

# Waste Treatment Technology

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WORLD TECHNOLOGIES

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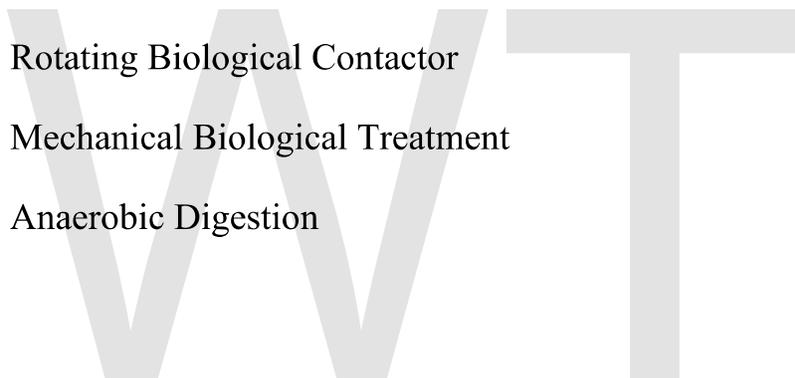
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## Chapter- 1

# Landfill



A landfill in Poland

A **landfill**, also known as a **dump**, **rubbish dump** or both, **Rubbish Landfill Dump** (and historically as a **midden**), is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. Historically, landfills have been the most common methods of organized waste disposal and remain so in many places around the world.

Landfills may include internal waste disposal sites (where a producer of waste carries out their own waste disposal at the place of production) as well as sites used by many producers. Many landfills are also used for other waste management purposes, such as the temporary storage, consolidation and transfer, or processing of waste material (sorting, treatment, or recycling).

A landfill also may refer to ground that has been filled in with soil and rocks instead of waste materials, so that it can be used for a specific purpose, such as for building houses. Unless they are stabilized, these areas may experience severe shaking or liquefaction of the ground in a large earthquake.

## ***Operations***



A section of a landfill located in Barclay, Ontario. This landfill is one of several landfills used by Dryden, Ontario.

Typically, in non hazardous waste landfills, in order to meet predefined specifications, techniques are applied by which the wastes are:

1. Confined to as small an area as possible.
2. Compacted to reduce their volume.
3. Covered (usually daily) with layers of soil.

During landfill operations the waste collection vehicles are weighed at a weighbridge on arrival and their load is inspected for wastes that do not accord with the landfill's waste acceptance criteria. Afterward, the waste collection vehicles use the existing road network on their way to the tipping face or working front where they unload their load. After loads are deposited, compactors or dozers are used to spread and compact the waste on the working face. Before leaving the landfill boundaries, the waste collection vehicles

pass through the wheel cleaning facility. If necessary, they return to the weighbridge in order to be weighed without their load. Through the weighing process, the daily incoming waste tonnage can be calculated and listed in databases. In addition to trucks, some landfills may be equipped to handle railroad containers. The use of 'rail-haul' permits landfills to be located at more remote sites, without the problems associated with many truck trips.

Typically, in the working face, the compacted waste is covered with soil daily. Alternative waste-cover materials are several sprayed-on foam products and temporary blankets. Blankets can be lifted into place with tracked excavators and then removed the following day prior to waste placement. Chipped wood and chemically 'fixed' bio-solids may also be used as an alternate daily cover. The space that is occupied daily by the compacted waste and the cover material is called a daily cell. Waste compaction is critical to extending the life of the landfill. Factors such as waste compressibility, waste layer thickness and the number of passes of the compactor over the waste affect the waste densities.

## **Impacts**



Landfill operation. Note that the area being filled is a single, well-defined "cell" and that a rubberized landfill liner is in place (exposed on the left) to prevent contamination by leachates migrating downward through the underlying geological formation.

A large number of adverse impacts may occur from landfill operations. These impacts can vary: fatal accidents (e.g., scavengers buried under waste piles); infrastructure damage (e.g., damage to access roads by heavy vehicles); pollution of the local environment (such as contamination of groundwater and/or aquifers by leakage and

residual soil contamination during landfill usage, as well as after landfill closure); offgassing of methane generated by decaying organic wastes (methane is a greenhouse gas many times more potent than carbon dioxide, and can itself be a danger to inhabitants of an area); harbouring of disease vectors such as rats and flies, particularly from improperly operated landfills, which are common in Third-world countries; injuries to wildlife; and simple nuisance problems (e.g., dust, odour, vermin, or noise pollution).

Environmental noise and dust are generated from vehicles accessing a landfill as well as from working face operations. These impacts are best to intercept at the planning stage where access routes and landfill geometrics can be used to mitigate such issues. Vector control is also important, but can be managed reasonably well with the daily cover protocols.

Most modern landfills in industrialized countries are operated with controls to attempt to manage problems such as these. Analyses of common landfill operational problems are available.

Some local authorities have found it difficult to locate new landfills. Communities may charge a fee or levy in order to discourage waste and/or recover the costs of site operations. Many landfills are publicly funded, but some are commercial businesses, operated for profit.

### **Trash dump communities**

In many developing countries around the world, communities exist in and around landfills. Residents of these communities, such as La Chureca in Nicaragua, often live in conditions of extreme poverty and use the landfills as a source of food and income. Scavengers work in the garbage in search of recyclables and other valuables.

### ***Landfill gas***

Gases are produced in landfills due to the anaerobic digestion by microbes on any organic matter. This gas can be collected and flared off or used to generate electricity in a gas fired power plant. Landfill gas monitoring can be carried out to alert for the presence of a build-up of gasses to a harmful level.

***Regional practice***



A landfill in Perth, Western Australia



South East New Territories Landfill, Hong Kong

## **United Kingdom**

Landfilling practices in the UK have had to change in recent years to meet the challenges of the European Landfill Directive. The UK now imposes landfill tax upon biodegradable waste which is put into landfills. In addition to this the Landfill Allowance Trading Scheme has been established for local authorities to trade landfill quotas in England. A different system operates in Wales where authorities are not able to 'trade' between themselves, but have allowances known as the Landfill Allowance Scheme.

In 2003, there were 254 licensed landfills in Scotland

## **United States**

In the U.S., landfills are regulated by the state's environmental agency that establishes minimum guidelines; however, none of these standards may fall below those set by the United States Environmental Protection Agency (EPA); such as was the case with the Fresh Kills Landfill in Staten Island, which is claimed by many to not only be the world's largest landfill, but the world's largest human structure. The landfill has since been closed and is being transformed into a park.

### ***Reclaiming materials***

Landfills can be regarded as a viable and abundant source of source materials and energy. In the developing world, this is widely understood and one may thus often find waste pickers scavenging for still usable materials. In a commercial context, landfills sites have also been discovered by companies and many have begun harvesting materials and energy. Well known examples are gas recovery facilities. Other commercial facilities include fossil fuel power plants and waste incinerators which have built-in material recovery. This material recovery is possible through the use of filters (electro filter, active carbon and potassium filter, quench, HCL-washer, SO<sub>2</sub>-washer, bottom ash-grating, etc.). An example of these is the AEB Waste Fired Power Plant. The AEB waste incinerator is hereby able to recover a large part of the burned waste in source materials. According to Marcel van Berlo (who helped build the plant), the processed waste contained higher percentages of source materials than any mine in the world. He also added that when the plant was compared to a Chilean copper mine, the waste fired plant could recover more copper. However, because of the high concentration of gases and the unpredictability of the landfill contents, which often include sharp objects, landfill excavation is generally considered dangerous. Furthermore, the quality of materials residing within landfills tends to degrade and such materials are thought to be not worth the risks required to recover them.

### ***Alternatives***

The alternatives to landfills are waste reduction and recycling strategies. Secondary to not creating waste, there are various alternatives to landfills. In the late 20th century, alternative methods of waste disposal to landfill and incineration have begun to gain

acceptance. Anaerobic digestion, composting, mechanical biological treatment, pyrolysis and plasma arc gasification have all begun to establish themselves in the market.

In recent years, some countries, such as Germany, Austria, Belgium, the Netherlands, and Switzerland, have banned the disposal of untreated waste in landfills. In these countries, only the ashes from incineration or the stabilized output of mechanical biological treatment plants may still be deposited.

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## Chapter- 2

# Sewage Treatment



The objective of sewage treatment is to produce a disposable effluent without causing harm to the surrounding environment and prevent pollution.

**Sewage treatment**, or **domestic wastewater treatment**, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for disposal or reuse (usually as farm fertilizer). Using advanced technology it is now possible to re-use sewage effluent for drinking water, although Singapore is the only country to implement such technology on a production scale in its production of NEWater.

## ***Origins of sewage***

Sewage is created by residential, institutional, and commercial and industrial establishments and includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. In many areas, sewage also includes liquid waste from industry and commerce. The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with greywater being permitted to be used for watering plants or recycled for flushing toilets.

Sewage may include stormwater runoff. Sewerage systems capable of handling stormwater are known as combined systems. Combined sewer systems are usually avoided now because precipitation causes widely varying flows reducing sewage treatment plant efficiency. Combined sewers require much larger, more expensive, treatment facilities than sanitary sewers. Heavy storm runoff may overwhelm the sewage treatment system, causing a spill or overflow. Sanitary sewers are typically much smaller than combined sewers, and they are not designed to transport stormwater. Backups of raw sewage can occur if excessive Infiltration/Inflow is allowed into a sanitary sewer system.

Modern sewered developments tend to be provided with separate storm drain systems for rainwater. As rainfall travels over roofs and the ground, it may pick up various contaminants including soil particles and other sediment, heavy metals, organic compounds, animal waste, and oil and grease. Some jurisdictions require stormwater to receive some level of treatment before being discharged directly into waterways. Examples of treatment processes used for stormwater include retention basins, wetlands, buried vaults with various kinds of media filters, and vortex separators (to remove coarse solids).

