Solid Waste Treatment

- ❖ The ***quality of life*** on the Earth is linked to the overall ***quality of the environment***.
- ❖ Unfortunately**,** ***the progress in science, technology and industry*** a large amount ranging from raw sewage to nuclear waste is dumped into the ecosystem thereby posing a serious problem for survival of mankind itself on earth.
- ▪ ***Solid waste management*** (SWM) is one of the ***most challenging issues faced by developing countries that suffer from serious pollution problems caused by the generation of large waste quantities.***
- ▪ The awareness that ***improper handling of SW*** leads to contamination of water, soil and atmosphere (causing global warming) and is a major impact on public health has caused developing nations to address this issue with increasing urgency: ***management of SW.***
- ❖ ***In the world, several type of waste with billion tonnes of wastes per year are generated.***
- ▪ ***Obviously, the biosphere system cannot absorb and recycle such a large amount of wastes.***
- ▪ Most wastes were traditionally disposed by digging a hole and filling it with waste material (**landfill sanitary**) and ***burning the organic wastes in open land (Incineration)***.
- ▪ This mode of waste disposal: ***difficult to sustain owing to lack of new place every time to dump and create air pollution to the surrounding community as well as global warming.***
- ❖ New technologies for waste disposal that use ***high-temperature incineration and chemical decomposition*** (e.g., base-catalyzed dechlorination, UV oxidation) have evolved.
- ▪ Although they are very effective at reducing wide a range of wastes/contaminants but have several ***drawbacks such as complex, uneconomical and lack public acceptance.***

➢ ***The associated deficiencies in these methods have focused efforts towards harnessing modern day bioremediation process as a suitable and sustainable alternative.***

- In Ethiopia, depending on local conditions, eating and drinking habits, climate and the degree of industrialization, between ***60% and 70%*** of **MSW** consists of Biodegradable Municipal Solid Waste (BMSW) such as food and green waste and paper waste, etc; consequently ***bioremediation*** has considered recycled of the above waste resource to product.

- Most industrialized countries have adopted the following philosophy about the MSW management hierarchy: ***(3R: Reduce, Recover, Recycle)***
  - Prevention or minimization in generation
  - Material recovery
  - Recycling (E.g. composting, Biogas production, etc)
  - Incineration and Disposal in controlled landfills

Waste Characterization

- ***Solid waste characterization*** supplies ***useful data for choosing appropriate disposal methods and developing collection and separation systems***.
- ***In characterization of municipal solid waste**, amounts and types of the waste components varies with location, season, population density, economic conditions and others*.
- Due to the ***heterogeneous nature of solid waste***, ***common sense and random sampling techniques*** have evolved for determining composition.
- ***Understanding the composition and nature of solid waste*** *at the source of generation plays an* ***important role in designing a method for an integrated waste management program***.
- ***Landfill life*** can be predicted and modification can be made in present waste management by using characterization data.

- ***Possible to be sorted into populations by size, material type or suspected contamination***.

  * Without a priori knowledge of the contents (percentages of type: paper, plastics, etc.) and the contaminants present (e.g., heavy metals, volatile organics, semivolatile organics, etc.) in a given collection site, it is difficult to selectively sort the material to obtain an estimate of the distribution of contaminants and decide methods of treatment.

❑ ***Therefore, solid waste characterization can be done using:***

1) Hand sorting or visual characterization *of samples from generators or disposal facility (for non contaminant composition).*

A) ***Hand sorting samples*** from *generator*, the waste samples are ***obtained at the location*** where they were generated.

- Waste collection at *disposal facility* is especially suitable for waste that is typically composed of many small pieces of numerous materials.

B) ***Visual characterization of solid waste samples for nearly homogeneous wastes***

- ***From generators*** is ideal for wastes that are nearly homogeneous, such as mill tailings, agricultural chaff, sawdust, etc.
- ***From vehicles*** is ideally suited for waste that is taken to a disposal facility and arrives in loads that are fairly homogenous individually.
- The usual approach in *visual characterization* is to estimate the composition of the entire load and to correlate the visual estimate with the net weight of the load.

2) Soli waste can be characterized chemically

- ***Chemical composition*** of the solid waste help to predict ***Leachate composition, Moisture content, Volatability, ash content, calorific value, etc*** and *develop necessary treatment option*.

3) In sampling heterogeneous wastes in a collection site, there are two requirements:

- The first is to *obtain sufficiently large samples* to ***encompass all the types with their composition and sizes*** of materials representative of each portion of the entire site.
- The second is to characterize based on ***analytical laboratory (MC, AC, VM FC, density CV and etc) .***

Basis of Biological Solid Waste Treatment

❖ ***Biological treatment processes use natural processes of ubiquitous living organisms.***

- During biodegradation, microbial activity 'recycles' organic molecules, and such continuous process is fundamental to biological treatment.
- Biological treatment processes are well understood and widely used for organic wastes, mainly *non-hazardous ones*, but also used for some ***hazardous wastes such as heavy metals, xenobiotic compounds, etc.***

❖ In solid waste, biological action takes place naturally within ***collection site, landfill sites and compost processes***, and natural process is encouraged and optimised in biological treatment facilities by control of ***temperature, nutrient supply, pH, inoculums type and size, etc***.

- *Complicating biodegradation by "**cometabolism**" where minimum two substrates are needed i.e., one compound cannot fulfill all the bacterial needs and act as the sole carbon and energy source, whereas a second compound is needed as growth substrate.*

❖ Different microbial actions take place in aerobic (or oxygen-rich), anoxic (low oxygen) and anaerobic (or absence of oxygen) conditions.

❖ Aerobic degradation can take place over wider temperature and moisture ranges than anaerobic processes, because of the methane bacteria.

❖ ***Aerobic processes*** may be ***open or contained, and in-vessel*** aerobic systems are increasingly being used for solid waste,

❖ ***Anaerobic treatment*** is typically used for liquid/moist wastes and is carried out in sealed containers or covered lagoons.

▪ ***Many industries with organic waste streams use anaerobic digestion techniques*** *as a*

* ***pre-treatment stage****, to reduce sludge disposal costs* (by volatile solids reduction) and

*** *to control odours***, with – in some cases - the additional benefit of methane collection which can be used to provide on-site energy needs.

▪ ***Biological degradation treatment systems have to be designed to take care of another secondary problems such as methane emission, NOx, removal efficiency, etc.***

❖ In most developing nations, among the technologies, ***composting and sanitary landfill*** are used to treat solid waste of the municipal and industries, although such methods have their own drawbacks.

Composting and Sanitary Land-filling for Solid Wastes Treatment

❖ At present, most of the biodegradable solid waste is disposed of in ***landfills***, but this practice has a negative effect on the environment so it is necessary to find and to apply alternative treatment methods to this waste stream in order to divert it from landfill disposal.

▪ ***Composting***, ***anaerobic digestion***, ***incineration, thermolysis and gasification*** are the most usual management methods.

▪ Another alternative is the ***recycling of organic wastes*** as ***animal feed, etc***.

* Since these organic fractions often have a very high nutritional value, they may be fed to livestock and could be a substitute for traditional feedstuffs.

Composting

- ***Composting*** is one of several methods for treating biosolids to create a ***humus-like*** marketable end product that is easy to handle, store and use: too restrictive.
- As intense microbial activity leading to decomposition of most biodegradable materials, usually mixtures of organic materials, which results in organic residue stability.
- Composting involves the complete or partial degradation of a variety of chemical compounds by a consortium of microorganisms, the composition of which changes as composting progress.
- The end product is usually ***a humus-like material*** ***without detectable levels of pathogens, heavy metals and toxic chemicals*** that can be applied as a ***soil conditioner and fertilizer*** to ***agricultural fields, gardens and rangelands***.
- Compost provides large quantities of ***organic matter and nutrients*** (***such as nitrogen, phosphorous, potassium, etc) to the soil***, ***improves soil texture, and elevates soil cation exchange capacity: all characteristics of a good organic fertilizer*****.**

- The estimated quantity of Municipal Solid Waste (MSW) generated worldwide is ***1.7–1.9 billion metric tons per year*** making cities a ***threat to the environment*** (UNEP, 2013).
- ***Expected to increase approximately to 2.2 billion metric tons per year by 2025.***
- In **Sub-Saharan Africa** is estimated approximately to **62 million tonnes per year** (UNEP, 2013; Hoornweg and Bhada-Tata, 2012).

- ***In Ethiopia, the solid wastes are being dumped or burnt without proper recycling.***
- The estimates of waste generated in ***Addis Ababa per capita per day*** varies in volume from ***0.4 to 1.23 lit/capita/day***, in weight from ***0.11 to 0.7 kg/capita/day***, and averagely about ***0.45 kg/capita/day*** and in density from 205 to 370 kg/m3 (AACA, 2002; Edward S., 2010; Desta et al. 2014).

- Despite this accelerated pace of solid waste production, waste collection rates are ***lower than 70% in developing countries.*** ***Similarly, in Addis Ababa the performance of the city's solid waste collection and disposal system remains poor*** (Edward S., 2010) as only ***65% of the waste produced per day*** is collected and disposed, ***5% is recycled, 5% is composted and the remaining 25% is uncollected and dumped in unauthorized areas*** (Ali and Eyasu, 2017).
- In Addis Ababa the generated solid waste management is difficult due to presence of organic and inorganic wastes (Desta et al. 2014), consequently, different management problems encountered by the public and the municipal authorities (Regassa et al. 2011).
- ***Uncollected garbage is a serious environmental hazard for all, the health situation of the community is under serious threat and deteriorating aesthetic quality of the city (ENDA, 2006).***
- Bahir Dar, also faces difficulty in handling of wastes generated daily (Lohri et al. 2014).
- Debre Birhan produces much of organic waste that mainly includes food and kitchen wastes in urban solid waste and the recycling possibilities are yet to be exploited (Tyagi et al. 2014).
- Debre Markos faces the difficulty of management of solid wastes produced by the city (Tiwari and Tiwari 2012).
- Jimma produces a huge amount of waste that needs to be recycled (Getahun et al. 2012).
- In Mekelle about 39792.9Kg of solid waste in a day and 1424408.5kg in a year were generated in 2001 (Gebretsadkan, 2001).

