Removal of heavy metal cations
- Removal of anions from strong acids, such as nitrate ($NO3^-$) and sulfate ($SO4^-$)
- Ammonia removal at low temperatures
- Production of high purity water

Advantages of Ion Exchange in Wastewater Treatment Processes

- Capability of handling and separating components from dilute wastes
- Possibility of concentrating pollutants
- Capability of handling hazardous wastes
- Possibility of recovery expensive materials from waste (e.g., precious metals)
- Possibility of regenerating ion exchanger
- Possibility of recycling components present in the waste and/or regenerating chemicals.

Disadvantages of Ion Exchange in Wastewater Treatment Processes

- Limitation on the concentration in the effluent to be treated
- In general, lack of selectivity against specific target ions
- Susceptibility to fouling by organic substances present in the wastewater
- Generation of waste as a result of ion exchanger regeneration
- Down time for regeneration

6.7.8 Filtration

Filtration is another ancient and widely used technology that removes particles and some of the microorganisms from water. It is the process of removing material, often but not always a solid, from a substrate in which it is suspended. Filtration is accomplished by passing the mixture to be processed through one of the many available sieves called filter media.

These are of two kinds:

Surface filters: The filtration using surface filters is essentially an exclusion process. The particles having size larger than the filter's pore size are retained on the surface of the filter called retentate and rest all other matter passes through the filter called permeate or filtrate. The filter papers, membranes, mesh sieves etc. are frequently used filters to separate the solids from the filtrate.

Depth filters: The depth filters in contrast to surface filters retain particles both on their surface and throughout their thickness. They are more likely to be used in industrial processes to clarify liquids for purification.

A variety of filter media and filtration processes are available for treatment of water but, the effectiveness, ease of use, availability, and affordability of these filtration media and methods vary widely and often depend on local factors.

6.7.8.1 Filters and Filtration Media

Porous granular media including sand, anthracite, crushed sandstone or other soft rock and charcoal are used for filtration. It is the most widely used physical method for water treatment at the community level, and it has been used extensively for on-site treatment of both community and household water since ancient times.

Sand filters: From the early 19th century slow sand filtration of drinking water has been practiced and various scales of slow sand filters have been widely used to treat water at the community and sometimes local or household level (Cairncross and Feachem, 1986; Chaudhuri and Sattar, 1990; Droste and McJunken, 1982; Logsdon, 1990). Sand filtration is a process where the suspended particles and microorganisms are removed due the slime layer that develops within the top few centimeters of sand. The enteric pathogens and microbial indicators are relatively removed in the range of 99% or more, depending on the type of microbe. However, slow sand filters often do not achieve high microbial removals in practice, especially when used at the household level due to inadequacies in construction, operation and maintenance.

Fiber, fabric and membrane filters: The main objective is to carry out the filtration as rapidly as possible while retaining the precipitate on the filter with a minimum loss. So, the proper filter must be selected with regard to porosity and residue (or ash). If filter used is too coarse, very small crystals may pass through, while use of too fine filters will make filtration unduly slow.

Filters composed of compressed cellulose fibers, spun or woven thread have been used to filter water since ancient times. These filters are simply placed over the opening of a water vessel through which particulate-laden water is poured. The particles are removed and collected on the filter media as the water percolates through it. These filters can also be used in the form of porous cartridges through which water is poured, or alternatively are partially submerged in water so that filtered water passes to the inside and accumulates within. More advanced applications employ filter holders in the form of porous plates and other supports to retain the filter medium as water flows through it.

Porous ceramic filters: Porous ceramic filters made of clay, porous stone, diatomaceous earth, glass and other fine particles in the form of hollow cylindrical "candles" have been used to filter water. The water to be filtered generally passes from the exterior of the hollow porous ceramic cylinder to the inside, although some porous clay filters are designed to filter water from inside to outside. This is a simplest and commonly used practice to filter drinking water in households.

With the passage of time the pores get clogged so, all porous ceramic filters require regular cleaning to restore normal flow rate and prevent biofilm formation on the filter surface. Many commercially produced ceramic filters are impregnated with silver to act as a bacteriostatic agent. Ceramic filters were found to reduce turbidity by 90% and bacteria by 60%.

Diatomaceous earth filters: Diatomaceous earth (DE) and other fine granular media also can be used to remove particulates and microbial contaminants from water. Such filters have achieved high removal efficiencies of a wide range of waterborne microbial contaminants without chemical pre-treatment of the water (Cleasby, 1990). A thin layer of the fine powdery filter medium is coated onto a permeable material held by a porous, rigid support to comprise the filter. As water passes through the filter, particulates are removed and the system maintains target flow rates while achieving high efficient particulate removal.

Filter Aids: During filtration certain gummy, gelatinous, flocculent, semi colloidal or extremely fine particulates often quickly clog the pores of a filter paper. Filter aids consist of diatomaceous earth and are sold under the trade names of Celite or Filter Aid. They are pure and inert powder like materials that form a porous film or cake on the filter medium. In use, they are slurried or mixed with the solvent to form a thin paste and then filtered through the paper. An alternative procedure involves the addition of the filter aid directly to the problem slurry with thorough mixing. Filter aids cannot be used when the object of the filtration is to collect a solid product because the precipitate collected also contains the filter aid.

Types of filtration

The various types of filtration method used depends on the type of solid (suspended or dissolved) to be separated from the solution. The most basic form of filtration is using earth's gravitational pull to filter the particulate matter from the water. The water to be filtered is simply poured over the filter medium, the liquid flows below it due to gravitational pull and the solids are left on the filter. The process is time consuming as the clogging of the pores with fine particles hinders the overall process.

Vacuum Filtration

Vacuum filtration is the process in which pressure gradient is maintained by creating vacuum below the filter medium. The vacuum is normally provided by a water aspirator, although a vacuum pump, protected by suitable traps, can also be used. Because of the inherent dangers of flask collapse from the reduced pressure, thick-walled filter flasks should be used Hardened papers are designed for use in vacuum filtrations on Büchner funnels. These papers possess great wet strength and hard lint less surfaces, and will withstand wet handling and removal of precipitates by scraping. They offer high chemical resistance to strong acids and alkalies.

Vacuum filtration is advantageous when the particles to be separated are crystalline. It should not be employed for gelatinous particles, as clogging will occur. The solutions of very volatile liquids and hot solutions are not filtered conveniently with suction. The suction may cause excessive evaporation of the solvent, which cools the solution enough to cause precipitation of the solute.

Membrane Filtration

Membrane filtration has received considerable attention for the purification of water in the 1960s with the development of high performance synthetic membranes. It is a separation process in which pressure driven force allows the solution to pass through a semi permeable membrane that allows the passage of solvent but not for suspended substances. The presence of pressure gradient is the driving force for the process and is capable of removing suspended solid, organic compounds and inorganic contaminants from the water. Depending on the size of the particle that can be retained, various types of membrane filtration such as ultra filtration, nano-filtration and reverse osmosis can be employed for wastewater.

Types of membranes: The water treatment process employs following type of membranes made up of cellulose triacetate or polysulfone based upon their pore size range.

1. **Microfiltration**
2. **Ultrafiltration**
3. **Nanofiltration**
4. **Reverse osmosis**

Micro-filtration (MF) has the largest pore size and separate large particles and microorganisms suspended in water. The molecular weight cutoff is >105 Dalton.

Ultra filtration (UF) utilizes membrane with pore size (0.1-0.01μm) to separate suspended substances/solids, macromolecules from solution. The molecular weight cutoff is 103-105 Da.

Nano-filtration employs "loose" reverse osmosis membranes with the pore size and molecular weight cutoff 102-104 Da between ultra filtration and reverse osmosis. It separates dissolved organic carbon and larger ions from the water reverse osmosis (RO) The membranes (molecule weight ut off 102 Da) used for reverse osmosis effectively non-porous and, therefore, exclude particles and even many low molar mass species such as salt ions, organics, etc. Reverse osmosis involves a diffusive mechanism, so that separation efficiency is dependent on solute concentration, pressure, and water flux rate.

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Unit 7: Sludge Management

Unit Structure

7.0 Learning Objectives

After going through this unit you will be able to:

- Understand the process of sludge production
- Describe the process of sludge management
- Explain various types of sludge treatment stages
- Discuss the final disposal of sludge

7.1 Introduction

In the previous unit, we have discussed about various physical, chemical and biological treatment processes for waste water. All these processes result in one solid or semi-solid part and other clean water. The solid / semi-solid part is known as Sludge. The sludge primarily consists of organic matter (around 10-12% solids) and water (80-90%). This sludge is also put to various uses after applying suitable treatment processes, though, processing and disposal of sludge is the most complex subject in any wastewater treatment plant. In this unit we will discuss about the various steps of sludge management and its disposal.

7.2 Sludge

The residue that accumulates in sewage treatment plants is called sludge (or biosolids). The main solid by-products produced in wastewater treatment are screened material, grit, scum, primary sludge, secondary sludge, chemical sludge (if a physical–chemical stage is included). Sludge is known to be the largest by-product from treatment of wastewater and its disposal is one of the most challenging environmental problems. Sludge is a by-product of water and wastewater treatment operations. Sludge produced from biological treatment operations may be referred to as wastewater bio-solids. Sludge is needed to be treated to a certain degree before it can be disposed off. The type of treatment needed depends on the disposal method proposed. There are principally three final disposal strategies for wastewater sludge and sludge components even though there are many “grey zones” between these are clear-cut alternatives. Sludge and sludge components may be deposited on land (in landfills or special sludge deposits), in the sea (ocean disposal) or to a certain extent in the air (mainly as a consequence of incineration). The solids in the sludge contain nutrients which may be valuable to plants, as well as humus like material which improves the capacity of poor soils to hold water and air. Unfortunately, industrial sources, including household wastes and urban runoff, introduce quantities of toxic materials into municipal sludge. Human waste also contains harmful organisms, disease-causing bacteria, viruses and parasites.

Sewage sludge consists of the organic and inorganic solids that were present in the raw waste and were removed in the primary clarifier, in addition to organic solids generated in the secondary/biological treatment and removed in the secondary clarifier or in a separate thickening process. The generated sludge usually is in the form of a liquid or semisolid, containing 0.25 to 12 percent solids by weight, depending upon the treatment operations and processes used. Treatment and disposal of sewage sludge are major factors in the design and operation of all wastewater treatment plants. Two basic goals of treating sludge before final disposal are to reduce its volume and to stabilize the organic materials. Stabilized sludge does not have an offensive odour and can be handled without causing a nuisance or health hazard. Smaller sludge volume reduces the costs of pumping and storage.

The problems of dealing with sludge are complex because:-

1) It is composed largely of the substances responsible for the offensive character of untreated waste water.

2) The portion of sludge produced from biological treatment requiring disposal is composed of the organic matter contained in the waste water but in another form, and it too, will decompose and become offensive.

3) Only a small part of the sludge is solid matter

7.3 Sludge Treatment Stages

The main stages in sludge management, with their respective objectives are:

1) **Thickening:** removal of water (volume reduction)
2) **Stabilization:** removal of organic matter – volatile solids (mass reduction)
3) **Conditioning:** preparation for dewatering (principally mechanical)
4) **Dewatering:** removal of water (volume reduction)
5) **Disinfection:** removal of pathogenic organisms
6) **Final disposal:** final destination of the by-products

Thickening	• Gravity
	• Floatation
	• Centrifuge
	• Belt filter Press
Stabilization	• Anaerobic Digestion
	• Aerobic Digestion
	• Thermal Treatment
	• Chemical Stabilization
Conditioning	• Chemical
	• Thermal
Dewatering	• Drying beds
	• Sludge Lagoons

	• Filter press
	• Centrifuge
	• Belt Filter Press
	• Vacuum Filter
	• Thermal Drying
Disinfection	• Lime
	• Thermal
	• Composting
	• Wet air oxidation
	• Others (Gamma Radiation)
Final Disposal	• Recycling
	• Recovery of degraded areas
	• Land Faming
	• Wet air oxidation
	• Non-agricultural use
	• Incineration
	• Sanitary landfill

7.3.1 Thickening

It is a physical concentrating of the sludge for minimizing its water content. The main processes used for sludge thickening are:

- gravity thickeners
- dissolved air flotation
- centrifuges
- belt presses

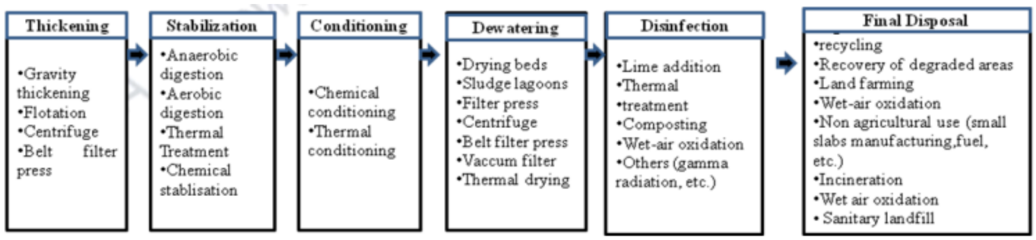


Fig 20.1: Sludge management process and flow sheet

a) **Gravity thickeners:** They have a identical structure to settling tanks. It is usually circular having central feeding, a bottom sludge exit and a supernatant side exit. The thickened sludge is used for the next stage i.e. stabilization), while the supernatant is returned to the head of the works.

b) **Dissolved air flotation:** With high pressure the air is introduced in a solution and in such conditions air gets dissolved. The dissolved air is released in the form of small bubbles when there is depressurization. The sludge particles are carried to the surface with the upward movement of bubbles and hence removed.

c) **Thickening by flotation:** It has a good applicability for activated sludge which does not thicken well in gravity thickeners.

d) **Dissolved air flotation:** It also has good applicability in wastewater treatment plants with biological phosphorus removal, in which the sludge needs to remain in aerobic conditions in order not to release the phosphorus into the liquid mass.

7.3.2 Stabilization

It is the removal of biodegradable organic matter of the sludge and hence reduction in in the solids mass in the sludge. The raw sewage sludge is rich in microorganisms, decomposes easily and quickly releases offensive odours. With the objective of digesting the biodegradable fraction of the organic matter present in the sludge, the stabilization processes were developed, thus decreasing the risk of putrefaction, as well as reducing the concentration of pathogens. The stabilization processes can be divided into:

a) **Biological stabilization:** The stabilization of sludge is done by using specific bacteria to promote the stabilization of the biodegradable fraction of the organic matter

b) **Chemical stabilization:** the stabilization of the sludge is achieved by the chemical oxidation of the organic matter.

c) **Thermal stabilization:** obtained from the action of heat on the volatile fraction in hermetically closed recipients.

The most frequently used sludge stabilization process is anaerobic digestion. Aerobic digestion is less diffused, but has a good applicability in the stabilization of the excess activated sludge originating from WWTPs with biological nutrient removal. Composting processes are very common in urban areas, but it is limited to very less number of small-scale wastewater treatment plants. The other used processes are alkaline treatment and thermal drying.

The process of anaerobic digestion has been known by sanitary engineers since the end of the 19th century and is characterized by the stabilization of the organic matter in an environment free from molecular oxygen. Due to its high efficiency, anaerobic digestion is used in simple domestic septic tanks, up to completely automated plants and for serving large metropolitan regions. In a conventional activated sludge or trickling filter plant, the mixture of primary sludge and excess biological sludge is stabilized under anaerobic conditions and can be converted into methane (CH4) and carbon dioxide (CO2). Anaerobic digesters are employed for anaerobic digestion. The digester is fed in a continuous or batch form and certain detention time is maintained. The anaerobic digesters are made up of concrete or steel. The raw sludge is mixed and heated in closed chamber and the gas is produced and the gas is stored in floating gasholders for processing or burning in temperate climate countries. According to land availability, the need for maintaining a completely-mixed regime and the removal of grit and scum, the configuration of the digesters is differentiated.

7.3.3 Conditioning

It is a process in which sludge dewatering capacity is improved for capturing of solids in the sludge dewatering systems by adding of chemical products (coagulants, poly electrolytes)

7.3.4 Dewatering

Dewatering of sludge can be done through natural or mechanical methods. In this phase further removal of water is done as it has an important impact in its transport and final disposal costs, besides influencing its subsequent handling, since the mechanical behavior varies with the water content level.

Digested sludge is used for dewatering and it has an important impact on the sludge transportation and final disposal costs. The main factors for sludge dewatering are:

- The transportation cost to the final disposal site is reduced;
- Improvement of the handling conditions and transportation of the sludge
- The reduction of the water increase the calorific value of the sludge aiming at preparing it for incineration;
- Disposal in a landfill or for agricultural use may get a reduced volume;
- Minimization in the production of leach ate when the sludge is disposed of in landfills.

Natural or mechanized processes are generally used for the sludge dewatering. Natural processes use evaporation and percolation for dewatering. Although they are very simple and cheap to operate but need larger areas and volumes for installation. In contrary, mechanized processes are based filtration, compaction, or centrifugation to accelerate dewatering, resulting in compact and sophisticated units, from an operational and maintenance point of view.

The main sludge dewatering processes are listed below:

Natural

• Drying beds

• Sludge lagoons

Mechanized

• Vacuum filters

• Belt presses

• Filter presses

• Centrifuges

For increase of dewatering capacity and the solids capture, the sludge is incorporated to a conditioning stage before starting of the dewatering stage itself. Chemical products or physical processes are used for conditioning and for physical process; the most common is heating of the sludge. The chemical products are applied to the sludge favors the aggregation of the solids particles and formation of flocs. The conditioning can be also employed upstream of the mechanized thickening units. The very common coagulants used are metallic salts and poly electrolytes (polymers).

The most common metallic coagulants are:

• Aluminium sulphate

• Ferric chloride

• Ferrous sulphate

• Ferric sulphate

• Quicklime/ hydrated lime

The dewatering processes are discussed here:

a) **Sludge drying beds:** It is one of the earliest techniques and excessively used for solids-liquid separation in sludge. In comparison with mechanical dewatering options the construction cost is generally low, specifically for small-sized commodities. The setup generally having a rectangular tank with concrete walls and a concrete bottom. In the inside of the tank, these are the following devices to drain the water present in the sludge:

• Support layer (bricks and coarse sand), on top of which the sludge is placed

• Draining medium (fine to coarse sand followed by fine to coarse gravel)

• Drainage system (open or perforated pipes)

Some portion of the liquid evaporates and some percolates through the sand and support layer. The dewatered sludge remains in the layer present above the sand. Drying beds are suggested for small and medium sized communities with a population of around 20,000 inhabitants.

b) **Sludge drying lagoon:** These are used for thickening, integral digestion, dewatering and even for the final disposal of sewage sludge. Generally excavated in the soil, drying lagoons are located in natural depressions in the land, or put inside banks. The discarded sludge is kept for long time periods generally from 3 to 5 years. The sludge is condensed by the action of gravity and further digested by the microorganisms present in the sludge and further it is dewatered through drainage.

This process is advocated for dewatering the earlier digested sludge by aerobic or anaerobic processes, but not for the dewatering of primary or mixed sludge. Sludge lagoons are much less used than drying beds among the natural dewatering processes. The main difference between these two processes is in the fact that evaporation is the principal mechanism of influence in the dewatering process.

Percolation has a lesser effect than in the drying beds. The dewatering of the sludge in the lagoon can be done with the use of devices for the removal of the supernatant water at various levels after the loading of the sludge. But use of drains at the bottom is not a very common practice in drying lagoons, as the sewage sludge has lessened the ability of draining and there may be the risk of pipe clogging.

As soon as the lagoon gets filled to the top, it can be put out of operation without the removal of the sludge, thus serving as a solution for final disposal. Another feasible solution is the removal of the sludge from the fully- filled lagoon and which is then allowing to reuse and utilization as a continuous dewatering unit.

c) **Centrifuge:** It is the solid or liquid forced by the action of a centrifugal force. In a first stage, the sludge particles settle down at a velocity which is much higher than the action of gravity. Sludge loses its part of the capillary water under the continuous action of centrifugation and compaction takes place. After this last stage of dewatering, cake is removed. One can say that, centrifuges are equipment that are be used for sludge thickening and dewatering and it is possible to place the centrifuges in series, the first for the thickening of the sludge and the second for the dewatering. Vertical and horizontal-shaft centrifuges are the main types of centrifuges used for sludge dewatering. The type of feeding of the sludge, the intensity of the centrifugal force and the manner in which the cake and the liquid are unloaded from the equipment are the main factors considered for differences in the process.

d) **Vacuum filter:** Vacuum filters were mainly used in industrialized countries for sludge dewatering until the 1970s. Their use entered into decline due to the high-energy consumption and lower efficiency when compared with modern sludge dewatering processes. A vacuum filter is made up of a rotating cylindrical drum which is installed with partial submergence in a tank with conditioned sludge. About 10- 40% of the drum surface is kept submerged in the tank and this part performs the filtration or you can say cake formation zone. The cake formation takes place in the outer part of the cylinder, while the filtered liquid drained to the interior, where there is a vacuum. In next stage, there is a dewatering region that occupies between 40-60% of the cylinder surface in the direction of the rotation. In the final region of the cylinder, there is the unloading zone. A valve takes the surface of the cylinder to the atmospheric pressure in this region and the sludge cake is then separated from the filtering medium.

e) **Filter press:** A filter press operates in a fitful mode having cycles consisting of sludge loading, filtration and cake unloading stages. The liquid sludge is pumped into plates which are surrounded by filter cloths. The pumping of the sludge in the space between the plates increases the pressure and encourages the sludge to pass through the filter cloth.

The cake is formed as the solids are retained on the filtering medium. Next, a hydraulic piston pushes a steel plate against the other polyethylene plates, making up the pressing. The filtrate (liquid) filters goes through the filter cloths and is being possessed by the plate outlet ports. When the pneumatic piston is retreated, cake is easily removed from the filter and the plates are separated. Here, the dry cake falls from the plate and can be used for storage or final destination.

f) **Belt press:** Belt presses work on a continuous mode system. The process can be categorized into three different stages or zones: (a) zone of gravity drainage, (b) low-pressure zone and (c) high-pressure zone. In zone of gravity, drainage is constructed at the entrance of the press where the sludge is applied onto an upper screen and under the action of gravity the free water percolates through the opening pores present in the screen. After this step, the rest of the free water is removed as the sludge is directed to the low-pressure zone and the sludge is gently compressed between the upper and lower screens. Finally, scrapers remove the sludge and high-pressure water jets wash the screens. Low acquisition costs and reduced energy consumption are the main advantages.

7.3.5 Sludge Disinfection

The main objective of introduction of sludge disinfection stage is lowering of pathogens in the sludge and when it is disposed off, it may not cause health risks to the population and to the workers who will handle it and also negative effects to the environment. However, the need to adopt a disinfection system will totally depend on the final disposal alternative to be adopted. Higher sanitary level is required if the sludge is applied in public parks and gardens or its recycling in agriculture. These requirements can be met by a sludge disinfection process or by temporary restrictions to public use and access. It is a very important part and is to be done if the sludge is used for agricultural recycling as the anaerobic or aerobic digestion processes do not decrease the pathogens contents. If the sludge is to be incinerated or disposed of in landfills, then disinfection is not necessary.

The most important processes are described below.

a) Composting: Composting is a decomposition of organic matter aerobically which can be achieved through controlled conditions of temperature, water content, oxygen and nutrients. The resultant product i.e. compost can be used as a soil conditioner and has high agricultural value. The inactivation of the pathogens is done mainly by the increase of temperature during the highest activity phase of the process. The temperature can reach between 55-65 ◦C due to of biochemical reactions. Both the raw sludge and digested sludge can be composted. Materials like wood chips, leaves, green waste, rice straw, sawdust need to be added to the sludge which helps in improving the water retention capacity, increase the porosity and balance the ratio between carbon and nitrogen. The three methods are employed for this are: • Windrows. Periodical turning, in order to allow aeration and mixture. Detention time must be between 50 and 90 days. • Aerated static pile. Aeration done by perforated pipes from air blowers or exhausting systems. Detention time must be between 30 and 60 days. • In-vessel biological reactors. Closed systems, with a greater control and lower detention time. Detention time must be at least 14 days in the reactor and 14 to 21 days for cooling.

b) Thermophilic aerobic digestion: The process of thermophilic aerobic digestion also termed as auto-thermal digestion works on the same principles as of conventional aerobic digestion system. The difference is that it operates in a thermophilic phase due to some alterations in the concept and operation of the system. The sludge is generally pre-thickened in this stage and is operated with two aerobic stages, and there is no need of outsourced energy to raise the temperature. In the small and closed chamber, the concentration of solids in the sludge is higher, the heat released from the aerobic reactions heats the sludge to temperatures higher than 50◦C in the first stage and 60◦C in the second. Pathogenic microorganisms are reduced to values lower than the detection limits if the sludge is maintained at a temperature between 55–60 ◦C for 10 days. The two most important factors for the operational success of the system are mixing and aeration efficiency.

c) Lime stabilization: A reduction of the population of microorganisms, pathogens and the potential occurrence of odours takes place when a sufficient quantity of lime is added to the sludge to increase the pH to 12. Lime can be added to liquid or dewatered sludges. Lime stabilization is used to treat primary, secondary, or digested sludge. d) Pasteurization: It involves the heating of the sludge to 70◦C for 30 minutes, followed by a rapid cooling to 4◦C. The sludge can be heated by heat exchangers or by hot steam injection. The steam injection process is more commonly used and the sludge is pasteurized in batch to decrease the recontamination risks. e) Thermal treatment: Thermal treatment consists of passing the sludge through a heat source that causes the evaporation of the existing moisture in the sludge and consequently the thermal inactivation of the microorganisms. To be economically feasible, the sludge needs to be previously digested and dewatered to a solids concentration in the order of 20–35%, before being thermally treated. The dried sludge has a granular aspect and presents a very high level of solids, in the region of 90–95%.