## ***Process overview***

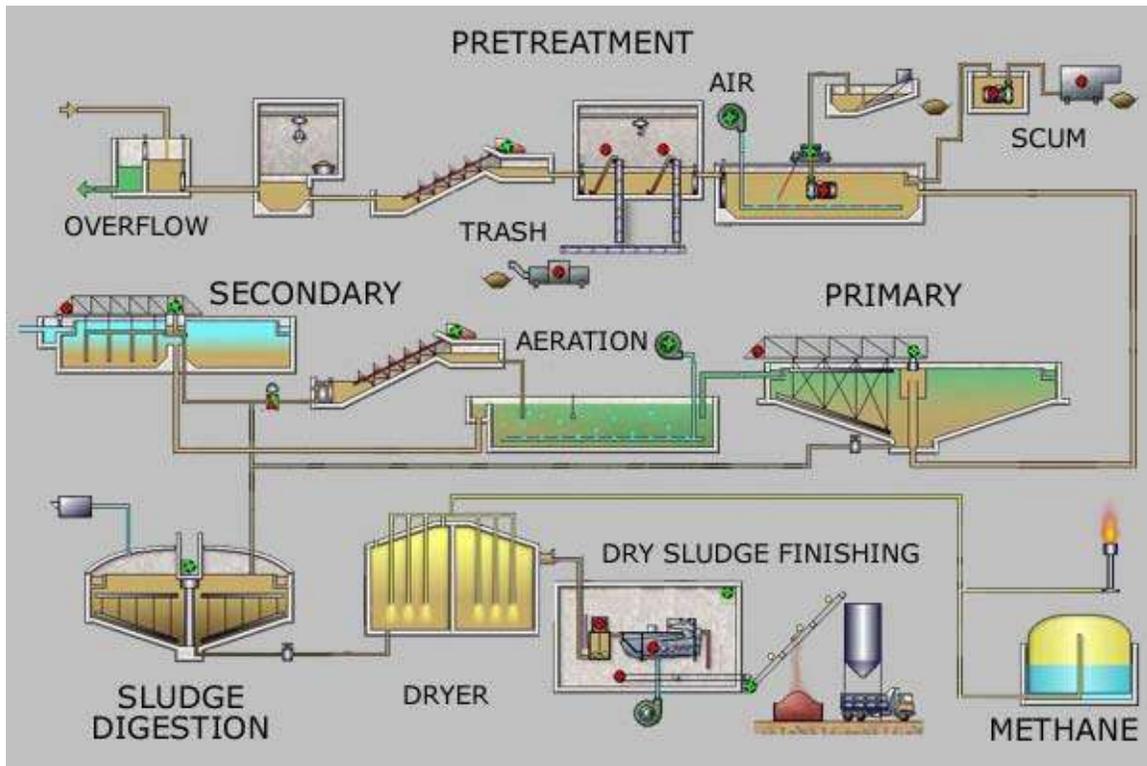
Sewage can be treated close to where it is created, a decentralised system, (in septic tanks, biofilters or aerobic treatment systems), or be collected and transported via a network of pipes and pump stations to a municipal treatment plant, a centralised system. Sewage collection and treatment is typically subject to local, state and federal regulations and standards. Industrial sources of wastewater often require specialized treatment processes.

Sewage treatment generally involves three stages, called primary, secondary and tertiary treatment.

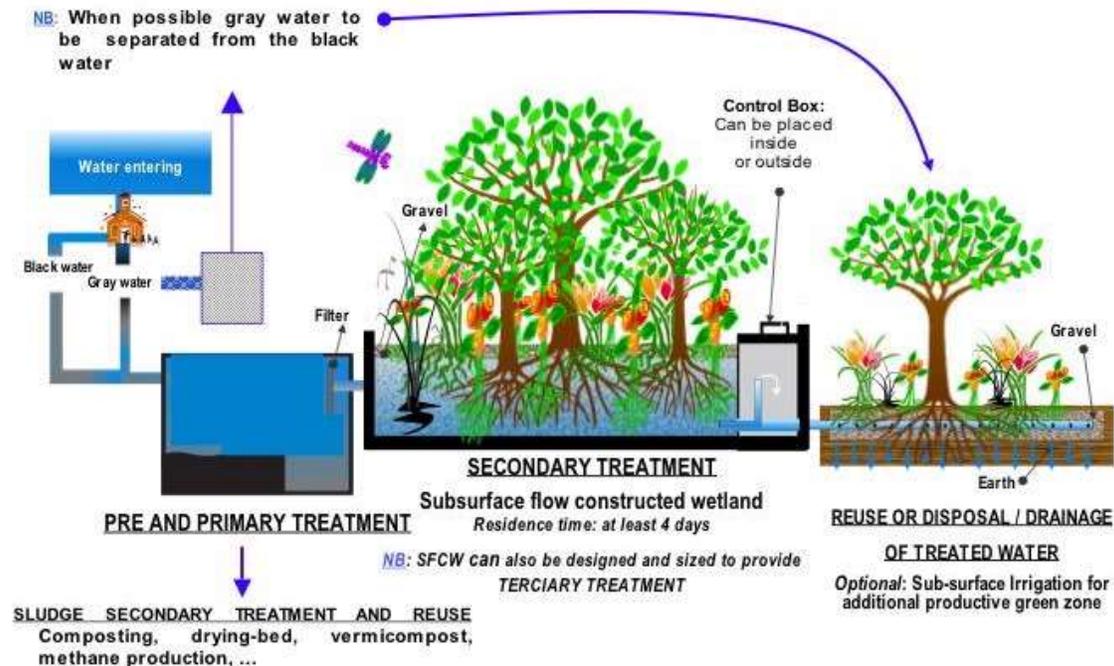
- *Primary treatment* consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.
- *Secondary treatment* removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-

organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.

- *Tertiary treatment* is sometimes defined as anything more than primary and secondary treatment in order to allow rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs,...). Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes.



Process Flow Diagram for a typical large-scale treatment plant



Process Flow Diagram for a typical treatment plant via Subsurface Flow Constructed Wetlands (SFCW)

## Pre-treatment

Pre-treatment removes materials that can be easily collected from the raw waste water before they damage or clog the pumps and skimmers of primary treatment clarifiers (trash, tree limbs, leaves, etc.).

## Screening

The influent sewage water is screened to remove all large objects carried in the sewage stream. This is most commonly done with an automated mechanically raked bar screen in modern plants serving large populations, whilst in smaller or less modern plants a manually cleaned screen may be used. The raking action of a mechanical bar screen is typically paced according to the accumulation on the bar screens and/or flow rate. The solids are collected and later disposed in a landfill or incinerated. Bar screens or mesh screens of varying sizes may be used to optimize solids removal. If gross solids are not removed they become entrained in pipes and moving parts of the treatment plant and can cause substantial damage and inefficiency in the process.

## Grit removal

Pre-treatment may include a sand or grit channel or chamber where the velocity of the incoming wastewater is adjusted to allow the settlement of sand, grit, stones, and broken glass. These particles are removed because they may damage pumps and other

equipment. For small sanitary sewer systems, the grit chambers may not be necessary, but grit removal is desirable at larger plants.



An empty sedimentation tank at the treatment plant in Merchtem, Belgium

### **Fat and grease removal**

In some larger plants, fat and grease is removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as a froth. In most plants however, fat and grease removal takes place in the primary settlement tank using mechanical surface skimmers.

### **Primary treatment**

In the primary sedimentation stage, sewage flows through large tanks, commonly called "primary clarifiers" or "primary sedimentation tanks." The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities. Grease and oil from the floating material can sometimes be recovered for saponification.

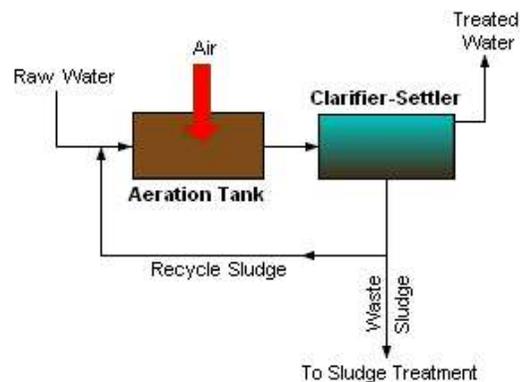
The dimensions of the tank should be designed to effect removal of a high percentage of the floatables and sludge. A typical sedimentation tank may remove from 60 to 65 percent of suspended solids, and from 30 to 35 percent of biochemical oxygen demand (BOD) from the sewage.

## Secondary treatment

**Secondary treatment** is designed to substantially degrade the biological content of the sewage which are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. To be effective, the biota require both oxygen and food to live. The bacteria and protozoa consume biodegradable soluble organic contaminants (e.g. sugars, fats, organic short-chain carbon molecules, etc.) and bind much of the less soluble fractions into floc. Secondary treatment systems are classified as *fixed-film* or *suspended-growth* systems.

- **Fixed-film** or **attached growth** systems include trickling filters and rotating biological contactors, where the biomass grows on media and the sewage passes over its surface.
- **Suspended-growth** systems include activated sludge, where the biomass is mixed with the sewage and can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems.

Roughing filters are intended to treat particularly strong or variable organic loads, typically industrial, to allow them to then be treated by conventional secondary treatment processes. Characteristics include filters filled with media to which wastewater is applied. They are designed to allow high hydraulic loading and a high level of aeration. On larger installations, air is forced through the media using blowers. The resultant wastewater is usually within the normal range for conventional treatment processes.