  * the lower, the middle and the higher income groups generate 0.277 kg,, 0.301 kg and 0.412 kg per capita per day respectively.
- ***Composting technology can be one solution, but be integrated with other possibilities.***

  * **composting results in stabilization of wastes, allowing a more complete recovery of resources and alternative use endpoints.**

The Principles of Composting Technologies

- Compost facilities have traditionally utilized **open windrows** to process compostable organics (mostly agricultural and green material) into finished compost.
- Some compost facilities incorporate more sophisticated technologies, such as aerated static piles and biofilters, to meet air quality requirements.
- There are several ***naturally occurring microorganisms*** that are able to convert organic waste into valuable resources such as ***plant nutrients by reduce the C:N ratio to support soil productivity.***
- These microorganisms are also important ***to maintain nutrient flows from one system to another and to minimize ecological imbalance.***
- Dessalegn et al. (2012) have suggested that the source separated municipal solid waste can be composted and used as manure.
- ***Thus,*** the result is the ***creation of a valuable, stable, end product*** through ***the increase of nutrient retention and availability***, ***cation exchange capacity, and humic components*** that serve as a source of organic matter.
- Compost can be considered a ***soil conditioner*** that ***contributes to soil fertility, structure, porosity, organic matter, water holding capacity, cation exchange capacity, and disease suppression, provided it is properly prepared.***
- *However, there is* ***significant variation in the amount of carbon present*** *in different municipal solid waste streams which* ***critically need to be considered in waste selection for composting****.*

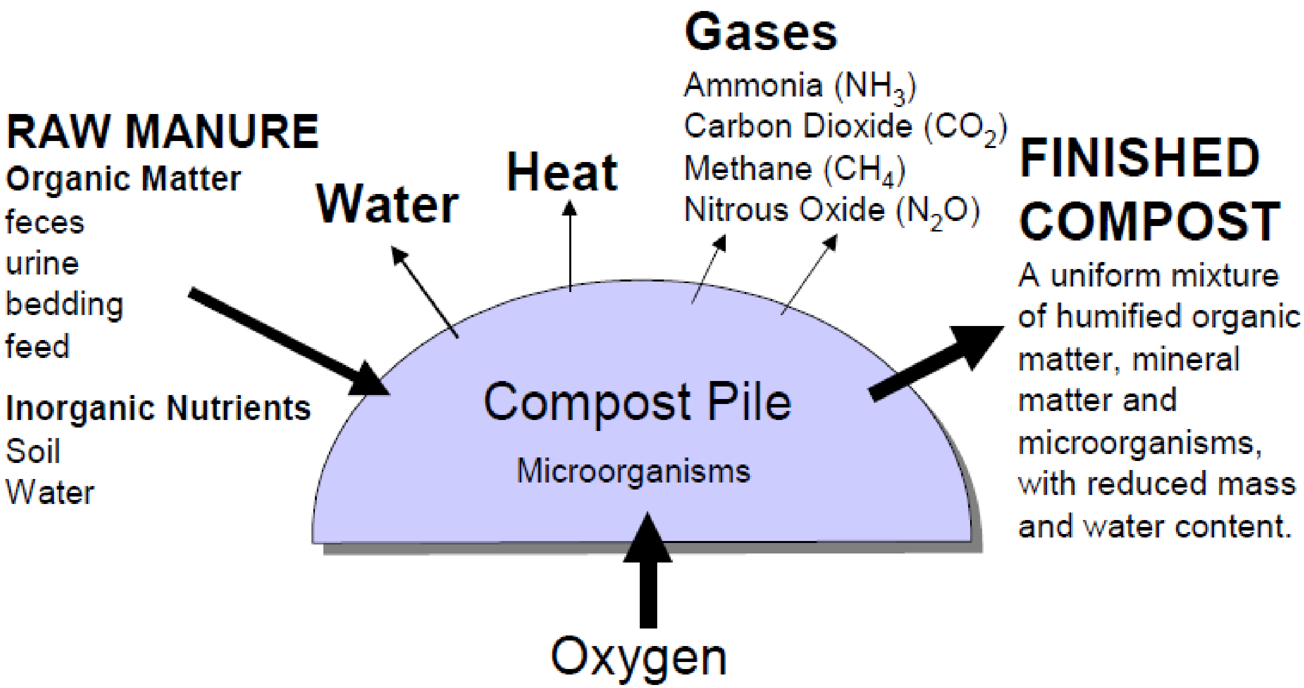
In Ethiopia, what is the trend?

- Although the climate of Ethiopia create favorable condition for the development of economic important of enormous microorganisms, due to several reasons could not utilized them.

The Principle of Composting

1) Composting Process

❖ Composting of manure and other organic wastes is a microbiologically mediated process with which the readily degradable organic matter in organic wastes is degraded and stabilized.



❑ The following diagram illustrating the composting process for raw manure, and inputs and outputs of the composting.

- Depending on the characteristics of materials, stage of degradation, pH and temperature, ***degradation of organic Carbon during composting is carried out by bacteria, fungi, and actinomycetes***.
- ***During the process, part of organic carbon is released as gases (CO2), heat and water, part incorporated into microbial cells and part humified.***
- The ***organic nitrogen*** primarily as protein prior to composting is ***mineralized to inorganic N*** (NH4-N and NO3-N), which is then ***re-synthesized into other forms of organic N in microbial biomass and humic substances*** during the composting process.

Types of Microbes Involved

- ❑ Characteristics of the microbial populations and their rate of change depends on the ***substrate and physical conditions under which composting takes place.***

a) Actinomycetes prefer **moist but aerobic conditions** with **neutral or slightly alkaline pH**.

- ▪ There are many thermophilic actinomycetes, which can tolerate composting temperatures in the range of **50 °C to 60 °C**.
- ▪ Actinomycetes tend to be common in ***the later stages of composting*** and ***can exhibit extensive growth.***

b) Bacteria are the most important decomposers during the ***most active stages of composting due to rapid growing ability on soluble substrates and tolerant of high temperatures.***

- ▪ Thermophilic bacteria are dominant species at **temperatures above 55 °C**, which kill pathogens.

c) Fungi have a limited role in composting.

- ▪ Most fungi are **eliminated above 50 °C**, and their optimal temperatures are much lower.

❖***Bacteria*** can utilize materials with ***narrow C:N of 10-20:1***, while ***fungi*** can use materials with ***wide C:N of 150-200:1.***

- ▪ ***These microorganisms assimilate C and N in a different way.***
  * Indicating differing nutrients available during composting will preferentially favor diverse microbial populations.
- ▪ In the study of composting of MSW indicated, *high temperature during thermophilic* degradation phase *caused a marked change in bacterial community*.
  * E.g.: *E. Coli* and faecal *Streptococci*, as well as *yeasts and filamentous fungi*, populations decreased sharply, whereas *Bacilli* predominated beyond the initial ***mesophilic phase***.

❖ ***Therefore, in compost process temperature, moisture, aeration and type of substrates are very important for the growth of microbial cell that can be used for degradation of organic wastes, although time, pH, co-composting are also have impacts.***

❖ ***A balanced, healthy compost depends upon five things:***

* Oxygen/aeration

* Temperature

* Moisture

* Types of substrate (Surface area, Carbon/Nitrogen ratio, composition, etc.)

Oxygen/Aeration

➢ A compost pile must be aerated to provide oxygen that the microorganisms need to survive, fosters the growth of aerobic bacteria and avoid the generation of odours.

- Aerobic bacteria are bacteria that grow and live in the presence of oxygen and are very efficient and rapid in breaking down of waste.
- This can be ***achieved by mixing in coarse materials like leaves or green twigs to create air voids*** and periodically turning the pile with a pitchfork or shovel.
- To provide oxygen to your compost simply **turn the drum once per week , and t**his will aerate all the compost inside the drum evenly.
- More frequent turning could result in the pile becoming too cool for the microbes to work.

Moisture

❖ Moisture is also required by the micro-organisms in a compost pile.

- Too dry a mixture of materials will inhibit their activity.
- Excessive moisture will also hinder aeration.
- As a general rule, the material should be as wet as a squeezed out sponge.

Substrate type and composition/C:N ratio

- For best results, the microorganisms breaking down the organic materials in your compost pile require a mix of materials containing carbon and nitrogen.
- An ideal mix is 25 to 30 times more carbon than nitrogen (25-30:1).
- It's important to mix different materials to achieve a proper balance of carbon and nitrogen in a composter.

Temperature

- In addition to providing oxygen, aeration removes heat, water vapor and other gases trapped within the composting materials.
- In fact, the required rate of aeration for heat removal can be 10 times greater than for supplying oxygen.
- ***Temperature frequently determines how much and how often aeration is required.***
- Composting is most efficient when the temperature of the composting material is within the two ranges known as ***Mesophilic (80-120 °F) and Thermophilic (105-150 °F).***
- Mesophilic temperatures allow effective composting, but most experts suggest maintaining temperatures between 110 and 150 °F, because they destroy more pathogens, diseases, weed seeds and insect larvae in the composting materials.
- The regulations have set the critical temperature for killing human pathogens at 55°C (131°F) for a specified time. This time and temperature should destroy most plant pathogens as well.
- The critical temperature for destroying most weed seed is 145°F.
- Heat is generated from the decomposition of organic matter, as ***Temperature*** rises when sufficient heat is trapped within the compost pile. This will encourages thermophilic growth.

Phases of Composting Process Based on Temperature

- *Composting can generally be divided into three stages/phases based on the **temperature** in the composting pile.*
- The composting process uses diverse microflora such as ***bacteria, fungi and mesophilic (****Streptomyces rectus*) ***and thermophilic Actinomycetes*** (*Actinobifida chromogena*, (*Thermomonospora fusca*), *Microbispora (Thermopolyspora) bispora*, *Therinomnonospora curvata*, *Thermoactinomyces sp*.) eventually converting organic waste to humus.

Four phases:

a) During the ***first phase,*** acidic pH is created ***along with mesophilic temperature ~45 °C***.

- *The substrate is reduced due to the degradation of sugar and proteins by the action of mesophilic organisms.* Mesophilic organic acid producing bacteria such as Lactobacillus spp. and Acetobacter spp.

b) The ***second phase*** leads to an ***increase of the temperature*** in the compost piles from ***45 °C to approximately reaches 71 - 80 °C*** and the ***mesophiles are replaced by thermophiles.***

- Large numbers of ***pathogenic*** organisms are degraded during this time.
- *The major degradation products are **CO_2, H_2O, and NH_3** that can be further transformed into **NO_2 and then NO_3 by nitrification**.*

c) The ***third phase*** begins with the ***decrease of temperature*** (cooling) of the compost pile and reach to ambient temperature.