7.3.6 Final Disposal of the Sludge

Final disposal of the sludge is done in the following ways:

a) **Ocean disposal:** After pre-conditioning, the sewage is disposed in the sea. This type of disposal is without any beneficial use.

b) **Incineration:** Thermal decomposition process by oxidation, in which the volatile solids of the sludge are burnt in the presence of oxygen and are converted into carbon dioxide and water. The fixed solids are transformed into ashes. Disposal without beneficial uses.

c) **Sanitary landfill:** Disposal of the sludges in ditches or trenches, with compaction and covering with soil, until they are totally filled, after which they are sealed. The sewage sludge can be disposed of in dedicated landfills or co-disposed with urban solid wastes. Disposal without beneficial uses.

d) **Land farming:** Land disposal process, in which the organic substrate is biologically degraded in the upper layer of the soil and the inorganic fraction is transformed or fixed into this layer. Disposal without beneficial uses. Land reclamation: Disposal of sludge in areas that have been drastically altered, such as mining areas, where the soil does not offer conditions for development and fixation of vegetation, as a result of the lack of organic matter and nutrients.

e) **Agricultural reuse:** Disposal of the sludge in agricultural soils, in association with the development of crops.

Summary

The unit provides an overview of the sludge management process in wastewater treatment, including the main stages of sludge management and the various methods for sludge thickening, stabilization, dewatering, and final disposal.

Unit 8: Solid Waste Management

Unit Structure

8.0 Learning Objectives

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

- Explain the wastes and its types
- Discuss the problems of waste generation
- Describe the waste collection and transportation
- Discuss the various waste treatment and disposal methods
- Explain the various environmental impacts of waste generation and disposal

8.1 Introduction

Waste is defined as any unwanted or unusable substance that is discarded after primary use. Wastes are normally generated as a result of human and animal activities. Urbanization and rapid advancements in industrialization has led to an increase in the production and consumption processes resulting in the generation of wastes from various sectors that include agricultural, commercial, domestic, industrial, institutional, social and from community activities. Over time, these waste accumulate and can have real impacts on the health and the environment. Waste management is intended to reduce adverse effects of waste on health, the environment or aesthetics.

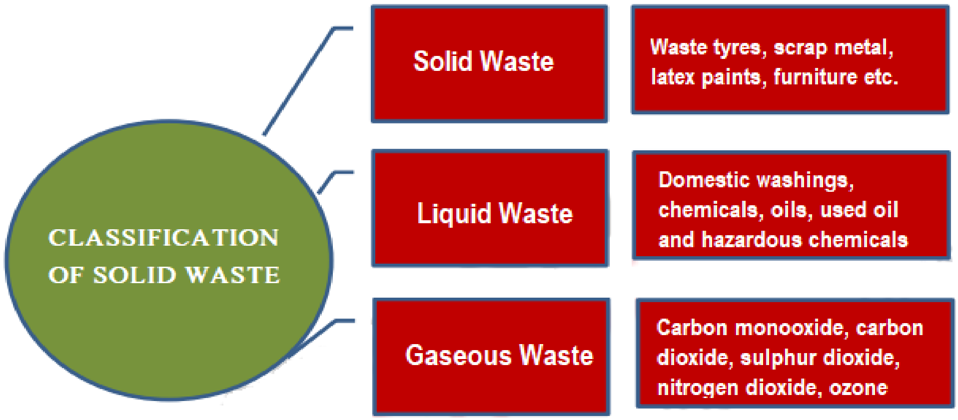
The waste management involves various steps namely waste collection, segregation, transport, processing, treatment and disposal. Disposal is the final step in the waste management. Ultimately all solid waste ends in disposal site either directly or after some processing and treatment it ends in disposal sites. Most of the developing and under developed countries, dispose or dump the solid waste in an open land without any protection or environmental control. Such dumping is not safe and is called as open dumps or open dumping. Solid waste is also disposed of in water bodies e.g. Sea, ocean, lake, river etc. Sometimes they are also burned in open areas, the phenomenon termed as open burning. The solid waste must be properly managed to avoid environmental and health hazards.

In order to carry out efficient management of wastes, one should have clear understanding or knowledge about the source of wastes, its types and classification. Thus, we will discuss in brief all these in the following paragraph.

8.2 Waste Generation: Source, types and environmental impacts

Wastes are commonly classified based on the physical state as follows:

- solid wastes
- liquid wastes
- Gaseous wastes.



Classification of waste based on their physical state

Solid wastes are any discarded or abandoned materials that can be solid, liquid, semi-solid or containerized gaseous material discarded by the human society. These include urban wastes, agricultural wastes, biomedical wastes and radioactive wastes. The term refuse is also used for solid wastes. Examples of solid wastes include waste tires, septage, scrap metal, latex paints, furniture and toys, garbage, appliances and vehicles, oil and anti-freeze, empty aerosol cans, paint cans and compressed gas cylinders, construction and demolition debris, asbestos, plastics, Styrofoam containers, bottles etc.

Liquid wastes can be defined as liquids/fluids that are generated from washing, flushing or manufacturing processes of the industries. They are also called as sewage. The most common practice of disposing liquid waste is to discharge it in ground or rivers and other water bodies without treatment. Examples: domestic washings, chemicals, oils, waste water from ponds, Wastewater from manufacturing industries, manure, waste oil, fats, oils or grease (FOG), used oil, and hazardous household liquids.

Gaseous waste is a waste product released in the form of gases from automobiles, factories, industries, burning of fossil fuels etc and gets mixed in the atmosphere. These gases include carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen dioxide, ozone and methane etc.

8.2.1 Factors influencing waste generation

The rate of change of quantity of solid waste generation with respect to stipulated time is termed as waste generation. The waste generation rate is governed by various factors (i.e) it depends mainly upon the geographical location, customs, climate, living conditions and economic standard of the area. The characteristics, quantities, volume and composition of solid waste generated may differ from one country to another and between urban and rural areas. The factors influencing waste generation are population, economic status and life style, geographical location of an area, whether the place is urban or rural, seasons, public attitude, legislations and law enforcements.

8.2.2 Impacts of solid waste

Waste generation, its improper disposal has resulted in a number of impacts to environment and human society. It affects all the segments of environment i.e., water, air, land, soil and biosphere (the living world). The various impacts of solid waste are as follows:

A) Environmental Impacts

a) **Water pollution:** Improper waste management (i.e) open dumping of waste results in surface and ground water pollution. Waste generates watery liquid termed 'leachate' oozes out due to the field capacity. This watery liquid slowly infiltrates through the soil into the ground water and affects them. Precipitation over the waste leads to the leaching of pollutants into the surface run off. Also, leachate gets mixed with the surface run off and is carried to surface water bodies like rivers, streams, lakes etc. Eutrophication and loss in water quality of the water body might be the consequences.

Likewise, the entry of leachate alters the pH of the groundwater. Changes in pH favours dissociation of minerals in the aquifers into the water. This might cause increased loss in water quality. Moreover, the contamination can spread depending on the characteristics of the aquifer especially sand and gravel. Soil also plays a great role in restricting the movement of ions into the groundwater. Clay soil might restrict the movement of ion by capturing them in the soil matrix.

b) **Soil Pollution:** Open dumping of waste without any liners or other protection causes the entry of pollutants into the soil. As mentioned earlier, the pollutants bind to the soil and its minerals thereby increasing the pollutant level in the soil.

The accumulation of metals in the soil reduces its productivity and microbial diversity. The microbial diversity gets altered due the pollutants in the soil. Metals like Cd, Cu, Ni, Pb and Zn alters the soil chemistry. The pH of the soil is too disturbed by the waste. This results in the loss of various minerals thereby affecting the overall nature of the soil.

c) **Vegetation is also affected by the waste dumping.** The pollutants and heavy metals in the soil gets absorbed through the root system into the plants. The pollutants hinder the normal metabolism in plants thereby leading to invisible injuries that might on a later stage lead to plant death. Poor vegetation is observed in those places where the waste has been dumped for many years. Sometimes the waste dumping affects and destroys the entire ecosystem.

d) **Air pollution:** The surrounding air is affected by the emission of methane, carbon dioxide, oxides of Sulphur and nitrogen and other volatile organic compounds during the waste decomposition. Their emissions alter the air quality initially on local level which might extend to regional level depending on the rate of emissions and meteorological conditions. Likewise burning of waste in open areas leads to the emission of particulate matter (ash) and various gaseous emissions. Open burning also results in the emissions of many carcinogens namely the dioxins and furans. Polychlorinated dibenzofurans (PCDFs) commonly called as dioxins and furans are released during the burning of plastics. They are of more significance because their carcinogenic and mutagenic property. Incinerators without air pollution control devices also result in the release of particulate matter (ash) and gases. Hydrogen chloride, carbon monoxide, lead, mercury, arsenic, cadmium and selenium are other pollutants released during burning. Noise pollution: Noise pollution is generally generated during the transport of waste in vehicles. Vehicles and machinery used in waste processing are the main source of noise pollution. The impacts of noise pollution can be reduced by proper maintenance of machinery and vehicles. Workers can be saved from occupational hazard by using ear plugs, muffs etc. Green belts can also minimize noise by acting as barrier.

e) **Odour and aesthetics:** Uncontrolled dumping might affect the aesthetics of the site. It creates visual hindrance to the trespassers and individuals living in nearby locality. The beauty of the city or town is lost due to open dumping of waste. Likewise, dumping or temporary storage of waste leads to odour problem due to decomposition of waste. The odour problem can be minimized by increasing the collection frequency from storage sites. Containment of waste in controlled landfill can also minimize the odour problem.

B) Health effects of waste generation and disposal

Waste disposal in open dumps, long period of storage in the collection site or processing site (transfer station), improper handling and management might lead to numerous health effects in human beings and animals. Occupational health hazards are also caused during accidents, waste transport and processing. Some of the health effects are discussed below.

- Waste dumps acts as a store house of infective microorganisms and pathogens. They provide suitable environment and food for their growth. So workers when they come in contact with the waste are affected with various diseases.
- The flies, mosquitoes, stray animals such as rats, cats, dogs, cows, pigs act as carrier to bring the infection to the residential area and population living the towns and cities.
- Epidemics can also be caused by the carriers that transport the vectors to the human beings
- Typhoid, salmonellosis, gastro-enteritis, dysentery, malaria, filaria and dengue are the popular diseases caused by flies and mosquitoes. Life cycle of the insect plays an important role in creating infection. The flies generally lay eggs in the warm, moist environment of decomposing food wastes. The organic content in the waste acts as feed for the larva. Once they get matured they migrate from waste to soil before transforming to pupae. The pupae remain dormant in soil and then migrate to the other area after it becomes an adult fly. Thus, the life cycle of fly occurs in

the waste pile. Proper cleaning of storage bins, frequent collection and dumping waste in controlled environment might avoid the infections associated with flies.

- Proper covering of the waste material can avoid the breeding of flies in the waste.
- Accumulation of water in broken furniture, tyres, broken vessel, tins and cans might act as breeding grounds for mosquitoes. Proper sanitary practices and cleanliness can eliminate the mosquito problems.
- Roaches: Typhoid, cholera and amoebiasis are the infections caused by roaches. Poor management of solid waste can result in these infections.
- Rats and other rodents causes the spread of diseases such as plague, murine typhus, leptospirosis, histoplasmosis, rat bite fever, dalmonelosis, trichinosis and many more. Waste dumps act as a source of food and shelter for the rodents.
- Pigs are involved in the spread of diseases like trichinosis, cysticerosis and toxoplasmosis, which are generally transmitted through infected pork, eaten either in raw state or improperly cooked. Solid wastes, when fed to pigs, should be properly treated otherwise it might cause infections.
- Occupational health hazards: Occupational health hazards are popular among workers handling waste and operating machineries. Accidents might also occur and can be considered as occupational hazard.
- Sharps, syringes, broken glass, blades in the waste causes cut to the workers involved in collecting and transporting the waste.
- Storage containers with sharp edges might cause injury and henceforth result in occupational hazard
- Infections of skin and blood results from direct contact with waste and previously infected area and wounds.
- dust from the waste materials affects eyes on exposure.
- diseases can also spread through animal bites o Inhalation of gases while burning wastes can lead to chronic respiratory diseases and cancer

- Accidents due to waste handling: Loading, unloading and carrying of waste containers might lead to muscle wear and tear, bone and muscle disorders. Dust in roads and smoke arising from burning of waste might reduce visibility and might cause accidents. Chemical burns can occur when workers are exposed to small amount of hazardous material such as pesticides, cleaning solutions and solvents in households and commercial establishments. Methane explosion in landfill sites is again a major threat of accident. Careless dumping of lead-acid, nickel-cadmium and mercuric oxide batteries might affect the children and adults.

8.3 Classification of solid wastes

It is mandatory to classify solid wastes into groups that pose similar risks to the environment and human health for safe disposal. According to the modern systems of waste management, solid wastes are classified based on their source, type, properties and its effect on human health and environment.

8.3.1 Classification based on source

Table 1. Solid waste – Sources, composition and waste generator

Source	Type of facility	Types of solid waste generated	Responsible for disposal of waste
Household	Single and multifamily dwelling, low, medium and high rise apartments.	Food waste, Paper, plastic, rubber, leather, cardboard, wood, glass bottle, tin cans and yard waste.	Tenant and Owner
Commercial	Shopping mall, Cinema threats, Complex, Marriage Hall, restaurants, hotels, motels etc.	Glass bottle, tin cans, oil, paint, Food waste, Paper, plastic, rubber, leather cardboard, wood and rich in packing materials.	Customer, Site manager and owner
Institutional	School, college Government and Hospital, Research organization	Paper, plastic, cardboard, wood, Food waste, Medicinal Waste	Students, Staff, Doctor, Patient and Head of the institute
Industrial	Light and heavy metal manufacture, electroplating	Steel scrap Paper, plastic, cardboard, wood, hazardous substance like chromium, Zinc and mercury from electroplating process	Employee and employer
Agricultural	Dairies vineyard field crops and farms.	Pesticides, Organic Solvents, Waste biomass	Renter and Proprietor

Solid waste refers to useless or unwanted and non-liquid material that has no longer value to the owner who is liable for it. Solid wastes are generated due to human activity, when the material consider as useless, unwanted or has no longer value. In connection with that, solid waste generation rates may differ from country to country which depends on the human life style, financial status, industrial structure and techniques used to minimize the waste.

Wastes are produced from different sources and are categorized as follows:

a) **Municipal solid waste (MSW):** Municipal solid waste commonly referred to as trash, garbage or refuse comprises of street wastes, dead animals, market wastes, abandoned vehicles, household garbage, rubbish, construction and demolition debris, sanitation residue, packaging materials, trade refuges etc. They are collected from residential houses, markets, streets and other places mostly from urban areas and disposed of by municipal bodies. The proportion of different constituents of municipal wastes varies from place to place and season to season depending on the food habits, life style, standard of living and extent of commercial and industrial activities in the area. Municipal wastes their contents and source are illustrated in table given below. Municipal solid wastes are further categorized based on their physical, chemical and biological properties.

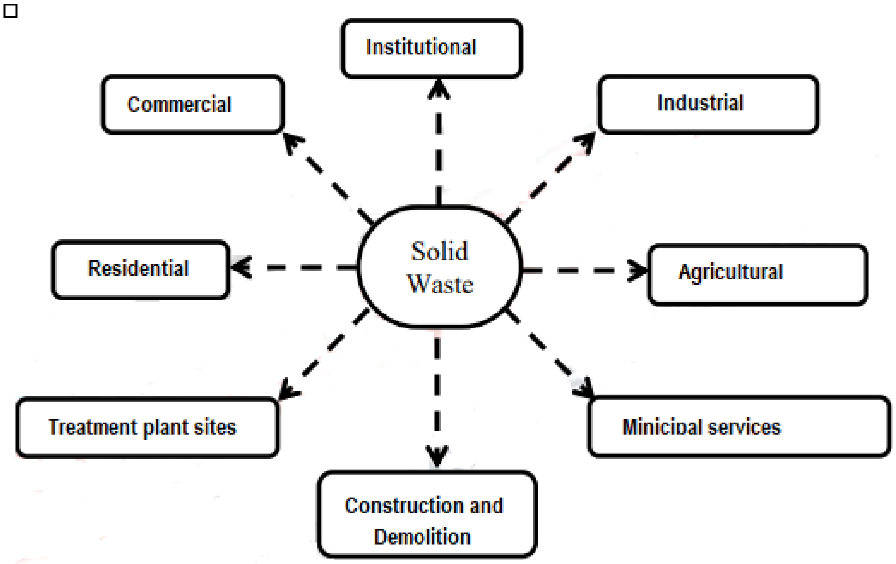


Figure 2: Sources of solid waste

b) Industrial wastes: Wastes generated during industrial activities such as manufacturing and processing involved in chemical plants, paint industry, cement factories, metallurgical plants, thermal power plants, petroleum, coal, gas, sanitary, textile, food processing and paper industry are referred to as industrial wastes. Some examples of industrial wastes are chemical solvents, paints, sandpaper, paper products, industrial by-products, metals, and radioactive wastes. Industrial solid wastes are further classified as hazardous and nonhazardous wastes.

Waste Generation per Capita in Indian cities	
Population range (million)	Average per capita waste generation(g/capita/day)
0.1 to 0.5	210
0.5 to 1.0	250
1.0 to 2.0	270
2.0 to 5.0	350
5.0 plus	500
Source: NEERI (1995)	

c) Institutional/ Commercial wastes: Solid wastes originating from administrative, educational and public buildings such as offices, schools, colleges, hospitals, government centers, prisons and other commercial establishments like wholesale and retail stores, restaurants, hotels, markets, warehouses. Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes are the examples of industrial and commercial wastes

Solid waste type and its constituents	
Type	Sources
Organic	Food scraps, yard (leaves, grass, brush) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cups. Strictly speaking paper is organic but unless it is contaminated by food residue, paper is not classified as organic.
Plastic	Bottles, packaging, containers, bags, lids, cups
Glass	Bottles, broken glassware, light bulbs, colored glass
Metal	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles
Other	Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials
Source: Urban Development series, World Bank, (2014)	

d) Agricultural wastes: Agriculture wastes include both natural (organic) and non-natural wastes generated through farming activities. These activities include but are not limited to dairy farming, horticulture, seed growing, livestock breeding, grazing land, market gardens, nursery plots, and even woodlands. Some of agricultural wastes include spoiled food grains, vegetables, animal and plant wastes, litter, pesticides, fertilizers etc. Other agricultural wastes are produced from agricultural products processing industries like sugarcane factories, tobacco processing units, slaughter houses, livestock, poultry etc. Agricultural wastes are mostly biodegradable but few wastes like pesticide and fertilizers are toxic. When discharged to the environment, agricultural wastes can be both beneficial and detrimental to living matter.

e) Biomedical wastes: Wastes produced from hospitals, medical centers and nursing homes are called biomedical wastes. Hospital wastes are generated during diagnosis, treatment or immunization of human beings/animals or in research activities in these fields or in the production/testing of biological. These wastes are highly infectious and may pose severe threat if not managed properly. Biomedical wastes may be solid or liquid wastes that includes discarded blood, sharps, soiled wastes, disposables, anatomical wastes, cultures, discarded medicines, chemical wastes etc.

8.3.2 Classification based on type

a) Garbage: Garbage wastes mean and include animal and vegetable wastes generated from kitchen, cooking, serving of foods, slaughter houses, market refuse.

b) Rubbish: Solid wastes arising as a result of households, commercial and institutional activities excluding garbage and ashes are termed as **rubbish**. They are categorized into combustible and non-combustible wastes.

c) Bulk waste: Bulky household wastes consists of household furniture; appliances such as stoves, washing machines and refrigerators; mattresses and springs, rugs, TV sets, water heaters, tires, lawn mowers, auto parts, tree and brush debris etc. Commercial bulky wastes include packaging and containers such as cardboard, wood boxes, fiber, plastic and steel drums, loose and bundled paper, bundles of textiles and plastics, wires, furniture and equipment etc. Industrial bulky waste includes crates, cartons; steel, fiber and plastic drums; bales and rolls of paper, plastics, and textiles; miscellaneous metal items etc.

d) Ashes: Ashes are defined as fine powdery residues, cinders and clinkers arising from the burning of wood, coal, charcoal, coke and other combustible materials during cooking and heating in houses, institutions and outer industrial establishments.

c) Street wastes: Wastes comprising of leaves, dirt, dust litter, paper, plastics and other vegetable matter collected from streets, walkways, alleys, parks, beaches and vacant lots are termed as street wastes.

d) Dead animals: Animals that die naturally or accidentally comprises of dead animal wastes. However, animal carcasses and animal parts from slaughterhouses are **excluded** from dead animal wastes and considered **as industrial wastes**.

e) Construction and demolition wastes: Construction and demolition wastes are the waste materials generated in large amounts during the construction, refurbishment, repair and demolition of houses, commercial buildings, roads and other structures.

f) Sewage wastes/sludge: Settled solid components, residual or semi-solid materials that are discharged from sewage treatment plants and septic tanks are classified as sewage waste.

g) Plastics: Plastic due to their versatile property of being light, durable, easy to mould and economical has invaded almost all sectors of the economy. Likewise, they are generated as wastes from almost all sectors that includes agriculture, construction, consumer goods, household, health care, hotel and catering, packaging, telecommunications, air and travel industries. Some of the plastic wastes include carry bags, bottles, plates, spoons, glasses, gloves, boxes, syringes, catheter tubes, surgical items etc. Plastics due to its non-biodegradable nature are now considered a serious threat to the environmental and health.

h) Mining wastes: Mining wastes are generated from extractive operations of mineral resources. They include materials such as topsoil, overburden and waste rock that must be removed to gain access to the mineral resource. Also, other waste material like slags, mine water, mine tailings, water treatment sludge and gaseous wastes etc are released during or after processing of mineral ores. Some of these wastes are inert and arenot considered as threat to the environment. However, other fraction, generated by the non-ferrous metal mining industry contains large quantities of dangerous substances such as heavy metals. These metals and metal compounds after extraction and subsequent mineral processing tend to become chemically more available resulting in the generation of acid or alkaline drainage. Therefore, mine wastes requires to be carefully characterized to prevent and minimize air, water, and soil contamination.

i) **Radioactive wastes:** Radioactive wastes are hazardous, by-products of nuclear reactions. They pose severe threat to human life and environment. Radioactive wastes decays over time ranging from a few days for highly radioactive isotopes to millions of years for slightly radioactive ones. Hence, these wastes have to be isolated and confined at appropriate disposal facilities for it to completely decay. The sources of radioactive wastes are from mining of radioactive substances, atomic explosion, nuclear fuel cycle, nuclear weapons reprocessing, medical and industrial wastes etc.

8.3.3 Classification based on properties

Solid wastes are also classified based on their biological and chemical properties as follows:

a) Biodegradable / Organic wastes: Biodegradable wastes are those that can be decomposed by the natural processes such as composting, aerobic/ anaerobic digestion and converted into the elemental form like carbon dioxide, methane, water or simple organic molecules. Some of the biodegradable wastes include municipal solid wastes (green waste, food waste, paper waste, biodegradable plastics, human and animal wastes, sewage, sludge, slaughter house wastes etc).

b) **Non-biodegradable /inorganic wastes:** Non-biodegradable wastes are those that cannot be decomposed and remain as such in the environment indefinitely. They are persistent and threaten to overwhelm landfills and create disposal problems creating environmental concern. As non-biodegradable wastes cannot be decomposed, recycling is the ideal option for managing it. Example of non-biodegradable wastes includes plastics, nuclear wastes, glass, rubber tyres, styrofoam, fiberglass and metals.

c) Hazardous wastes: Hazardous waste is defined as chemical material that can no longer be used for its intended purpose and is known to be harmful or potentially harmful to plants, animals and human health or to the environment. Hazardous wastes may be in the form of solids, liquids, sludge's or gases. In some cases, although the active agents may be liquid or gaseous, they are classified as solid waste because they are confined in solid containers. They are generated primarily by chemical production, manufacturing and other industrial activities. The hazardous waste materials may be toxic, reactive, ignitable, explosive, corrosive, infectious or radioactive. If improperly handled, they can cause substantial harm to human health and to the environment. So good management practice should ensure that hazardous wastes are collected, stored, transported and disposed off separately, to render them innocuous. Some of the important hazardous wastes are lead, mercury, cadmium, chromium, many drugs, leather, pesticides, dye, rubber, solvents, paints and effluents from different industries.

Types of wastes with examples

Properties	Type of wastes
Biodegradable waste	food and kitchen waste, green waste, paper
Recyclable materials	paper, cardboard, glass, bottles, jars, tin cans, aluminium cans, foil, metals, certain plastics, fabrics, clothes, tyres, batteries
Inert waste	Construction and demolition waste, dirt, rocks, debris
Electrical and electronic waste (WEEE)	Electrical appliances, light bulbs, washing machines, TVs, computers, screens, mobile phones, alarm clocks, watches etc
Composite wastes	waste clothing, tetra Packs, waste plastics such as toys
Hazardous waste	paints, chemicals, tyres, batteries, light bulbs, electrical appliances, fluorescent lamps, aerosol spray cans, fertilizers
Toxic waste	pesticides, herbicides, and fungicides
Biomedical waste	expired pharmaceutical drugs

d) Non-hazardous wastes: Non-hazardous wastes are defined as substances safe to use commercially, industrially, agriculturally or economically. Some of the non-hazardous wastes produced are from the food processing plants, cotton mills, paper mills, textile mills and sugarcane industries. Other non-hazardous waste includes paint, oil, antifreeze, buffers, salts etc.

8.4 Characteristics of Solid Waste

Since the characteristic of waste determines the method of its management it is important and useful to know about the physical, chemical and biological nature of the waste. These characteristics vary depending on the source and type of solid waste and this in turn will affect the leachate and gas production from landfills.