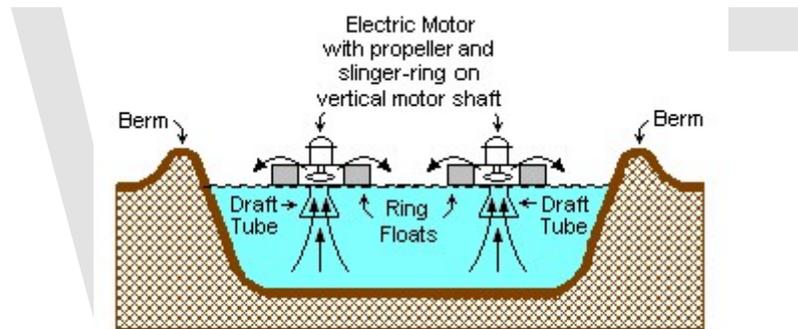
A generalized, schematic diagram of an activated sludge process

A filter removes a small percentage of the suspended organic matter, while the majority of the organic matter undergoes a change of character, only due to the biological oxidation and nitrification taking place in the filter. With this aerobic oxidation and nitrification, the organic solids are converted into coagulated suspended mass, which is heavier and bulkier, and can settle to the bottom of a tank. The effluent of the filter is therefore passed through a sedimentation tank, called a secondary clarifier, secondary settling tank or humus tank.

## Activated sludge

In general, activated sludge plants encompass a variety of mechanisms and processes that use dissolved oxygen to promote the growth of biological floc that substantially removes organic material.

The process traps particulate material and can, under ideal conditions, convert ammonia to nitrite and nitrate and ultimately to nitrogen gas.



**A TYPICAL SURFACE – AERATED BASIN**

Note: The ring floats are tethered to posts on the berms.

A Typical Surface-Aerated Basin (using motor-driven floating aerators)

## Surface-aerated basins (Lagoons)

Many small municipal sewage systems in the United States (1 million gal./day or less) use aerated lagoons.

Most biological oxidation processes for treating industrial wastewaters have in common the use of oxygen (or air) and microbial action. Surface-aerated basins achieve 80 to 90 percent removal of BOD with retention times of 1 to 10 days. The basins may range in depth from 1.5 to 5.0 metres and use motor-driven aerators floating on the surface of the wastewater.

In an aerated basin system, the aerators provide two functions: they transfer air into the basins required by the biological oxidation reactions, and they provide the mixing required for dispersing the air and for contacting the reactants (that is, oxygen,

wastewater and microbes). Typically, the floating surface aerators are rated to deliver the amount of air equivalent to 1.8 to 2.7 kg O<sub>2</sub>/kW·h. However, they do not provide as good mixing as is normally achieved in activated sludge systems and therefore aerated basins do not achieve the same performance level as activated sludge units.

Biological oxidation processes are sensitive to temperature and, between 0 °C and 40 °C, the rate of biological reactions increase with temperature. Most surface aerated vessels operate at between 4 °C and 32 °C.

## **Constructed wetlands**

Constructed wetlands (can either be surface flow or subsurface flow, horizontal or vertical flow), include engineered reedbeds and belong to the family of phytoremediation and ecotechnologies; they provide a high degree of biological improvement and depending on design, act as a primary, secondary and sometimes tertiary treatment. One example is a small reedbed used to clean the drainage from the elephants' enclosure at Chester Zoo in England; numerous CWs are used to recycle the water of the city of Honfleur in France and numerous other towns in Europe, the US, Asia and Australia. They are known to be highly productive systems as they copy natural wetlands, called the "Kidneys of the earth" for their fundamental recycling capacity of the hydrological cycle in the biosphere. Robust and reliable, their treatment capacities improve as time goes by, at the opposite of conventional treatment plants whose machinery ages with time. They are being increasingly used, although adequate and experienced design are more fundamental than for other systems and space limitation may impede their use.

## **Filter beds (oxidizing beds)**

In older plants and those receiving variable loadings, trickling filter beds are used where the settled sewage liquor is spread onto the surface of a bed made up of coke (carbonized coal), limestone chips or specially fabricated plastic media. Such media must have large surface areas to support the biofilms that form. The liquor is typically distributed through perforated spray arms. The distributed liquor trickles through the bed and is collected in drains at the base. These drains also provide a source of air which percolates up through the bed, keeping it aerobic. Biological films of bacteria, protozoa and fungi form on the media's surfaces and eat or otherwise reduce the organic content. This biofilm is often grazed by insect larvae, snails, and worms which help maintain an optimal thickness. Overloading of beds increases the thickness of the film leading to clogging of the filter media and ponding on the surface. Recent advances in media and process micro-biology design overcome many issues with Trickling filter designs.

## **Soil Bio-Technology**

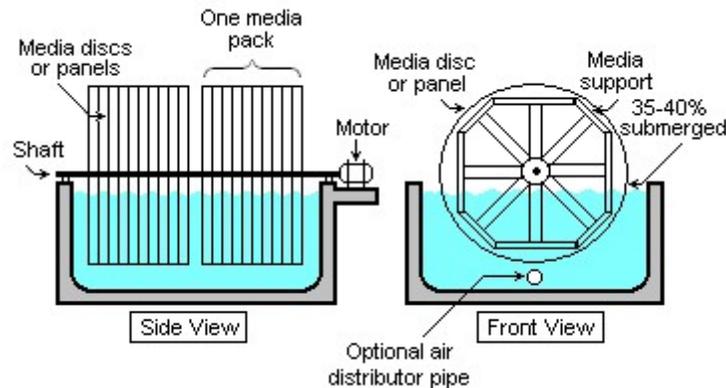
A new process called Soil Bio-Technology (SBT) developed at IIT Bombay has shown tremendous improvements in process efficiency enabling total water reuse, due to extremely low operating power requirements of less than 50 joules per kg of treated water. Typically SBT systems can achieve chemical oxygen demand (COD) levels less

than 10 mg/L from sewage input of COD 400 mg/L. SBT plants exhibit high reductions in COD values and bacterial counts as a result of the very high microbial densities available in the media. Unlike conventional treatment plants, SBT plants produce insignificant amounts of sludge, precluding the need for sludge disposal areas that are required by other technologies.

In the Indian context, conventional sewage treatment plants fall into systemic disrepair due to 1) high operating costs, 2) equipment corrosion due to methanogenesis and hydrogen sulphide, 3) non-reusability of treated water due to high COD (>30 mg/L) and high fecal coliform (>3000 NFU) counts, 4) lack of skilled operating personnel and 5) equipment replacement issues. Examples of such systemic failures has been documented by Sankat Mochan Foundation at the Ganges basin after a massive cleanup effort by the Indian government in 1986 by setting up sewage treatment plants under the Ganga Action Plan failed to improve river water quality.

### Biological aerated filters

Biological Aerated (or Anoxic) Filter (BAF) or Biofilters combine filtration with biological carbon reduction, nitrification or denitrification. BAF usually includes a reactor filled with a filter media. The media is either in suspension or supported by a gravel layer at the foot of the filter. The dual purpose of this media is to support highly active biomass that is attached to it and to filter suspended solids. Carbon reduction and ammonia conversion occurs in aerobic mode and sometime achieved in a single reactor while nitrate conversion occurs in anoxic mode. BAF is operated either in upflow or downflow configuration depending on design specified by manufacturer.



Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram.

### Rotating biological contactors

Rotating biological contactors (RBCs) are mechanical secondary treatment systems, which are robust and capable of withstanding surges in organic load. RBCs were first installed in Germany in 1960 and have since been developed and refined into a reliable

operating unit. The rotating disks support the growth of bacteria and micro-organisms present in the sewage, which break down and stabilise organic pollutants. To be successful, micro-organisms need both oxygen to live and food to grow. Oxygen is obtained from the atmosphere as the disks rotate. As the micro-organisms grow, they build up on the media until they are sloughed off due to shear forces provided by the rotating discs in the sewage. Effluent from the RBC is then passed through final clarifiers where the micro-organisms in suspension settle as a sludge. The sludge is withdrawn from the clarifier for further treatment.

A functionally similar biological filtering system has become popular as part of home aquarium filtration and purification. The aquarium water is drawn up out of the tank and then cascaded over a freely spinning corrugated fiber-mesh wheel before passing through a media filter and back into the aquarium. The spinning mesh wheel develops a biofilm coating of microorganisms that feed on the suspended wastes in the aquarium water and are also exposed to the atmosphere as the wheel rotates. This is especially good at removing waste urea and ammonia excreted into the aquarium water by the fish and other animals.

## **Membrane bioreactors**

Membrane bioreactors (MBR) combine activated sludge treatment with a membrane liquid-solid separation process. The membrane component uses low pressure microfiltration or ultra filtration membranes and eliminates the need for clarification and tertiary filtration. The membranes are typically immersed in the aeration tank; however, some applications utilize a separate membrane tank. One of the key benefits of an MBR system is that it effectively overcomes the limitations associated with poor settling of sludge in conventional activated sludge (CAS) processes. The technology permits bioreactor operation with considerably higher mixed liquor suspended solids (MLSS) concentration than CAS systems, which are limited by sludge settling. The process is typically operated at MLSS in the range of 8,000–12,000 mg/L, while CAS are operated in the range of 2,000–3,000 mg/L. The elevated biomass concentration in the MBR process allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. Thus increased sludge retention times, usually exceeding 15 days, ensure complete nitrification even in extremely cold weather.