d) Maturing: characterized by a continued, slow degradation of organic compounds

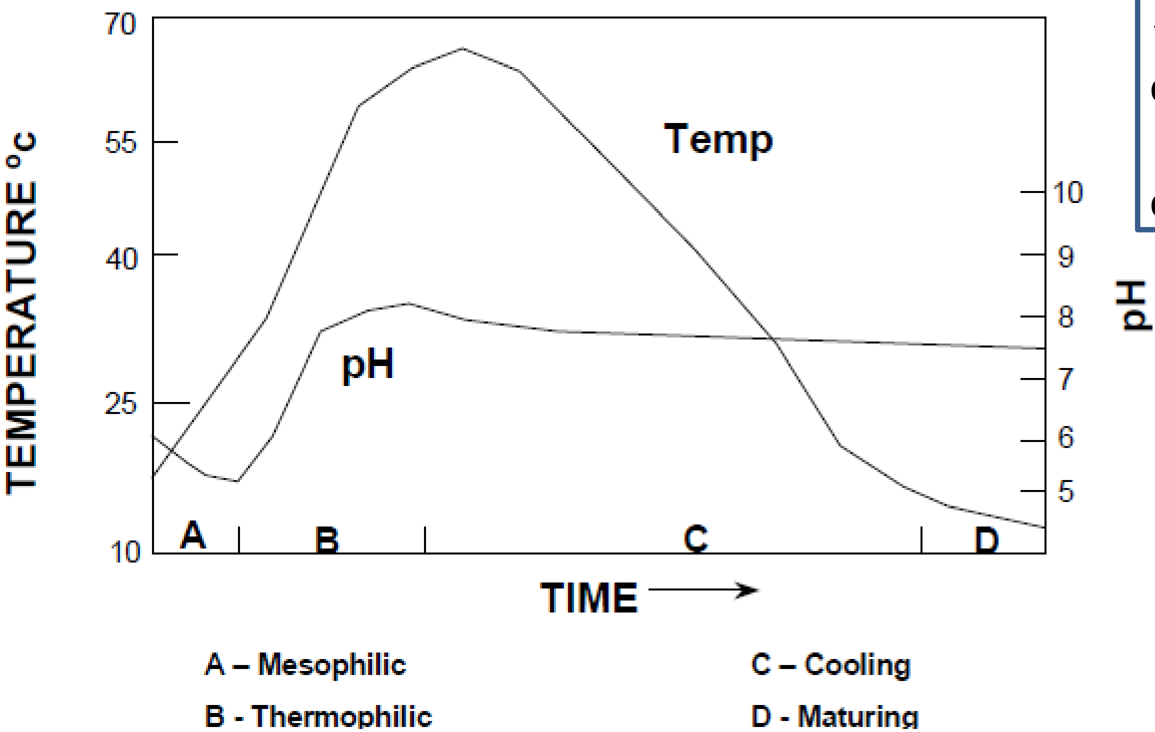
- During the composting process, various parameters including the ***C:N ratio, composting temperature, pH of the finished product, moisture content, and the presence of potential pathogens such as coliform bacteria, heavy metals and toxic substances*** are used to assess the quality and stability of the compost.

- **Decomposition**

ACxHyOz Np + B O2 –> CCO2 + DH2O + E(NH3) + Hv (1)

- **Nitrification**

NH3 + O2 –> NO3- + H2O + H+ (2)

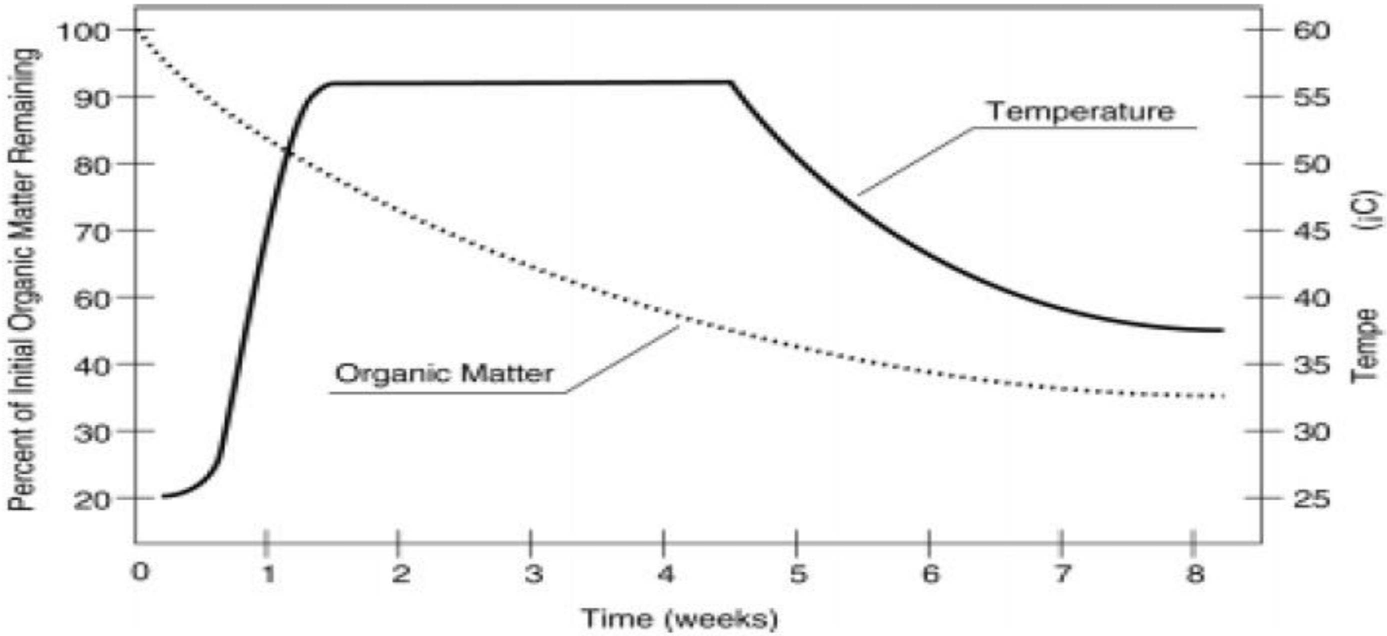


❖ The following graph shows a changes in temperature and pH of the composting pile during composting.

❖***In compost making either aeration or anaerobic condition can be used.***

- Compost turning or *aeration is critical for a rapid degradation* and *high quality compost* particularly for the agricultural waste composting.
- *Although organic matter can also be degraded under* ***anaerobic condition***, *the degradation is slow and less efficient, and produces less heat and more undesirable products*, including ***CH4 and N2O***, which are greenhouse gases contributing to global warming.

❖ ***Temperature Profile and Loss of Initial Organic Material During Composting***



➢ The composting process undergoes many fluctuations in chemical, physical and biological parameters. Successful composting is the result of a continual supply of basic needs to the microbial community: moisture, oxygen, temperature control and adequate mixing.

In the absence of parameter restrictions, the microbial community follows a predictable successional pattern: mesophilic zymogenous, thermophilic, and finally mesophilic autochthonous organisms

➢ The time scale for the entire cycle would range from about 8 weeks to 6 months, depending on the composition of the source material and management intensity.

- The rise in temperature and the rate of CO_2 release from the compost are directly related to O_2 consumption rate.

- Where the amount of readily degradable Carbon (sugars, carbohydrates, hemicellulose and cellulose) is adequate, and the compost pile is well aerated and insulated, the pile temperature will generally rise within several days to the mesophilic and then to the thermophilic phase (40 °C to 70 °C), reflecting a vigorous microbial activity and a rapid rate of organic Carbon degradation.

❑ ***The composting rates decrease when the temperature reaches 60℃ to 70℃.***

➢ The **temperature of the composting pile can be controlled** by several strategies including ***configuration of the compost heap (its size and shape), by turning and watering, or by temperature feedback controlled ventilation.***

❖ Recent studies have reported that organisms involved in organic decomposition processes were able to ***produce high levels of hydrolytic enzymes such as extracellular cellulase, amylase, protease and others enzymes***.

➢ **Composting process also is used to treat hazardous contaminated soils.**

- **Mixing** such wastes with ***highly biodegradable solids*** which serve as both ***bulking agent*** (creating void spaces for the passage of air) and ***thermal source*** (from their biological decomposition) enables composting to take place.
- good bulking agents eg wood chips, hay, crop residue, etc
- good thermal sources eg dry molasses make poor bulking agents.
- However, hazardous wastes do not typically contain ***high enough concentrations of organics*** to sustain composting on their own.

Water or Moisture Content

- **Water** is a critical factor in composting system.
  - *Microbial cells have a physiological need for water.*
  - **Water** can function as a ***solvent of substrates and salts***, a ***major heat storage medium*** due to its ***high specific heat capacity***, and as ***temperature adjusting substances through evaporation***.
  - On the other side, ***as water content increases***, ***the rate of O2 diffusion decreases***,
  - Thus, as **O2** becomes insufficient to meet the metabolic demand, the composting process slows down and become anaerobic. Thus it needs careful follow up.
  - The upper limit of water content is between ***60 to 80%,*** depending on the composting materials.

2) Methods of Composting

- The concerns over ***odor, phytotoxicity, nutrient availability, weed seeds, time, space, cost, heavy metal concentration*** in the waste stream, and ***impact of composting on surface water quality*** in modern time have led to development of various composting techniques with different shapes and sizes, degrees of sophistications and bulking agents used.
- ***The composting methods including:***

  a) ***static pile*** with different types based on methods of aeration of the composting pile, mechanical mixing, and odor control.

  b) ***windrows - long rows -*** which must be turned to ensure adequate aeration.

  c) ***in vessel*** where process control is automated.

3) Factors Affecting Compost Quality

- The sustainability and quality of composting is largely determined by ***its end use, health risk and consumer acceptance of the product.***
- ***Physical, chemical and biological factors are determining the quality of compost.***

- To protect human health, the US federal guidelines limit *E. Coli* to less than *3 E. coli g-1*, and *fecal coliforms* to *less than 1000 MPNg-1*, *Salmonella to less than 3 MPN per 4g of total solids*.

Physical

- In the use of physical characteristic including particle size, texture and the content of non-compostable debris (stone, plastic and glass) to define compost quality which is reflected by the wide difference in the percent of non-decomposable debris in defining compost quality.
- ***Unstable*** or ***immature compost*** is often odorous and phytotoxic, and interfere with seed germination due to the elevated concentration of NH_3, salt content, and/or organic acids.

Chemical

- Includes pH, nitrogen, phosphorous (soluble), total phosphorous, potassium, calcium, magnesium, sulfate, iron, zinc, Mn, Cu, Co, Mo and Bo.

Biological

- Includes total bacteria count, Actinomycetes, Fungi, Azotobacter, Root nodule bacteria, Phosphate solubilizer, coliform, etc.

- High C:N ratios may be lowered by adding grass clippings or manures.
- Low C:N ratios may be raised by adding paper, dry leaves or wood chips.
- If the C:N ratio is too high (excess carbon), decomposition slows down. If the C:N ratio is too low (excess nitrogen) you will end up with a stinky pile.

❑ ***Composting provides many benefits:***

- increases overall waste diversion from final disposal, especially since as much as 80% of the waste stream in low- and middle- income countries is compostable
- enhances recycling by removing organic matter from the waste stream to biofertilizer.
- produces a valuable soil amendment—integral to sustainable agriculture
- flexible for implementation at different levels, from household efforts to large-scale centralized facilities
- can be started with very little capital and operating costs
- addresses significant health effects resulting from organic waste, such as reducing Dengue Fever
- provides an excellent opportunity to improve a city's overall waste collection program
- can integrate existing informal sectors involved in the collection, separation and recycling of wastes

❑ ***Constrains on Composting for not wide-spread include:***

- inadequate attention to the biological process requirements;
- lack of technical skill;
- poor feed stock which yields poor quality finished compost;
- poor accounting practices which neglect that the economics of composting rely on externalities, such as reduced soil erosion, water contamination, climate change, and avoided disposal costs;
- sensible preoccupation by municipal authorities to first concentrate on providing adequate waste collection;
- inadequate pathogen and weed seed suppression; nuisance potential, such as odors;
- poor marketing experiences; poor integration with the agricultural community.