8.4.1 Physical characteristics of the solid waste

It includes density, moisture content, waste particle size, temperature and pH as these affect the extent and rate of degradation of waste.

a) **Density:** Density of a waste is its mass per unit volume (kg/m^3). It is essential for the design of all elements of the solid waste management system from storage to transportation to final disposal. In high-income countries, the collected waste is typically of low density as it contains more recyclables like cans, glasses etc. Here considerable benefit is derived through the use of compaction vehicles on collection routes, where a 75% reduction of volume is achieved. However, in low-income countries initial compaction are not favourable due to a high initial density of waste. Consequently, compaction vehicles offer little or no advantage and are not cost-effective. Also significant changes in density occur spontaneously as the waste moves from source to disposal, due to scavenging, handling, wetting and drying by weather etc.,

b) **Moisture content:** The moisture content of solid wastes usually is expressed as the weight of moisture per unit weight of wet or dry material. In the wet-weight method of measurement, the moisture in a sample is expressed as a percentage of the wet weight of the material; in the dry-weight method, it is expressed as a percentage of the dry weight of the material. In equation form, the wet-weight moisture content is expressed as follows:

$$\text{Moisture content (\%)} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} \times 100$$

Typically in MSW the moisture content varies between 15-40% and this further depends on the composition of the wastes, the season of the year, and the humidity and weather conditions. Moisture content is a critical determinant in the economic feasibility of waste treatment by incineration since energy must be supplied for evaporation of this moisture. Moisture content also plays an important role in other processing methods such as composting and anaerobic digestion. Most micro-organisms including bacteria require a minimum of approximately 12% moisture for growth.

c) **Particle size and distribution:** Since recovery of waste materials is a key element in solid waste management it is important to have knowledge on the size and distribution of the waste constituents. This knowledge is useful in the utilization of mechanical separators and shredders for waste stream processing. However, the particle size and shape of MSW are challenging to measure due to reasons such as their complex shape, difficulty in the movement of MSW particles along the sieve surface and variation in their area depending on the forces acting on it (von Blottnitz et. al, 2002). The major means of controlling particle size is through shredding. Shredding increases homogeneity increases the surface area/volume ratio and reduces the potential for preferential liquid flow paths through the waste. Particle size will also influence waste packing densities, and particle size reduction (by shredding) could increase biogas production through the increased surface area available to degradation by bacteria. However, the flip side is, the smaller particles allow higher packing density which decrease water movement, bacterial movement and the bacterial access to substrate. Therefore, it is important for the particle size to be in line with the treatment method to be adopted.

d) **Field capacity:** The field capacity of solid waste is the amount of moisture that can be retained in a waste sample subject to the downward pull of gravity. The field capacity of waste materials is of critical importance in determining the formation of leachate in landfills. Water in excess of the field capacity will be released as leachate. The field capacity varies with the degree of applied pressure and the state of decomposition of the waste. The field capacity of uncompacted commingled wastes from residential and commercial sources is in the range of 50 to 60 percent.

e) **Permeability:** Permeability is defined as the hydraulic conductivity of compacted waste. It is an important physical property and it governs movement of liquid and gases in landfill. It depends on pore size, surface area and pore size distribution. Permeability is inversely related to density, implying that denser refuse is less permeable. The reported range of permeability of refuse is 10-1 to 10-5 cm/sec. 2.2 Chemical characteristic of MSW Chemical composition of solid wastes is important while evaluating alternative processing and recovery options. Especially while looking at waste to energy processes where waste is used as fuel it is important to have knowledge of proximate and ultimate analysis of the substrate.

8.4.2 Chemical characteristics of the solid waste

The efficiency of any treatment process depends upon the chemical characteristics of waste. Therefore, it is necessary to have adequate knowhow of the chemical composition of the solid waste for choosing the best's method for treatment. Chemical characteristics include pH, nitrogen, phosphorus, potassium, total carbon, C/N ration, calorific value, and Biochemical components such as carbohydrate, proteins, fats, natural fibers and toxicity due to presence of heavy metals, pesticides, insecticides, leachate characteristics. Presence or absence of above components determines the overall chemical characteristics of the waste.

8.5 Traditional methods of solid waste disposal

The problem of waste generation is as old as the advent of human life. With time there has been evolution in the living pattern of humans and so has in the quantity and quality of waste generation. Earlier, the kind of waste generation was mainly biodegradable but gradually the wastes have been transformed to recalcitrant and toxic. During prehistoric times, human lived in a group like nomad and the waste they generated were degraded by the scavengers. The waste such as weapons, bones and stone tools (non-biodegradable) never accumulated to the level to pose problem. The general method employed for the management and disposal of waste was open dumping. Open dumping is still practiced widely as it is easy and cheap method.

There was no organized waste management system during the ancient civilization and people used to litter waste anywhere and in case of odor problem; they covered the waste with clay. The early history of waste dumping system can be traced back to 500 BC in Greece, where people first created town dump. The Greeks by law were directed to dump waste one mile from the city. During same time, Athens law prohibited littering of waste on the streets. The Egyptians on the other hand, dumped garbage in the river Nile. During 2nd century BC, the Chinese people had systematic workforce for organized cleaning of major cities. The Mayans in ancient times had proper waste disposal system, where they had special dumps for organic waste and reused materials like broken earthen pots. Industrial revolution accompanied major change in waste quality and quantity. Europe in 18th and 19th century saw widespread occurrence of epidemics due to industrial waste and human waste. The Americans generally collected waste in huge bags and dumped in sea.

In the twentieth century, humans have dealt with solid wastes in three basic ways:

(1) By burning the waste – Burning the waste results in generation of ash and release of gas and smoke to the environment. **Open burning of Wastes** is a kind of burning in which burning is done at lower temperature in an uncontrolled. Although it is a traditional method of waste management, practiced by major population of the country, is not proper method of waste management. It reduces the quantity of waste. Around 40% of the worldwide solid waste is eliminated by open burning. In developing countries, it is widely practiced because it is an easy, cheap and effective way to get rid of solid waste. Generally open burring is carried out near the dumping site as it reduces the cost of transportation. Burning of solid waste leads to air pollution which in turn helps in heating up of earth drastically. It has been scientifically proved that open burning releases harmful gases and causes soil and water pollution

(2) By storing wastes, including the leftover as from burning, in dumps, impoundments, and most recently sanitary landfills. Dumping of solid waste is one of the most common tradition methods of waste disposal. The waste is first cleared from the source of generation and dumped in specified location in such a way that it does not cause any serious implication to the humans and the environment. Nowadays urban local bodies have approved the dumping of waste as means of waste disposal. It is the responsibility of local association to ensure that the waste is safely disposed within its jurisdiction. In present scenario, there is no systematic or scientifically organized method for the treatment of waste, as a result of this there is build up of unhygienic condition around the dumping site. The mismanaged dumping sites pose serious threat to the environment and public health.

3) **By injecting or burying wastes** in rock cavities deep underground - a method proposed for the disposal of industrial and conventional toxic or hazardous waste.

4) **Disposal by tilling into the fields:** The waste is generally buried into the farmer's field and they are allowed to plough after some time. This practice is not much common and also not environment friendly.

5) **Dumping of solid wastes into the Sea:** Dumping solid waste into the sea is an age old practice because it is easy way to get rid of wastes. It is widely practiced in the coastal areas throughout the world. The waste is generally taken in the canal boat and dumped at least 15 to 30 km from the coastline. This practice of waste disposal is however expensive and Not environment friendly.

Prominent dumping sites (open dumping) in major cities in India

Cities	Dumping sites
Mumbai	Deonar, Mulund and Kunjur Marg. Nearly 50% of the total waste is dumped at Deonar
Delhi	Okhla, Ghazipur,Narela- Bawana and Bhalswa. These dumping sites cover total area of 150 acres land
Chennai	Kodungaiyur and Perungudi (open dumping)
Bengaluru	Mandur, Bingipura and Lakshmipura

Merits and demerits of solid wastes disposal into the Sea

Merits	Demerits
• Dumping of solid waste into the sea pose less hazard than landfill disposal and incineration of solid waste. • Coastal fisheries and communities residing beside coastline may be	• It is economical to dump waste near the shore by the communities but transporting and disposing waste deep in the ocean requires huge investment and well-designed system.

minimally affected due to waste dumping in the deep ocean. • The assimilative capacity of ocean is incredibly high as oceans are huge. • With properly organized and well-designed dumping method, waste can be collected, concentrated and disposed in deep particular confined area in the ocean, which can cause least damage to the overall marine life. • The waste dumped in ocean can be easily degraded due to abundant aeration and vast flora and fauna. • It is one of the cheapest methods of waste disposal for the communities residing in the coastal areas.	• The waste accumulated deep inside the ocean may have hidden risk in long run. In one of the investigations, the mercury level in the whale was found to be much higher than in the ocean, which may be due to bioaccumulation. • Once the toxins are dumped in ocean, the containment is not ensured, while in case of landfill disposal, consequences can be brought under control easily. • If the waste dumped contains more organic matter than it will result in the depletion of oxygen level. • Once, a damage is done to a particular area in the ocean, it will take long time to restore as the residence time of ocean is quite high.

8.6 Need of solid waste collection and its management

There are certain negative effects due to improper collection of waste or no collection of solid waste from the environment and therefore, waste collection is compulsory requirement of systematic solid waste management. Some of the harmful effects of improper or non-collection of waste are as follows:

(i) Effects on human health: Organic constituents of solid waste have tendency to degrade easily and during the process creates foul odour because of release of various gases. The accumulated organic solid wastes draw diseases causing vectors such as insects, pests and rodents. The diseases such as typhoid cholera are spread by such vectors. If the waste is not disposed properly, it can enter water bodies and cause contamination, block the drainage system, promote growth of mosquitoes and thus threaten human health.

(ii) Effects on the environment: The improper handling and management of waste very badly affects the physical environment. The contaminants of solid waste pollute water bodies, soil and air. The open burning of solid wastes lead to air pollution, which cause health problems and also subsequently distresses the sustainability of the environment.

(iii) Effects on aesthetic aspect of the Area: Solid waste if not disposed properly, affects the physical appearance of the locality. Littering of waste on streets spoils the scenic beauty of not only forest reserves and waster body but also the environment as whole.

(iv) Effects on Economic Growth: Cleaner cities are better able to invite tourists and private investments which help in creating more job opportunities and it can provide satisfactory services to its citizens. Thus proper solid waste management through improved waste collection facilitates can overcome all above effects.

8.7 Solid Waste Management

Management of solid waste is crucial to avoid environmental and health hazards. Solid waste management is highly complex as it involves different steps, technologies and public participation. The steps involved in solid waste management include reduction in waste generation, handling, storage, collection, segregation, transfer, transport, processing, treatment and disposal. The success of waste management depends on the public and the government. Both share equal responsibilities and they should work hand in hand to achieve proper waste management. Solid waste management includes the complete process of collection, storage, treatment and disposal of solid wastes.

In the waste management process, the wastes are collected from different sources and are disposed of, thus, the process includes storage, segregation, collection, transportation, treatment, analysis and disposal of waste. Thus, solid waste management can be divided into five major components:

- Waste minimization and reuse
- Storage and Segregation at source
- Collection
- Transportation
- Disposal

8.7.1 Waste Minimization and reuse

Waste generation is a continuous process and happens at all levels from houses to industries. Simply the wastes are some or other articles which is no more useful for the owner of the product or article. Thus, when a person or owner of the industry feels that some or other articles or goods have no usefulness for them, then such articles or goods become a part of waste, however, such waste may still be useful for some or other uses. Thus, in order to get rid of such goods/ articles, the owner either throws it in the nature or sells it to some 'Kabadiwala' (Scrap dealer). This is the informal sector (kabadi system or scrap dealer) is largely involved in collection of recyclables and material recovery. The initiatives, which encourage informal sector participation in collection of recyclables from consumers, benefit from the increased collection efficiency that this sector is able to achieve, which may then result in lower supply chain costs (collection costs).

As per the SWM Rules, 2016, the ULB (Urban Local Bodies) should create public awareness for minimizing waste generation and reusing waste to the extent possible. Source reduction is the most preferred tier in the ISWM (Integrated Solid Waste management) hierarchy because of its potential to directly reduce the quantity of waste generated and hence reduce associated financial and environmental costs (SWM Manual, 2016).

8.7.2 Storage and segregation at source

As per SWM Rules (2016), segregation is defined as sorting and separate storage of various components of solid waste namely biodegradable wastes including agriculture and dairy waste, non-biodegradable wastes including recyclable waste, non- recyclable combustible waste, sanitary waste and non-recyclable inert waste, domestic hazardous wastes, and construction and demolition wastes. Segregation at source is one of the important SWM steps that reduces contamination in the waste, thus, making better collection and safe transportation for further processing. It also optimizes waste processing and treatment technologies. Segregation also promotes reuse and recycling, leading to less consumption of virgin material. Indirectly, source segregation also impacts climate change and has many other advantages.

It is the duty of a every waste generator to segregate and store the waste generated by them in three separate streams namely **bio-degradable, non bio- degradable and domestic hazardous wastes** in suitable bins and handover segregated wastes to authorized waste pickers or waste collectors as per the direction or notification by the local authorities from time to time. S/he should wrap securely the used sanitary waste like diapers, sanitary pads etc., in the pouches provided by the manufacturers or brand owners of these products or in a suitable wrapping material as instructed by the local authorities and shall place the same in the bin meant for dry waste or non- bio-degradable waste. The waste related to construction and demolition should be stored separately, as and when generated, in his own premises and shall dispose off as per the Construction and Demolition Waste Management Rules, 2016. The horticulture waste and garden waste generated should be stored in the premises of waste generator and s/he should dispose it as per the directions of the local body from time to time.

a) **Household-level Storage of Segregated Waste**: At the household level, dry waste, wet waste, and domestic hazardous waste should be stored in separate garbage bins, of appropriate capacity and colour. The colour of the garbage bins should be in accordance with the SWM Rules, 2016; wet waste is to be placed in a covered green bin and dry waste in a covered white bin. Because the rule does not specify the colour of the bins for storage of domestic hazardous waste, urban local bodies (ULBs) should decide on an appropriately coloured bin. For example, Coimbatore City Municipal Corporation uses red bins for collection of domestic hazardous waste. Capacity of bins depends on frequency of collection (daily, alternate day, or on demand) and quantity of waste generated. A container of 12–15l (0.015 m3) capacity for a family of five members should be adequate for each dry and wet waste, if collection takes place daily. However, a household may keep larger containers or more than one container for waste produced in 24 hours, having a spare capacity of 100% to meet unforeseen delays in clearance or unforeseen extra loads. If dry waste is not collected daily, container capacity has to be enlarged accordingly. Wet waste collection bins should be washed by the household each time they are emptied. It is not desirable to use plastic bags in waste bins.

Bins for Collection of Dry, Wet and Domestic

In large apartment complexes and multistoried buildings, gated communities large waste collection bins for wet waste and dry waste should be placed at a convenient location. Residents should deposit segregated waste in the respective bins either themselves or through organized door-to-door collection system of the resident welfare association (RWA) or community-based organization (CBO). Specification of bins and containers shall be compatible with primary collection vehicles, if applicable. Typical specifications for garbage bins used in apartment complexes and large buildings are the following: 60l (25kg) bins suitable for 12 households, 120l (50kg) bins for 24 households, 240l (96 kg) bins for 48 households, etc. that are of standard quality, high-density polyethylene (HDPE), injection or roto molded, ultraviolet (UV) tested, durable and could withstand rough handling, and compatible with lifting mechanism on primary collection vehicle, if applicable. The specific size of the containers depends on the number of connected households and the frequency of collection.

b) **On-site Storage of Bulk Wastes:** “Bulk Waste Generator” means and includes buildings occupied by the Central government departments or undertakings, State government departments or undertakings, local bodies, public sector undertakings or private companies, hospitals, nursing homes, schools, colleges, universities, other educational institutions, hostels, hotels, commercial establishments, markets, places of worship, stadia and sports complexes having an average waste generation rate exceeding 100kg per day. Shops, commercial establishments, and businesses should store segregated waste on-site. Whereas vegetable and flower market waste generators should deposit their waste in conveniently located large green bins for preferable utilization of waste on site or as directed by ULB. Number and capacity of bins required may be computed by considering quantity of waste to be stored before collection plus an additional 100% storage. Storage bins should be compatible with the primary collection system to avoid multiple handling of waste. Typically, four-wheeled, HDPE, injection or roto molded, international standard, UV tested bins or metal bins of different capacities—e.g., for 240 l (96 kg), 600 l (270–280 kg), 770 l (315–350 kg), 1,100 l (449– 495 kg)—may be used for bulk waste. These bins should be compatible with auto lifting by standard universal bin lifting devices on mobile compactors and other vehicles.

c) **Storage of Municipal Solid Waste in Public Places or Parks**: With a view to ensure that streets and public places are not littered with waste, litter bins may be provided at important streets, markets, public places, tourist spots, bus and railway stations, large commercial complexes, etc. at a distance ranging from 25m to 250m depending on the local conditions. The collection from these bins should be segregated into wet and dry waste.

d) **Storage of Yard Waste or Garden Waste:** The SWM Rules, 2016 suggests that horticulture waste from parks and gardens should be collected separately and treated on-site to make optimum use of such wastes and also to minimize the cost of its collection and transportation. In large cities, the municipal authority may provide large containers for storage of waste or facilitate provision of large containers through private sector participation. In small cities, such waste may be stored on-site and the municipal authority may facilitate its periodic collection, either through the

SWM department or by involving the private sector. The skip bins or containers shall be of a standard design and amenable to automatic hydraulic lifting and unloading by a transport vehicle. This waste should not be mixed with domestic waste

8.7.3 Collection of waste

In order to store the solid waste, storage containers are required at the point of source and for safe transportation. Adequate portable storage containers of adequate size, type should be kept in every establishment or house to store all garbage, rubbish or waste. Storage containers shall be strong, watertight, not easily corrodible, rodent-resistant and insect-resistant. The covers of the container should not be removed except when necessary to place garbage and refuse in the storage container or to remove the same there from. All putrescible solid waste shall be drained of surplus liquids and shall be securely wrapped in paper or placed in watertight bags before being placed in the storage containers. Storage containers shall not be overloaded to the extent covers cannot be securely replaced.

Waste collection is the major and crucial step in waste management process. It is defined as the collection or gathering of waste from the source of generation and haul them to the transfer stations, processing sites, disposal site or landfills. Hence, waste collection does not only mean the gathering of waste alone but includes methods such as collection, storage, segregation, transportation etc. Waste collection containers play an important role in waste collection system. Their type, size and location determine the efficiency of waste collection. The size and type of the containers vary with the location and source of generation, example; residential colonies with the single family households require small containers unlike commercial, institutional and industries which require large containers. The size of the containers determines the handling of the containers (i.e.) small containers can be handled manually while the larger ones require mechanical handling

a) **The size and characteristics of storage container:** The size and characteristics of storage container plays an essential role in waste collection. Selection of good container can save collection energy, increase the speed of collection and reduce the crew size. The characteristics to be considered while selecting a container include:

- **Low cost:** The containers chosen for waste collection should be cheap and economical so as to minimize the cost of collection.
- **Size and weight:** Any collection containers should be of appropriate size to avoid occupational health hazard. A container should not weigh more than 20 kg. The containers that weigh more than 20 kg require more collection members as it would be difficult them manually. Further, if they are handled manually, it will cause muscular strain and ligament tear of waste collector. As mentioned earlier, single household families can use small sized containers unlike other residential, commercial and institutional sources. Smaller size containers can be unloaded manually where as large size containers require mechanical lifting.
- **Containers should not be rough:** Rough surface facilitates easy attachment of wastes there by leading to decomposition at the rough surfaces. Further containers with rough surface are difficult to clean. Example, containers made of wood.
- **Containers should not have sharp edges:** Sharp edges may cause injury to the waste collector crew.
- **Containers should be inert:** The containers should be made of inert materials to avoid the reactivity of waste with the container materials. Example, iron containers should be avoided because the moisture in the waste will corrode them and lead to rusting.
- **Containers should be covered:** Covered containers will prevent the entry of rain waste into the wastes. The rain water will accelerate the rate of decomposition leading to obnoxious odour. It will also increase the weight of solid waste stored within the container. Covered containers will prevent the entry of stray animals into the containers.
- **Strength and durability:** The containers should be strong and durable to avoid frequent breakage. It should withstand the rough handling by the crew members during manual and mechanical unloading of wastes. Strong and durable containers will last long and minimize the cost of collection.
- Containers should be provided with wheels to facilitate movement, handle for easy carrying and hoist and tail for lifting.

• **The containers should not absorb moisture:** Retention of moisture in the container will lead to bacterial and fungal growth, thereby accelerating the decomposition rate of wastes. Example, wooden containers, bamboo baskets should be avoided.

• The container material should be light, smooth, corrosion resistant, inert and recyclable.

Containers that lack above mentioned characteristics should be avoided in waste collection as they would create menace, increase the collection cost and decrease collection efficiency.

b) **Types of storage containers:** Broadly, there are two principle types of collection containers: stationary and hauled/ movable containers.

• **Stationary containers:** These are immovable and fixed at the site of storage. The waste stored in these containers is manually transferred by the waste collection crew at certain times the stationary containers are emptied directly into the collection vehicle by mechanical means.

Stationary container

• **Hauled/ movable containers:** These types of containers are fixed with wheels to facilitate its movement to waste processing site, transfer station or directly to the disposal site. These containers are used for special type of wastes (i.e.) when the wastes need separate treatment and processing. Generally, there is third type of containers called **communal or public** containers. It

Hauled containers

Source:

is conventional type of containers that is in use for almost 3 to 4 decades. Communal containers are those which are fixed in public places such as parks, residential colonies, shopping streets, office buildings and institutions. They can be stationary (i.e.) fixed on the ground and movable. In India, these are cemented structure which is used by public to dump their wastes. These containers are open and hence face problems during rain. It also attracts flies, insects, rodents and other stray animals. Communal containers require manual cleaning which further increases the cost of collection. In containers built below the vehicle level requires swiping, cleaning and loading of solid wastes into the transfer containers before loading into the collection vehicle. This increases the collection time. In recent times these communal containers are provided with hoists and tails compatible with collection vehicles lifting mechanisms. Such movable communal containers are generally of capacity, 1 to 4 m^3. However in places of high rate waste generation (large commercial centers, wet markets and other business establishments) thecapacity of communal containers ranges from 12 to 20 m^3. The major disadvantage of these communal containers is, they emit foul odour due to limited maintenance. High rate of failure is .observed in fixed communal containers.

Cemented communal container

8.7.1.1 Components of waste collection

As mentioned earlier waste collection is highly complex and costly process. It consists of the following components.

a) **Collection points:** Collection points are the sources from where the waste is generated or points where the waste is collected. These collection points can be located in residential, commercial of industrial area. The collection points determine the size of the crew, storage points and the time required for collection. The overall cost of waste collection is again determined by collection points.

b) **Collection frequency:** The rate at which the waste is collected from a collection is called as collection frequency. Collection frequency depends on many factors such as population, community, income group, life style and climatic conditions. In a hot humid climate, the waste collection must be frequent as this climate favor microbial activity resulting in faster decomposition of solid wastes. It also produces bad odour/foul smell and leachate (a watery liquid that oozes out from the waste). Henceforth this climate necessitates collection at least twice or thrice a week. This is applicable for putrescible material too. Frequent collection of putrescible waste will avoid health problems. Requirements of a locality are another factor that determines the collection frequency. Residential area requires frequent collection unlike the shops, institutions and industries. Likewise, urban areas generate more waste than rural areas and hence require frequent collection. The requirement of containers too determines the collection frequency. According to the population and quantity of waste generation the number of containers should also be increased. Apparently open containers necessitate waste collection on daily basis unlike the sealed containers. Inappropriate estimation of waste generation and irregular waste collection increases the overall cost of the collection. Proper planning and segregation of waste at source will minimize the cost involved in waste collection. **Storage containers:** The size and characteristics of storage container plays an essential role in waste collection. Selection of good container can save collection energy, increase the speed of collection and reduce the crew size. The characteristics to be considered while selecting a container include

- Durable
- Easy to handle
- Economical
- Resistant to corrosion, weather and animals
- Covered to prevent entry of water
- Should not have sharp edges
- Less than 20 kg weight to facilitate easy emptying
- Avoid wooden containers (e.g., bamboo, rattan and wooden baskets) readily absorb and retain moisture and their surfaces are generally rough, irregular and difficult to clean
- In residential areas, where refuse is collected manually, standardized metal or plastic containers are used.
- When mechanized collection systems are used, containers are specifically designed to fit the truck-mounted loading mechanisms

c) **Collection crew:** The persons involved in collecting the waste from house to house; trucks and taking it to the transfer station or disposal site if termed as 'collection crew'. The crew consists of 8-12 persons and headed by the supervisor. The size of the crew varies from community to community, region to region, amount of waste generation in a locality/ waste generation rate, frequency of waste collection, collection methods involved, space between the houses, size and type of collection vehicle and route characteristics. Labour and equipment costs also determine the crew size. The crew size increases when there is increase in the rate of waste generation. Less collection frequency also increases the crew size because the quantum of waste per individual stop will be high. The crew size has a great effect on collection costs which leads to:

- Improper collection frequency
- Segregation of material at source
- Implementation of automation in collection

d) **Collection routes:** The route planned by collection crew to collect waste in a specific area is called as collection routing. A proper planning of the collection routes will decrease the overall cost in addition to labour cost, conserve energy by minimizing vehicle fuel consumption and reduce the working hours. The size of each route is decided based on • the amount of waste collected per stop, • distance between stops, • loading time • traffic conditions. • Barriers, such as railroad, embankments, rivers and roads with heavy traffic, can be considered to divide route territories. All these factors determine the collection routing. Proper planning will improve efficiency of collection and decrease the collection cost. It will also help the supervisor to track the collection crew.

8.7.1.2. Collection of comingled and source separated wastes

Waste collection differs for comingled and source separated wastes. **Source separated wastes** (i.e.) biodegradables, recyclables and non recyclables are collected separately from different collection centre's or containers and taken for further processing, whereas the **comingled waste** is carried to transfer station for further separation and processing.

Waste collection is most difficult and complex in an urban environment because the generation of residential and commercial-industrial solid waste and recyclables takes place in every home, every apartment building, and every commercial and industrial facility, and in the streets, parks, and even vacant areas. Henceforth, the waste collection becomes complex with increasing waste quantity and diffused waste generation pattern. More diffuse is the waste collection, more is waste generation and more complex is waste collection. Waste collection is costly component of waste management. Around 50 to 70 percent of the total waste management cost is utilized for waste collection. The cost can be reduced if the waste collection is properly planned and managed. Waste collection depends on number of containers, collection vehicles, routes and collection frequency.