The cost of building and operating an MBR is usually higher than conventional wastewater treatment. Membrane filters can be blinded with grease or abraded by suspended grit and lack a clarifier's flexibility to pass peak flows. The technology has become increasingly popular for reliably pretreated waste streams and has gained wider acceptance where infiltration and inflow have been controlled, however, and the life-cycle costs have been steadily decreasing. The small footprint of MBR systems, and the high quality effluent produced, make them particularly useful for water reuse applications.

## Secondary sedimentation



Secondary Sedimentation tank at a rural treatment plant

The final step in the secondary treatment stage is to settle out the biological floc or filter material through a secondary clarifier and to produce sewage water containing low levels of organic material and suspended matter.

## Tertiary treatment

The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.). More than one tertiary treatment process may be used at any treatment plant. If disinfection is practiced, it is always the final process. It is also called "effluent polishing."

## Filtration

Sand filtration removes much of the residual suspended matter. Filtration over activated carbon, also called *carbon adsorption*, removes residual toxins.

## Lagooning



A sewage treatment plant and lagoon in Everett, Washington, United States

Lagooning provides settlement and further biological improvement through storage in large man-made ponds or lagoons. These lagoons are highly aerobic and colonization by native macrophytes, especially reeds, is often encouraged. Small filter feeding invertebrates such as *Daphnia* and species of *Rotifera* greatly assist in treatment by removing fine particulates.

### **Nutrient removal**

Wastewater may contain high levels of the nutrients nitrogen and phosphorus. Excessive release to the environment can lead to a build up of nutrients, called eutrophication, which can in turn encourage the overgrowth of weeds, algae, and cyanobacteria (blue-green algae). This may cause an algal bloom, a rapid growth in the population of algae. The algae numbers are unsustainable and eventually most of them die. The decomposition of the algae by bacteria uses up so much of oxygen in the water that most or all of the animals die, which creates more organic matter for the bacteria to decompose. In addition to causing deoxygenation, some algal species produce toxins that contaminate drinking water supplies. Different treatment processes are required to remove nitrogen and phosphorus.

## **Nitrogen removal**

The removal of nitrogen is effected through the biological oxidation of nitrogen from ammonia to nitrate (nitrification), followed by denitrification, the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water.

Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia ( $\text{NH}_3$ ) to nitrite ( $\text{NO}_2^-$ ) is most often facilitated by *Nitrosomonas* spp. (nitroso referring to the formation of a nitroso functional group). Nitrite oxidation to nitrate ( $\text{NO}_3^-$ ), though traditionally believed to be facilitated by *Nitrobacter* spp. (nitro referring the formation of a nitro functional group), is now known to be facilitated in the environment almost exclusively by *Nitrospira* spp.

Denitrification requires anoxic conditions to encourage the appropriate biological communities to form. It is facilitated by a wide diversity of bacteria. Sand filters, lagooning and reed beds can all be used to reduce nitrogen, but the activated sludge process (if designed well) can do the job the most easily. Since denitrification is the reduction of nitrate to dinitrogen gas, an electron donor is needed. This can be, depending on the wastewater, organic matter (from faeces), sulfide, or an added donor like methanol.

Sometimes the conversion of toxic ammonia to nitrate alone is referred to as tertiary treatment.

Many sewage treatment plants use axial flow pumps to transfer the nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. These pumps are often referred to as *Internal Mixed Liquor Recycle* (IMLR) pumps. The sludge in the anoxic tanks must be mixed well (mixture of recirculated mixed liquor, return activated sludge [RAS] and raw influent) by using submersible mixers in order to achieve the desired denitrification.

## **Phosphorus removal**

Phosphorus removal is important as it is a limiting nutrient for algae growth in many fresh water systems. It is also particularly important for water reuse systems where high phosphorus concentrations may lead to fouling of downstream equipment such as reverse osmosis.

Phosphorus can be removed biologically in a process called enhanced biological phosphorus removal. In this process, specific bacteria, called polyphosphate accumulating organisms (PAOs), are selectively enriched and accumulate large quantities of phosphorus within their cells (up to 20 percent of their mass). When the biomass enriched in these bacteria is separated from the treated water, these biosolids have a high fertilizer value.

Phosphorus removal can also be achieved by chemical precipitation, usually with salts of iron (e.g. ferric chloride), aluminum (e.g. alum), or lime. This may lead to excessive sludge production as hydroxides precipitates and the added chemicals can be expensive. Chemical phosphorus removal requires significantly smaller equipment footprint than biological removal, is easier to operate and is often more reliable than biological phosphorus removal. Another method for phosphorus removal is to use granular laterite.

Once removed, phosphorus, in the form of a phosphate-rich sludge, may be stored in a land fill or resold for use in fertilizer.

## **Disinfection**

The purpose of disinfection in the treatment of waste water is to substantially reduce the number of microorganisms in the water to be discharged back into the environment. The effectiveness of disinfection depends on the quality of the water being treated (e.g., cloudiness, pH, etc.), the type of disinfection being used, the disinfectant dosage (concentration and time), and other environmental variables. Cloudy water will be treated less successfully, since solid matter can shield organisms, especially from ultraviolet light or if contact times are low. Generally, short contact times, low doses and high flows all militate against effective disinfection. Common methods of disinfection include ozone, chlorine, ultraviolet light, or sodium hypochlorite. Chloramine, which is used for drinking water, is not used in waste water treatment because of its persistence.

Chlorination remains the most common form of waste water disinfection in North America due to its low cost and long-term history of effectiveness. One disadvantage is that chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine or chloramines may also be capable of chlorinating organic material in the natural aquatic environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

Ultraviolet (UV) light can be used instead of chlorine, iodine, or other chemicals. Because no chemicals are used, the treated water has no adverse effect on organisms that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of reproduction. The key disadvantages of UV disinfection are the need for frequent lamp maintenance and replacement and the need for a highly treated effluent to ensure that the target microorganisms are not shielded from the UV radiation (i.e., any solids present in the treated effluent may protect microorganisms from the UV light). In the United Kingdom, UV light is becoming the most common means of disinfection because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water. Some sewage treatment systems in Canada and the US also use UV light for their effluent water disinfection.

Ozone (O<sub>3</sub>) is generated by passing oxygen (O<sub>2</sub>) through a high voltage potential resulting in a third oxygen atom becoming attached and forming O<sub>3</sub>. Ozone is very unstable and reactive and oxidizes most organic material it comes in contact with, thereby destroying many pathogenic microorganisms. Ozone is considered to be safer than chlorine because, unlike chlorine which has to be stored on site (highly poisonous in the event of an accidental release), ozone is generated onsite as needed. Ozonation also produces fewer disinfection by-products than chlorination. A disadvantage of ozone disinfection is the high cost of the ozone generation equipment and the requirements for special operators.

## **Odour Control**

Odours emitted by sewage treatment are typically an indication of an anaerobic or "septic" condition. Early stages of processing will tend to produce smelly gases, with hydrogen sulfide being most common in generating complaints. Large process plants in urban areas will often treat the odours with carbon reactors, a contact media with bio-slimes, small doses of chlorine, or circulating fluids to biologically capture and metabolize the obnoxious gases. Other methods of odour control exist, including addition of iron salts, hydrogen peroxide, calcium nitrate, etc. to manage hydrogen sulfide levels.

## ***Package plants and batch reactors***

To use less space, treat difficult waste and intermittent flows, a number of designs of hybrid treatment plants have been produced. Such plants often combine at least two stages of the three main treatment stages into one combined stage. In the UK, where a large number of wastewater treatment plants serve small populations, package plants are a viable alternative to building a large structure for each process stage. In the US, package plants are typically used in rural areas, highway rest stops and trailer parks.

One type of system that combines secondary treatment and settlement is the sequencing batch reactor (SBR). Typically, activated sludge is mixed with raw incoming sewage, and then mixed and aerated. The settled sludge is run off and re-aerated before a proportion is returned to the headworks. SBR plants are now being deployed in many parts of the world.

The disadvantage of the SBR process is that it requires a precise control of timing, mixing and aeration. This precision is typically achieved with computer controls linked to sensors. Such a complex, fragile system is unsuited to places where controls may be unreliable, poorly maintained, or where the power supply may be intermittent. Extended aeration package plants use separate basins for aeration and settling, and are somewhat larger than SBR plants with reduced timing sensitivity.

Package plants may be referred to as *high charged* or *low charged*. This refers to the way the biological load is processed. In high charged systems, the biological stage is presented with a high organic load and the combined floc and organic material is then oxygenated for a few hours before being charged again with a new load. In the low

charged system the biological stage contains a low organic load and is combined with flocculate for longer times.

## ***Sludge treatment and disposal***

The sludges accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner. The purpose of digestion is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. The most common treatment options include anaerobic digestion, aerobic digestion, and composting. Incineration is also used albeit to a much lesser degree.

Sludge treatment depends on the amount of solids generated and other site-specific conditions. Composting is most often applied to small-scale plants with aerobic digestion for mid sized operations, and anaerobic digestion for the larger-scale operations.

## **Anaerobic digestion**

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be *thermophilic* digestion, in which sludge is fermented in tanks at a temperature of 55°C, or *mesophilic*, at a temperature of around 36°C. Though allowing shorter retention time (and thus smaller tanks), thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.

Anaerobic digestion is the most common (mesophilic) treatment of domestic sewage in septic tanks, which normally retain the sewage from one day to two days, reducing the BOD by about 35 to 40 percent. This reduction can be increased with a combination of anaerobic and aerobic treatment by installing *Aerobic Treatment Units* (ATUs) in the septic tank.