❖ The other means of solid waste treatment method is ***sanitary landfill***.

- ❖ If reduction of organic matter degradation is occurs, it ***can be alleviated by blending more bulking agent*** or finished compost with the composting mixture.
- Considering that the end use of compost is primarily for nutrient recycling and promoting plant growth, *aerobic stabilization process is the preferred method of composting to produce a stabilized or mature organic amendment.*

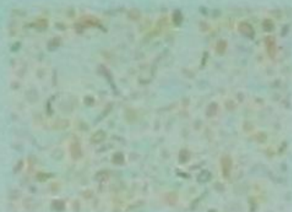
- ❖ *Composting may also produce **leachate**, potentially **high in BOD, heavy metals, etc**, which should not be discharged into water bodies.*
- This is *achieved by reducing the concentrations of BOD, heavy metals, etc* produced as a byproduct from the decomposition of leaves and metals ***mobilized by the formation of carbonic acid from the decomposing organics***.
- Collecting and re-circulating the leachate into active compost piles to enhance the compost process.

- ➢ ***A pilot scale bacteria-based composting system has successfully been used for treating diesel-fuel contaminated soils.***
- Aeration is provided by mechanical or an air compressor that draws a vacuum at the bottom of the pile and returns the air at the top. Additional air is added **as necessary.**
- Nutrients and water are provided through an irrigation system located at the top of the pile.
- The system is a fully enclosed vessel that is batch loaded.

B. Agricultural uses: Bio-organic fertilizer, Animal feed, Biocides

- Eco- or Bio-farming that uses bio-organic fertilizers for boost **productivity**
- **High-quality and nutritive animal feeds to advance organic agriculture.**

1. Development of Bio-organic Fertilizer



Microbes

Biofertilizers

\+ Compost +

- Nitrogen fixing
- Potash and Phosphate-Solubilizing
- Phosphate mobilizing
- PGP

→ Bioorganic fertilizer

Biomass

Pellets

SANITARY LAND-FILLING

- ❖ Besides households and urban activities, the industry is directly associated with the production of large amounts of solid wastes.
- ❖ ***Landfilling*** is still widely accepted and used in any waste management strategy, ***but it can constitute a hazard for the environment if not properly designed and handled*.**
- ▪ This method generally offers lower cost of operation and maintenance when compared to other methods, such as incineration, biogas, etc.

What is a Sanitary Landfill?

- ❖ *The **sanitary landfill** is a technique for the **final disposal of solid waste in the ground** that **causes no nuisance or danger to public health or safety; neither does it harm the environment during its operation or after its closure.***
- ❖ *S*anitary landfill can be also defined as a ***facility designed and operated as a basic sanitation project that has sufficiently safe elements of control***, and the ***success*** of which lies ***in the selection of the suitable site, its design, and of course, its effective and efficient operation and control methods.***
- ▪ This technique uses engineering principles to ***confine the waste to as small an area as possible, covering it daily with layers of earth*** and ***compacting*** it to reduce its volume.
- ▪ *In addition, it **anticipates the problems that could be caused by the liquids and gases produced** during the decomposition of organic matter.*
- ➢ Some materials such as paints, cleaners, chemicals, motor oil, batteries, and pesticides are some of the common items that are banned from MSW's disposal landfill.

❖ In spite of all environmental policies, the majority of municipal and industrial wastes still ***end up at the landfill and the amount of deposited wastes is significant***.

- ***For example:*** in EU countries in 2010: Landfill still accounted for nearly **40%** of municipal waste treated in the EU.
  * **502 kg** of *municipal waste was generated per person*, while **486 kg** of *municipal waste was treated per person:*
    # **38% was landfilled**, ***22% incinerated, 25% recycled, and*** **15% composted**.

❖ ***A major problem regarding disposal of solid wastes using landfill is***
  * lack/shortage of available landfilling sites,
  * production of landfill leachates and
  * biogas production, consisted mainly of ***carbon dioxide and methane***, which methane has 19-28 times higher global warming potential than CO_2 in a 100-year cycle.

Types of Sanitary Landfill

- It involves researching into the type and amount of wastes, planning, site selection, amount of land, design and execution of the fill, infrastructure required for receiving the waste and for the control of operations, amount and management of the investments, and operating and maintenance costs.

❑ Accordingly, three types of sanitary landfills could be proposed as follows for final disposal:

a) Mechanized sanitary landfill: is designed for large cities and populations that produce more than 40 tons of waste daily.

- To operate this type of sanitary landfill, a solid waste compactor is required, as well as specialized earth-moving equipment: track-type tractor, backhoe, loader, dump truck, etc.

b) Semi-mechanized sanitary landfill: When a town needs to dispose of ***16 - 40 tons daily*** of MSW in the sanitary landfill, *it is advisable to use heavy machinery to support the manual labor, to ensure that the garbage will be thoroughly compacted, and the fill banks properly stabilized, thereby prolonging the useful life of the landfill.*

- A farm tractor adapted with bulldozer or blade and with a scraper or roller for compacting could be suitable for operating this "semi-mechanized" landfill.

E.g.: In Mexico, using an adapted 31 HP tractor, and with the help of one laborer, they require only 8 hours of work to confine the waste generated by towns of up to 80,000 inhabitants, or approximately 40 ton/day of garbage in a sanitary landfill.

- Previous experience shows that it is necessary to use earth-moving equipment (track-type tractors or backhoes) permanently when the sanitary landfill receives more than 40 t/d of MSW.
- The farm tractor can be used to provide the waste collection service, or at least to support the regular service, if it is coupled to a hydraulic dumping trailer of some 6 to 8 m3 capacity or a compaction unit, depending on the needs and resources of the locality.

c) Manual sanitary landfill: This is an adaptation of the sanitary landfill project for small communities which, in view of the quantity and type of waste produced ***less than 15 t/d*** and their precarious economic situation, cannot afford to buy heavy equipment because of its high operating and maintenance costs.

- The term "manual" refers to the fact that the task of compacting and confining the waste can be carried out by a team of laborers using hand tools.

❖ Sanitary landfills are the ultimate repository of a city's Municipal Solid Waste (MSW) after all other Municipal Solid Waste Management (MSWM) options have been exercised."

Retail store on top of a landfill

Golf course on top of a landfill.

Construction methods for a sanitary landfill

❖ The ***construction method and subsequent operation of a sanitary landfill*** are ***mainly determined by the topography of the terrain***, ***the type of soil*** ***and*** ***the depth of the water table***.

❖ There are ***two basic ways*** of making a sanitary landfill.

1) Trench method

➢ Used in *flat regions* and *consists of* ***periodically digging trenches 2 or 3 ms*** *deep with a backhoe or a track-type tractor*. Some trenches have been dug as deep as **7 m**.

- The solid waste is placed and spread in the trench, later to be compacted and covered with the excavated soil.
- ***Special care should be taken during rainy periods, since water can flood the trenches.***
  * To prevent this, drainage ditches should be dug around the perimeter to divert the waters, and internal drainage can also be provided for the trenches.
  * In extreme cases ***a roof can be erected over them***, or the accumulated water can be pumped out.
- The slopes or walls should be cut corresponding to the settling angle of the excavated soil.
- The digging of trenches demands favorable conditions *with regard to the depth of the water table as well as to the type of soil*, mainly **shell soil** is preferred.
  * Terrain with a high water table or one close to the surface is not appropriate because of the risk of contamination of the aquifer.
  * Rocky terrain is not suitable either, because it is difficult to dig.

2) Area method

- In relatively flat areas where it may not be feasible to dig pits or trenches to bury the waste, it can be **deposited directly on the original ground,** which should be raised several meters after the terrain has been made waterproof.

- In these cases the cover material will have to be brought from other places or, if possible, extracted from the surface layer.
- The pits are made with a gentle slope to prevent landslides and ensure greater stability as the landfill rises.
- *The area method can also be used to fill natural depressions or abandoned quarries that are several meters deep.*
- The cover earth is excavated from the sides of the terrain or from a nearby site in order to avoid or reduce the haulage expense.
- The operation of unloading and construction of the cells should begin from the bottom up.
- The landfill is made supporting the cells on the natural slope of the terrain, that is, the waste is unloaded at the toe or base of the slope, where it is spread and packed against it, and it is covered daily with a layer of soil.
- This activity is repeated as the operation continues, advancing over the site, ***maintaining a gentle slope of some 18.4 to 26.5 degrees***, that is, a vertical/horizontal ratio of 1:3 to 1:2, respectively, and of 1 to 2 degrees on the surface, that is, a ***2 to 3.5% grade.***

3) Combination of both methods

- It is possible to combine them to make full use of the site and the cover material, and to obtain better results.

Advantages and disadvantages of the sanitary landfill

Advantages	Disadvantages
1. The initial capital investment is lower than that required to establish incineration plants or composting facilities for waste treatment.	1. The acquisition of the terrain is often a problem due to local inhabitants' opposition to the selected site (known as the NIMBY phenomenon: Not In My Back Yard) for various reasons: - Lack of knowledge of the sanitary landfill technique. - The term sanitary landfill is associated with the open dump. - Citizens' evident distrust of local administrations that do not guarantee the quality or the sustainability of the work. - Legal problems regarding land registration.
2. It has lower operating and maintenance expenses than treatment methods.	2. The rapid process of urban growth that limits the amount of land available and makes it more expensive, causing the sanitary landfill to be located at a distance from the town.
3. A sanitary landfill is a complete and definitive method, given its capacity to receive every kind of MSW.	3. The vulnerability of the quality of operation of the landfill and the high risk of its becoming an open dump, mainly because of a lack of political decision on the part of local governments to invest the necessary funds for its correct operation and maintenance.
4. It creates employment for unskilled labor, which is available in abundance in developing countries.	4. The finished landfill is not recommended for building homes, schools, etc.
5. Methane gas can be collected in sanitary landfills that receive more than 500 t/day, and this gas can be an alternative source of energy for some cities.	5. The restriction against building heavy infrastructure because of settling and sinking after the landfill is finished.
6. Its location can be as close to the urban area as the existence of available sites permits, which reduces hauling costs and facilitates supervision by the community.	6. It is necessary to monitor the site after closure of the sanitary landfill, not only to check for negative environmental impacts, but also to prevent undue use of the site by the inhabitants.
7. It allows lands considered unproductive or marginal to be recuperated, making them useful for constructing parks, recreational facilities, green areas, etc.	7. It can cause a long term environmental impact if the necessary precautions are not taken in the selection of the site and if mitigation measures are not applied. In the case of large sanitary landfills, it is advisable to analyze the effects of vehicular traffic, in particular the trucks carrying the waste on the roads that converge on the site and that produce dust, noise and windblown litter. In the immediate neighborhood the impact is produced by the liquids, gases and bad odors that can emanate from the landfill.
8. A sanitary landfill can start operating in a short time as a waste elimination method.	8. The properties or lands surrounding the sanitary landfill may be devalued.
9. It is considered flexible because it can receive greater additional quantities of waste with a small increase in personnel.	9. Usually it cannot receive hazardous waste.