The collection of waste varies with the characteristics of the facilities, activities, or locations. Two types of collection services generally used include:

- Commingled (unseparated) wastes
- Source-separated wastes

a) **Collection of commingled waste:** The residential dwellings are classified as low rise (below four stories), medium rise (from four to seven stories) and high rise (above seven stories). These dwellings accordingly have differences in the solid waste handling operations. The residential collection services for low rise detached dwellings include (1) curb, (2) alley, (3) setout- setback, and (4) set out and (5) backyard carry. In case of curb service, the resident is supposed to place the containers which are to be emptied at curb on collection day and to return the empty containers to their storage location till next collection happens. Alleys include basic layout or pathways of any given residential area where the collection containers are placed. These alleys are used for placing the storage containers and facilitate collection of solid waste. In setout- setback collection service, the containers are set out in the property of resident and it is set back on emptying with the help of additional crew working in the conjunction with the collection crew. Collection crew is responsible for loading the collection vehicle. Setout service is similar to the setout-setback service except that residents are responsible to return the containers to their storage site. The collection of residential waste is also done manually by either direct lifting or carrying loaded containers to the collection vehicle for emptying it or rolling of loaded containers having wheels to the collection vehicle for mechanically emptying. In case of low and medium rise apartments, curbside collection service is generally used. Usually the maintenance staff (watchman, servants) is responsible for manually or mechanically transporting the containers to the street for curbside collection. In high rise apartments, the commingled waste is usually bagged and placed by the tenants in waste chute system, used for the collection of waste at a centralized service location. The wastes are also in some case picked up by the building maintenance personnel from different floors and taken to the basement or service area. In commercial and industrial facilities, both, manual and mechanical collection of waste is used. The collection of waste is usually carried out in late evening and early morning hours in the commercial establishments because of traffic congestion during day.

In addition to the waste generated on the premises, waste is also generated along the road **sides and streets**. The waste presents in streets are as follows:

1) Natural waste-waste blown from adjoining open spaces
2) Behavioral waste – waste deposited by pedestrians and people using the streets. Besides, waste from residences is often thrown by road sides
3) Wastes generated on road such as accidental spillage from loaded vehicles, construction wastes, animal droppings, oil spillage from vehicles and rubber during traffic congestion.
4) The wastes generated from nearby residential, commercial and industrial areas
5) Wastes generated by the roadside vegetable and fruit vendors, street hawkers and slum dwellers. Sweepers generally clean only major streets and drainage and avoid narrow street lanes. The sweepers usually don't stop at each and every door step to collect waste but as per state Municipal act, they ought to collect household waste from each and every doorstep while sweeping the streets on daily basis. The sweeping is carried out manually by using short handled brooms, although there is a perceptible trend towards use of long handled brooms. Only major roads are swept every day according to the Municipal rules, the sweepers must and minor roads are swept once in a week. The manual cleaning work is usually carried out commonly (i.e.) one person sweeping the road and another will collect the waste materials in a hand cart. The work in two shifts from 6 to 12 AM in the first shift and 3 to 5 PM in the second shift. They work on six days a week but it is desirable that the work be carried out daily and holidays to different workers are staggered. The lack of manpower and insufficient available fund prove to be inefficient in dealing with this aspect properly.

b) **Collection of wastes separated at the source:** The separation of waste at the source is carried out for the recovery and reuse. There are three methods for the collection of the recyclable materials from the residential areas which include, (1) curbside collection using conventional and specially designed collection vehicles. (2)

Incidental curbside collection by charitable organization. (3) Delivery by residents to drop- off and buyback centers. Drop off centers are places where the recyclables are dropped off in specific sites. This will facilitate collection of specific materials so that they can be recycled further. Buy back centre is one where the materials are bought for minimum price. Electronic wastes are disposed off in the buyback centre's of respective companies. In curbside system, the recyclables are separated at the source and collected separately from commingled waste at the curbside in the alley or at commercial facilities from low rise detached dwellings. Curbside program differs from community to community. In some programs, residents are required to separate different materials which are stored in their own containers and collected separately. Other programs use only one container to store comingled recyclables or two containers, one for paper and the other for heavy recyclables (glass, aluminum, and tin can). The no containerized yard wastes are collected using claw and a modified vehicle. The waste collected is then emptied into a specially equipped compactor type collection vehicle with a wide receiving hopper. The collected yard wastes are usually taken to a compost facility. The streets are then swept once the wastes have been collected. From low and medium rise apartments, two methods are used for the collection of source separated wastes. (1) Curbside collection with the help of conventional and specially designed mechanized collection vehicle. (2) Collection from designated storage areas with mechanizes collection vehicle. In high rise apartments, the handling of commingled and source separated waste involves following methods.

(1) Recyclables and commingled wastes picked up by building maintenance personnel from different floors and taken to the basement or service area and placed in separate containers

(2) Recyclables and commingled wastes taken to the basement or service area by the occupants itself and placed in separate containers (3) Recyclables wastes taken to the basement or service area and placed in separate containers and where available, other commingled waste is placed in specially designed waste chutes.

From commercial facilities, source separated materials are typically collected by private haulers. Recyclables are stored in separate containers. In large commercial facilities, baling equipment is used for paper and cardboard and can crusher for aluminum cans.

8.7.4 Transportation of waste from source to processing site

It includes transportation of waste collected from the source of production to transfer stations and then **transfer stations** to the site of final disposal of waste. **Transfer station** is a centralized facility located between the collection and disposal site. It is also called as an **intermediate station** where waste from smaller collection vehicles are unloaded and re-loaded back into large vehicles for transport to a disposal or processing site. It is built in between the source of generation and disposal site. In addition to loading and unloading of waste, transfer stations are also used as storage and waste processing sites. They have facilities for waste separation/ segregation, size and volume reduction (shredding, compaction) and component separation. In some cases, they also have waste treatment facilities such as incineration, pyrolysis and composting. In areas with narrow and congested lanes where use of compacted trucks is limited, the transfer stations are used as a facility to transfer the waste from small vehicles and non-compacted trucks for segregation reloading into large vehicles. Likewise, when waste is not dense, they are brought to transfer station and compacted. The transfer station also serves best when the distance between the collection zone and disposal site is very high. The transfer station also serves as a garage for temporary parking and vehicles servicing. The major limitation of transfer station includes additional construction for building transfer stations and labour cost. It also consumes high amount of energy for waste transfer, segregation and processing. The problems associated with transfer station are that it attracts flies and other insect vectors and creates odours. Traffic and noise due to small and large collection vehicles, collectors, drivers, etc., invite the resentment of the communities living in the vicinity of transfer stations.

The need for transfer station is based on the following criteria:

- **Type of waste received**: Co-mingled waste requires an intermediate facility, transfer station for segregation and sorting of waste before disposal. Likewise, the amount of waste generation also destines the need for transfer station. Considerable amount of waste essentially requires transfer station.

- **Process involved in recovering materials**: waste that has been already segregated does not require a transfer station. However, co-mingled waste that contain recyclables are to be segregated before been transported to respected industries. The segregation, be in manual or mechanical is done and the materials are recovered at the transfer station. Example, ferrous and non-ferrous waste present in comingled waste is separated.
- **Types of collection vehicle:** The collection vehicles are chosen depending upon the depending characteristic of the area. Areas with narrow and congested lanes require small vehicles for waste collection. However, areas with wide lanes can utilize compacted trucks as collection vehicles. As mentioned earlier, the small collection vehicles require transfer station for unloading the waste and reloading them to bigger collection vehicles.
- **Site** topography and access

8.7.4.1Types of transfer station

Based on the size, the transfer station are classified into three types:

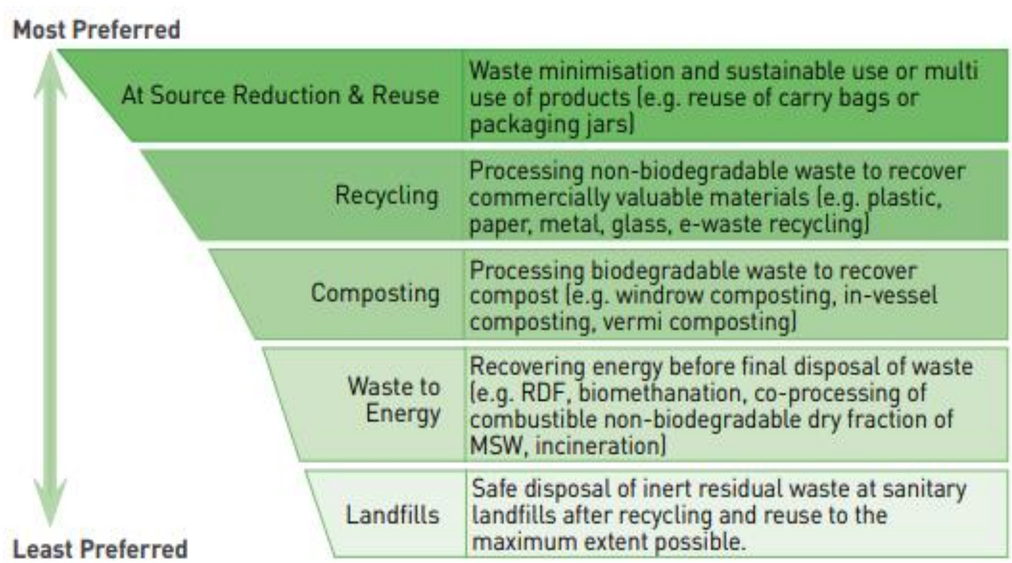
- **Small transfer stations:** small transfer stations can hold waste up to 100 tonnes per day. It is a direct discharge station and does not have intermediate waste storage area. Depending upon the site characteristics and weather conditions the transfer station can be Indore or outdoor. A small transfer station focuses only on segregation and hence does not have processing and treatment facilities (size and volume reduction units). Population, population density and frequency of collection determine the size of transfer station.
- **Medium transfer station:** It is similar to small transfer station except for the capacity of waste it can hold in a day. The capacity of medium transfer station is about 100 to 500 tonnes per day. They can also be constructed indoor or outdoor. In some cases few processing units are made available in medium transfer stations.

- **Large transfer station:** Such station is designed especially for municipal collection vehicles. Sometimes private companies hold these large transfer stations for heavy commercial use. Mostly the large transfer stations are constructed outdoors. In addition to segregation, component separation size and volume reduction is carried out in the large transfer station. Few large transfer stations have inbuilt incinerators and composting facilities. Before the vehicle enters into the large transfer stations, it is weighed and taken to an area provide with a pit, platform and a waiting trailer. The waste is unloaded and taken through the trailer for segregation and processing.

8.7.5 Treatment and Disposal of waste

Municipal solid waste management (MSWM) and adoption of processing technologies depend largely on the quantity and characteristics of the total waste generated in an urban local body (ULB).

Integrated Solid Waste Management Hierarchy



The least preferred option of ISWM is disposal of waste in landfills, where no landfill gas capture is planned. Normally, landfills that integrate the capture and use of methane are preferred over landfills that flare landfill gas. However, Indian laws and rules do not permit disposal of organic matter into sanitary landfills and mandate that only inert rejects (residual waste) from processing facilities, inert street sweepings, etc. can be land filled. In cases where old dumps are to be closed, there is a possibility of capturing methane gas for further use, which may be explored. However, repeated burning of the waste significantly decreases the potential of capturing methane.

8.7.5.1 Recycling and reuse

Solid Waste Management (SWM) Rules, 2016 defines **recycling** as “the process of transforming segregated solid waste into a new product or a raw material for producing new products.” Further, it also states that “arrangement shall be made to provide segregated recyclable material to the recycling industry through waste pickers or any other agency engaged or authorized by the urban local body for the purpose.” According to the ISWM hierarchy, recycling is a preferred waste management strategy after source reduction and reuse. Recycling systems should be adopted before planning for any waste processing or treatment facilities.

Advantages of Recycling

Recycling diverts a significant fraction of municipal, institutional and bulk waste from being dumped or disposed in landfills. This results in saving of scarce resources as well as reducing environmental impacts and the burden of waste management on public authorities. If appropriate market mechanisms are established, recycling can generate revenues, contributing to the overall cost recovery for municipal solid waste service provision

a) Advantages for the ULB

– Reduces waste volume.

– Cost savings in collection, transportation and disposal

– Longer life span for landfills.

– Reduced environmental management efforts.

b) Advantages for the economy

– Reduction of imports of raw materials, fertilizers etc. and hence foreign currency required.

– Livelihood opportunities for recyclers in the recycling industry.

c) Advantages for the environment

– Sustainable use of resources

– Reduced amount of waste going to storage sites and reduced requirement of land.

– Reduced environmental impacts including impacts of climate change.

Important Recycling Material: Recycling Potential and Special Conditions		
Material	Recycling Potential	Special Conditions
Aluminium	• It has a high market value. • It can be recycled easily by shredding and melting. • It can be recycled indefinitely because it does not deteriorate through reprocessing. • It requires significantly less energy than producing aluminium ore	• Separate collection is important
Batteries	• It recovers valuable metals. • It protects environment from heavy metals such as lead, cadmium, and mercury.	• There is a large variety in types and sizes of batteries. • Only some types allow adequate material recovery.
Construction and demolition waste	• Demolition waste can be sorted, crushed and reused for production of pavement material, flooring tiles, road construction, landscaping and other purposes. • Due to the amounts of demolition waste, its recycling allows significant reduction of otherwise required disposal capacities	• Standards for recycled products are yet to be stipulated.
Glass	• It has a moderate market value. • It can be melted and sorted into colours. • Recycling glass saves energy compared with processing raw material. • It can be recycled indefinitely because it does not deteriorate through reprocessing	• Broken glass can contaminate and eliminate opportunities for recycling of other material such as paper
Paper and	• It is easily recycled.	• Recycling potential is reduced

cardboard	• Paper or cardboard from recycled paper requires less energy during production and helps protect the forests.	with each recycling cycle through deterioration of fibres.
Polyethylene terephthalate (PET)**	• It can be recycled if segregated from other waste.	• Quality of recycled product decreases with every processing cycle. • Recycled products have specific designated uses and cannot be used for other purposes.
Other plastics	• Other plastics, such as polyethylene or polyvinyl chloride, can be recycled but have less value in the market than PET. The value depends on recycling and manufacturing options in the vicinity	• Clean segregated plastics, are subjected to mechanical recycling into the same plastic type. • Where recycling is not possible due to mixed plastics, they are then coprocessed for energy recovery or used as aggregates in road material.
Electronic waste	• It contains high value metals. • Electronic items can be dismantled and its components reused or recycled.	• If recycling is not carried out under controlled conditions, metal is often covered with polyvinyl chloride or resins, which are often smelted or burned, causing toxic emissions. • Disaggregation of electronic waste for recycling can be costly
Metal (steel, copper, nickel, zinc, silver, etc.)	• Scrap metal has a high market value, especially steel, copper, and silver. • It can be recycled indefinitely because it does not deteriorate through reprocessing.	• High value metals, such as copper and silver, are incorporated in electronic devices, but extraction can cause severe environmental impacts, if uncontrolled.
Thermocol or	• It can be processed to recover fuel and other by-	• Fuel production is through

Styrofoam	products • It can be re-ground with new expanded polystyrene for further use. • It can be powdered and made into sheets, which can be used to make furniture.	pyrolysis, gasification, and hydrocracking. • Regulated facilities with appropriate environmental controls are required for handling thermocol recycling

Recycling of Plastics: It is estimated that approximately 4,000 to 5,000 TPD of plastic waste is generated in India; that is roughly 4%–5% by weight of MSW. The major problems in plastic waste management are collection, segregation and disposal. At present, plastic waste collection is done through the informal sectors such as the kabadi system and waste-pickers.

Thermocol recycling: Thermocol or Styrofoam, scientifically known as expanded polystyrene, is produced from a mixture of about 90%–95% polystyrene and 5%–10% gaseous blowing agent (pentane gas or carbon dioxide). Thermocol is an excellent material for packaging goods (especially electronic goods) and for the construction and decorating industry because it is light and has good insulating properties. Environmentally sound recycling of thermocol still remains to be commercially established in India, and thermocol recycling regulation is yet to be notified.

Different methodologies are available for recycling thermocol, e.g., grinding and mixing it with new eads, shredding it into fine powder, reducing its volume using solvents (Bhabha Atomic Research entre [BARC] process), etc.

Pune's Science and Technology Park has set up a plant at Ranjangaon to recycle discarded thermocol into cheap furniture items. The furniture manufactured from recycled thermocol is relatively cheap, durable, and fireproof. A hub of electronic industries, Ranjangaon produces 10 TPD of thermocol waste.

A thermocol compactor may also be used to reduce the bulk of thermocol waste generated within a ULB. This compacted thermocol is then sold to the recycling market for further processing or recycling.

Recycling Paper and Board: In India, the informal sector mainly performs the collection of waste paper through door-to-door collectors, kabadi system, and waste pickers. The informal sector carries out as much as 95% of the collection of waste paper in the country. The value chain comprises direct collection from various source points and small shops, where primary sorting of waste into different categories takes place; (ii) zonal segregation centres owned by wholesalers, where the waste material gets collected from small shops and baled; and (iii) finally dispatched to end users, which are usually paper mills.

Paper recyclers are developing new technologies for handling, identifying and separating paper grades for recycling. One such technology allows segregation of paper fibres during the recycling process according to fibre length, coarseness, and stiffness through a sequential centrifuging and screening process.

Recycling of garden waste or yard waste: Yard waste consists of grass, leaves, and tree and bush trimmings. The horticulture waste from parks and gardens should be composted at the site or at a decentralized facility, thereby reducing the amount of yard waste entering the solid waste stream. Additionally, grass clippings, leaves, and woody yard wastes can also be used as mulch in gardens and around shrubs to keep the soil moist, control weed growth, and add nutrients. Organic material, e.g., straw, dried stems, etc., containing higher percentage of lignocellulosic material takes much longer time for composting process to complete. These can be readily converted into mulch in shorter period of time.

Construction and Demolition Waste

Construction and demolition (C&D) waste generally constitutes about 10%–20% of total urban solid waste. The report of the Supreme Court's expert committee in 1999 and the SWM Rules, 2016 recommend that ULBs shall facilitate the separate collection and transportation of C&D waste. Due to the challenges associated with processing and disposal of C&D waste, separate rules have been established namely Construction and Demolition Waste Management Rules, 2016 that describes the management of C&D waste and roles and responsibilities of various stakeholders.

C&D and other inert waste may be utilized for making bricks, pavement blocks, construction materials such as aggregates etc. Ward level debris deposit sites should be created. Containers could be provided at such locations, and a small collection charge could be levied for receiving such waste and transporting it for disposal. Rates may be prescribed for such collection by the ULB, and contracts could be given for managing such sites. Helplines should be created to ensure prompt clearance of C&D waste.

ULBs must make serious efforts to utilize C&D waste and should motivate the private sector to set up processing plants. There are several plants of various capacities in India to make bricks, paver blocks, aggregates, etc. out of such waste material. Profitable use of C&D waste will minimize the cost of managing such waste and requirement for valuable landfill space, besides giving employment opportunities to unemployed youth. It will also save natural resources and reduce the use of virgin soil.

8.7.5.2 Composting

Municipal solid waste (MSW) primarily consists of organic, inorganic, and inert fractions. Under natural conditions, the organic fraction of waste continually decomposes, accompanied by a strong foul odour and production of gases, which are predominantly methane or CO2 depending on the aerobic condition of the decomposing mass. Vector infestation during the natural decomposition is a common phenomenon.Composting is a process of controlled decomposition of the organic waste, typically in aerobic conditions, resulting in the production of stable humus-like product, i.e., compost.

Considering the typical composition of wastes and the climatic conditions, composting is highly relevant in India and should be considered in all municipal solid waste management (MSWM) concepts. Composting of the segregated wet fraction of waste (see Section 2.2 of Part II) is preferred. Mixed waste composting, with effective and appropriate pre-treatment of feedstock, may be considered as an interim solution; in such cases, stringent monitoring of the compost quality is essential.

Benefits of Composting

- The real economic benefits of compost use include improved soil quality, enhanced water retention capacity of soil, increased biological activity, micronutrient content, and improved pest resistance of crops.

- Composting minimizes or avoids GHG emissions from anaerobic decomposition of organic waste (such as in a large unturned heap).
- Composting increases the design life of other waste management facilities.
- Stringent design requirements and associated costs for catering to management of leachate from organic waste decomposition may be reduced in those landfills that do not receive organic waste.
- Compost is particularly useful as organic manure; it contains macronutrients (nitrogen, phosphorous, and potassium) as well as micronutrients. When used in conjunction with chemical fertilizers, optimum results are obtained.
- The use of compost reduces the dependency on chemical fertilizers for agricultural operations. When used as a soil amendment, compost reduces the need for water, fertilizers, and pesticides. Compost acts as a soil conditioner, therefore supporting the long-term fertility of soil.
- Compost may be used to revitalize vegetation habitats and add life to marginal, impoverished soils and waste lands.
- Compost may also be used as a bio matrix in remediation of chemical contaminants and as a remediated soil in contaminated sites; compost helps in binding heavy metals and other contaminants, reducing leachate and bio-absorption.

Unit 9: Hazardous Waste Management

Unit Structure

9.0 Learning Objectives

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

- Explain the wastes and its types
- Discuss the problems of waste generation
- Describe the waste collection and transportation
- Discuss the various waste treatment and disposal methods
- Explain the various environmental impacts of waste generation and disposal

9.1 Introduction

A hazardous substance is defined according to Resource Conservation and Recovery Act (RCRA) 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 an increase in mortality or an increase in serious irreversible or incapacitating reversible illness, or pose a substantial hazard to human health or the environment when improperly managed.

A hazardous waste is a hazardous substance that

- Is discarded, accumulated, stored, physically, chemically, or biologically treated prior to being discarded; or
- Has served its original intended use and sometimes is discarded; or
- Is a manufacturing or mining by-product and sometimes is discarded.

According to U.S. Resource Conservation and Recovery Act of 1976 (RCRA), any waste that is toxic and/or hazardous if they "cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed off or otherwise managed."

The RCRA regulations (40 CFR 261 and 262) specify that a solid waste is a hazardous waste if it is not excluded from regulation, and meets any of the following conditions:

• Exhibits any of the characteristics of a hazardous waste

• Has been named as a hazardous waste and listed as such in the regulations

• Is a mixture containing a listed hazardous waste and a nonhazardous solid waste

• Is a waste derived-from the treatment, storage, or disposal of a listed hazardous waste?

Any solid waste that exhibits one or more of these characteristics is classified as hazardous: Ignitability, Corrosivity, Reactivity and Toxicity.

9.2 Characterization of Hazardous waste

The characteristics of hazardous waste and the risks associated with it are given in table 1.

Characteristics	Relevant features	Associated risk
Ignitability	• A liquid, except aqueous solutions containing less than 24% alcohol that has a flashpoint less than 60°C (140°F) • A no liquid capable, under normal conditions, of spontaneous and sustained combustion • An ignitable compressed gas per DOT regulations • An oxidizer per DOT regulation	That which identifies wastes that pose a fire hazard during routine management. Fires not only pose immediate dangers of heat and smoke, but also can spread harmful particles over wide areas.
Corrosivity	• An aqueous material with pH less than or equal to 2, or greater than or equal to 12.5 • A liquid that corrodes steel at a rate greater than 0.25 inch per year at a temperature of 55°C (130°F)	That which identifies wastes requiring special containers because of their ability to corrode standard materials, or requiring segregation from other wastes because of their ability to dissolve toxic contaminants.
Reactivity (or explosiveness)	• Normally unstable and reacts violently without detonating • Reacts violently with water • Forms an explosive mixture with water • Generates toxic gases, vapors, or fumes when mixed with water • Contains cyanide or sulfide and generates toxic gases, vapors, or fumes at a pH of between 2 and 12.5 • Capable of detonation if heated under confinement or subjected to strong initiating source • Capable of detonation at standard temperature and pressure • Listed by DOT as Class A or B explosive	That which identifies wastes that, during routine management, tend to react spontaneously, to react vigorously with air or water, to be unstable to shock or heat, to generate toxic gases or to explode.
	As determined by the Toxicity Characteristics	That which identifies wastes that,

	Leaching Procedure (TCLP), that is designed to produce an extract simulating the leachate that may be produced in a land disposal situation. The extract is then analyzed to determine if it includes any of the toxic contaminants listed in Table 2. If the concentrations of any of the Table 2 constituents exceed the levels listed, the waste is classified as hazardous. Toxicity of a waste may also be declared by the generator based upon knowledge of the waste and/or the generating process.	when improperly managed, may release toxicants in sufficient quantities to pose a substantial hazard to human health or the environment.

The concentration at which a particular chemical is toxic is summarized in Table 2. Heptachlor is toxic at a minimum concentration of 0.008 mg/L. Cresol and other phenolic compounds show a toxic concentration at 200 mg/L.

Table 2 - Maximum Concentration of Contaminants for the Toxicity Characteristics

Contaminant	Regulatory level (mg/L)	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
Source: 40 CFR 261.24 (Blackman Jr)			

The effect of toxic chemicals in the environment can produce wide range of health effects, such as acute or chronic illness. It depends on the dosage, frequency, duration, concentration etc., which can be determined by carrying out a risk assessment. The purpose of risk assessment is to insure with a reasonable margin of safety, that human health effects do not result from exposures caused by production or waste management practices.

9.4 Source

The inclusive listing adopted by EPA includes separate lists of nonspecific source wastes, specific source wastes, and commercial chemical products. These lists are described briefly, as follows:

9.4.1 Nonspecific source wastes

It is called “F” wastes because their EPA waste identification codes begin with the letter F, are generic wastes, commonly produced by manufacturing and industrial processes. Examples from this list include spent halogenated solvents used in degreasing and wastewater treatment sludge from electroplating processes as well as dioxin wastes, most of which are “acutely hazardous” wastes due to the danger they present to human health and the environment. benzene, methylene chloride, trichloroethylene, carbon tetrachloride are few of the solvents listed in F list. Solvent blends with 10% or greater are included in F list.

9.4.2 Specific source wastes

It is called "K" code is from specially identified industries such as wood preserving, petroleum refining, and organic chemical manufacturing. These wastes typically include sludges, still bottoms, waste waters, spent catalysts, and residues, e.g., wastewater treatment sludge from pigment production.