One major feature of anaerobic digestion is the production of biogas (with the most useful component being methane), which can be used in generators for electricity production and/or in boilers for heating purposes.

## **Aerobic digestion**

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. The operating costs used to be characteristically much greater for aerobic digestion because of the energy used by the blowers, pumps and motors needed to add oxygen to the process.

Aerobic digestion can also be achieved by using diffuser systems or jet aerators to oxidize the sludge.

## **Composting**

Composting is also an aerobic process that involves mixing the sludge with sources of carbon such as sawdust, straw or wood chips. In the presence of oxygen, bacteria digest both the wastewater solids and the added carbon source and, in doing so, produce a large amount of heat.

## **Incineration**

Incineration of sludge is less common because of air emissions concerns and the supplemental fuel (typically natural gases or fuel oil) required to burn the low calorific value sludge and vaporize residual water. Stepped multiple hearth incinerators with high residence time and fluidized bed incinerators are the most common systems used to combust wastewater sludge. Co-firing in municipal waste-to-energy plants is occasionally done, this option being less expensive assuming the facilities already exist for solid waste and there is no need for auxiliary fuel.

## **Sludge disposal**

When a liquid sludge is produced, further treatment may be required to make it suitable for final disposal. Typically, sludges are thickened (dewatered) to reduce the volumes transported off-site for disposal. There is no process which completely eliminates the need to dispose of biosolids. There is, however, an additional step some cities are taking to superheat sludge and convert it into small pelletized granules that are high in nitrogen and other organic materials. In New York City, for example, several sewage treatment plants have dewatering facilities that use large centrifuges along with the addition of chemicals such as polymer to further remove liquid from the sludge. The removed fluid, called centrate, is typically reintroduced into the wastewater process. The product which is left is called "cake" and that is picked up by companies which turn it into fertilizer pellets. This product is then sold to local farmers and turf farms as a soil amendment or fertilizer, reducing the amount of space required to dispose of sludge in landfills. Much sludge originating from commercial or industrial areas is contaminated with toxic materials that are released into the sewers from the industrial processes. Elevated concentrations of such materials may make the sludge unsuitable for agricultural use and it may then have to be incinerated or disposed of to landfill.

## ***Treatment in the receiving environment***



The outlet of a wastewater treating plant flows into a small river

Many processes in a wastewater treatment plant are designed to mimic the natural treatment processes that occur in the environment, whether that environment is a natural water body or the ground. If not overloaded, bacteria in the environment will consume organic contaminants, although this will reduce the levels of oxygen in the water and may significantly change the overall ecology of the receiving water. Native bacterial populations feed on the organic contaminants, and the numbers of disease-causing microorganisms are reduced by natural environmental conditions such as predation or exposure to ultraviolet radiation. Consequently, in cases where the receiving environment provides a high level of dilution, a high degree of wastewater treatment may not be required. However, recent evidence has demonstrated that very low levels of specific contaminants in wastewater, including hormones (from animal husbandry and residue from human hormonal contraception methods) and synthetic materials such as phthalates that mimic hormones in their action, can have an unpredictable adverse impact on the natural biota and potentially on humans if the water is re-used for drinking water. In the US and EU, uncontrolled discharges of wastewater to the environment are not permitted under law, and strict water quality requirements are to be met. A significant threat in the coming decades will be the increasing uncontrolled discharges of wastewater within rapidly developing countries.

## Effects on Biology

Sewage treatment plants can have multiple effects on nutrient levels in the water that the treated sewage flows into. These effects on nutrients can have large effects on the biological life in the water in contact with the effluent. Stabilization ponds (or treatment ponds) can include any of the following:

- Oxidation ponds, which are aerobic bodies of water usually 1-2 meters in depth that receive effluent from sedimentation tanks or other forms of primary treatment.
  - Dominated by algae
- Polishing ponds are similar to oxidation ponds but receive effluent from an oxidation pond or from a plant with an extended mechanical treatment.
  - Dominated by zooplankton
- Facultative lagoons, raw sewage lagoons, or sewage lagoons are ponds where sewage is added with no primary treatment other than coarse screening. These ponds provide effective treatment when the surface remains aerobic; although anaerobic conditions may develop near the layer of settled sludge on the bottom of the pond.
- Anaerobic lagoons are heavily loaded ponds.
  - Dominated by bacteria
- Sludge lagoons are aerobic ponds, usually 2-5 meters in depth, that receive anaerobically digested primary sludge, or activated secondary sludge under water.
  - Upper layers are dominated by algae

Phosphorous limitation is a possible result from sewage treatment and results in flagellate-dominated plankton, particularly in summer and fall.

At the same time a different study found high nutrient concentrations linked to sewage effluents. High nutrient concentration leads to high chlorophyll a concentrations, which is a proxy for primary production in marine environments. High primary production means high phytoplankton populations and most likely high zooplankton populations because zooplankton feed on phytoplankton. However, effluent released into marine systems also leads to greater population instability.

A study done in Britain found that the quality of effluent effected the planktonic life in the water in direct contact with the wastewater effluent. Turbid, low-quality effluents either did not contain ciliated protozoa or contained only a few species in small numbers. On the other hand, high-quality effluents contained a wide variety of ciliated protozoa in

large numbers. Due to these findings, it seems unlikely that any particular component of the industrial effluent has, by itself, any harmful effects on the protozoan populations of activated sludge plants.

The planktonic trends of high populations close to input of treated sewage is contrasted by the bacterial trend. In a study of *Aeromonas* spp. in increasing distance from a wastewater source, greater change in seasonal cycles was found the furthest from the effluent. This trend is so strong that the furthest location studied actually had an inversion of the *Aeromonas* spp. cycle in comparison to that of fecal coliforms. Since there is a main pattern in the cycles that occurred simultaneously at all stations it indicates seasonal factors (temperature, solar radiation, phytoplankton) control of the bacterial population. The effluent dominant species changes from *Aeromonas caviae* in winter to *Aeromonas sobria* in the spring and fall while the inflow dominant species is *Aeromonas caviae*, which is constant throughout the seasons.

### ***Sewage treatment in developing countries***

Few reliable figures on the share of the wastewater collected in sewers that is being treated in the world exist. In many developing countries the bulk of domestic and industrial wastewater is discharged without any treatment or after primary treatment only. In Latin America about 15% of collected wastewater passes through treatment plants (with varying levels of actual treatment). In Venezuela, a below average country in South America with respect to wastewater treatment, 97 percent of the country's sewage is discharged raw into the environment. In a relatively developed Middle Eastern country such as Iran, Tehran's majority of population has totally untreated sewage injected to the city's groundwater. However now the construction of major parts of the sewage system, collection and treatment, in Tehran is almost complete, and under development, due to be fully completed by the end of 2012.

In Israel, about 50 percent of agricultural water usage (total use was 1 billion cubic metres in 2008) is provided through reclaimed sewer water. Future plans call for increased use of treated sewer water as well as more desalination plants.

## Chapter- 3

# Compost



Compost

**Compost** is plant matter that has been decomposed and recycled as a fertilizer and soil amendment. Compost is a key ingredient in organic farming. At its most essential, the process of **composting** requires simply piling up waste outdoors and waiting a year or more. Modern, methodical composting is a multi-step, closely monitored process with measured inputs of water, air and carbon- and nitrogen-rich materials. The decomposition process is aided by shredding the plant matter, adding water and ensuring proper aeration by regularly turning the mixture. Worms and fungi further break up the material. Aerobic bacteria manage the chemical process by converting the inputs into heat, carbon dioxide

and ammonium. The ammonium is further refined by bacteria into plant-nourishing nitrites and nitrates.

Compost can be rich in nutrients. It is used in gardens, landscaping, horticulture, and agriculture. The compost itself is beneficial for the land in many ways, including as a soil conditioner, a fertilizer, addition of vital humus or humic acids, and as a natural pesticide for soil. In ecosystems, compost is useful for erosion control, land and stream reclamation, wetland construction, and as landfill cover.

## ***History***

Composting as a recognized practice dates to at least the early Roman Empire since Pliny the Elder (AD 23-79) who refers to compost in his writings. Traditionally, composting was to pile organic materials until the next planting season, at which time the materials would have decayed enough to be ready for use in the soil. The advantage of this method is that little working time or effort is required from the composteer and it fits in naturally with agricultural practices in temperate climates. Disadvantages (from the modern perspective) are that space is used for a whole year, some nutrients might be leached due to exposure to rainfall, and disease producing organisms, some weed, weed seeds and insects may not be adequately controlled.

Composting was somewhat modernized beginning in the 1920s in Europe as a tool for organic farming. The first industrial station for the transformation of urban organic materials into compost was set up in Wels/Austria in the year 1921. The early personages most cited for propounding composting within farming are for the German-speaking world Rudolf Steiner, founder of a farming method called biodynamics, and Annie Francé-Harrar, who was appointed on behalf of the government in Mexico and supported the country 1950–1958 to set up a large humus organization in the fight against erosion and soil degradation. In the English-speaking world it was Sir Albert Howard who worked extensively in India on sustainable practices and Lady Eve Balfour who was a huge proponent of composting. Composting was imported to America by various followers of these early European movements in the form of persons such as J.I. Rodale (founder of Rodale Organic Gardening), E.E. Pfeiffer (who developed scientific practices in biodynamic farming), Paul Keene (founder of Walnut Acres in Pennsylvania), and Scott and Helen Nearing (who inspired the back-to-land movement of the 1960s). Coincidentally, some of these personages met briefly in India - all were quite influential in the U.S. from the 1960s into the 1980s.