Reactions Take Place Inside a Sanitary Landfill

❖ The MSW deposited in a sanitary landfill undergoes a series of ***physical, chemical, and biological changes*** that are simultaneous and interrelated.

a) <u>Physical changes</u>: The most important physical changes are those associated with the ***compacting of the MSW***, ***the migration of gases within and outside the sanitary landfill***, ***the intake of water and the movement of liquids in the interior and toward the substratum***, and ***settling caused by the consolidation and decomposition of the organic matter present in the waste.***

- The ***migration of gases*** is of particular importance for the operational and maintenance control of the system. For example, ***when biogas is trapped, internal pressure can cause cracking of the cover and fissures. This condition allows rain water to penetrate inside the sanitary landfill.***
- ***This water, in turn, causes a greater production of gases and leaching***, contributing to differential sinking and settling at the surface and the destabilization of the fill banks due to the greater weight of the mass of wastes.

b) <u>Chemical reactions</u>: Chemical reactions that occur within the sanitary landfill and also in open garbage dumps include the ***dissolving and suspension of matter and products of biological conversion*** *in the liquids that filter through the mass of MSW*, ***the evaporation of chemical compounds and water***, **the adsorption of volatile organic compounds**, the **dehalogenation and decomposition of organic compounds**, and the ***reactions of oxidation-reduction that affect the dissolving of metals and metallic salts.***

- The significance of the decomposition of organic products is that these materials can be transported out of the sanitary landfill or out of the garbage dump with the leachates.

c) <u>Biological reactions</u>: The most important biological reactions that occur in sanitary landfills are carried out by ***aerobic and anaerobic microorganisms***, *and are* ***associated with the organic part of the MSW***, ***which produces gases and leachates***.

- The process of decomposition starts with the ***presence of oxygen*** (aerobic phase); once the waste is covered, the oxygen starts to be consumed by biological activity.

  **** During this phase the principal product is carbon dioxide.***

- Once the oxygen is consumed, decomposition takes place without it (***anaerobic phase***): at this stage the organic matter is ***transformed into carbon dioxide, methane, and traces of ammonia and hydrogen sulfide.***

Generation of Liquids, Gases and Solids

❖ Almost all solid waste suffers a certain degree of decomposition, but it is the organic component that undergoes the greatest changes.

- ***The byproducts of decomposition include liquids, gases and solids.***

a) Leached or percolated liquid.

- The natural decomposition or putrefaction of garbage ***produces a foul-smelling black liquid,*** known as ***leached or percolated liquid***, that looks like domestic water waste, but much more concentrated.
- ***Rain water filtering*** through the layers of waste increases its volume in a far greater proportion than does the moisture of the MSW.
- It is therefore ***important to intercept the water and divert it to prevent an increase in leaching***; otherwise there could be problems in the operation of the landfill and contamination in the water courses, sources of water, and neighboring wells.

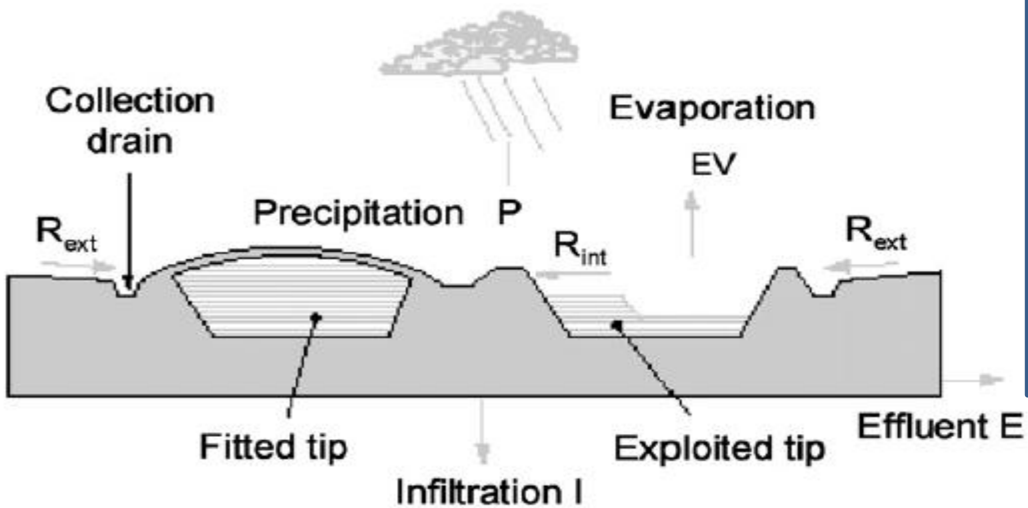
❖ Landfill leachate is created when moist waste or water percolates through the waste and biological and chemical constituents from the waste is brought into solution.

Leachate characteristics

- The characteristics of the landfill leachate can usually be represented by the basic parameters ***COD, BOD, the ratio BOD/COD, pH, suspended solids (SS), ammonium nitrogen (NH3-N), total Kjeldahl nitrogen (TKN), heavy metals and other toxic substances.***
- ***Leachate flow rate (E)*** *is closely linked to* ***precipitation (P), surface run-off (Rin, Rext), and infiltration (I) or intrusion of groundwater percolating through the landfill (see fig).***

- ***Landfilling technique*** such as waterproof covers, liner requirements such as clay, geotextiles and/or plastics, shell soil, etc remains primordial to control the quantity of water entering the tip and so, to reduce the threat pollution.
- ***The climate*** has a great influence on leachate production ***because it affects the input of precipitation (P) and losses through evaporation (EV).***
- **L**eachates production depends also on the nature of the waste itself, mainly its water/moisture and chemical content and its degree of compaction into the tip.

  * The production is generally greater whenever the waste is less compacted, since compaction reduces the infiltration rate.



- There are many factors affecting the quality of leachates, i.e., age, precipitation, seasonal weather variation, waste type and composition (depending on the standard of living of the surrounding population, structure of the tip).

- The figure shows Water cycle in a sanitary landfill.

Composition of landfill leachate

- Significant components of leachate at the beginning of landfill operation are heavy metals and degradable organics, while persistent organic pollutants usually appear later as a result of ***biotic and abiotic processes in the system.***

- *Among these substances, several compounds are classified as potentially hazardous:*
  * bio-accumulative, toxic, genotoxic (chemical compounds that damage the genetic information within a cell causing mutation that may lead to cancer), and they could have endocrine disruptive effect.
- Hazardous substances from the leachate should be caught and removed properly, to avoid spreading in the receiving environment.
- Efficient treatment methods must be matched to the actual characteristics of a particular leachate and they could vary with time.
- Often, biological processes are employed if biotreatability in terms of low toxicity and at least moderate biodegradability of the leachate is indicated.

▪Toxicity tests must be accomplished prior to the biodegradability determination to assess the impact of landfill leachate components on microorganisms of the aerobic or anaerobic activated sludge and starts with the determination of ready biodegradation in common environmental conditions.

➢ Freshly produced landfill leachates are usually high strength wastewater characterized by:

- low pH (5-6)
- high BOD5 (4000-13000 mg/l) and high COD (10000-60000 mg/l) value, as well as by the presence of several toxic/hazardous compounds.

- *The main applicable methods are biological, chemical, membrane separation and thermal treatment process.*
- The physico-chemical processes are generally of higher cost and low effectiveness.
- Biological processes based up on suspended growth biomass, such as conventional activated sludge process, were proved to be effective for the removal of organic carbon and nutrients content.
- ***Bioaugmentation*** is the addition of wastewater of bacterial cultural products, containing different strains of microorganisms and/or enzymes with the purpose of providing sufficient quantity and diversity of microorganisms or constituents, which can help improve the performance of landfill leachates.
- The preliminary experiments reveal that effective microorganisms could ***remove 25% and 40%*** of chemical oxygen demand (COD) from leachate in ***fine sand and sabuolus clay column***, respectively.
- In the last few decades, researchers also confirmed the ***great potential of white rot fungi*** for ***removal of hazardous as well as toxic pollutants***.
- They produce various extracellular ligninolytic enzymes, including laccase (Lac) and manganese peroxidase (MnP), which are involved in the degradation of lignin in their natural lignocellulosic substrates, and offer also an interesting potential for the landfill leachate treatment.

- The tests include: measurement of chemical oxygen demand (COD) or dissolved organic carbon (DOC) removal, O2 consumption, etc.

❖ Untreated leachates can permeate groundwater or mix with surface waters and contribute to the pollution of soil, ground water, and surface waters.

- Thus, **careful site management** can reduce the quantity and increase the purity of the formed leachate.
- Its composition is therefore ***site- and time specific***, based on the characteristics of deposited solid wastes, physico-chemical conditions, rainfall regime that regulates moisture level, landfill age and others.

❖ ***The landfill can be considered as a complex environment or even a biochemical reactor, where many interacting physical, chemical and biological processes take place.***

b) Gases produced from landfills:

- A sanitary landfill behaves like an anaerobic digester.
- The emission of landfill gases (LGs) and odour produced by the anaerobic and aerobic decomposition of organic matter is a major source of Greenhouse gases (GHG) which are responsible for global warming and ozone depletion.
- Experimental research and process modeling demonstrate that from ***1Mt about 0.2 Mt would be converted to landfill gases (LGs)*** consisting of ***0.11 Mt carbon dioxide and 0.09 Mt methane, and other trace constituents.***
- ***LG emissions from landfills account for nearly half of the world's total anthropogenic sources of methane.***

- *It is therefore essential to do research to develop mechanisms to collect or eliminate methane, CO_2 and bad odour emissions and leachates from landfill so that it can substantially lower the world's overall GHG emissions and reduce the environmental pollution of the ecosystem.*

Gases production

- The decomposition of organic matter by action of microorganisms present in the medium has two stages: aerobic and anaerobic.

a) During the *aerobic stage* the oxygen that is present in the air contained in the interstices of the mass of buried waste is rapidly consumed.

b) The *anaerobic stage*, on the contrary, is the one that predominates in the sanitary landfill because the air does not pass through it and there is no circulation of oxygen; thus appreciable quantities of methane (CH_4) and carbon dioxide (CO_2) are produced, as well as traces of foul-smelling gases, such as **H_2S, ammonia (NH_3), and mercaptans** are produced.

- Methane gas deserves the greatest attention because, although it is odorless and colorless, it is inflammable and explosive if it is concentrated in the air in a proportion of ***5 to 15% in volume***; gases have a tendency to accumulate in empty spaces inside a landfill and take advantage of any fissure in the terrain or permeability in the cover to leak out.
- When methane gas accumulates inside the landfill and migrates to adjacent areas, there is a risk of explosion.
- It is therefore recommended that there be adequate venting of this gas. However, in small landfills this is not a significant problem.

- Generally, the following ***sequential and distinct consecutive stages*** will be ***involved and*** used to ***treat solid waste*** and ***landfill stabilization***.

1. **Aerobic phase**, characterized by processes enabled by oxygen present.

- In this acclimation phase, sufficient moisture develops to support active microbial communities.
- Initial changes in compounds occur in order to establish the appropriate conditions for further biochemical degradation.