9.4.3 Commercial chemical products

It is denoted by "P" and "U" codes and includes specific commercial chemical products or manufacturing chemical intermediates. Commercial pure grade chemicals or any formulations with either of chemicals as active ingredient are listed in P and U list. P list is differentiated from U list based on the quantity at which the chemical is regulated. Acute toxic wastes whose accumulation or waste generation exceeds 1 kg per month is categorized under unlike U list whose waste generation 25 kilograms per month. This list includes chemicals such as chloroform and creosote, acids such as sulfuric and hydrochloric, and pesticides such as DDT etc., EPA has also ruled that most mixtures of solid wastes and listed hazardous wastes are considered hazardous wastes and must be managed accordingly. This applies regardless of what percentage of the waste mixture is composed of listed hazardous wastes. Without such a regulation, generators could evade RCRA requirements simply by mixing or diluting the listed wastes with nonhazardous solid waste. Wastes derived from hazardous wastes, such as residues from the treatment, storage, and disposal of a listed hazardous waste are considered a hazardous waste as well.

9.5 Classification Hazardous waste

Hazardous waste is classified into six broad categories. Hazardous waste includes a lot more compounds or chemicals either as single or in combinations. The waste categories are detailed below.

- **Radioactive wastes:** Substances that emit ionizing radiation is called as radioactive substances and the waste generated from these substances are termed as radioactive wastes. Although they are categorized as a separate group still they are studied as hazardous waste due to the harmful effects they cause to living beings. They also persist in the environment for a long period of time. Half life determines their persistence in the environment.

- **Biomedical wastes:** Toxicity and infectivity are the two important characteristics of biomedical wastes. The toxic nature of biomedical waste places them under hazardous waste category. Biomedical waste is generated from hospitals, health centers and research facilities.
- **Chemicals:** Chemicals can be organic, synthetic, metals, acidic or basic or salts. They are hazardous when they cause toxicity. A waste stream containing these wastes at levels equal to or greater than threshold values, such streams should be considered hazardous.
- **Flammable wastes:** Once again dual grouping is done for this particular waste. Flammable substances can be a gas, liquid or solid. Organic sludges, plasticizers, solvents are some of the examples of flammable wastes. These wastes are hazardous and needs special management.
- **Explosives:** Similar to flammables, they also need special management method. They are produced from ordnance manufacturing and generated from industrial gases.
- **Household hazardous wastes:** In our everyday life we generate a lot of hazardous substances which is disposed of as commingled waste. They are disposed along with municipal solid waste. Some of the hazardous waste generated from households includes oil paints, nail polish, latex, paints, batteries, cleaning chemicals, e waste, pesticides, chlorinated and non chlorinated solvents and many more.

9.6 Collection and storage

The hazardous waste collection methods and containers mainly depend on the nature and characteristics of waste. Precautionary measures have to be taken while handling, storage and transport of hazardous waste. Moreover, the compatibility of waste needs to be assessed before storing them in same container. Collection and storage of hazardous waste also depends on the amount of generation. If waste is generated in less quantity, they can be stored and disposed of at regular intervals.

However, large quantity of hazardous waste generation necessitates every day transfer and disposal. The containers used to store or collect hazardous waste includes fiberglass or glass-lined containers for corrosive acids or caustic solutions. Lined containers are used to avoid the reaction of metals with the container. Other containers used include PVC lined containers, single walled drums used as pressure vessels, exotic metal drums made of aluminum, nickel, stainless steel and Laboratory packs used in universities and research laboratories. Single walled drums are filled with nitrogen and used for storing reactive, flammable and explosive wastes. According to EPA guidelines, the containers used for collection and storage of hazardous waste must be closed or sealed except when waste is to be removed or added. Care should be taken to avoid rupture in the containers which might further lead to spillage or leakage issues.

Two types of storage area are designated for hazardous waste: Central accumulation area and satellite accumulation area. Liquid wastes should be collected and stored in a manner to avoid inhalation; accidental spill and vapor build up. To prevent these containers must either be fitted with drum funnel screw lid or latching drum lids. Drum funnel screw is fitted with closed lid containers and Latch drum lids are for open lid containers. The lids should have a good gasket mechanism to keep the container sealed, leak proof and air tight. Containers filled with solid or semi-solid hazardous waste must be closed with lid with continuous gaskets and fusible plugs. These plugs will help in collecting the vapors escaping from the wastes. All the lids and seals should be checked periodically as the chemicals inside the containers will erode these seals resulting in release of vapours.

Table 3 Collection equipment for various hazardous wastes

S. No.	Waste Category	Collection equipment and accessories
1.	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.
2.	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, fiber glass or rubber.
3.	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.
4.	Flammable wastes	Same as those for toxic chemicals, with special colourings and safety warning printed on vehicles.
5.	Explosives	Same as those for toxic chemicals with some restriction on transport routes, especially through residential areas.
Source: Tchobanoglous, et al., (1977 and 1993); https://nptel.ac.in/courses/120108005/lecture9.pdf		

Labeling is very important in hazardous waste collection and storage. Details such as symbol of manufacturer, year of manufacturing, specification, capacity and single trip or multiple trip containers. Waste stored in large storage tanks are pumped into the collection vehicle and taken to treatment or disposal. However, sealed containers are transferred to collection vehicle and taken as such to treatment or disposal site. Flatbed trucks are used for short distances and drum storage collection containers. A larger tank truck, trailers and railroad tank is used for long distance travel.

9.7 Segregation

The hazardous waste materials are first segregated based upon their physical forms such

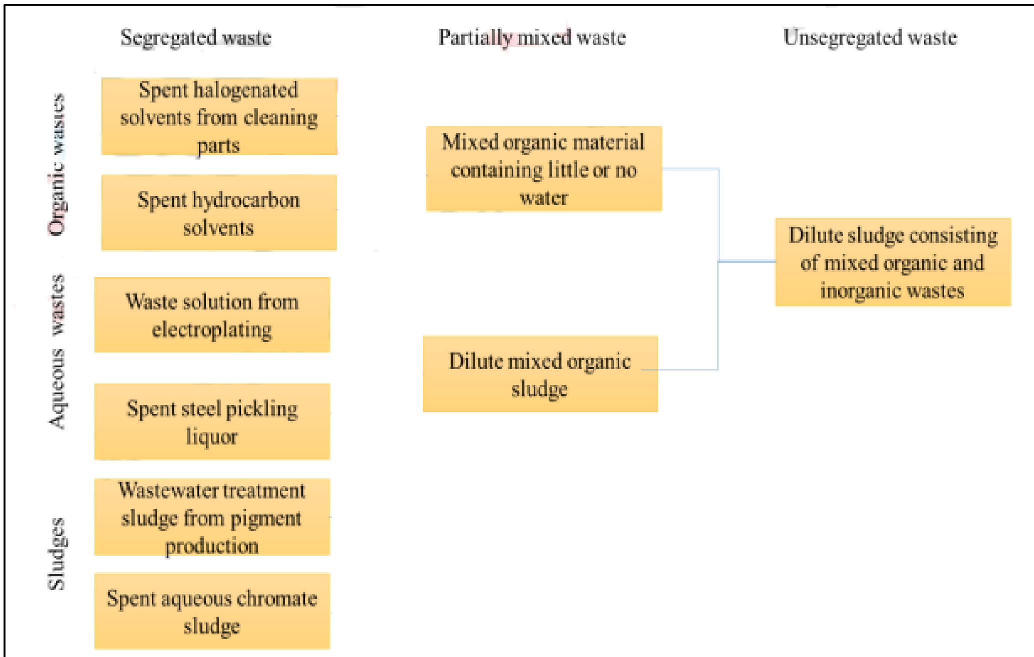


Figure 1 – Illustration of waste segregation (Source: Manahan 1993)

as organic materials, aqueous materials and sludges. These forms determine the course of action that would be taken in the treatment and disposal of these wastes. The level of segregation of hazardous wastes (Figure 1) that should be followed is very important in the treatment, storage and disposal of different kinds of wastes. It is relatively easy to deal with wastes that are highly segregated.

A waste that has been concentrated is generally much easier and more economical to handle than the one that is dispersed in a large quantity of water or soil. Dealing with hazardous wastes is facilitated when the original quantities of wastes are minimized and the wastes remain separated and concentrated. Once the waste is segregated, it is ideally subjected to treatment and disposal upon further processing. The transport of hazardous substance and waste into the environment is plausible based on the characteristics of the waste itself. The physical properties of hazardous wastes such as volatility and solubility contribute to a large extent to their transport in the environment. Highly volatile hazardous wastes are more likely to be transported through the atmosphere and the more soluble ones will be carried by water.

The compound volatility determines the distribution of hazardous waste constituent between atmosphere, geosphere or hydrosphere. Usually in the hydrosphere, and often in soil, hazardous waste constituents are dissolved in water; therefore, the tendency of water to hold the constituent is a factor of its mobility. For example, although ethyl alcohol has a higher evaporation rate and lower boiling temperature than toluene, the vapor of the latter is more readily evolved from the soil because of its limited solubility in water in comparison with ethanol. Chemical factors also contribute to the transport of wastes.

For example, the clay minerals in the soil tend to bind some elements more strongly (Cd, Hg, Pb, Zn); some elements moderately (K, Mg, Fe, Si) and some other elements (Na, Ca, Mn, B) very poorly. It should be noted that retention of iron and manganese is a strong function of their oxidation state in that the reduced forms of Fe and Mn are poorly retained, whereas the oxidized forms of $Fe_2O_3.xH_2O$ and MnO_2 are insoluble and stay on soil as solids.

9.8 Transfer station

Unlike municipal solid waste, hazardous waste management does not involve a transfer station. Since the collection vehicles carry the containers with hazardous waste directly to the treatment or disposal site, the requirement of transfer station stays nullified.

9.9 Treatment of Hazardous Waste

9.9.1 Hazardous waste reduction and minimization

Due to the high potential for public health and environmental damage, some hazardous wastes require special control procedures. Management of these wastes means awareness and control over them from the time of generation through their transportation, temporary storage, treatment and disposal. Effective identification and labeling of wastes by the generators is essential to the effective operation of any manifest-based system. In addition, management of hazardous waste means more than careful disposal. It implies consideration of alternate methods and schemes, both institutional and technical, to hazardous waste reduction. The following measures are commonly adopted as part of Hazardous waste reduction and minimization measures:

i) Elimination: The primary priority is to find ways to eliminate uses of hazardous substances altogether. Elimination might be achieved by changing manufacturing processes or by substituting products that can satisfy the same need without creating hazardous wastes (an example would be the substitution of concrete posts in place of, creosote-treated wooden posts).

ii) Reduction: The next priority is to reduce the amount generated. Again manufacturing processes can be modified to yield substantial waste reduction. For example, changes in the chemical reaction conditions can minimize production of by-product hazardous substances. In some instances, potentially hazardous catalysts, can be replaced by catalysts that are nonhazardous or that can be recycled rather than discarded.

iii) Recycling: The third strategy is to recycle hazardous substances such as solvents and acids to maximize their use before treatment and disposal becomes necessary. Many industrial processes that use solvents are equipped for solvent recycle for reasons of both economics and pollution control. A number of operations are used in solvent purification. Entrained solids are removed by settling, filtration, or centrifugation. Drying agents may be used to remove water. Fractional distillation is used to separate solvent from impurities, water and other solvents.

iv. Reduction in volume and toxicity: Finally, hazardous substances can be treated to reduce their volume and toxicity.

Eliminating, reducing, and recycling hazardous substances reduces treatment and disposal costs and often the generators can find it in their own economic best interest to actively seek out these source reduction opportunities as a way to reduce the overall cost of doing business.

9.9.2 Hazardous waste treatment technologies

The selection of a treatment process for a waste stream depends on among other factors the nature of the waste, desired characteristics of the output stream. Even with after vigorous hazardous waste reduction program, there will still be large quantities of hazardous wastes that will require treatment and disposal. The treatment technologies have been categorized as physical, chemical, biological, thermal, or stabilization/fixation. A summary of technologies is presented in Table below:

Treatment Technologies	**Types**
Physical treatment processes	gravity separation
	phase change systems such as air and steam stripping of volatiles from liquid wastes
	filtering operations
	carbon adsorption
Chemical treatment	pH neutralization
	oxidation or reduction
	precipitation
Biological treatment	microorganisms to degrade organic compounds in the waste stream
Thermal destruction	incineration

	pyrolysis
Stabilization techniques	removal of excess of water
	Solidification

Most treatment measures have both physical and chemical aspects. The appropriate treatment technology for the hazardous wastes depends on the nature of the wastes. The type of physical treatment to be applied to wastes depends strongly upon the physical properties of the material treated, including the state of matter, solubility in water and organic solvents, density, volatility, boiling point and melting point.

9.9.2.1 Physical treatment methods

a) Adsorption: Adsorption on activated carbon occurs when a molecule is brought up to its surface and held there by physical and /or chemical forces. This process is reversible, thus allowing activated carbon to be regenerated and reused by proper application of heat and steam, or solvent. The factors that relate to adsorption capacity are:

i) **Greater surface area** produces greater adsorption capacity (Eg: Activated carbon has large surface area (500-1500 m2 /g)]

ii) **Absorptivity** increases as the solubility of the solute (in solvent) decreases. Thus, for hydrocarbons, adsorption increases with molecular weight

iii) For solutes with ionizable groups, maximum adsorption will be achieved at a pH corresponding to minimum ionization.

iv) Adsorption capacity decreases with increasing temperature.

One additional point to be noted is that biological activity usually takes place in a carbon bed. If the concentration of the adsorbed species is high enough and the material is biodegradable and nontoxic to the bacteria, then biological activity may significantly increase the effective removal capacity. Removal through adsorption by activated carbon has been applied to non-aqueous waste stream such as petroleum fraction, syrups, vegetable oils, and pharmaceutical preparations. Color removal is the most common objective in such cases. Current waste treatment applications are limited to aqueous solutions.

b) Resin adsorption: Waste treatment by resin involves two basic steps: (1) contacting the liquid waste stream with resin and allowing the resin to absorb the solutes from the solution; and (2) subsequently regenerating the resins by removing the adsorbed chemicals, by simply washing with proper solvent. The adsorption of a no polar molecule on to a hydrophobic resin (e.g., styrene divinyl-benzene-based resin) results primarily from the effect of Vander Waal's forces. In other cases, other type of interactions such as dipole-dipole interaction and hydrogen bonding are important. In a few cases ion exchange mechanism may be involved. For the removal of organic dye wastes from water, two different resins were employed: In this case the waste stream is first contacted with a normal polymeric adsorbent and then with an ion exchange resin.

c) Sedimentation: Sedimentation is a physical process whereby particles suspended in a liquid settle by means of gravity. The fundamental elements of most sedimentation processes are:

i) a basin or container of sufficient size to maintain the liquid to be treated in a relatively quiescent state for a specified period of time

ii) a means of directing the liquid to be treated into the above basin in a manner conducive to settling.

iii) a means of physically removing the settled particles from the liquid.

Sedimentation can be either a batch or a continuous process. Continuous processes are by far the most common, particularly when large volumes of liquid are to be treated. This technique has been widely used in the removal of heavy metals from iron and steel industry wastewater; removal of fluoride from aluminium production wastewater; and removal of heavy metals from wastewater from copper smelting and from metal finishing industry and wastewater stream from organic chemicals.

d) Electro dialysis: The electro dialysis involves the separation of an aqueous stream (more concentrated in electrolyte than the original) and a depleted stream. Success of the process depends on special synthetic membranes, usually based on ion exchange resins, which are permeable only to a single type of ion. Cation exchange membranes permit passage only of positive ions, under the influence of electric field, while anion exchange membranes permit passage only of negatively charged ions.

The feed water is passed through compartments formed by the spaces between alternating cation permeable and anion permeable membranes held in a stack. At each end of the stack is an electrode having the same area as the membranes. A dc potential applied across the stack causes the positive and negative ions to migrate in opposite directions. This technique has been used for desalination to produce potable water from brackish well water. In food industry electro dialysis is used for desalting whey. The chemical industry uses this technique for enriching or depleting solutions, and for removing mineral constituents from product streams.

e) Reverse osmosis: This technique which is most widely used consists of a membrane permeable to solvent but impermeable to most dissolved species, both organic and inorganic. These devices use pressure to force the contaminated water against the semi permeable membrane. The membrane acts as a filter, allowing the water to be pushed through the pores, but restricting the passage of larger molecules that are to be removed.

Cellulose acetate membranes were used in the past, but nowadays polysulphones and polyamides are increasingly popular for use at high pH values. Because of the susceptibility of the membranes to chemical attack and fouling, and the susceptibility of the flow system to plugging and erosion, it is common to preprocess the feed water to remove oxidising materials. The reverse osmosis technique has been widely used for desalination of sea or brackish water. It has also been successfully used in the treatment of electroplating rinse waters, not only to meet effluent discharge standards, but also to recover concentrated metal salt solutions for reuse. It has also been used for treatment of waste stream from paper and food processing industries.

f) Solvent extraction: Solvent extraction is the separation of the constituents of a liquid solution by contact with another immiscible liquid. If the substances comprising the original solution distribute themselves differently between the two liquid phases, a certain degree of separation will result and this may be enhanced by the use of multiple contacts.

The major application of solvent extraction to waste treatment has been in the removal of phenol from by-product water produced in coal coking, petroleum refining, and chemical synthesis that involve phenol.

The use of supercritical fluids (SCFs) most commonly CO2 as extraction solvent, has been one of the more promising approaches to solvent extraction. SCFs are fluids existing at or above the lowest temperature at which condensation may occur. Above the critical temperature certain fluids exhibit characteristics that enhance their solvent properties. Organic materials, which are only slightly soluble in particular solvents at room temperature, become completely miscible with the solvent when under supercritical conditions. The excellent solvent properties result from the rapid mass transfer ability and the very low density that characterizes an SCF. Major advantages of SCFs are short residence times with no char formation. Some of the important application of these SCFs, has been in the extraction of organ halide pesticide from soil, extraction of oil from emulsions used in aluminium and steel processing, and regeneration of spent activated carbon. Supercritical ethane has been used to purify waste oils contaminated with PCBs, metals and water.

g) Distillation: Distillation is expensive and energy intensive and can probably be justified only in cases where valuable product recovery is feasible (e.g., solvent recovery). This technique has only limited application in the treatment of dilute aqueous hazardous wastes.

h) Evaporation: Evaporation process is used for the treatment of hazardous waste such as radioactive liquids and sludges and concentrating of plating and paint solvent waste among many other applications. It is capable of handling liquids, slurries and sometimes sludges, both organic and inorganic, containing suspended or dissolved solids or dissolved liquids, where one of the components is essentially nonvolatile. It can be used to reduce waste volume prior to land fill disposal or incineration.

The major disadvantages of evaporation are high capital and operating costs and high energy requirements. This process is more adaptable to waste waters with high concentrations of pollutants.

i) Filtration: Filtration is well-developed economical process used in the full scale treatment of many industrial waste waters and waste sludges. Energy requirements are relatively low, and operational parameters are well defined. However, it is not a primary treatment process and is often used in conjunction with precipitation, flocculation, and sedimentation to remove these solids.

j) Flocculation: The various phenomena that occur during flocculation can be grouped in to two sequential mechanisms.

i) Chemically induced destabilization of repulsive surface related forces, thus allowing particles to stick together when they touch and

ii) Chemical bridging and physical enmeshment between the non-repelling particles, allowing for the formation of large particles.

Chemicals used for flocculation include alum, lime, ferric chloride, ferrous sulphate and poly electrolytes. Poly electrolytes consist of long chain, water soluble polymers such as polyacrylamides. They are used either in conjunction with inorganic flocculants, or as primary flocculating agent. The inorganic flocculants such as alum, upon mixing with water, the slightly higher pH of water causes them to hydrolyze to form gelatinous precipitates of aluminium hydroxide. It is partially because of their large surface area, they are able to enmesh small particles, and thereby create larger particles. Once suspended particles have been flocculated into larger particles, they usually can be removed from the liquid by sedimentation, provided that a sufficient density difference exists between the suspended matter and the liquid.

9.9.2.2 Chemical treatment methods

a) Chemical Oxidation and reduction:

i) Oxidation reduction is one important route used for the treatment of hazardous wastes. It is a process by which the hazardous wastes are converted into a form that shows reduced or no toxicity, reduced or no mobility and remains inert. The process can be short or medium term technology and uses oxidizing agents for the treatment of hazardous waste. Few examples of oxidizing agents include ozone, hydrogen peroxides, chlorine, chlorine dioxide and others. Some examples of oxidation reduction treatment of hazardous wastes are given below. Chemical redox treatment applied for cyanide wastes released from metal finishing industry is given below.

Chlorine in alkali solution is used, which converts the CN to cyanate (less toxic form). More addition of chlorine oxidizes the cyanate to CO2 and N2.

$NaCN + Cl_2 + 2NaOH \rightarrow NaCNO + 2NaCl + H_2O$…………………………………. (1)

$2NaCNO + 3Cl_2 + 4NaOH \rightarrow 2CO_2 + N_2 + 6NaCl + 2H_2O$ ……..………………....... (2)

ii. Hexavalent chromium Cr(VI) is reduced to trivalent chromium Cr(III) by using Sulphur dioxide as reducing agent.

$3SO_2 + 3H_2O \rightarrow 3H_2SO_3$... (3)

$2CrO_3 + 3H_2SO_3 \rightarrow Cr_2(SO_4)_3 + 3H_2O$..(4)

iii. Iron (II) is oxidize and precipitated as ferric hydroxide

$4Fe^{2+} + O_2 + 10H_2O \rightarrow 4Fe(OH)_3 + 8H^+$.. (5)

iv. Sulphur dioxide is oxidized to sulphuric acid

$2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_4$.. (6)

b) Ozonolysis: Ozone is used to oxidize a wide variety of contaminants present in waste water and sludge. Ozone is generated by an electrical discharge through dry air or oxygen. Ozone is also used to destruct TCDD and PCBs. TCDD demonstrated that if the dioxins were suspended as an aerosol in combination with CCl4, degradation of 97% TCDD would be possible. Destruction of polychlorinated phenols and pesticides by ozone can be done in conjunction with UV radiation. In both the cases the key requirements were to concentrate the TCDD in a medium where they were susceptible to attack and provide a free radical for reaction with dioxin molecule.

$(CH_2O) + 2[O] \rightarrow CO_2 + H_2O$………………………………………………………… (7)

$CH_3CHO + [O] \rightarrow CH_3COOH$……………………………………………………... (8)

c) Acid-base neutralization: A waste showing a pH less than 2 or more than 12.5 are categorized as corrosive hazardous wastes. They can be neutralized by acid base reactions. Lime is used to neutralize acid wastes. Addition of slaked lime [Ca(OH)2] to acidic wastes in a continuously stirred chemical reactor results in neutralization of hazardous waste. Lime is commonly preferred due to its economic nature and optimum solubility. Due to limited solubility, excess lime does not increase the pH values. Similar to lime, sulphuric acid and acetic acid is used for neutralizing alkaline wastes. Though sulphuric acid is inexpensive, at certain times acetic acid is preferred as it is nontoxic and biodegradable. Certain alkaline wastes are also neutralized by bubbling gaseous CO2 forming carbonic acid. CO2 is easily available and can be collected from the exhaust gas of any combustion process. In addition to this, may other waste treatment processes require prior pH adjustment. The process includes oxidation/reduction, adsorption, wet air oxidation, ion-exchange, and stripping and biochemical treatment.

d) Chemical precipitation: Precipitation is applicable for mixed wastes that contain both organic and inorganic species. By this method the toxic substances or metals are precipitated using chemicals and removed from the solution by sedimentation or settling or filtration. Alteration of solution pH will minimize the solubilization of heavy metals which can further be precipitated as perceptible hazardous constituent. Slaked lime [Ca(OH)2] or caustic soda is used for precipitation of the metal ions as metal hydroxides. For example, the following reaction suggests the use of lime to precipitate the metal as hydroxide.

$M_2 + Ca(OH)_2 \leftrightarrow M(OH)_2 + Ca^{2++}$ …………………………………..…………….. (9)

Chromium is precipitated as hydroxide.

$Cr^{3+} + 3(OH^-) \rightarrow Cr(OH)_3$ ………………………………………………………………… (10)

Sodium carbonate is also used to precipitate metals as hydroxides. (Fe(OH)3. XH2O), carbonates ($CdCO_3$), basic carbonate salts ($2PbCO_3.Pb(OH)_2$). Carbonate ion hydrolyses in water to give hydroxide ion.

$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$ ………………………………………..……………. (11)

Metals can be precipitated as sulphides from solution. Precipitating the metals as sulphides will facilitate removal of low concentration of metals. Ferrous sulphide is popularly used. Sodium borohydride is another reducing agent that precipitates metal in elemental form.

$4Cu^{2+} + NaBH_4 + 2H_2O \rightarrow 4Cu + NaBO_2 + 8H^+$ ……………………….……………. (12)

e) Hydrolysis: Hydrolysis treatment can be given to those hazardous waste constituents which shows high reactivity with water. Examples of those substances are halides, carbide, hydride, alkoxide, and active metal.

$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$…………………………………………………………… (13)

$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$………………………………………………………… (14)

$NaAlH_4 + 4H_2O \rightarrow 4H_2 + NaOH + Al(OH)_3$………………………………………… (15)

$NaOC_2H_5 + H_2O \rightarrow NaOH + C_2H_5OH$…………………………………………………... (16)

$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$……………………………………………………………..(17)

f) Ion exchange: Ion exchange is best suited for wastes that have undergone pretreatment or minimum treatment with other chemical and physical methods. It is suitable for removing inorganic chemical species that are in the dissolved form unlike precipitation, flocculation or sedimentation. Basically it is used as a final polishing step to reduce an inorganic species that could not be reduced to satisfactory levels by preceding treatment processes. Nickel cyanide complex and chromate ions from hazardous waste solutions are removed by anion ion exchangers.

$2Res\ OH^- + [Ni(CN)_4]^{2-} \rightarrow (Res^+)_2 [Ni(CN)_4]^{2-} + 2OH^-$ ……………………..…. (18)

$2Res\ OH^- + CrO_4^{2-} \rightarrow (Res^+)_2 (CrO_4^{2-}) + 2OH^-$ ………………………………… (19)

Ion exchange resins have also been used in the removal of radionuclide's from radioactive wastes

9.9.2.3 Thermal treatment methods

Thermal destruction of hazardous waste is done by **incineration** and **pyrolysis**.