There are many modern proponents of rapid composting which attempt to correct some of the perceived problems associated with traditional, slow composting. Many advocate that compost can be made in 2 to 3 weeks. Many such short processes involve a few changes to traditional methods, including smaller, more homogenized pieces in the compost, controlling carbon to nitrogen (CN) ratio at 30 to 1 or less, and monitoring the moisture level more carefully. However, none of these parameters differ significantly from early writings of Howard and Balfour, suggesting that in fact modern composting has not made significant advances over the traditional methods which take a few months

to work. For this reason and others, many modern scientists who deal with carbon transformations are sceptical that there is a "super-charged" way to get nature to make compost rapidly. They also point to the fact that it is the structure of the natural molecules - such as carbohydrates, proteins, and cellulose - that really dictate the rate at which microbial-mediated transformations are possible.

Some cities such as San Francisco and Seattle require food and yard waste to be sorted for composting.

## ***Ingredients***



Home compost barrel in the Escuela Barreales, Chile

Composting organisms require four equally important things to work effectively:

- Carbon — for energy; the microbial oxidation of carbon produces the heat.
  - High carbon materials tend to be brown and dry.
- Nitrogen — to grow and reproduce more organisms to oxidize the carbon.
  - High nitrogen materials tend to be green (or colorful, such as fruits and vegetables) and wet.
- Oxygen — for oxidizing the carbon, the decomposition process.
- Water — in the right amounts to maintain activity without causing anaerobic conditions.



Materials in a compost pile

Certain ratios of these materials will provide beneficial bacteria with the nutrients to work at a rate that will heat up the pile. In that process much water will be released as vapor ("steam"), and the oxygen will be quickly depleted, explaining the need to actively manage the pile. The hotter the pile gets, the more often added air and water is necessary; the air/water balance is critical to maintaining high temperatures until the materials are broken down. At the same time, too much air or water also slows the process, as does too much carbon (or too little nitrogen).

The most efficient composting occurs with a carbon:nitrogen mix of about 30 to 1. Nearly all plant and animal materials have both carbon and nitrogen, but amounts vary widely, with characteristics noted above (dry/wet, brown/green). Fresh grass clippings have an average ratio of about 15 to 1 and dry autumn leaves about 50 to 1 depending on species. Mixing equal parts by volume approximates the ideal C:N range. Few individual situations will provide the ideal mix of materials at any point in time - in this respect, home composting is like horseshoes, perfect is great, but close still works. Observation of amounts, and consideration of different materials as a pile is built over time, can quickly achieve a workable technique for the individual situation.

## Urine

People excrete far more of certain water-soluble plant nutrients (nitrogen, phosphorus, potassium) in urine than in feces. Human urine can be used directly as fertilizer or it can be put onto compost. Adding a healthy person's urine to compost usually will increase temperatures and therefore increase its ability to destroy pathogens and unwanted seeds. Urine from a person with no obvious symptoms of infection, is generally much more sanitary than fresh feces. Unlike feces, urine doesn't attract disease-spreading flies (such as house flies or blow flies), and it doesn't harbor the most hardy of pathogens, such as parasitic worm eggs. Urine usually does not stink for long, particularly when it is fresh, diluted, or put on sorbents.

Urine is primarily composed of water and urea. Although metabolites of urea are nitrogen fertilizers, it is easy to over-fertilize with urine creating too much ammonia for plants to absorb, acidic conditions, or other phytotoxicity.

## Micro-organisms

With the proper mixture of water, oxygen, carbon, and nitrogen, micro-organisms are allowed to break down organic matter to produce compost. The composting process is dependant on micro-organisms to break down organic matter into compost. There are many types of microorganisms found in active compost of which the most common are:

- Bacteria- The most numerous of all the microorganisms found in compost.
- Actinomycetes- Necessary for breaking down paper products such as newspaper, bark, etc.
- Fungi- Molds and yeast help break down materials that bacteria cannot, especially lignin in woody material.
- Protozoa- Help consume bacteria, fungi and micro organic particulates.
- Rotifers- Rotifers help control populations of bacteria and small protozoans.

In addition, earthworms not only ingest partly composted material, but also continually re-create aeration and drainage tunnels as they move through the compost.

A lack of a healthy micro-organisms community is the main reason why composting processes are slow in landfills with environmental factors such as lack of oxygen, nutrients or water being the cause of the depleted biological community.

## Uses

Compost is generally recommended as an additive to soil, or other matrices such as coir and peat, as a tilth improver, supplying humus and nutrients. It provides a rich *growing medium*, or a porous, absorbent material that holds moisture and soluble minerals, providing the support and nutrients in which plants can flourish, although it is rarely used alone, being primarily mixed with soil, sand, grit, bark chips, vermiculite, perlite, or clay granules to produce loam.

Generally, direct seeding into a compost is not recommended due to the speed with which it may dry and the possible presence of phytotoxins which may inhibit germination, and the possible tie up of nitrogen by incompletely decomposed lignin. It is very common to see blends of 20–30% compost used for transplanting seedlings at cotyledon stage or later.

## **Destroying pathogens, seeds, or unwanted plants**

Composting can destroy pathogens or unwanted seeds. Unwanted living plants (or weeds) can be destroyed by covering with mulch/compost.

The "microbial pesticides" in compost may include thermophiles and mesophiles, however certain composting detritivores such as black soldier fly larvae and redworms, also reduce many pathogens. Thermophilic (high-temperature) composting is well known to destroy many seeds and nearly all types of pathogens (exceptions may include prions). However, thermophilic composting requires a fair amount of material, around a cubic meter.

The sanitizing qualities of (thermophilic) composting are desirable where there is a high likelihood of pathogens, such as with manure. Applications include humanure composting or the deep litter technique.

## ***Types***

### **Compost tea**

Compost tea is a liquid solution or suspension made by steeping compost in water. It is used as both a fertilizer and in attempts to prevent plant diseases. The liquid is applied as a spray to non-edible plant parts, or as a soil-drench (root dip), such as seedlings, or as a surface spray to reduce incidence of harmful phytopathogenic fungi in the phyllosphere. Compost tea has been shown to cause a 173.5% increase in plant growth by mass over plants grown without castings. These results were seen with only 10% addition of castings to produce these results.

## Vermicompost



Rotary screen harvested worm castings

Vermicompost is the product of composting utilizing various species of worms, usually red wigglers, white worms, and earthworms to create a heterogeneous mixture of decomposing vegetable or food waste, bedding materials, and vermicast. Vermicast, also known as worm castings, worm humus or worm manure, is the end-product of the breakdown of organic matter by species of earthworm.

The earthworm species (or **composting worms**) most often used are Red Wigglers (*Eisenia foetida* or *Eisenia andrei*), though European nightcrawlers (*Eisenia hortensis*) could also be used. Red wigglers are recommended by most vermiculture experts as they have some of the best appetites and breed very quickly. Users refer to European nightcrawlers by a variety of other names, including *dendrobaenas*, *dendras*, and Belgian nightcrawlers.

Containing water-soluble nutrients, vermicompost is a nutrient-rich organic fertilizer and soil conditioner.

### **Bokashi composting**



Inside a recently started Bokashi bin. The aerated base is just visible through the food scraps and Bokashi bran.

Bokashi is a method of intensive composting. It can use an aerobic or anaerobic inoculation to produce the compost. Once a starter culture is made, it can be used to extend the culture indefinitely, like yogurt culture. Since the popular introduction of effective microorganisms (EM), Bokashi is commonly made with only molasses, water, EM, and wheat bran.

In home composting applications, kitchen waste is placed into a container which can be sealed with an air tight lid. These scraps are then inoculated with a Bokashi EM mix. This usually takes the form of a carrier, such as rice hulls, wheat bran or saw dust, that has been inoculated with composting micro-organisms. The EM are natural lactic acid bacteria, yeast, and phototrophic bacteria that act as a microbe community within the kitchen scraps, fermenting and accelerating breakdown of the organic matter. The user would place alternating layers of food scraps and Bokashi mix until the container is full.

## Hugelkultur

The practice of making raised beds filled with rotting wood. It is in effect creating a Nurse log though covered with dirt. The buried decomposing wood will give off heat, as all compost does, for several years. This effect has been used by Sepp Holzer for one to allow fruit trees to survive at otherwise inhospitable temperatures and altitudes.

## *Alternative to landfilling*

As concern about landfill space increases, worldwide interest in recycling by means of composting is growing, since composting is a process for converting decomposable organic materials into useful stable products. Industrial scale composting in the form of in-vessel composting, aerated static pile composting, and anaerobic digestion takes place in most Western countries now, and in many areas is mandated by law. There are process and product guidelines in Europe that date to the early 1980s (Germany, Holland, Switzerland) and only more recently in the UK and the US. In both these countries, private trade associations within the industry have established loose standards, some say as a stop-gap measure to discourage independent government agencies from establishing tougher consumer-friendly standards. The USA is the only Western country that does not distinguish sludge-source compost from green-composts, and by default in the USA 50% of states expect composts to comply in some manner with the federal EPA 503 rule promulgated in 1984 for sludge products. Compost is regulated in Canada and Australia as well.

## Industrial systems



A large (and over sized) compost pile that is steaming with the heat generated by thermophilic microorganisms.

Industrial composting systems are increasingly being installed as a waste management alternative to landfills, along with other advanced waste processing systems. Mechanical sorting of mixed waste streams combined with anaerobic digestion or in-vessel composting, is called mechanical biological treatment, increasingly used in developed countries due to regulations controlling the amount of organic matter allowed in landfills. Treating biodegradable waste before it enters a landfill reduces global warming from fugitive methane; untreated waste breaks down anaerobically in a landfill, producing landfill gas that contains methane, a potent greenhouse gas.