2. **Hydrolysis and fermentation stage**, where complex molecules are broken into smaller fragments and an aerobic environment is transferred to an anaerobic, the amount of entrapped oxygen is drastically reduced and the reducing conditions occur.

- ***The main electron acceptors are nitrates and sulfates.***

3. **Anaerobic acetogenic stage**, characterized by continuous hydrolysis of solid wastes, preceded by the production of ***volatile fatty acids at high concentrations***.

- ***Low hydrogen*** levels promote the activity of methanogenic bacteria, which produce methane and carbon dioxide from organic acids.
- ***This stage could be recognized by a high concentration of metals in the leachate, due to their increased mobility because of the lower pH, even below 4.***

4. **Anaerobic methanogenic stage**, where significant methane production is evident.

- pH is again increased to 7-8, due to the degradation of intermediate acids and the buffering capacity of bicarbonates.
- The concentration of heavy metals is reduced again, due to their complexation and precipitation.
- During this stage, the mesophilic bacteria, which are active in temperatures of 30°C-35°C, and thermophilic bacteria, active in the range of 45°C-65°C, dominate the microbial population.

5. **Maturation stage**, as the final stage of landfill stabilization, could be recognized by low microbial activity due to degradation of biodegradable fraction and limiting impact of nutrients.

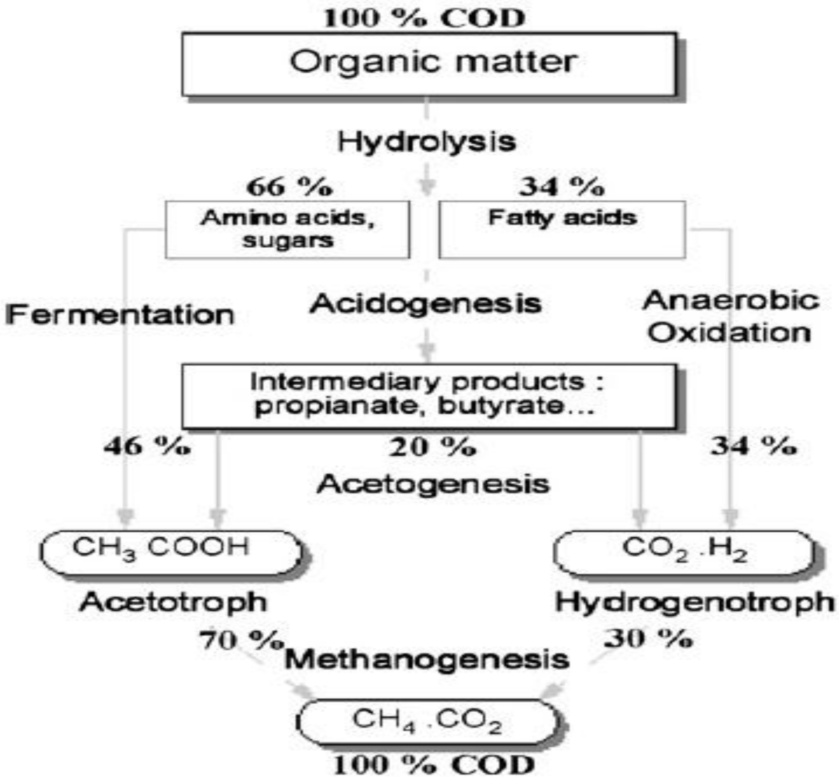
- As a result, the methane production decreases, as does the amount of pollutants in the leachate, which usually stays at a constant level.
- Slow degradation activity of the resistant organic pollutants can be observed by the production of humic and fulvic substances.

Anaerobic Degradation Scheme for the Organic Material in a Sanitary Landfill

❖The figure in the next slide proposes anaerobic degradation scheme for the organic material in a sanitary landfill.

- In young landfills, containing large amounts of biodegradable organic matter, a rapid anaerobic fermentation takes place, resulting in ***volatile fatty acids (VFA)*** as the main ***fermentation products***.
- ***Acid fermentation*** is enhanced by a high moisture content or water content in the solid waste.
- This early phase of a landfill's lifetime is called *the acidogenic phase*, and leads to the release of large quantities of free VFA, as much as 95% of the organic content.
- ***As a landfill matures***, the **methanogenic phase occurs**. Methanogenic microorganisms develop in the waste, and the VFA are converted to biogas (CH4, CO2).
- The organic fraction in the leachate becomes dominated by refractory (non-biodegradable) compounds such as humic substances.

❖ The figure below proposes anaerobic degradation scheme for the organic material in a sanitary landfill, as well as shows ***COD balance of the organic fraction*** in a sanitary landfill.



Basic Principles of a Sanitary Landfill

❖ ***The following basic practices for the construction, operation, and maintenance of a sanitary landfill should be emphasized:***

a) **Constant supervision** during the construction, to make sure that a high level of quality is maintained in the building of the landfill infrastructure and in the routine daily operations of unloading the waste, covering it, and compacting the cell to keep the landfill in an optimal condition.

- This means appointing one person to be responsible for its operation and maintenance.

b) Diversion of runoff waters to prevent as far as possible their filtering into the sanitary landfill.

- Verifying the height of the daily cell to reduce problems of sinking and ensure greater stability.
- The daily cell is the construction unit of the sanitary landfill.

c) Daily covering with a layer of 0.10 to 0.20 m of soil or similar cover material.

d) Compacting the MSW with layers 0.20 to 0.30 m thick and final compaction when the whole cell is covered with soil.

- The success of the daily work largely depends on this task, since in the long term it enables a greater density to be achieved and prolongs the useful life of the site.

e) Achieving greater density (specific gravity) since this is more advisable from the economic and environmental points of view.

f) Control and drainage of percolated liquids and gases to maintain ideal operating conditions and protect the environment.

g) The final cover, some 0.40 to 0.60 m thick, is installed using the same methodology as for the daily cover; the final earth cover must be capable of producing and sustaining vegetation for the integration of the closed site into the natural landscape.

Treatment of Xenobiotic Compounds

Basic Concepts

❖ The term ***xenobiotic*** is derived from Greek where _***xenos***' means ***foreign or strange*** and ***-bios*** means ***life***, and defined as ***xenobiotics compounds are chemicals which are alien to the biosphere***.

❖ ***Man made chemicals present in the nature at high concentrations*** polluting the environment is known as **Xenobiotic compounds**. E.g. DDT, PCB, BHC, polyethylene, polystyrene, PVC,

- These compounds are not commonly produced by nature.
- Some microbes have been seen to be capable of breaking down of xenobiotics to some extent.
- *But most of the xenobiotic compounds are* ***non degradable*** *and* ***recalcitrant*** ***i****n nature.*
- The ***properties*** of xenobiotic compounds attributing to its recalcitrant properties are:

  a) *Non recognizable* as substrate by microbes to act upon and degrade it.

  b) It does *not contain permease* which is needed for transport into microbial cell.

  c) *Large molecular nature* makes it difficult to enter microbial cell.

  d) They are *highly stable and insolubility* to water adds to this property.

  e) *Mostly toxic in nature*.

❖***The recalcitrant xenobiotic compounds can be divided into different groups depending on their chemical composition:***

a) ***Halocarbons***: consist of halogen group in their structure.

- Mainly used in ***solvents, pesticides, propellants*** etc, and are ***highly volatile and escape into nature leading to destruction of ozone layer of atmosphere.***
- ***The compounds present in insecticides, pesticides etc,. leach into soil where they accumulate and result in*** **biomagnification.**

b) Polychlorinated biphenyls (PCBs): consist of a halogen group and benzene ring.

- They are mainly used in plasticisers, insulator coolants in transformers etc.
- They are ***chemically and biologically inert*** adding on to its recalcitrant nature.

c) Synthetic polymers: are mainly used to form plastics like polyester, polyvinyl chloride etc.

- They are insoluble in water and of high molecular weight explaining the recalcitrant property.

d) Alkylbenzyl Sulphonates: consist of a sulphonate group which resists break down by microbes.

- They are mostly found in detergents.

e) Oil mixtures: When oil spills occur covering a huge area the break down by action of microbes becomes non effective.

- They become recalcitrant as they are insoluble in water and some components of certain oils are toxic in higher concentrations.

Status of Xenobiotic

❖The total annual world production of synthetic organic chemicals is over **300 million tons** with more than *1000 new compounds fabricated every year*, so that the actual diversity of chemicals reaches approximately **20 millions of substances**.

- ***If not treated, all these compounds sooner or later appear in the environment.***
- Majority of the xenobiotics (foreign agents to the biological system) after deliberate or inadvertent release enter in the ***soil, sediment and water***.

❖ *Such foreign molecules are either broken down to simpler forms or remain unaltered for long time because of their persistent nature and its toxicity, posing a great threat to the ecosystem which includes various non target species at the apex of which are the human being.*

- They include pesticides, plastics, phenols, pharmaceutical and personal care products, solvents, alkanes, polycyclic hydrocarbons (PAHs), antibiotics, synthetic azo dyes, pollutants (dioxins and polychlorinated biphenyls), polyaromatic, chlorinated and nitro-aromatic compounds.

- Some of the xenobiotics undergo ***bioaccumulation/biomagnification*** and produce deleterious effects to the environment; while others are ***converted into even less desirable residues so that they cause untoward effects***.
- Several xenobiotics have toxic effects to wildlife and human and the release of antibiotics in the environment may cause the development of bacterial resistance.
- Some compounds such as polycyclic aromatic hydrocarbons (PAH) can be degraded by bacteria, fungi and yeast. Benzene, toluene, xylene, ethylbenzene are degraded by bacteria.
- However, the presence of ***methyl, chloro, nitro, amino and sulphonyl group in benzene ring*** cause recalcitrance of the compounds.

❖ ***In soil, herbicides and pesticides are degraded at different rates. For example:***

1) Diquat and paraquat are ***photolysed*** to alpha-picolinate and N-methyl-isonicotinate, respectively, which are then ***degraded by microbes***.
   * Binding of herbicides to soil particles retard their biodegradation.
2) ***Parathion hydrolase*** from *Pseudomonas diminuta* is encoded by **plasmids**, which hydrolyze *parathion to p-nitrophenol*, the later is then degraded by other microbes.

❑ Generally, xenobiotics are *Persistent organic pollutants which* are long-lived organic compounds that ***become concentrated as they move through the food chain***.

- They are also known as persistent toxins that ***bioaccumulate*** or as ***pseudo-oestrogenic chemicals.***
- They have toxic effects on animal reproduction, development, and immunological function.
- It is quite shocking that some xenobiotic compounds (phenols, biphenyl compounds, phthalates, etc.) act as **endocrine disruptors**.

- ***In natural habitats, the physiochemical properties of the environment may affect and even control biodegradation performances.***
- **Substances that are *present in abnormally high concentrations* can also be considered as xenobiotics.**
  - For example, the antibiotic drugs found in the human body are considered as xenobiotics as they are neither produced by human body itself nor a normal part of diet.
  - Even a natural substance can be considered a xenobiotics if it has entered the body of another organism.
- Depending on their fate in air, water, soil or sediment, xenobiotic pollutants may become available to microorganisms and plants in different environmental compartments.