Incineration is a process that combusts the wastes at high-temperature (900-1100 ºC) in the **presence of oxygen**. This process converts waste to an inert, less toxic and less bulky material namely, the ash. Ash is an noncombustible inorganic residue. Incineration reduces the volume of waste by 90%. The organic elements such as carbon, hydrogen and oxygen are converted wholly or partially to gaseous form. The principal products of incineration are CO2, water vapor and ash.

$C(organic) + O_2 \rightarrow CO_2 + heat$……………………………………………………... (20)

$4H(organic) + O_2 \rightarrow 2H_2O + heat$……………………………………………….... (21)

The heat generated during the incineration process is used for destruction of organochlorine hazardous wastes. The heat cleaves the C-Cl bonds of organochlorine compounds. If the organochlorines are inflammable, then supplementary fuel such as methane or petroleum-liquid is used. Though incineration process comes with many advantages, still its application is limited due to the release of by-products of hazardous waste incineration such as sulphur, nitrogen, halogen and heavy metals (mercury, arsenic, selenium, lead and cadmium). This results in problems of air pollution. To overcome the air pollution problem, the incinerators need to be fitted with air pollution control equipment. Temperature, Availability of sufficient oxygen and ample residence time are the critical factors governing incineration process. Destruction removal efficiency (DRE) is used to assess the efficiency of hazardous-waste incinerators. DRE can be calculated as the percentage of mass difference of input (feed) and output (stack emission) waste constituents through the incinerator. DRE has to be calculated separately for different compound/ constituent. According to RCRA (Resource conservation and Recovery Act) requirement, a minimum DRE of 99.99 % for most of organic compounds and a DRE of 99.9999 % for dioxins and dibenzo furans should be achieved for efficient combustion.

Advantages and disadvantages of incineration	
Advantages	Disadvantages
• Reduces 90% volume of waste • Can be scaled to handle large volumes of liquid waste. • It is the best method for "mixed wastes" and biologically hazardous wastes. • Does not require large area of land. • Compact units	• Capital and operation cost is very high • The ash must be disposed of properly. • The gaseous and particulate products of combustion should be controlled by air pollution control devices.

b) Wet air oxidation: Wet air oxidation is the process by which the dissolved or suspended organic substances are oxidized in aqueous phase at high temperature and pressure of 150-3250C and 2000 kPa to 20,000 kPa, respectively. Water acts as a catalyzing agent and moderator by removing excess heat in the reaction mixture. Water also acts as an excellent heat transfer medium so that the wet air oxidation process becomes thermally self-sustaining at low organic feed conditions. In wet air oxidation, the waste is pumped into the system through a heat exchanger into the reactor with high-pressure pump and mixed with air from an air compressor. High pressure facilitates dissolving of oxygen in water. Within the reactor, the organic waste is reacted with atmospheric oxygen. Sometimes the oxidation is carried out in the presence of catalysts. Cyanide from electroplating waste solutions are removed by wet air oxidation process. The process can be used for the removal of.

$2Na^+ + 2CN^- + O_2 + 4H_2O \rightarrow 2Na^+ + 2HCO_3^- + 2NH_3$………………… (22)

c) Photolysis: In photolysis, light is used as an agent to cleave the chemical bonds of hazardous waste materials. Initially, the chemical species is excited by light. It is usually a diradical state because diradical possess sufficient energy to undergo chemical reaction. The success or effectiveness of the process depends on the chemical structure of the compound, efficiency of radiation source and medium in which the reaction is carried out. The end product also determines the efficiency of the process. Polychlorinated biphenyls (PCBs) and chlorinated dibenzo-p-dioxins (CDDs) are destroyed by photolysis. The three requirements of photolysis of tetrachloro dibenzo-p-dioxin (TCDD) are 1) Dissolution in a light transmitting film 2) presence of organic hydrogen odor and 3) ultraviolet light. Generally, during photolysis reactions, HO• is formed which plays an important role in chain reactions resulting in destruction of the compound.

9.9.2.4 Biological treatment of hazardous wastes

Biological processes are a simple, cost effective and eco-friendly process. However its application to hazardous waste is slightly limited due to toxic nature of the waste which is harmful to the biological agents. The biodegradability of the waste depends on the physical and chemical properties of the compound. Selection of appropriate organism and optimum conditions can favor degradation of chemical compounds that are considered harmful or biocidal. Eg. Phenol and phenolic compounds can be treated by proper acclimatization of microorganisms to the hazardous waste. Likewise, biorefractory compounds eg. DDT and PCBs are also degraded by bacteria. DDT is degraded by Pseudomonas and PCB by anaerobic bacteria. According to studies, optimum pH and oxygen levels can result in better degradation of waste. Both aerobic and anaerobic bacteria are used for hazardous waste biodegradation. The presence of inorganic substances limit the biodegradation of waste as they inhibit enzymatic activity and further get adsorbed on to the microbial cell coating. Landfill leachate is treated with microorganisms. During the process H2S is generated which precipitates toxic heavy metal ions as their respective sulphides. The overall degradation of the hypothetical organic compound (CH2O) can be written as follows.

$$2(CH_2O) \rightarrow CO_2 + H_2O \ldots\ldots (23)$$

9.9.2.5 Land treatment

The application of waste to soil surface in a controlled manner is termed as land treatment of hazardous wastes. This process facilitates containment of waste followed by biological and chemical degradation of organic waste. This type of treatment is different from land filling. Here, the soil is used to detoxify, immobilize, and degrade all or a portion of the applied waste. Landfills contain the waste and control its migration from the site. Hazardous wastes should not be placed in a land treatment site unless the waste can be made less hazardous or nonhazardous by the reactions occurring in the soil. The waste is added or mixed to the aerobic soil horizon in a controlled manner at appropriate conditions. By this process, the physical, chemical and biological characteristics of the waste are altered. Bacteria, fungi and actinomycetes plays a major role in land treatment. Genus Agrobacterium, Anthrobacteri, Bacillus, Flavobacterium, Pseudomonas are some of the bacteria involved in degradation. Wastes from petroleum refining, biodegradable organic chemical wastes including organo-chlorine compounds are suitable for land treatment. Land treatment should not be applied to waste containing acids, bases, toxic inorganic compounds, salts, heavy metals and excessively soluble volatile and flammable organic compounds.

9.10. Land disposal of Hazardous Waste

After treatment, the hazardous wastes are converted into suitable form for disposal. Immobilization, stabilization, fixation, and solidification are some of the popularly used techniques for preparation of waste for disposal. Land disposal techniques include Landfills, surface impoundments and underground injection wells.

9.10.1 Landfills

In order to protect public health and environment the design of hazardous waste landfills should be adequate. Figure 2 shows the typical cross section of a hazardous waste landfill. The liner system, waste emplacement and cover system are the three components of landfills. Liners should be impermeable and avoid the contact between waste and the surrounding environment. Leachate collection system, drains and leak detectors too form an integral part of the landfill system. They ensure that leachate does not leave the disposal site. Hazardous wastes are contained in secured landfills provided with double liner system.

The liner system consists of natural (clay), synthetic material (polymers), and a leachate collection. The primary barrier is a synthetic polymeric flexible membrane with a separation layer of thin geotextile or polymeric material (HDPE, LDPE, PVC etc). Secondary barrier is composed of clay, bentonite enhanced soil or geosynthetic clay. A leachate collection tubes are layered between the waste and the protection layer. It channelizes the leachate to a pumping station where they are removed and taken up for further treatment. An intermediate high permeability drainage layer is incorporated between primary and secondary barrier. This layer is for the collection of leachate and gas. Every barrier is separated by geotextile fabric. The landfill is sloped to avoid infiltration of water and run off associated with it. The leachate that is collected is treated by (1) passing it through a column containing sorbent material such as carbon or flyash. (2) Subjected to suitable physical-chemical units such as chemical addition, flocculation, sedimentation, pressure filtration, pH adjustment, and reverse osmosis to remove the dissolved waste. The secondary leachate collection system acts as backup system which will be useful during failure of primary leachate system. Continuous monitoring of ground water from the wells will help us to determine the failure of primary and secondary liner system.

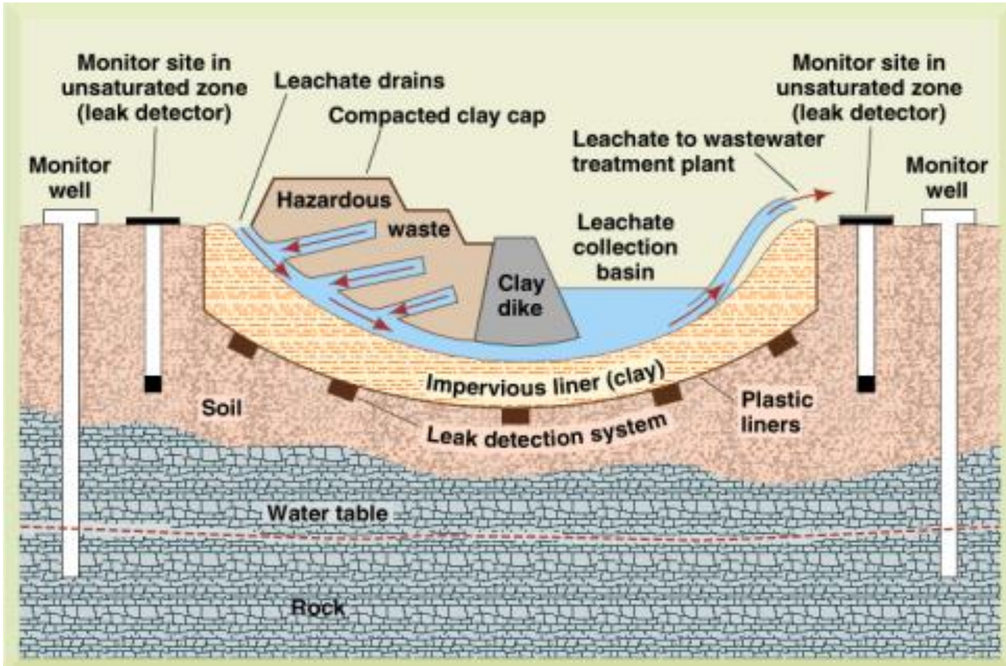


Figure 2 – Schematic of hazardous waste landfill

Waste is loaded inside the landfill after preliminary treatment (i.e) solidification, stabilization etc. The cover or capping is also essential component of the waste landfill. The purpose of the landfill cover is to protect the waste, prevent the entry of rain and surface water into the waste, control the release of landfill gas, to prevent ingress of air and enable the growth of short rooted plant when covered with top soil. Landfills are allowed with sufficient vent points so that if methane is generated, it may be burned off continuously.

9.10.2 Surface impoundments

A surface impoundment is a man-made excavation, diked area, or natural topographic depression designed to hold an accumulation of liquid wastes. The construction is similar to landfill where the bottom walls function like a liner which is impermeable to liquids. The surface impoundments are also provided with provision for leachate collection. Geological siting and selection of low permeable material like soil and clay are very important as they will arrest or minimize the chances of pollution.

9.10.3 Underground injection

Underground injection or deep-well disposal is a method by which the hazardous waste materials are injected into underground strata under pressure. The underground strata must be impermeable and separated from the aquifers. During this process, the chance of chemical reactions with waste constituent and mineral is possible. This will result in corrosion, clogging problems. The main concern with underground injection is the potential for contaminating underground drinking water supplies, if the disposal well is not properly cased or if it is damaged.

Summary

This unit explains:

- Defined hazardous waste
- Understood the characteristics of hazardous waste
- Identified the sources of generation: Specific, non-specific and commercial chemical products
- Classified hazardous waste
- Familiarized the collection methods, storage and collection containers
- Understood the importance of segregation of hazardous waste.
- Reduction and minimization measures for hazardous waste
- Physical methods of hazardous waste treatment namely adsorption, resin adsorption, sedimentation, electrodialysis and others
- Chemical treatment of hazardous waste through chemical oxidation, reduction, precipitation, ion exchange, hydrolysis, ozonation etc.
- Thermal destruction of hazardous waste via incineration and pyrolysis.
- Biological treatment and various disposal options available for hazardous waste.

Unit 10: Waste Water Treatment

Unit Structure

10.0 Learning Objectives

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

- Explain concept of waste water treatment
- Discuss various treatment technologies for waste water

10.1 Introduction

The development of human societies is heavily dependent upon availability of water with suitable quality and in adequate quantities, for a variety of uses ranging from domestic to industrial supplies. An estimate infers that every year, the wastewater discharges from domestic, industrial and agricultural practices pollute more than two-thirds of total available run-off through rainfall, thereby, what can be called a "man-made water shortages." (Vigneswaran and Sundaravadivel, 2004) Thus, in spite of seeming abundance, water scarcity is endemic in most parts of the world. It is because of these concerns, the Agenda 21 adopted by the United Nations Conference on Environment and Development, popularly known as the "Earth Summit" of Rio de Janeiro, 1992, identified protection and management of freshwater resources from contamination as one of the priority issue, that has to be urgently dealt with to achieve global environmentally sustainable development.

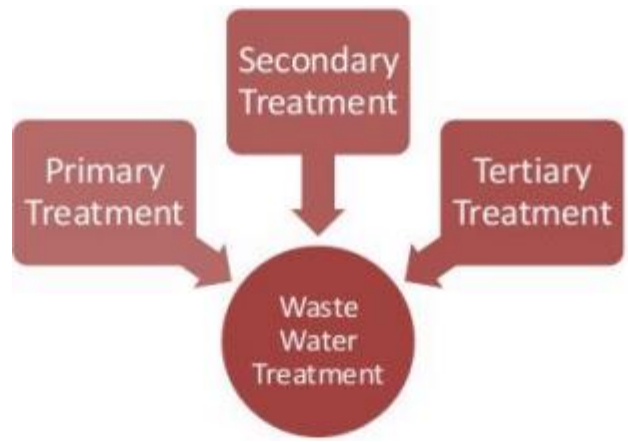


Figure: 1 Different phases of waste water treatment

The term "Wastewater" properly means any water that is no longer wanted, as no further benefits can be derived out of it. About 99 percent of wastewater is water, and only one percent is solid wastes. The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Water treatment is a process of making water suitable for its application or converting used water into environmentally acceptable water or even drinking water or to its natural state. Thus, water treatment is required before and after depending on the application. The treatment may include mechanical, physical, biological, and chemical methods and is an integrated system comprising of the conventional series of primary and secondary treatment processes, but also includes tertiary treatment (Figure 1) and individual treatment of certain streams. All water treatments involve the removal of solids, bacteria, algae, plants, inorganic compounds, and organic compounds. The primary and secondary treatment processes handle most of the nontoxic wastewaters while the water having toxic wastes needs to be pre-treated before adding to this flow.

The schematic diagram in Figure 2 and 3 illustrates the outline of waste water treatment system treating the sewage and industrial effluents.

A typical waste water treatment plant is the conventional series of primary and secondary treatment processes, but may also include tertiary treatment. The primary and secondary treatment processes handle most of the nontoxic waste waters; while some pre-treatment of the waste water before being added to this flow is necessary to prevent the damage to the downstream equipment.

Table1: Major classes of municipal wastewater contaminants, their significance & origin

Contaminant	Significance	Origin
Settleable solids (sand, grit)	Settleable solids may create sludge deposits and anaerobic conditions in sewers, treatment facilities or open water	Domestic, runoff
Organic matter (BOD); Kjeldahl nitrogen	Biological degradation consumes oxygen and may disturb the oxygen balance of surface water; if the oxygen in the water is exhausted anaerobic conditions, odour formation, fish kills and ecological imbalance will occur	Domestic, industrial
Pathogenic microorganisms	Severe public health risks through transmission of communicable water borne diseases such as cholera	Domestic
Nutrients (N and P)	High levels of nitrogen and phosphorus in surface water will create excessive algal growth (eutrophication). Dying algae contribute to organic matter	Domestic, rural run off, industrial
Micro-pollutants (heavy metals, organic compounds)	Non-biodegradable compounds may be toxic, carcinogenic or mutagenic at very low concentrations (to plants, animals, humans). Some may bio accumulate in food chains, e.g. chromium (VI), cadmium, lead, most pesticides and herbicides, and PCBs	industrial, rural runoff (pesticides)
Total dissolved solids (salts)	High levels may restrict wastewater use for agricultural irrigation or aquaculture	Industrial, (salt water intrusion)

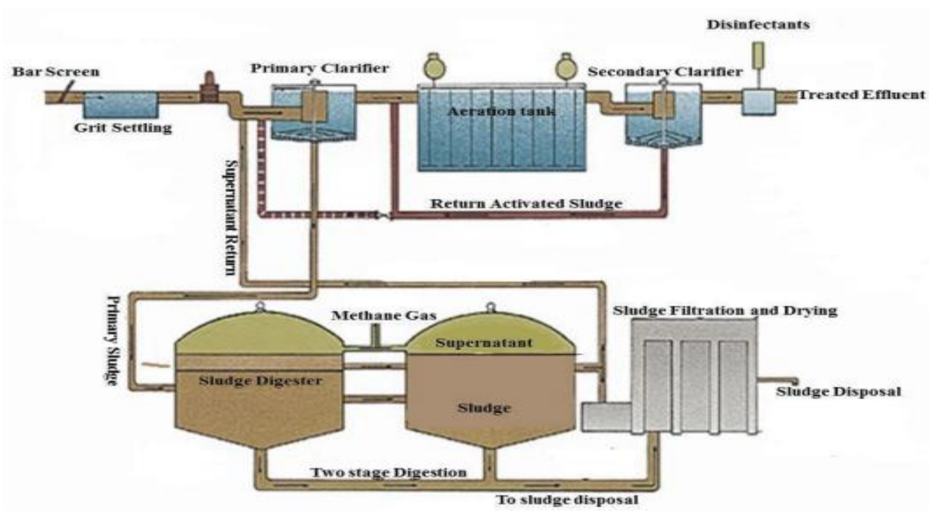


Figure 2: Outline of Sewage Treatment Plant
(Image: http://www.dec.ny.gov/chemical/97463.html)

10.2 Preliminary treatment

In many waste water treatment plants the preliminary treatment is the part of the primary treatment, which includes only the mechanical processes. The pretreatment of the influent involves one or all the following steps depending upon the kind of the waste water to be treated.

10.2.1 Screening

It is the first unit operation used at wastewater treatment plants. Screening removes large solid chunks and objects such as rags, paper, plastics, and metals to prevent damage and clogging of downstream equipment, piping, and appurtenances. Some modern wastewater treatment plants use both coarse screen and fine screen filters as a part of the pretreatment process. Coarse screens remove large solids, rags, and debris from wastewater, and the types of coarse screens include mechanically and manually cleaned bar screens, including trash racks. Fine Screens are typically used to remove material that may create operation and maintenance problems in downstream processes, particularly in systems that lack primary treatment. Typical opening sizes for fine screens are 1.5 to 6 mm (0.06 to 0.25 inches). Very fine screens with openings of 0.2 to 1.5 mm (0.01 to 0.06 inches) placed after coarse or fine screens that can further reduce suspended solids to levels near those achieved by primary clarification.

Table 2: Types of Screens used in Preliminary treatment of Waste water

Screen Type	Description
Trash Rack	Designed to prevent large debris from entering treatment processes. Opening size: 38 to 150 mm.
Manually Cleaned Bar Screen	Designed to remove large solids, rags, and debris. Opening size: 30 to 50 mm. Bars set at 30 to 45 degrees from vertical to facilitate cleaning. Primarily used in older or smaller treatment facilities, or in bypass channels.
Mechanically Cleaned Bar Screen	Designed to remove large solids, rags, and debris. Opening size: 6 to 38 mm. Bars set at 0 to 30 degrees from vertical. Always used in new installations because of large number of advantages relative to other screens.

Source: Design of Municipal Wastewater Treatment Plants, WEF MOP 8, Fourth Edition, 1998

10.2.2 Comminutors and Grinders

The processing of coarse solids using comminutors and grinders reduces their size of coarser particles so that they can be removed during downstream treatment operations, such as primary clarification, where both floating and settle able solids are removed.

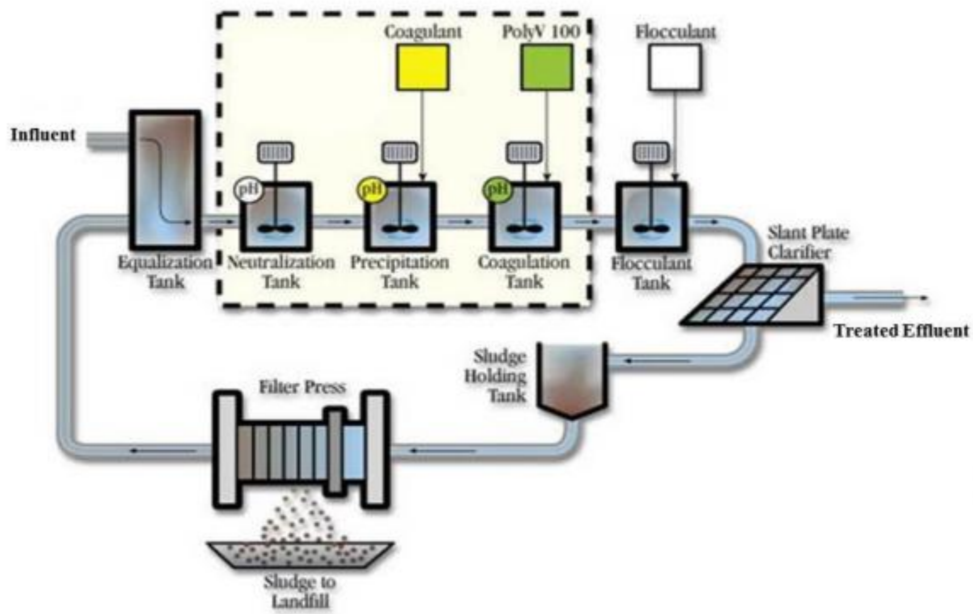


Figure 3: Outline of Industrial wastewater Treatment Plant (Image: http://www.water-technology.net/projects/metal_beckart/)

Comminuting and grinding devices are installed in the wastewater flow channel to grind and shred material in the size range of 20 mm (0.75 inches). Comminutors consist of a rotating slotted cylinder through which wastewater flow passes. Solids that are too large to pass through the slots are cut by blades as the cylinder rotates, reducing their size until they pass through the slot openings. Grinders consist of two sets of counter rotating, intermeshing cutters that trap and shear wastewater solids into a consistent typically 6 mm particle size.

10.2.3 Grit Removal

Grit includes sand, gravel or other heavy solid materials that are "heavier" (higher specific gravity) than the organic biodegradable solids in the wastewater. The removal of grit prevents unnecessary abrasion and wear of mechanical equipment, grit deposition in pipelines and channels, as well as the accumulation of grit in anaerobic digesters and aeration basins. Grit removal facilities typically precede primary clarification and follow screening and comminution. Many types of grit removal systems exist, including aerated grit chambers, vortex-type (paddle or jet induced vortex) grit removal systems, detritus tanks (short term sedimentation basins), horizontal flow grit chambers (velocity-controlled channel), and hydrocyclones (cyclonic inertial separation). The collected grit must be removed from the chamber, dewatered, washed, and conveyed to a disposal site. Some smaller plants use manual methods to remove grit, but grit removal is usually accomplished by an automatic method. The four methods of automatic grit removal include inclined screw or tubular conveyors, chain and bucket elevators, clamshell buckets, and pumping.

10.2.4 Flow Equalization

The influent before the actual treatment is subjected to flow equalization in a mixing tank to level out the hour-to-hour variations in flows and concentrations. There are spill pond to retain slugs of concentrated wastes that could interfere with the downstream processes.

10.2.5 Fat and grease removal: In some larger waste water treatment plants, fat and grease are removed by passing the wastewater through a small tank where mechanical skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help the recovery of the fat as froth. Many plants, however, use primary clarifiers with surface skimmers for fat and grease removal.

10.3 Primary Treatment

The equalization tank is followed by neutralization tank where required as streams of different pH partly neutralize each other when mixed. The oils, greases, and suspended solids are removed by floatation, sedimentation, filtration or some-times special equipment is also used to remove grit that gets washed into the waste water. The primary treatment prepares the wastewater for the next secondary (biological) treatment. This involves the separation of suspended organic matter (or human waste) from the wastewater. This is done by putting the wastewater into large settlement tanks for the solids to sink or settle down to the bottom of the tank. The settled solids are called ‘sludge’. At the bottom of these circular tanks, large scrappers continuously scrape the floor of the tank and push the sludge towards the pump away for further treatment. The rest of the water is then moved to the secondary treatment.

10.4 Secondary Treatment

The secondary treatment is the biological degradation of soluble organic compounds that escapes primary treatment. This process is usually done aerobically in an open, aerated vessel or lagoon where the microorganisms degrade this organic matter, which serve as “food” for them. Microorganisms combine this matter with oxygen from the water to yield the energy they need to thrive and multiply. Unfortunately, this oxygen is also needed by fish and other organisms in the river. So, the heavy organic pollution in the river or water bodies can lead to “dead zones” where no fish can be found and sudden releases of heavy organic loads can lead to dramatic “fish kills”. The water, at this stage, is put into large rectangular tanks. These are called aeration lanes. Air is pumped into the water to encourage bacteria to break down the organic contaminants of sludge that escaped the sludge scrapping process. The biological process is then followed by additional settling tanks (secondary sedimentation) to remove more of the suspended solids and microorganisms called as activated sludge. A fraction of this sludge is recycled in certain processes, but ultimately the excess sludge along with the sediment solids has to be disposed-off. Next, the ‘almost’ treated wastewater is passed through a settlement tank, where, more sludge is formed at the bottom of the tank from the settling of the bacterial action. Again, the sludge is scraped and collected for treatment. The water at this stage is almost free from harmful substances and chemicals. The water is allowed to flow over a wall where it is filtered through a bed of sand to remove any additional particles. The filtered water is then discharged into the water bodies. About 85% of the suspended solids and BOD can be removed by a well running plant with secondary treatment. Secondary treatment technologies include the basic activated sludge process, the variants of pond and constructed wetland systems, trickling filters, rotating biological contactors and other forms of treatment which use biological activity to break down organic matter. The existing treatment systems can also be modified so as to broaden the capabilities and performance. One example is the addition of powdered activated carbon (PAC) to the biological treatment process, to adsorb organics that the microorganisms cannot degrade. Another example is to add coagulants at the end of the biological treatment to remove phosphorus and residual suspended solids and nutrients like N and P.