Large-scale composting systems are used by many urban centers around the world. Co-composting is a technique which combines solid waste with de-watered biosolids, although difficulties controlling inert and plastic contamination from municipal solid waste makes this approach less attractive. The world's largest MSW co-composter is the Edmonton Composting Facility in Edmonton, Alberta, Canada, which turns 220,000 tonnes of residential solid waste and 22,500 dry tonnes of biosolids per year into 80,000 tonnes of compost. The facility is 38,690 meters<sup>2</sup> (416,500 ft<sup>2</sup>), equivalent to 4½ Canadian football fields, and the operating structure is the largest stainless steel building in North America, the size of 14 NHL rinks. In 2006, the State of Qatar awarded Keppel Seghers, a subsidiary of Keppel Corporation to begin construction on a 275,000 tonne/year Anaerobic Digestion and Composting Plant. This plant, with 15 independent anaerobic digestors will be the World's Largest Composting facility once fully operational in early 2011 and forms part of the Qatar Domestic Solid Waste Management Center, the largest integrated waste management complex in the Middle East.

## Chapter- 4

# Phytoremediation

**Phytoremediation** (from the Ancient Greek *φυτο* (*phyto*, *plant*), and Latin *remedium* (*restoring balance* or *remediation*) describes the treatment of environmental problems (bioremediation) through the use of plants that mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere.

Phytoremediation consists in mitigating pollutant concentrations in contaminated soils, water, or air, with plants able to contain, degrade, or eliminate metals, pesticides, solvents, explosives, crude oil and its derivatives, and various other contaminants from the media that contain them.

### **Application**

Phytoremediation may be applied wherever the soil or static water environment has become polluted or is suffering ongoing chronic pollution. Examples where phytoremediation has been used successfully include the restoration of abandoned metal-mine workings, reducing the impact of sites where polychlorinated biphenyl have been dumped during manufacture and mitigation of on-going coal mine discharges.

Phytoremediation refers to the natural ability of certain plants called hyperaccumulators to bioaccumulate, degrade, or render harmless contaminants in soils, water, or air. Contaminants such as metals, pesticides, solvents, explosives, and crude oil and its derivatives, have been mitigated in phytoremediation projects worldwide. Many plants such as mustard plants, alpine pennycress, and pigweed have proven to be successful at hyperaccumulating contaminants at toxic-waste sites.

Phytoremediation is considered a clean, cost-effective and non-environmentally disruptive technology, as opposed to mechanical cleanup methods such as soil excavation or pumping polluted groundwater. Over the past 20 years, this technology has become increasingly popular and has been employed at sites with soils contaminated with lead, uranium, and arsenic. However, one major disadvantage of phytoremediation is that it requires a long-term commitment, as the process is dependent on plant growth, tolerance to toxicity, and bioaccumulation capacity.

## ***Advantages and limitations***

- **Advantages:**
  - the cost of the phytoremediation is lower than that of traditional processes both *in situ* and *ex situ*
  - the plants can be easily monitored
  - the possibility of the recovery and re-use of valuable metals (by companies specializing in “phyto mining”)
  - it is potentially the least harmful method because it uses naturally occurring organisms and preserves the environment in a more natural state.
- **Limitations:**
  - phytoremediation is limited to the surface area and depth occupied by the roots.
  - slow growth and low biomass require a long-term commitment
  - with plant-based systems of remediation, it is not possible to completely prevent the leaching of contaminants into the groundwater (without the complete removal of the contaminated ground, which in itself does not resolve the problem of contamination)
  - the survival of the plants is affected by the toxicity of the contaminated land and the general condition of the soil.
  - bio-accumulation of contaminants, especially metals, into the plants which then pass into the food chain, from primary level consumers upwards and/or requires the safe disposal of the affected plant material.

## ***Various phytoremediation processes***

A range of processes mediated by plants or algae are useful in treating environmental problems:

- *Phytoextraction* — uptake and concentration of substances from the environment into the plant biomass.
- *Phytostabilization* — reducing the mobility of substances in the environment, for example, by limiting the leaching of substances from the soil.
- *Phytotransformation* — chemical modification of environmental substances as a direct result of plant metabolism, often resulting in their inactivation, degradation (phytodegradation), or immobilization (phytostabilization).
- *Phytostimulation* — enhancement of soil microbial activity for the degradation of contaminants, typically by organisms that associate with roots. This process is also known as *rhizosphere degradation*. Phytostimulation can also involve aquatic plants supporting active populations of microbial degraders, as in the stimulation of atrazine degradation by hornwort.
- *Phytovolatilization* — removal of substances from soil or water with release into the air, sometimes as a result of phytotransformation to more volatile and/or less polluting substances.

- *Rhizofiltration* — filtering water through a mass of roots to remove toxic substances or excess nutrients. The pollutants remain absorbed in or adsorbed to the roots.

## Phytoextraction

Phytoextraction (or *phytoaccumulation*) uses plants or algae to remove contaminants from soils, sediments or water into harvestable plant biomass. Phytoextraction has been growing rapidly in popularity worldwide for the last twenty years or so. In general, this process has been tried more often for extracting heavy metals than for organics. At the time of disposal, contaminants are typically concentrated in the much smaller volume of the plant matter than in the initially contaminated soil or sediment. 'Mining with plants', or **phytomining**, is also being experimented with.

The plants absorb contaminants through the root system and store them in the root biomass and/or transport them up into the stems and/or leaves. A living plant may continue to absorb contaminants until it is harvested. After harvest, a lower level of the contaminant will remain in the soil, so the growth/harvest cycle must usually be repeated through several crops to achieve a significant cleanup. After the process, the cleaned soil can support other vegetation.

**Advantages:** The main advantage of phytoextraction is environmental friendliness. Traditional methods that are used for cleaning up heavy metal-contaminated soil disrupt soil structure and reduce soil productivity, whereas phytoextraction can clean up the soil without causing any kind of harm to soil quality. Another benefit of phytoextraction is that it is less expensive than any other clean-up process.

**Disadvantages:** As this process is controlled by plants, it takes more time than anthropogenic soil clean-up methods.

### Two versions of phytoextraction:

- **natural hyper-accumulation**, where plants naturally take up the contaminants in soil unassisted, and
- **induced or assisted hyper-accumulation**, in which a conditioning fluid containing a chelator or another agent is added to soil to increase metal solubility or mobilization so that the plants can absorb them more easily. In many cases natural hyperaccumulators are metallophyte plants that can tolerate and incorporate high levels of toxic metals.

### Examples of phytoextraction:

- Arsenic, using the Sunflower (*Helianthus annuus*), or the Chinese Brake fern (*Pteris vittata*), a hyperaccumulator. Chinese Brake fern stores arsenic in its leaves.

- Cadmium, using Willow (*Salix viminalis*): In 1999, one research experiment performed by Maria Greger and Tommy Landberg suggested Willow (*Salix viminalis*) has a significant potential as a phytoextractor of Cadmium (Cd), Zinc (Zn), and Copper (Cu), as willow has some specific characteristics like high transport capacity of heavy metals from root to shoot and huge amount of biomass production; can be used also for production of bio energy in the biomass energy power plant.
- Cadmium and zinc, using Alpine pennycress (*Thlaspi caerulescens*), a hyperaccumulator of these metals at levels that would be toxic to many plants. On the other hand, the presence of copper seems to impair its growth.
- Lead, using Indian Mustard (*Brassica juncea*), Ragweed (*Ambrosia artemisiifolia*), Hemp Dogbane (*Apocynum cannabinum*), or Poplar trees, which sequester lead in its biomass.
- Salt-tolerant (moderately halophytic) barley and/or sugar beets are commonly used for the extraction of Sodium chloride (common salt) to reclaim fields that were previously flooded by sea water.
- Caesium-137 and strontium-90 were removed from a pond using sunflowers after the Chernobyl accident.
- Mercury, selenium and organic pollutants such as polychlorinated biphenyls (PCBs) have been removed from soils by transgenic plants containing genes for bacterial enzymes.

## Phytostabilization

Phytostabilization focuses on long-term stabilization and containment of the pollutant. For example, the plant's presence can reduce wind erosion; or the plant's roots can prevent water erosion, immobilize the pollutants by adsorption or accumulation, and provide a zone around the roots where the pollutant can precipitate and stabilize. Unlike phytoextraction, phytostabilization focuses mainly on sequestering pollutants in soil near the roots but not in plant tissues. Pollutants become less bioavailable, and livestock, wildlife, and human exposure is reduced. An example application of this sort is using a vegetative cap to stabilize and contain mine tailings.

## Phytotransformation

In the case of organic pollutants, such as pesticides, explosives, solvents, industrial chemicals, and other xenobiotic substances, certain plants, such as Cannas, render these substances non-toxic by their metabolism. In other cases, microorganisms living in association with plant roots may metabolize these substances in soil or water. These complex and recalcitrant compounds cannot be broken down to basic molecules (water, carbon-dioxide, etc.) by plant molecules, and, hence, the term *phytotransformation* represents a change in chemical structure without complete breakdown of the compound. The term "Green Liver Model" is used to describe phytotransformation, as plants behave analogously to the human liver when dealing with these xenobiotic compounds (foreign

compound/pollutant). After uptake of the xenobiotics, plant enzymes increase the polarity of the xenobiotics by adding functional groups such as hydroxyl groups (-OH).

This is known as Phase I metabolism, similar to the way that the human liver increases the polarity of drugs and foreign compounds (Drug Metabolism). Whereas in the human liver enzymes such as Cytochrome P450s are responsible for the initial reactions, in plants enzymes such as nitroreductases carry out the same role.