Mechanisms of Reduction/Removal

- **Xenobiotics in the body are removed by the process called *xenobiotic metabolism*.**
- In this process, these compounds are *degraded by liver where enzymes by the process of oxidation, hydrolysis, reduction or hydration degrade xenobiotics* and then these ***excreted out*** of the body by the usual ***excretion routes of urination, exhalation, sweating and excretion***.
- ***But, it needs seriously developed treatment methods for the reduction of health risk.***
- Certain abiotic mechanisms and photo-oxidation also play an important role in the degradation of certain organic chemicals but such transformations are generally incomplete because these processes cannot convert the compounds into inorganic form.

1) Biodegradation: means transformation of a chemical compound from highly complicated form (organic) to simple (inorganic) form through biological means.

- Microbes play the most important role in the process of biodegradation.
- If we say a compound is biodegradable, it means that it can be converted into various inorganic forms or be mineralized, i.e., possible to ***convert into carbondioxide and water.***
- **Bioremediation:** is the most effective method for the removal of wide variety of organic pollutants.
- ***Bioremediation*** is defined as the ***use of biological mechanisms to destroy, transform, or immobilize environmental contaminants in order to protect potential sensitive receptors*.**
- Many compounds that are considered to be hazardous can be converted into harmless products, and eradicates the chance of potential problems associated with treatment and disposal of contaminated material.
- **Biotransformation** is the ***metabolic modification of the molecular structure*** of a compound, resulting in the loss or alteration of some characteristic properties of the original compound, with no (or only minor) loss of molecular complexity.

➢ ***Biotransformation may effect the solubility and mobility in the environment or toxicity of the organic compound.***

- The hazards posed by xenobiotics are huge, since these compounds are highly toxic in nature and can affect survival of lower as well as higher eukaryotes.
- These compounds are persistent and remain in the environment for many years leading to ***bioaccumulation* or *biomagnification***.
- Metabolic dead-end products will accumulate in the environment, become part of the soil humus, or enter the food chain leading to biomagnification.

2) Phytoremediation: the use of plants for cleaning up and remediation of xenobiotic compounds.

❖ *Phytoremediation* is based on one basic principle that is the use of plant that takes the pollutant through the roots.

- It is ***applicable at sites containing organic nutrients, or metal pollutants*** for ***in situ treatment*** that can be ***accessed by the roots of plants and sequestered, degraded, immobilized or metabolized in place.***

❖ ***The pollutants can be stored in the plant, volatized by the plant, and metabolized by the plant, or any combination of these techniques.***

❖ ***Some of the most commonly used techniques for phytoremediation are the following:***

A) Phytoextraction is the uptake and storage of pollutants in the plants stem or leaves.

* Some plants, called hyper-accumulators, extract pollutants through the roots.

* *After the pollutants accumulate in the stem and leaves, the plants are harvested either burned or sold. This method is particularly useful when remediating metals.*

B) Phytovolatization is the uptake and vaporization of pollutants by a plant.

- ***This mechanism takes a solid or liquid contaminant and transforms it to an airborne vapor.***

- The ***pollutant can be metabolized by the plant before it is vaporized***, as in the case of ***mercury, lead and selenium.***

C) Phytodegradation is the metabolization of pollutants by plants.

- Contaminants are accumulate in plants tissues, then degrades the pollutant through metabolism.

❖ Although plants have ***inherent ability to detoxify some xenobiotic pollutants***, they generally ***lack the catabolic pathway for complete degradation/mineralization*** compared to microbes.

❖ ***Therefore, to be effective it needs an interdisciplinary approach involving both plants and microbes.***

➢ ***Table shows advantages and limitations of the phytoremediation technology***

Advantages	Limitations
Applicable to a wide variety of inorganic and organic contaminants.	Limited by depth (roots) and solubility and availability of the contaminant.
Reduces the amount of waste going to landfills.	Although faster than natural attenuation, it requires long time periods (several years).
Does not require expensive equipment or highly specialized personnel.	Restricted to sites with low contaminant concentration.
It can be applied *in situ*. Reduces soil disturbance and the spread of contaminants.	Plant biomass from phytoextraction requires proper disposal as hazardous waste.
Early estimates of the costs indicate that phytoremediation is cheaper than conventional remediation methods.	Climate and season dependent. It can also lose its effectiveness when damage occurs to the vegetation from disease or pests.
Easy to implement and maintain. Plants are a cheap and renewable resource, easily available.	Introduction of inappropriate or invasive plant species should be avoided (non-native species may affect biodiversity).
Environmentally friendly, aesthetically pleasing, socially accepted, low-tech alternative.	Contaminants may be transferred to another medium, the environment, and/or the food chain.
Less noisy than other remediation methods. Actually, trees may reduce noise from industrial activities.	Amendments and cultivation practices may have negative consequences on contaminant mobility.

Biological Treatment Processes of Xenobiotics Compounds

➢ In natural waters and soils, the mineralization or complete biodegradation of an organic molecule is almost always a result of ***microbial activity***.

▪ A huge number of bacteria and fungi generally possess the capability to degrade organic pollutants.

▪ ***The most rapid and complete degradation of the majority of pollutants is brought about under aerobic conditions.***

❖ ***The essential characteristics of aerobic microorganisms degrading organic pollutants are consists of: (as shown in the figure presented in the next slide)***

1. ***Metabolic processes*** for optimizing the *contact between the microbial cells and the organic pollutants.*

▪ The chemicals must be accessible to the organisms having biodegrading activities.

▪ For example, hydrocarbons are water-insoluble and their degradation requires ***biosurfactants.***

2. ***The initial intracellular attack*** of organic pollutants is an **oxidative process**, the activation and incorporation of oxygen is the enzymatic key reaction catalyzed by ***oxygenases and peroxidases.***

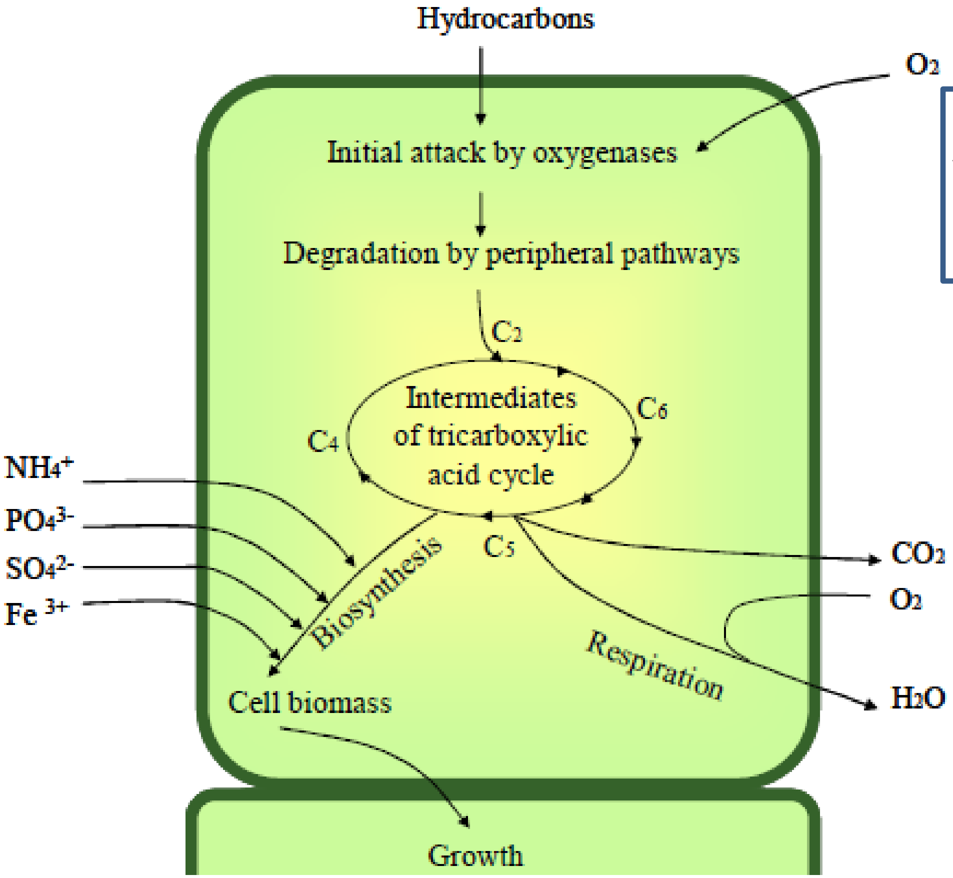
3. ***Peripheral degradation pathways*** convert organic pollutants step by step into ***intermediates*** of the central intermediary metabolism, e.g., the tricarboxylic acid cycle.

4. ***Biosynthesis of cell biomass*** from the central precursor metabolites, e.g., acetyl-CoA, succinate, pyruvate.

▪ Sugars required for various biosyntheses and growth must be synthesized by ***gluconeogenesis***.

▪***Biodegradation*** *is defined as the biologically catalyzed reduction in complexity of chemical compounds based on two processes:* ***growth and cometabolism****.*

- **In the case of cell growth**, organic pollutants are used as sole source of carbon and energy, consequently the process results in complete degradation (mineralization) of organic pollutants.
- **Cometabolism** is defined as the ***metabolism of an organic compound without being able to use that compounds as a growth substrate or as an energy source.*** As such those MOs would need another substrate as carbon and energy source on which to grow.
- ***Cometabolism*** has been observed in the transformation of a number of important xenobiotic compounds, including dioxin, trichloroethene (TCE) and polychlorinated biphenyls (PCBs).



❖ Figure show the main principle of aerobic biodegradation of hydrocarbons: growth associated processes.

❖ Enymatic key reactions of aerobic biodegradation are oxidations catalyzed by oxygenases and peroxidases.

❖ Thus in the presence of molecular oxygen, compounds such as benzoates, phenols, anilines and aromatic hydrocarbons are initially oxidized by mono- or dioxygenases & converted to catechols or protocatechuates with subsequent mineralization.

❖ A study has indicated that rapid decomposition of herbicide, dalapon, without an increase in bacterial numbers in soil samples.

- This is due to *breakdown of the herbicide by a chemical process or decomposition by fungi*, and the possibility of a co-metabolic degradation of dalapon appears to be equally probable.