10.5 Disinfection

The disinfection typically with chlorine can be the final step before discharge of the effluent. However, some environmental authorities are concerned that chlorine residuals in the effluent can be a problem in their own right, and have moved away from this process. Disinfection is frequently built into treatment plant design, but not effectively practiced, because of the high cost of chlorine, or the reduced effectiveness of ultraviolet radiation where the water is not sufficiently clear or free of particles.

10.6 Tertiary treatment

Many existing wastewater-treatment systems were built for primary and secondary treatment only, but now tertiary treatment processes are added on beyond secondary treatment in order to remove specific type of residuals. The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality to the desired level by removing more than 99 per cent of all the impurities from wastewater, producing an effluent of almost drinking-water quality. This advanced treatment can be accomplished by a variety of methods such as coagulation sedimentation, filtration, reverse osmosis, and extending secondary biological treatment to further stabilize oxygen-demanding substances or remove nutrients. In various combinations, these processes can achieve any degree of pollution control desired. As wastewater is purified to higher and higher degrees by such advanced treatment processes, the treated effluent can then be reused for urban, landscape, and agricultural irrigation, industrial cooling and processing, recreational uses and water recharge, and even indirect and direct augmentation of drinking water supplies. The related technology can be very expensive, requiring a high level of technical know-how and well trained treatment plant operators, a steady energy supply, and chemicals and specific equipment which may not be readily available.

10.6.1 Coagulation- Sedimentation

Chemical coagulation sedimentation is used to increase the removal of solids from effluent after primary and secondary treatment. The solids heavier than water settle out of wastewater by gravity in the primary and secondary sedimentation tanks but the lighter particles are made to settle down with the addition of specific chemicals, like alum Al2(SO4)3, lime (CaO), or ferric salts of iron (Fe3+). With the addition of these chemicals, the smaller particles clump or 'floc' together into large masses. The larger masses of particles will settle out in the sedimentation tank reducing their concentration in the final effluent.

10.6.2 Filtration

A variety of filtration methods are available to ensure high quality water. Sand filtration, which consists of simply directing the flow of water through a sand bed, is used to remove residual suspended matter. Filtration over activated carbon results in the removal of: non-biodegradable organic compounds, absorbable organic halogens, toxins, color compounds and dyestuffs, aromatic compounds. Although there are a number of different methods of filtration are practised, but in tertiary treatment the most mature is pressure driven membrane filtration. This relies on a liquid being forced through a filter membrane with a high surface area and small pore size (0.02- 0.2μm) to remove bacteria, viruses, pathogens, metals, and suspended solids.

10.6.3 Reverse osmosis

In the reverse osmosis process, pressure is used to force effluent through a membrane that retains contaminants on one side and allows the clean water to pass to the other side. Reverse osmosis is actually a type of membrane filtration called microfiltration because it is capable of removing much smaller particles including dissolved solids such as salt.

10.6.4 Nutrient Removal

The nutrients in the form of Nitrogen and Phosphorus present in te treated water are also needed to be removed to prevent “Eutrophication” of the water bodies where the water is discharged.

Nitrogen control: Nitrogen present in the waste water as ammonia can be toxic to aquatic life in certain instances and can be removed by additional biological treatment beyond the secondary stage. The nitrifying bacteria are employed for removal of ammonia present in wastewater. These bacteria can biologically convert ammonia to the non-toxic nitrate through a process known as **nitrification**. The nitrification process is normally sufficient to remove the toxicity associated with ammonia in the effluent but the product formed nitrate is a nutrient and inexcess amounts can contribute to eutrophication in the receiving waters.

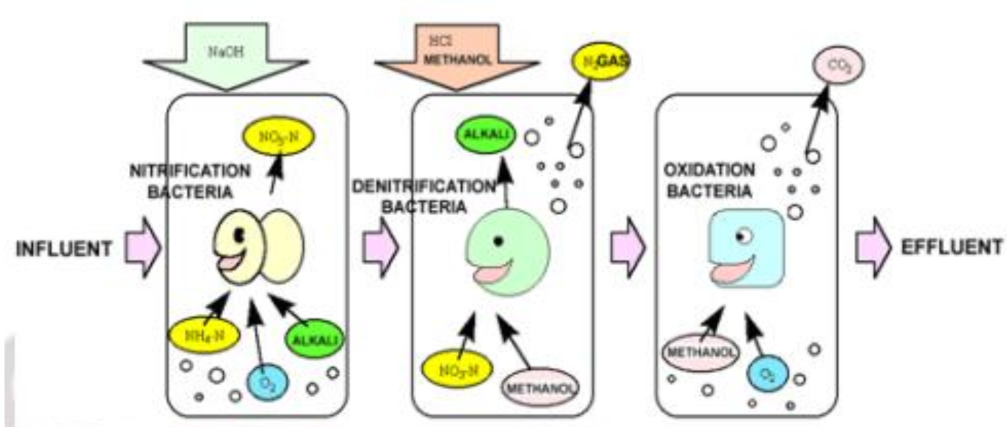
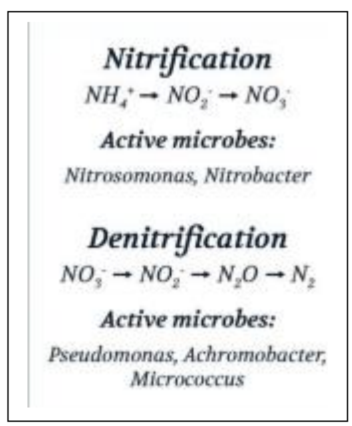


Figure 4: The process of nitrification and denitrification in nutrient removal process (http://nett21.gec.jp/WATER/data/img/wtfig_32-2-2.gif)

In such situations where nitrogen must be completely removed from effluent, an additional biological process can be added to the system to convert the nitrate to nitrogen gas. The conversion of nitrate to nitrogen gas is accomplished by denitrifying bacteria in a process known as denitrification. Effluent with nitrogen in the form of nitrate is placed into a tank devoid of oxygen, where carbon-containing chemicals, such as methanol, are added. In this oxygen-free environment, bacteria use the oxygen attached to the nitrogen in the nitrate form releasing nitrogen gas. Because nitrogen comprises almost 80% of the air in the earth's atmosphere, the release of nitrogen into the atmosphere does not cause any environmental harm.



Phosphorus control: Like nitrogen, phosphorus is a necessary nutrient for the growth of algae. Phosphorus reduction is often needed to prevent eutrophication before discharging effluent into lakes, reservoirs, and estuaries. Phosphorus can be removed either through chemical or biological processes. In biological process, specific bacteria, called polyphosphate accumulating organisms (PAOs), are selectively enriched in sludge. They can accumulate large quantities of phosphorus within their cells (up to 20% of their mass) and these biosolids after their separation from the treated water have a high fertilizer value. Phosphorus removal can also be achieved by chemical precipitation, usually with salts or iron, alum, or lime. This may lead to excessive sludge productions as hydroxides precipitates and the added chemicals can be expensive. Despite this, chemical phosphorus removal requires a significantly smaller equipment footprint than biological removal, is easier to operate, and is often more reliable than biological phosphorus removal.The existing treatment systems can also be modified so as to improve the performance and broaden the possibilities of waste water treatment

References

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Unit 11 Ecological Sanitation (ECOSAN)

Unit Structure

11.0 Learning Objectives

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

- Explain the concept of ecological sanitation
- Discuss nutrients in human excreta and their recycling
- Discuss sanitization and treatment of human excreta
- Explain grey water, its characteristics and management

11.1 Ecological Sanitation[1]

Ecological sanitation (ECOSAN) works on the principle that human excreta is not a waste product but contains many of the nutrients required for growth and development of plants and organisms, therefore, it should be used to fertilize land. Therefore one of the main goals of ecological sanitation is to capture the nutrients present in human excreta and recycle them back to agriculture. Thus, a key part of an eco-san system is the destruction of most or all disease-producing organisms before re-use of excreta products. Results from scientific studies of pathogen destruction in ecosan systems are now providing us with guidelines for the treatment of urine and faeces before re-use as fertilizer.

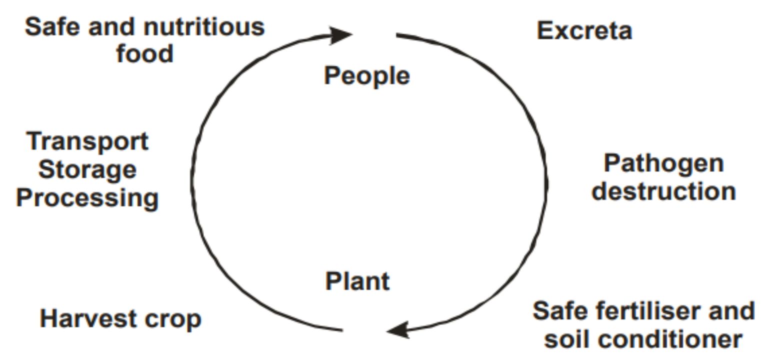

Figure 1: Showing the pri Ecological sanitation is to return the valuable nutrients from urine and faeces back to the environment and avoid the pollution often caused by conventional sewerage whilst contributing to the food production. [Adapted from: Esrey and Andersson, 2001]

The ecological sanitation cycle begins with containment, where excreta are held in the sanitation installation. The waste is then sanitized through one or several processes which cause pathogen die off, the resultant safe soil conditioner (from faeces) and fertilizer (from urine) is then recycled and used to assist crop production. Figure 1 shows these processes alongside the harvesting, production and consumption of food that keeps the nutrients within the ecological cycle.

11.2 Recycling the Nutrients

Ecological sanitation regards human excreta as a resource to be recycled rather than as waste for disposal. The use of human excreta for crop fertilization has been widely practiced in many regions of the world. The Chinese have been composting human and animal excreta for a few thousand years, and Japan introduced the practice of recycling human faeces and urine for agriculture in the twelfth century and continued until the 1950s. In Europe, until modern times, it was common for farmers to recycle human excreta with animal manure.

The very idea that excreta are waste with no useful purpose is a modern misconception.4 It is at the root of the pollution problems that result from conventional approaches to sanitation, particularly flush-and-discharge. In nature there is no waste: all the excreta of living things are used as raw materials by others. Recycling sanitized or well composted human urine and faeces by returning them to the soil serves to restore the natural cycling of life-building substances that has been disrupted by our current sanitation practices.

11.2.1 Why to recycle nutrients?

a) **Food security and poverty alleviation:** In parts of the world, particularly in sub-Saharan Africa, rural people suffer from periodic famines due to drought, small plot size, soil erosion, poverty (inability to purchase sufficient food) and political factors. In urban areas around the world, poor people also suffer from under nutrition due to poverty, although urban agriculture is a growing phenomenon. However, growing food for the immediate family within confined spaces is a challenge. The products from eco-toilets with their nutrients can be used in rural and urban areas to increase food security for all households, particularly the poor. To ensure that the increased food security results in improved health, it is important that users follow the guidelines given in this chapter. The products from eco-toilets can be used directly at the homestead level, in backyard gardens. As this chapter shows, about 1.5 liters of undiluted urine can be used to fertilize 1 square meter of soil. 1.5 liters is the amount produced by one adult in one day. Even without an eco-toilet, people could collect their own urine and use it on backyard gardens to increase yields. However, the fertilizing effect of urine works best in soil with high organic matter content and this can be increased by adding the humus from eco-toilets and garden composts.

In urban areas, the sanitized humus from eco-toilets can be used as a rich and nutritious soil for planting in pots, and the urine can be used to fertilize the soil before planting and for continued fertilization of plants during growth. This chapter shows that vegetable and fruit crops grown using urine fertilization produce 2–10 times the amount of crop by weight as those grown in unfertilized, poor soil. If people use urine to grow vegetables and fruits, the increased production results in greater food security at virtually no cost. Soil enriched with humus from eco-toilets holds water longer than soils not enriched with compost. Research has shown that plants grown in soils enriched with large amounts of humus require less watering and survive droughts better than plants grown in ordinary soils without this humus.6 In times of drought, when whole fields of grain may die, backyard crops grown on humus may well survive and produce enough vegetables to help a family through a difficult period. If, over time, families can collect enough humus from their eco-toilet, they may be able to enrich larger and larger areas, leading to increasing food security.

b) **Cost savings to farmers:** The formulation of nutrients in urine is similar but not exactly the same as that in commercial fertilizers. But urine and commercial fertilizers give similar result in boosting plant growth. Urine is high in nitrogen and lower in phosphorous and potassium. Some top-up of phosphorous and potassium is often needed to get the best possible use of nitrogen. As faeces and ash are high in phosphorous and potassium, farmers can replace commercial fertilizers with urine and top up with sanitized faces from eco-toilets at little or no extra cost. A study in China calculated the cost savings of using urine and dried faecal humus from eco-toilets as a fertilizer in a 3000 square metre greenhouse owned by one farmer in Jilin province of northern China. The farmer not only used the dried faeces and urine from his own household but also purchased additional dried faeces from other homes with eco-toilets and was given their urine free of charge.

He did not calculate the cost of transport of dried faeces (which was transported by tractor) or the cost of transporting urine, which was carried in buckets on shoulder poles. He used to buy 350–400 kg commercial fertilizer per year, but now this has been replaced by the free urine. The farmer calculated his cost savings per year to be the equivalent of CNY 740 (USD 90) per 1000 square metres.

Such calculations could become even more important at the community level, especially where farmers are struggling to make a living. A city of 100,000 people would produce about 500,000 kg of elemental nitrogen, phosphorous and potassium (NPK) per year in excreta. While the cost of commercial fertilizer varies between countries, as does its content of elemental NPK, it is possible to make a rough cost comparison of buying commercial products or collecting and transporting locally produced urine and faeces.

c) **Preventing nitrogen pollution:** Pit toilets as well as sewers are frequently a source of groundwater pollution, especially in areas where the water-table is high. Urine is rich in nitrogen and up to 50% of the nitrogen leaches out of the pit toilet, passes through the soil and reaches groundwater.9 Water with NO3 concentration higher than 50 mg/liter is considered to be unfit for human consumption. It is not unusual to find such high concentrations of nitrogen in wells in communities with pit toilets. Recommendations that toilets be sited at least 30 meters from wells are meant to protect well water from pollution, but plenty of experience shows that soil conditions vary considerably and both pathogen and nitrogen pollution can still result.

d) **Restoring lost top soils:** According to FAO, the Earth is losing 25 billion tonnes of topsoil per year because of erosion.11 Chemical fertilizers, while boosting plant growth, cannot replace topsoil. Topsoil contains humus formed from decayed plant and animal matter and is rich in carbon compounds and micro-organisms necessary for healthy plant growth, which are not found in chemical fertilizers. The addition of humus is therefore necessary to maintain and renew the topsoil. With the loss of topsoil comes the loss of human food security. In many parts of the world people are experiencing reduced productivity on their lands due to loss of top soils

11.2.2 Nutrients in human excreta

a) Urine: Most of the plant nutrients in human excreta are found in the urine. Based on data from five countries (China, Haiti, India, South Africa and Uganda) we estimate that on average each person produces about 5 kg of elemental NPK in excreta per year, about 4 kg in the urine and 1 kg in the faeces.12 Urine is therefore worth using as fertilizer, especially as its content of NPK is readily available to the plants.

In Sweden the total yearly production of human urine contains elemental nitrogen, phosphorous and potassium equivalent to approximately 20% of the amounts of these nutrients used as mineral fertilizers in 1999/2000.13 The concentrations of heavy metal in human urine are negligible – an important advantage over chemical fertilizer. When urine is collected for use as a fertilizer, it is important that the storage method prevents odours and the loss of nitrogen to the air.

Swedish research indicates that most of the nitrogen in urine, which is initially in the form of urea, is quickly converted to ammonia within the collection and storage device (if this device has been used several times and is not more or less sterile). Ammonia loss to the air can be minimized by storage in a covered container with restricted ventilation. When urine is applied to open soil before planting it can be undiluted. If used on growing plants it can be applied without or with dilution, typically one part urine to 2–5 parts of water. Care should always be taken to apply the urine to the soil and not on the plants.

b) Faeces: Human faeces consist mainly of undigested organic matter such as fibers made up of carbon. Although faeces contain fewer nutrients than urine, the humus produced from faeces actually contains higher concentrations of phosphorus and potassium. After pathogen destruction through dehydration and/or decomposition the resulting inoffensive material may be applied to the soil to increase the amount of available nutrients, to increase the organic matter content and to improve the water-holding capacity.

The simplest form of recycling is when the individual household can use the product as fertilizer in its own garden or on its own farm land. In urban situations many householders will have neither the land nor the inclination to use the product themselves. Lack of land need not hinder food production.

Comparison of nutrient levels in natural topsoil and humus from Fossa Alterna pits

Source of soil	N (mg/kg)	P (mg/kg)	K (mg/kg)
Natural dry land top soil	38	44	192
Fossa Alterna soil	275	292	1763

c) Nutrients in combined systems: The humus formed in toilets where urine and faeces are combined, such as the Zimbabwean 'Arborloo' and the 'Fossa Alterna', is rich in nutrients. Studies undertaken in Zimbabwe compared major nutrient levels in samples of naturally occurring topsoil and in humus from pits where urine and faeces have been combined and supplemented with soil and wood ash and allowed to decompose for one year.

11.2.3 Application of nutrients derived from excreta

Nutrients from human excreta may be applied as two separate products (urine and composted faeces), or as one combined product (composted urine and faeces). When they are applied separately, it is usually because they have been collected separately. When urine and faeces are applied in combination, it is because they have been collected together and composted as a mix, as in the Arborloo or Fossa Alterna. The most efficient way to recover excretal nutrients, however, is to collect urine and faeces separately. Most toilets collecting urine and faeces mixed allow leaching of the liquid from the toilet, which means that some nitrogen will be lost.

Application of urine: Urine can be applied in a variety of ways:

- Undiluted before or at sowing/planting or to the young plant.
- Urine can be applied in one large dose or several smaller ones during the cropping season.

- As a liquid plant food mixed with water. Diluted urine can be added to the soil where vegetables (and plants like maize) are growing – once a week or even twice or three times a week, provided that the plants are also watered frequently at other times. This addition of urine makes a big difference to the growth of plants.
- Undiluted to soil beds before planting. Bacteria in the soil change the urea into nitrate which can be used by the plants.
- As an 'activator' for compost heaps. The transformed organic nitrogen will be available to plants when the compost has matured.
- Concentrated fermented urine can be applied to beds of dried leaf mold, as a medium for growing vegetables and ornamental plants

A future possibility, when large amounts of diverted urine are available from urban areas, is to use human urine to produce a concentrated fertilizer in powder form.

Application of faeces: Faeces are removed from the vault of dehydrating toilets as a dehydrated, sanitized powder or lumps. This dry material is usually given a secondary treatment (for example in the form of high temperature composting, see 2.4) before being dug into the ground or into flower beds where the material comes into contact with the living soil. From composting toilets faeces are removed as humus, which is not dry but slightly moist. The same applies to its removal from secondary composting sites, if the partly decomposed faeces, in combination with soil and ash, have been moved from the toilet to be further processed elsewhere. To make best use of this valuable asset, it can be applied in furrows or holes close to where the plants will later be growing.

Application of humus from urine and faeces combined: In the Fossa Alterna, a mix of urine and faeces, in combination with an almost equal volume of soil, and often combined with wood ash or leaves, is dug out of the shallow pit after 12 months of composting. This material is either bagged awaiting further use or mixed with local topsoil in equal proportions and applied to vegetable gardens, where it enhances plant growth.

Effects of nutrients on plant growth: Urine can be applied in one large dose for the growing season or once or twice a week in smaller doses to vegetables – with additional watering to keep the plants healthy. With the same total dose of urine during the vegetative part of the growing season, the yield is usually about the same, irrespective of the number of doses. In a series of experiments carried out in Harare, Zimbabwe, during 2002, it was shown that by adding the 3:1 water urine mix to vegetables planted in 10-litre containers three times per week, with all other irrigation carried out with water alone, spinach yield was increased up to 6 times, covo yield 1.5–4 times, lettuce yield was doubled and the weight of tomatoes increased up to 3.6 times, compared with similar plants growing in similar soil and similar containers, but irrigated with water only. Maize production in fields was also increased by between 29–39% by the application of undiluted urine watered with natural rainfall.

Urine works better if the soil to which it is added contains humus. Such humus is rich in living material and beneficial soil bacteria, and these convert the urine nitrogen into a form that the plants can use. With poor soils, the best way of enhancing plant growth using processed human excreta is in two stages. The first stage involves improving the texture and humus content of the soil by combining it with humus formed from processed faces or faces and urine. Leaf compost and garden compost can also be used at this stage. The second stage involves enhancing and sustaining the nutrient levels in the soil with urine. It should be noted that during their growth, all plants take up nutrients, and the nutrients removed from the field with the crop must be replaced if the soil is to remain a fertile medium for growing of healthy plants. It is wise to irrigate the plants most of the time with plain water and to supplement this irrigation with the application of urine or urine and water mix, according to the chosen fertilizing plan. This appears to maintain a healthy soil over the growing period of plants tested. Urine does contain salt, and this must be kept in check (by regular plain watering) if the plants are to remain healthy.

Effect of urine and faeces combined on plants: Humus derived from Fossa Alterna pits (where urine and faeces are mixed) contains about eight times the amount of N, P and K found in poor local top soils in Zimbabwe. These combined products, therefore, can make a valuable addition to poor soils and result in improved vegetable production. The improvement in vegetable yield depends on the state of the original soil. If the soil is poor, significant increases in vegetable growth are possible. In fact, the weight of vegetables grown on the mix of soils can be many times the weight of vegetables grown on the poor soil alone. The Fossa Alterna soil behaves like a good compost or fertilizer and improves soil texture.

In a series of informative experiments undertaken in Harare, Zimbabwe during 2002, vegetables like spinach, covo, lettuce, green pepper, tomato and onion were grown in 10-litre buckets or basins of very poor soil from Epworth or Ruwa, and their growth was compared with plants grown in similar containers filled with a 50:50 mix of Epworth (or Ruwa) soil and Fossa Alterna soil. In each case the growth of the vegetables was monitored and the crop weighed after growing for a certain number of days. Table 5.3 shows the results of these trials. The significant increases in vegetable production are due entirely to the nutrients available in the Fossa Alterna humus.

11.3 Sanitizing Human Excreta

One of the main goals of ecological sanitation is to capture the nutrients present in human excreta and recycle them back to agriculture. Thus a key part of an eco-san system is the destruction of most or all disease-producing organisms before re-use of excreta products.

Recommended Swedish guideline storage times for urine mixture a based on estimated pathogen content b and recommended crop for larger systems

Storage Temperature	Storage time	Possible pathogens in the urine mixture after storage	Recommended crops
4^0C	>1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4^0C	>6 month	Viruses	Food crops that are to be processed, fodder crops
20^0C	>1 month	Viruses	Food crops that are to be processed, fodder crops
20^0C	>1 month	Viruses	All crops

- Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l. Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized as causing any of the Infections of concern.
- A larger system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from which the urine was collected. Not grasslands for production of fodder.
- For food crops that are consumed raw it is recommended that the urine be applied at least 1 month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

Results from scientific studies of pathogen destruction in ecosan systems are now providing us with guidelines for the treatment of urine and faeces before re-use as fertilizer.

11.3.1 Urine Sanitization

Urine contains few disease-producing organisms, while faeces may contain many. Storing undiluted urine for one month will render urine safe for use in agriculture. Undiluted urine provides a harsher environment for micro-organisms increases the die-off rate of pathogens and prevents the breeding of mosquitoes. At the homestead level, where crops are intended for the household's own consumption, urine can be used directly. It is recommended, however, that there should be 1 month between urine application and harvesting. When urine is collected from many urban households and transported for re-use in agriculture, the recommended storage time at temperatures of 4–20 °C varies between 1 and 6 months depending on the type of crop to be fertilized.

11.3.2 Faeces sanitization

The main concerns about the safety of excreta are with the faeces.The most important pathways for the transmission of diseases from faeces are hands, flies, water, soil as well as food that have been contaminated by any of the first four factors. The F-diagram below summarizes these main pathways. (Each of these factors has been given a name beginning with the letter 'F' in order to make it more easily remembered.). One purpose of an eco-san system is to form a set of barriers between faeces and flies, fields and fluids. This is done by containment of the faces in a processing chamber or shallow pit where pathogens are reduced to an acceptable level before re-use. Then the contents may be removed for further secondary treatment to make them even safer.

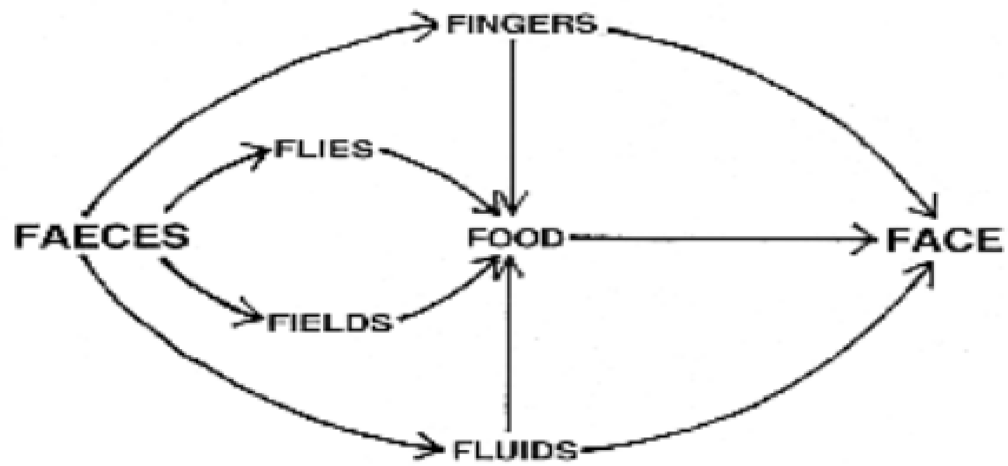

Figure 2: The F-diagram summarizes the main ways faecal pathogens are spread by contaminating fingers, flies, fields, food and fluids and then eventually being swallowed

Every eco-san system should also include a device for hand washing in order to block this remaining important pathway for faecal-oral transmission. Every eco-san educational campaign must emphasize not only proper use and management of toilets but also the importance of hand washing after defecation, after helping a child who defecates and before preparing food or feeding a child. (This is of course not unique to eco-san. Hand washing is as important in the use of conventional sanitation facilities.)

What kills pathogens in faeces?

A number of environmental factors are known to kill off faecal disease organisms. These are increases in storage time, temperature, dryness, pH, ultraviolet radiation, and competing natural soil organisms.

Physiochemical and biological factors that affect the survival of micro-organisms in the environment

Temperature	Most micro-organisms survive well at low temperatures (below 5°C) and die off rapidly at high temperatures (above 40° C). This is the case in water, soil and sewage and on crops. At temperatures of 55–65°C all types of pathogens (except bacterial spores) die within hours.
pH	Highly alkaline conditions will inactivate microorganisms. Inactivation is rapid at pH 12 but takes longer at pH 9.
Ammonia	Pathogens in excreta can be inactivated by the addition of ammonia.
Dryness	Moist soil favours the survival of micro-organisms. Dehydration of faeces in an eco-toilet processing chamber will decrease the number of pathogens.
Solar radiations	Survival time of pathogens on soil and crop surfaces will be reduced by UV radiation.
Presence of other organisms	The survival time of micro-organisms may be shortened by the presence of other organisms. Different types of organisms affect each other by predation, release of antagonistic substances or competition for nutrients.
Nutrients	Bacteria adapted to living in the gut are not always capable of competing with other organisms in the general environment for scarce nutrients. This may limit the ability of faecal bacteria to reproduce and survive in the environment.
Oxygen	Most enteric bacteria are anaerobic and thus are likely to be out-competed by other organisms in an aerobic environment.

11.4 Treatment of Human Excreta

Eco-san systems are designed to use some of the physiochemical and biological factors listed in Table 2.1 to kill disease organisms in faeces. This occurs usually in two steps: primary processing and secondary processing.

Figure 3. An eco-toilet with processing chambers. The toilet has a moveable seat-riser with urine collector. The processing chambers below the bathroom floor can be emptied from outside. (Design: César Añorve, Cuernavaca, Mexico, 1992)

11.4.1 Primary processing

The purpose of primary processing is to reduce the volume and weight of faecal material to facilitate storage, transport and further (secondary) treatment. Primary processing takes place in chambers below the toilet. Here the faeces are kept (‘contained’) for a certain period. During this containment the number of pathogens will be reduced as a result of storage time (6–12 months), decomposition, dehydration (ventilation and the addition of dry material), and increased pH (addition of ash, lime, urea) as well as the presence of other organisms and competition for nutrients. In some of the basic models developed in Zimbabwe the processing takes place in a shallow pit beneath the eco-toilet.

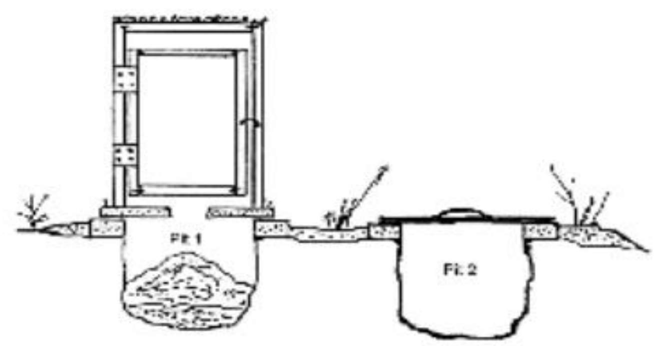

Figure 4. A basic eco-toilet from Zimbabwe with processing chambers in the form of shallow pit. During the first year the squatting slab and superstructure are mounted over Pit 1. Next year they are shifted to Pit 2 (see also 3.1.4). (Design: Peter Morgan, Harare, Zimbabwe, 1998)

11.4.2 Secondary processing

The purpose of secondary processing is to make human faeces safe enough to return to the soil. Secondary processing takes place either on site – in the garden, or off site – at an eco-station. This step includes further treatment by high temperature composting or pH increase by the addition of urea or lime as well as longer storage time.If a completely sterile end product is required the secondary processing could be carbonization or incineration. In areas where ambient temperatures reach up to 20 °C , a total storage time of 1.5 to 2 years (including the time stored during primary treatment) will eliminate most bacterial pathogens (if kept dry) and will substantially reduce viruses, protozoa and parasites. Some soil-borne parasite eggs may persist. In areas where the ambient temperatures reach up to 35 °C, a total storage period of one (1) year will achieve the same result, as pathogen die-off is faster at higher temperatures. Where high temperature composting, 50–60 °C , can be carried out, either in an open compost or in a mechanical composting bin the storage period could be further reduced.

Treatment with alkaline materials also requires time for pathogens to die off to an acceptable level. A pH over 9 for at least 6 months to 1 year is sufficient in most climates to kill most pathogenic organisms. For additional safety the material can be bagged (in sacks) and stored for a further period. Where there is concern about the persistence of intestinal worm eggs, carbonization or incineration as the secondary treatment will ensure a sterile product.

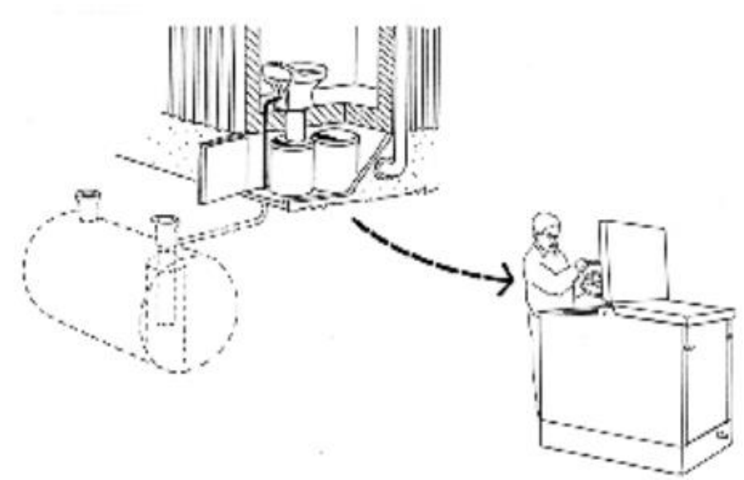

Figure 5. Primary processing in a chamber directly under the urine diverting eco-toilet followed by secondary processing at an eco-station.

11.4.3 Dehydration and composting

Before explaining these pathogen destruction systems in detail, we must step back and explain at this point that there are three main eco-san systems that operate in slightly different ways to achieve more or less the same result. These are **dehydrating systems**, **composting systems**, and **soil composting systems**. These three, and the different toilet designs that go with them, are exemplified in Chapter 3. For now, to understand how pathogens are destroyed, it is only necessary to understand the broad outlines of these systems. Figures 2.4–2.6 show the key points of the three systems.

11.4.3.1 Dehydration

In a dehydrating system, we direct urine away from faces to keep the processing chamber contents dry and the volume of material small. This also makes it possible for us to use the urine separately as a fertilizer. Faces are dropped into a processing chamber where they are safely kept out of the environment for a period of 6–12 months, and ash, lime or urea is added after each defecation to lower the moisture content and raise the pH to 9 or higher. The system thus creates conditions of dryness, raised pH and time for pathogen die-off. The partly treated faecal material is then removed from the processing chamber and subjected to one of the four secondary treatments (high temperature composting, alkaline treatment, further storage, carbonization / incineration).

11.4.3.2 Composting

In a composting toilet human faeces, or in some cases faeces plus urine, are deposited in a processing chamber along with organic household and garden refuse and bulking agents (straw, peat moss, wood shavings, twigs, etc). A variety of organisms in the pile break down the solid into humus –just as eventually happens to all organic materials in the natural environment. Temperature, airflow, moisture, carbon materials and other factors are controlled to varying degrees to promote optimal conditions for decomposition. After a certain retention time (normally 6–8 months) the partly decomposed material can be moved to garden compost or an eco-station for secondary processing through high temperature composting.

11.4.3.3 Soil composting

In a soil composting system faeces, in some cases faeces and urine are deposited in a processing chamber together with a liberal amount of soil. There are two main sub-types with slightly different processes: with a shallow pit or a raised processing chamber. Ordinary soil is added after each defecation, often with wood ash as well. Most pathogenic bacteria are destroyed within 3–4 months as a result of competition with soil-based organisms and unfavorable environmental conditions. The material is then removed and can be subjected to any one of the same four secondary treatments or, within one family homestead, can be directly spread on fields and worked into the existing soil. A period of 12 months of composting in shallow pits is recommended before application to gardens. There further pathogen die-off occurs because of UV radiation, dryness and competition with other soil organisms. After 1 month, crops that are not eaten raw can be sown with relative safety

The application of these systems will result in a community environment that is better than the conditions often found in homestead and urban areas where sanitation services are poor and where open defecation may occur. The simple containment of faeces in processing chambers or shallow soil composting pits is a great improvement on open defecation.

11.5 Grey water

The wastewater from kitchens, baths and laundries is known as grey water. In eco-san systems grey water is not mixed with toilet water containing human excreta. This significantly reduces the hygiene and environmental problems associated with wastewater management. But grey water still has to be managed in some kind of technical system where it can be returned to Nature in a responsible way. The objectives of including grey water systems within the context of eco-san can be summarized as:

- To use grey water as a resource for plant growth, ground water reclamation and landscaping.
- To avoid damage to buildings and surrounding areas from inundation, water logging and freezing.
- To avoid the creation of bad odours, stagnant water and breeding sites for mosquitoes and other insects.
- To prevent eutrophication of sensitive surface waters.
- To prevent contamination of groundwater and drinking water reservoirs.

In rural areas the handling of grey water is seldom a major problem. Volumes are small and the content of hazardous or infectious substances is low. Grey water can be infiltrated into the ground or used for irrigation of trees.

In urban areas, the situation is different. Consumption of water and the use of household chemicals are greater than in rural areas. More buildings per unit of surface area limit the space for processing the grey water and increase the risks of environmental problems and human contact with polluted water. Urban areas require carefully designed and well-maintained systems for collection, treatment and discharge of grey water.

The design and operation of technical systems for grey water management depend on a number of factors: climate, land-use pattern, existing drainage systems and pollution load. The choice of treatment is also affected by how grey water is regarded by the community. The best system must therefore be found by considering local conditions and potential risks of alternative options.

11.5.1 Characteristics of Grey water

a) **Water amounts:** The amount of grey water produced varies between households. While the water consumption in poor areas may be as little as 20–30litres per person a day, a person in a richer area may use several hundreds of litres a day. Water consumption can be reduced with the introduction of water-saving devices and a payment system based on the amount of water consumed.

b) **Biodegradable compounds:** The composition of greywater varies greatly and reflects the lifestyle of the residents and their choice of household chemicals for dishwashing, laundry, etc. A characteristic of greywater is that it often has high concentrations of easily degradable organic material like fat, oil and other substances from cooking, as well as soap and tensides (surfactants) from detergents.

c) **Pathogens:** The content of pathogens in greywater is low. The risk of infection is related to its faecal contamination. As source-separated greywater normally contains no faeces it is often regarded as harmless. Still, many public authorities around the world regard greywater as a health hazard. One explanation for this is that there may be high numbers of indicator bacteria in greywater. Recent research has shown that enteric coliform bacteria tend to grow in greywater because it contains easily degradable organic compounds. The use of coliform bacteria as bacterial indicators therefore tends to overestimate the faecal load and the potential risk posed by greywater. The fact that greywater easily turns anaerobic and creates bad odors may contribute to the belief that it is a health hazard.

In recent years other methods have been developed to assess the hygiene quality of water. By measuring chemical biomarkers, such as faecal sterols, a more accurate estimate of the faecal contamination can be made. Studies of a local treatment system in Vibyasen, north of Stockholm, concluded that conventional measurements using traditional bacteria indicators overestimated the faecal load by 100 –1000 fold as compared with measurements using chemical biomarkers. Using new methods (with coprostanol as a biomarker) thefaecal load in the greywater in Vibyasen was estimated at 0.04 grams per person a day.3 (A normal faecal load in mixed toilet- and greywater from households is about 150 grams per person a day.) The important conclusion is that untreated greywater is likely to contain far lower densities of pathogens than effluent water, even from an advanced wastewater treatment plant.

d) **Nutrients:** Greywater normally contains low levels of nutrients compared with ordinary wastewater from water-borne systems. The biochemical oxygen demand (BOD) of wastewater in Sweden is 60–70% of that in normal mixed wastewater. Nitrogen is 5–10% of that in normal mixed wastewater and phosphorous is 5–50%. Levels of nitrogen and other plant nutrients are always low but in some greywater high concentrations of phosphorous are found. This phosphorous comes from detergents, where it is used for softening the water. Phosphate free detergents are available on the market. In general these are as cheap and as good as those containing phosphorous. If people were to use only phosphorous-free detergents, the phosphorous content in greywater would be reduced to levels lower than that normally found in wastewater after advanced treatment. Some countries in Europe and some cities in East Asia have banned phosphorous-containing detergents to protect freshwater bodies. This explains why the levels of phosphorous in greywater in Norway are only 10–20% of those normally found in Sweden.

e) **Heavy metals and other toxic pollutants:** The content of heavy metals and organic pollutants in greywater is generally low but can increase as a result of addition of environmentally hazardous substances. The levels of heavy metals in greywater are, for most substances, approximately the same as in mixed wastewater from a household. However for some metals such as zinc and mercury the levels are lower.5 Metals in greywater originate from the water itself, from corrosion of the pipe system and from dust, cutlery, dyes, and household chemicals. Most organic pollutants in wastewater are in the greywater fraction, hence the levels are in the same concentration range as in mixed household wastewater. Organic pollutants are present in many of our ordinary household chemicals, e.g. shampoos, perfumes, preservatives, dyes and cleaners. They are also in fabrics, glue, detergents and floor coating. By using environment friendly household chemicals, and by not pouring hazardous substances such as paints and solvents into the sink, the levels of metals and organic pollutants in greywater will be kept low.

11.5.2 Components in greywater management

Successful management of greywater involves proper design, and taking into account the size of the different technical components involved. Also the 'soft' aspects of the system, such as user participation in running and maintaining the system, are important. Rural greywater can be managed using relatively simple householdbased methods like soil infiltration and evapo-transpiration beds. When planning greywater systems for urban, high density locations the following collection and treatment components should be considered:

- control at source
- pipe systems
- pre-treatment
- treatment
- end uses

a) **Control at source:** Any strategy for managing greywater will be made easier by watersaving measures as well as attention to reducing the use of household chemicals. Technical components for a greywater system such as septic tanks, sand filters, soil infiltration systems and other treatment applications are designed in relation to the amount of water and BOD. Reducing these parameters at the point of origin gives us more options for cost-efficient and volume- and space-saving solutions. Source control makes the maintenance of the system more robust and efficient in terms of purification. To reach and maintain a conservative use of water, experience shows that water-saving equipment installed in households should be combined with economic incentives, i.e. a fee system based on water consumed. By combining technical and economic tools for water saving, greywater production can be reduced significantly without jeopardizing comfort and hygiene standards for the users.

The BOD load should be controlled at the household level. Such control includes information on proper behaviour and appropriate design of systems. In industrialized countries overdosing with household chemicals is common and is responsible for the increased levels of BOD often observed in wastewater during recent years. Correct use of such products is therefore an important part of greywater management. BOD levels in greywater are also a function of greaseand oil used in food preparation.

Larger particles, fibres and grease should be removed at source to prevent clogging of the pipe system. Outlets from kitchen sinks, showers, bathtubs, washing machines and other fixtures and appliances should therefore be fitted with appropriate screens, filters or water traps. For greywater from restaurants and in households where large amounts of grease and oil are handled, special grease traps may be necessary to protect the pipe system from clogging.

As mentioned above, high levels of organics, phosphorous, organic pollutants and some of the heavy metals found in greywater come from household chemicals. Greywater management should therefore promote the use of environment-friendly household chemicals.

b) Pipe systems: A pipe system is needed to collect and transfer water to where it will be treated and used. Design and plumbing for greywater collection systems are similar to those for mixed wastewater. In eco-san, as there is no need to flush toilet waste, smaller pipes can be used compared with mixed wastewater (flushing-and-discharge) systems.

All pipe systems must have evacuation of air and odours. Normally a self-ventilating pipe arranged as a chimney above the roof is enough. Bad odours will sooner or later arise in the collecting systems. All pipe connections in the house must therefore be equipped with water traps. In extensive pipe systems, special consideration needs to be given to the problem of toxic and corrosive hydrogen sulphate produced from anoxic conditions.

Clogging from grease is a potential risk that must always be considered in greywater management, especially when the pipe system is extensive. Pipes must be laid straight with a gradient of at least 5 mm per meter. Pipe systems need to have flushing pipes and/or traps for use in case clogging occurs. In smaller systems direct treatment and use is often the most appropriate option. In these systems, greywater is led directly to a mulchbed where water is used for growing plants or trees. Such a system must be designed and sized so that also big particles can be digested by the soil ecosystem. The most appropriate solution is to connect each source of greywater to an individual mulch bed. Then the pipe system can be simple, and no flow splitter needs to be used. In countries with cold winters and water shortage, as in the Erdos project in China, a summer/winter system can be used. Such a system can be operated for direct use in summertime and for treatment and percolation in wintertime

c) **Pre-treatment:** Pre-treatment is needed as soon as greywater is collected in larger pipe systems or stored for longer periods. Without such pretreatment fats and other biodegradable organic compounds will clog the system or create bad odours. In pre-treatment suspended solids are removed mechanically by gravity, screens, seals or filters. The need for removal of suspended solids depends on how the water will be treated and used. The septic tank concept is an efficient and reliable technique that is useful in most treatment systems in rural as well as urban areas.

d) **Septic tank:** A septic tank is used for separation of particles and water. Floating particles are collected in the scum at the top of the tank and sinking particles are collected as sludge at the bottom. Transporting grey water in a pressurized system may have a negative effect on this separation. Untreated greywater should never be stored in open ponds. Such ponds will create odours and nuisance for people and provide a perfect site for the increase of bacteria and other organisms that thrive on organic carbon.

e) **Screens, seals and filters:** Different pre-treatment devices based on screens, seals and filters are available commercially. Prefabricated devices are useful in large wastewater systems and in special applications such as drip-irrigation systems. For ordinary home-applications they will seldom be cost-efficient and reliable enough.

Homemade seals or filters based on gravel may be appropriate in small-scale systems. In rural areas in warm climates an open gravel filter combined with soil infiltration can provide full treatment.

f) Treatment: Greywater is relatively harmless compared with mixed wastewater. Besides, greywater problems tend to have only local impact. But if not managed properly, greywater may turn malodorous. We must therefore reduce the high levels of easily degradable compounds that are responsible for the bad smell. This should be done right away as anaerobic conditions and odours develop within hours if the weather is warm. Wherever greywater is exposed to the atmosphere, it should first be treated to ensure that BOD does not cause anaerobic conditions.

Reduction in the levels of micro-organisms, organic pollutants and heavy metals is also desired. This is especially important when greywater is infiltrated to groundwater or used for irrigation. The most appropriate method for achieving the above targets is to use attached aerobic biofilm techniques. In these techniques, the biological degradation of organics typically takes place in aerated conditions. The treatments range from extensive land applications to intensive applications, such as trickling filters and biorotors. Where climatic conditions are favourable, aquatic systems, such as ponds and wetlands, can be used for greywater management. But such systems may not be appropriate for wastewater in cold climates and where water is scarce.

All aerobic attached biofilm techniques trap suspended solids in a filter medium, and then they are digested by micro-organisms well supplied with air. The most appropriate solution for greywater treatment is to filter it through soil.

i) **Sorption and irrigation:** Sorption and irrigation systems (slow-rate systems) use a soil filter to convert polluted water into a valuable plant asset. These systems should therefore be designed according to the water requirements of the plants. The amount of water that can be applied to an area varies typically from 2 to 15 litres per square metre per day depending on the local evapo-transpiration rate.

ii) **Vertical soil filters:** Soil filters can be used for greywater treatment. In the literature various terms are found for these systems: rapid infiltration, high-rate or vertical soil-filter systems. Appropriately designed and operated, a soil filter has high removal efficiency for suspended solids and organic compounds. Removal efficiency for suspended solids and BOD is typically around 90–99%. Removal of bacteria and viruses is also high: 95–99% removal can be expected for most pathogens.8, 9, 10 the treated greywater from a vertical soil filter thus has low levels of pathogens compared with mixed wastewater.

In natural soil-filter systems, phosphorous and heavy metal removal is significant. Depending on soil properties, depth of unsaturated zone and wastewater load, removal efficiency of phosphorous in a soil filter has been estimated to be 30% to 95% over its lifetime (25–30 years). Also, nitrogen is reduced in a soil filter bed by nitrification and denitrification. Soil filters fed by mixed wastewater typically show a nitrogen removal efficiency of about 30%.

The design of vertical soil filters is based on wastewater load and BOD load. Typical loads for soil infiltration filters are 40–80 litres per square metre per day, or 4–6 grams BOD per square metre per day. The soil in the filter must be neither too coarse nor too fine. If the natural soil is not appropriate for infiltration, its capacity can be improved by using filter sand as an infiltration layer. A soil filter with special filter sand, and a bottom drainage layer for collection and discharge of treated water, is called a sand filter.

Vertical soil filters can be constructed in many ways. The challenge is to find a practical way to treat as much water as possible without clogging and saturating the soil with water. To achieve this, water must be distributed evenly over the filter surface. In gravity systems, so-called 'controlled clogging' has proved to be a feasible method: water is distributed over clogged bottoms (e.g. a narrow trench) while infiltration takes place through the walls. Techniques for spreading water in pressurized systems can be divided into surface flooding techniques, application through perforated horizontal pipes, and spraying or sprinkling systems.

iii) **Trickling filters and biorotors:** These systems purify water by using attached biofilm in filters with a high water load. In a trickling filter, the water is spread over the filter medium by rotating arms or nozzles. The filter is filled with a strong filter medium with a large surface area and large pores so that it is not clogged by biofilm. Earlier applications used brick towers filled with round stones but nowadays, prefabricated plastic materials are used. By using a trickling filter or other more intensive applications (e.g. biorotors, or activated sludge) the space needed for treatment is reduced. Drawbacks of these systems are that they need electricity and that they produce sludge.

iv) **Semi-wet wetland systems:** By semi-wet wetlands we mean artificial wetlands to which water is intermittently loaded and drained. The idea behind this concept is to promote efficient spreading of water over the surface where filtering of suspended solids and sorption mechanisms take place. During the periods of drainage biodegradation and chemical sorption mechanisms are promoted because of the air contact. In overland flow systems, water is flooded over a gentle slope typically covered with grass. In many countries the technique is frequently used in rural areas for fertilizing pastureland or for irrigating meadows for hay production.

v) **Ponds and aquaculture:** Ponds and wetlands differ from the techniques described above in that they use a medium continuously saturated with water. Such conditions are normally unfavourable for oxygen-consuming processes, as gas movement is slow in water. Also movement of air by dispersion is slow in water. This explains why anaerobic conditions occur easily in water but never on land. It also explains why aquatic media in conventional biological treatment have to be aerated to work. In warm climates, use of oxygen produced by growing plants can save the cost of aeration. Such systems use the symbiotic relationship between heterotrophic bacteria that produce carbon dioxide and micro-algae that produce oxygen. To prevent secondary pollution from the micro-algae that are produced, or oxygen depletion and a release of sorbed phosphorous following plant die-off, the plant biomass has to be removed from the system. This can be done by harvesting plant biomass directly, or transforming it via the food chain into secondary or tertiary production that can be harvested later. Examples of pond systems using primary production directly are the so-called high-rate ponds where, typically, blue green algae are cultivated for single-cell protein production. Well-developed techniques for carp fish polyculture production are found in several countries in Asia. In other parts of the tropical world, a grass-eatingfish, tilapia, is used as a biomass converter in wastewater aquaculture.

g) **End uses:** After treatment, water is used for irrigation or returned to nature. The following recipients (end uses) can be identified:

- discharge to surface water
- percolation to groundwater
- use in irrigation

i) **Discharge to surface water:** Discharge to surface water is often the easiest and most natural way to return treated greywater to the environment. If the water is treated in a soil filter or a trickling filter, it can normally be discharged in open ditches and drained away together with storm water. Treated greywater can be used for landscaping, like the creation of wetlands and dams in parks. The water may, however, in spite of treatment, still contain oxygen-consuming substances or nutrients that are too high to produce attractive and stable aquatic ecosystems. In this case, the treated greywater would have to be given a second treatment, for example by letting water trickle through the root zone in a trench before it is discharged into a pond.

ii) **Percolation to groundwater:** When treated greywater is returned to groundwater the following precautions should be taken:

- Use only reliable methods that include the removal of suspended solids, BOD and bacteria.
- After treatment let the water percolate through the ground in an unsaturated zone of 1 metre depth or more. The subsoil should consist of sand.
- Leave a safety zone between percolation fields and wells. The extent of the safety zone must be determined according to local soil and groundwater conditions.

iii) **Use in irrigation:** When greywater is used for irrigation special precautions are required. The following recommendations should always be followed:

- **Method of application:** Water should be applied to the soil or sub-surface rather than sprinkled.
- **Choice of crop:** Crops where leaves or stems are not eaten directly as well as fruit trees and bushes are most suitable for greywater irrigation.
- **Waiting period:** When irrigating edible crops, a certain waiting time between irrigation and harvest should be observed.

Summary

The ecological sanitation concept can provide many benefits to communities and individual households. The recycling of nutrients not only improves the environment, but can provide safe sanitation in areas with water shortage and improve food security by providing cheap fertilizers.

However, the systems put a lot of emphasis on the householder to operate the facility and, more critically, they must operate it effectively else they will place themselves and the local community at risk. In urban areas there is likely to be a need for good service provision to empty facilities and take the compost to a suitable place to be used.

In order to realize the benefits of ecological sanitation care must be taken to develop a suitable solution for the area in question. Careful planning must take place to assess people's willingness to handle the by-product of ecosan, and whether they will be willing to use this for agriculture. There are a range of ecosan toilet options, some of which are more suited for communities who have not used ecosan previously. Further details of these systems can be found in the technical brief 'Composting and other ecosan toilets.

References

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[1] Adapted from Eco Sanitation A Concept (ctc-n.org)