❑ ***The following table shows list of xenobiotic compounds and degrading bacterial genera.***

Target compounds	Bacteria degrading the compounds	References
Pesticides		
Endosulfan compounds	*Mycobacterium* sp.	Sutherland et al., 2002
Endosulphate compounds	*Arthrobacter* sp.	Weir et al., 2006
HCH	*Pseudomonas putida*	Benezet and Matusumura, 1973
2,4-D	*Alcaligenes eutrophus*	Don and Pemberton, 1981
DDT	*Dehalospirilum multivorans*	Chaudhry and Chapalamadugu, 1991
Halogenated organic compounds		
Vinylchloride .	*Dehalococcoides* sp.	He et al., 2003
Atrazine .	*Pseudomonas* sp.	Bruhn et al., 1988
PCE	*Dehalococcoides ethenogenes*195	Magnuson et al., 2000
PAH compounds		
Napthalene	*Pseudomonas putida*	Habe and Omori, 2003
PCP	*Psedomonas* sp.	Yen and Serdar, 1988
3CBA	*Arthrobacter* sp.	Pignatello et al., 1983
1,4DCB	*Alcaligenes* sp.	Don and Pemberton, 1981
2,3,4-chloroaniline	*Pseudomonas* sp.	Spain and Nishino, 1987
2,4,5-T	*Pseudomonas* sp.	Latorre et al., 1984
Fluoranthrene	*Pseudomonas cepacia* AC1100	Karns et al., 1983
Pyrene	*Mycobacterium*PYR-1	Kanaly and Harayama, 2000
	Sphingomonas paucimobilis	Habe and Omori, 2003
Phthalate compounds		
Phthalate	*Burkholderiacepacia*DBO1	Chang and Zylstra, 1999
Other compounds		
PCB	*Rhodococcus*RHA1	Kimbara, 2005
Dioxins	*Dehalococcoides* sp.	Bunge et al., 2003
RDX	*Desulfovibrio* sp.	Boopathy and Kulpa, 1998
Benzene	*Dechloromonas* sp.	Coates et al., 2001
Petroleum products		
	Achromobacter sp. *Acinetobacter* sp. *Micrococcus* sp. *Nocardia* sp. *Bacillus* sp. *Flavobacterium* sp.	Austin et al., 1977
Azo dyes	*Bacillus* sp. *Pseudomonas* sp. *Sphingomonas* sp. *Xanthomonas* sp.	Dykes et al., 1994 Stolz, 2001 Stolz, 2001 Reife and Freeman, 2000

Factors Influencing Microbial Degradation of Xenobiotics

➢ ***Numerous factors can affect the biodegradation processes.***

- They depend on the ***nature of chemical molecules to be degraded*** (e.g. molecule size, charge, number and position of functional groups, solubility and toxicity) as well as the ***environmental conditions.***
- For instance, some molecular features can *increase recalcitrance; environmental factors influence the growth of organisms, the availability of xenobiotics* and more subtly, they can *affect the gene expression*.

❖ ***Therefore, basic information is required to achieve a successful biotreatment:***

- o nature of the xenobiotic chemicals,
- o concentration of the xenobiotic chemicals,
- o presence and activity of the xenobiotic degrading microorganisms,
- o appropriate conditions of cultivation which are required for the growth of the target MOs.

➢ ***Usual factors which play a significant role during biological treatments are:***

- o compound bioavailability, solubility, toxicity
- o pH and temperature of the medium,
- o nutrients,
- o oxygen availability,
- o residence time
- o dilution rate.

➢ Whenever they are identified and controllable, ***chemical and environmental*** factors should be taken into account during ***the engineering development process*** and all along the xenobiotic degradation.

PCB Biodegradation Mechanisms

❖ Polychlorinate biphenols (PCB) are very toxic chemicals and suspected carcinogens.

- They include polychlorinated dibenzodioxins (PCDD), polychlorinated dibenzofurans (PCDF), and chlorinated benzenes.
- They have been found in ***sediments*** where they are a threat to the drinking water, crop, etc

❖ A consortium of bacteria has been isolated that appears able to degrade PCBs at varying degrees of degrading competence. Some **25 strains of indigenous** and **chemically mutated** (***grown naturally in diverse PCB sediments***) have been isolated and tested.

❖ The bacteria metabolized the PCBs by using **enzymes** specific to the strain.

- *In many cases* ***a particular isomer may not be completely degraded, and a second species is needed to catalyze the degradation of the intermediate*** *(although it cannot degrade the parent compound).*

❑ **Of these 25 strains:**

- ***Alcaligenes eurrophs and Pseudomonal putida*** degraded **13 different isomers** to the extent of between 80 and 100%.
- ***Arthrobacteria*** were found to degrade most isomers.
- ***Alcaligenes*** are believed to have a ***dioxygenase*** that attacks the ***carbon at position 3,4.***
- ***Corynebacterium sp*** *MBl* is believed to have a ***2,3 dioxygenase***.
- The degradation pathway may occur via **oxidation of *PCBs to Chlorobenzoic acid***.
- ***Effective strains usually contain plasmids.***
- A mutant strain that has lost its plasmid can no longer metabolize PCBs.

Mechanisms

➢ The mechanism of detail hydroxylation of **PCBs** has not been elucidated, nor an enzyme isolated.

❖ ***However, two pathways have been proposed:***

a) The first involves initial *hydroxylation in the 2,3 position* of the less substituted ring, followed by *meta cleavage* and subsequent degradation **of the *alphatic portion to form unsubstituted benzoic acids.***

***** *In this process, the chlorines on the aliphatic carbon are lost*.

b) A second pathway may be the preferential *3,4 dioxygenase* of *A.eurrophus* H850 or the *2,3 dioxygenase* of *Corynebacterium* sp MB1.

❖ In Bioclean Naturally Adapted Microbial Process, the microbes can be bacteria or fungi; the method being aerobic, anaerobic or facultative.

▪ *This has been successful with cleaning pentachlorophenol bearing sediments.*

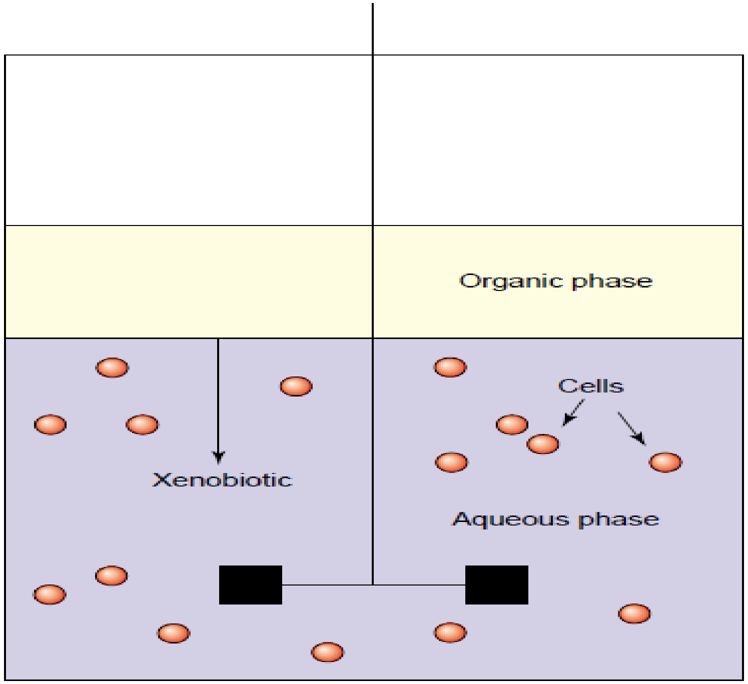
▪ The bacterial destruction of the contaminant have take place over a **three day period** and have the capacity for treating **22-28 m3/day**.

❖ ***The processing cycle has the following stages:***

1. The contaminated sediment is fed to a digester in a ***semi-solid*** if that is how it is received.
   * The final digester charge is 2/3 water and 1/3 solids.
   * It is made alkaline by the addition of sodium hydroxide and then the temperature raised to **82°C** for one hour. The mix is agitated throughout.
2. It is extracted, cooled to **30°C**, and **neutralized**.
   * Bacteria is inoculated and left for 48-72 hours.
   * The process is aerobic so sterile filtered air is fed through.
3. The treated batch is discharged to a dewatering pit where the sediment is separated for redeposition.
4. A decontamination period follows after which Stage 1 can begin again.

Two-Phase Partitioning Bioreactors (TPPB)

- ❖ Toxic organic compounds (xenobiotics) pose serious environmental and health risks worldwide.
- ❖ Biological treatment of these materials is severely constrained by ***their toxic and inhibitory nature*** and great care is required with respect to the rate at which they are provided to cells.
- ▪ Toxic levels of xenobiotic substrates can range from ***a few tens of milligrams per litre to a few hundred***, so that ***precise and controlled delivery*** of these materials is exceedingly important.
- ❖ The **TPPB** concept is based on the ***use of a water immiscible*** and ***non-aquesous organic solvent*** that is allowed to float on the surface of a cell-containing aqueous phase (see fig.).
- ▪ The solvent is used to dissolve large concentrations of xenobiotic substrates (most organic contaminants are very hydrophobic), which then partition into the aqueous phase at low levels (determined by the partition coefficient of the compound in question).



- ➢ The figure shows schematic diagram of a two-phase partitioning bioreactor.
- ▪ The upper (organic) phase is used to dissolve high concentrations of xenobiotic substrates, which partition into the aqueous phase based on the demand by the cells.
- ▪ Thus, although very high amounts of toxic organic substrates can be added to a bioreactor, the cells experience only very low (sub-inhibitory) concentrations.

- Moreover, ***as the cells consume some of the substrate***, ***disequilibrium is created***, which causes more of the xenobiotic substrate to be partitioned into the aqueous phase as the system tries to maintain ***thermodynamic equilibrium***.
- Thus, *appropriate amounts of xenobiotic substrates get delivered to the cells*; *substrate delivery is ongoing (until the organic phase becomes completely depleted)* and *the rate is determined by the metabolic activity of the cells*.
- As the total cell concentration increases, or as the cells become more adapted to the inhibitory substrate, the increasing demand for substrate is met by equilibrium partitioning.
- ***This represents cell-based process control in which the demand and supply of substrate are entirely driven by cellular processes.***

Xenobiotic substrate	Organism	Solvent phase
Styrene	Mixed culture	Silicone oil
Phenanthrene (PAH)[a]	*Pseudomonas aeruginosa*	2,2,4,4,6,8,8-Heptamethylnonane
Naphthalene (PAH)	*Corynebacterium* sp.	Decane, dodecane, hexadecane
Various PAHs	Mixed culture	Silicone oil
2,4,6-Trichlorophenol	*Pseudomonas* sp.	Silicone oil
Dioxins	Mixed culture	Decane
Pentachlorophenol	*Arthrobacter* sp.	Diethyl sebacate
Phenol	*Pseudomonas putida*	2-Undecanone
Phenanthrene	*Pseudomonas* sp.	Silicone oil
Benzene, toluene	*Pseudomonas* sp.	Oleyl alcohol
Toluene, xylene	*Pseudomonas* sp.	Oleyl alcohol
BTX	*Pseudomonas* sp.	Oleyl alcohol
Various PAHs	Mixed culture	2,2,4,4,6,8,8-Heptamethylnonane
Benzene	*Alcaligenes xylosoxidans*	Hexadecane
Benzene	*Klebsiella* sp.	1-Octadecene
Benzene	*Alcaligenes xylosoxidans*	Hexadecane

[a]PAH, polyaromatic hydrocarbon.

- ***Table shows the recent example of the use of TPPB systems for treating Xenobiotics.***