In the second stage of phytotransformation, known as Phase II metabolism, plant biomolecules such as glucose and amino acids are added to the polarized xenobiotic to further increase the polarity (known as conjugation). This is again similar to the processes occurring in the human pancreas where glucuronidation (addition of glucose molecules by the UGT (e.g. UGT1A1) class of enzymes) and glutathione addition reactions occur on reactive centres of the xenobiotic.

Phase I and II reactions serve to increase the polarity and reduce the toxicity of the compounds, although many exceptions to the rule are seen. The increased polarity also allows for easy transport of the xenobiotic along aqueous channels.

In the final stage of phytotransformation (Phase III metabolism), a sequestration of the xenobiotic occurs within the plant. The xenobiotics polymerize in a lignin-like manner and develop a complex structure that is sequestered in the plant. This ensures that the xenobiotic is safely stored, and does not affect the functioning of the plant. However, preliminary studies have shown that these plants can be toxic to small animals (such as snails), and, hence, plants involved in phytotransformation may need to be maintained in a closed enclosure.

Hence, the plants reduce toxicity (with exceptions) and sequester the xenobiotics in phytotransformation. Trinitrotoluene phytotransformation has been extensively researched and a transformation pathway has been proposed.

### ***The role of genetics***

Breeding programs and genetic engineering are powerful methods for enhancing natural phytoremediation capabilities, or for introducing new capabilities into plants. Genes for phytoremediation may originate from a micro-organism or may be transferred from one plant to another variety better adapted to the environmental conditions at the cleanup site. For example, genes encoding a nitroreductase from a bacterium were inserted into tobacco and showed faster removal of TNT and enhanced resistance to the toxic effects of TNT. Researchers have also discovered a mechanism in plants that allows them to grow even when the pollution concentration in the soil is lethal for non-treated plants. Some natural, biodegradable compounds, such as exogenous polyamines, allow the plants to tolerate concentrations of pollutants 500 times higher than untreated plants, and to absorb more pollutants.

## ***Hyperaccumulators and biotic interactions***

A plant is said to be a hyperaccumulator if it can concentrate the pollutants in a minimum percentage which varies according to the pollutant involved (for example: more than 1000 mg/kg of dry weight for nickel, copper, cobalt, chromium or lead; or more than 10,000 mg/kg for zinc or manganese). This capacity for accumulation is due to **hypertolerance**, or *phytotolerance*: the result of adaptative evolution from the plants to hostile environments through many generations. A number of interactions may be affected by metal hyperaccumulation, including protection, interferences with neighbour plants of different species, mutualism (including mycorrhizae, pollen and seed dispersal), commensalism, and biofilm.

WWT

## Chapter- 5

# Incineration



The Spittelau incineration plant in Vienna, designed by Friedensreich Hundertwasser



SYSAV incineration plant in Malmö, Sweden capable of handling 25 metric tons (28 short tons) per hour household waste. To the left of the main stack, a new identical oven line is under construction (March 2007).

**Incineration** is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high temperature waste treatment systems are described as "thermal treatment". Incineration of waste materials converts the waste into ash, flue gas, and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power.

Incineration with energy recovery is one of several waste-to-energy (WtE) technologies such as gasification, Plasma arc gasification, pyrolysis and anaerobic digestion. Incineration may also be implemented without energy and materials recovery.

In several countries, there are still concerns from experts and local communities about the environmental impact of incinerators.

In some countries, incinerators built just a few decades ago often did not include a materials separation to remove hazardous, bulky or recyclable materials before combustion. These facilities tended to risk the health of the plant workers and the local environment due to inadequate levels of gas cleaning and combustion process control. Most of these facilities did not generate electricity.

Incinerators reduce the solid mass of the original waste by 80–85% and the volume (already compressed somewhat in garbage trucks) by 95-96 %, depending on composition and degree of recovery of materials such as metals from the ash for recycling. This means that while incineration does not completely replace landfilling, it significantly reduces the necessary volume for disposal. Garbage trucks often reduce the volume of waste in a built-in compressor before delivery to the incinerator. Alternatively, at landfills, the volume of the uncompressed garbage can be reduced by approximately 70% by using a stationary steel compressor, albeit with a significant energy cost. In many countries, simpler waste compaction is a common practice for compaction at landfills.

Incineration has particularly strong benefits for the treatment of certain waste types in niche areas such as clinical wastes and certain hazardous wastes where pathogens and toxins can be destroyed by high temperatures. Examples include chemical multi-product plants with diverse toxic or very toxic wastewater streams, which cannot be routed to a conventional wastewater treatment plant.

Waste combustion is particularly popular in countries such as Japan where land is a scarce resource. Denmark and Sweden have been leaders in using the energy generated from incineration for more than a century, in localised combined heat and power facilities supporting district heating schemes. In 2005, waste incineration produced 4.8 % of the electricity consumption and 13.7 % of the total domestic heat consumption in Denmark. A number of other European countries rely heavily on incineration for handling municipal waste, in particular Luxembourg, the Netherlands, Germany and France.

## ***History***

The first incinerators for waste disposal were built in Nottingham by Manlove, Alliott & Co. Ltd. in 1874 to a design patented by Albert Fryer. They were originally known as destructors.

## ***Technology***

An incinerator is a furnace for burning waste. Modern incinerators include pollution mitigation equipment such as flue gas cleaning. There are various types of incinerator plant design: moving grate, fixed grate, rotary-kiln, and fluidised bed.

### **Burn pile**

The burn pile, or burn pit is one of the simplest and earliest forms of waste disposal, essentially consisting of a mound of combustible materials piled on bare ground and set on fire. Indiscriminate piles of household waste are strongly discouraged and may be illegal in urban areas, but are permitted in certain rural situations such as clearing forested land for farming, where the stumps are uprooted and burned. Rural burn piles of organic yard waste are also sometimes permitted, though not asphalt shingles, plastics, or other petroleum products.

Burn piles can and have spread uncontrolled fires, for example if wind blows burning material off the pile into surrounding combustible grasses or onto buildings. As interior structures of the pile are consumed, the pile can shift and collapse, spreading the burn area. Even in a situation of no wind, small lightweight ignited embers can lift off the pile via convection, and waft through the air into grasses or onto buildings, igniting them.

### **Burn barrel**

The burn barrel is a somewhat more controlled form of private waste incineration, containing the burning material inside a metal barrel, with a metal grating over the exhaust. The barrel prevents the spread of burning material in windy conditions, and as the combustibles are reduced they can only settle down into the barrel. The exhaust grating helps to prevent the spread of burning embers. Typically steel 55-gallon drums are used as burn barrels, with air vent holes cut or drilled around the base for air intake. Over time the very high heat of incineration causes the metal to oxidize and rust, and eventually the barrel itself is consumed by the heat and must be replaced.

Private burning of dry cellulosic/paper products is generally clean-burning, producing no visible smoke, but the large amount of plastics in household waste can cause private burning to create a public nuisance and health hazard, generating acrid odors and fumes that make eyes burn and water. The temperatures in a burn barrel are not regulated, and usually do not reach high enough or for enough time to completely break down chemicals such as dioxin in plastics and other waste chemicals. Therefore plastics and other petroleum products must be separated and sent to commercial waste disposal facilities.

Private rural incineration is typically only permitted so long as it is not a nuisance to others, does not pose a risk of fire such as in dry conditions, and the fire is clean-burning, producing no visible smoke. People intending to burn waste may be required to contact a state agency in advance to check current fire risk and conditions, and to alert officials of the controlled fire that will occur.

## Moving grate



Control room of a typical moving grate incinerator overseeing two boiler lines

The typical incineration plant for municipal solid waste is a moving grate incinerator. The moving grate enables the movement of waste through the combustion chamber to be optimised to allow a more efficient and complete combustion. A single moving grate boiler can handle up to 35 metric tons (39 short tons) of waste per hour, and can operate 8,000 hours per year with only one scheduled stop for inspection and maintenance of about one month's duration. Moving grate incinerators are sometimes referred to as Municipal Solid Waste Incinerators (MSWIs).

The waste is introduced by a waste crane through the "throat" at one end of the grate, from where it moves down over the descending grate to the ash pit in the other end. Here the ash is removed through a water lock.



Municipal solid waste in the furnace of a moving grate incinerator capable of handling 15 metric tons (17 short tons) of waste per hour. The holes in the grate elements supplying the primary combustion air are visible.

Part of the combustion air (primary combustion air) is supplied through the grate from below. This air flow also has the purpose of cooling the grate itself. Cooling is important for the mechanical strength of the grate, and many moving grates are also water cooled internally.

Secondary combustion air is supplied into the boiler at high speed through nozzles over the grate. It facilitates complete combustion of the flue gases by introducing turbulence for better mixing and by ensuring a surplus of oxygen. In multiple/stepped hearth incinerators, the secondary combustion air is introduced in a separate chamber downstream the primary combustion chamber.

According to the European Waste Incineration Directive, incineration plants must be designed to ensure that the flue gases reach a temperature of at least 850 °C (1,560 °F) for 2 seconds in order to ensure proper breakdown of toxic organic substances. In order to comply with this at all times, it is required to install backup auxiliary burners (often fueled by oil), which are fired into the boiler in case the heating value of the waste becomes too low to reach this temperature alone.

The flue gases are then cooled in the superheaters, where the heat is transferred to steam, heating the steam to typically 400 °C (752 °F) at a pressure of 40 bars (580 psi) for the electricity generation in the turbine. At this point, the flue gas has a temperature of around 200 °C (392 °F), and is passed to the flue gas cleaning system.

In Scandinavia scheduled maintenance is always performed during summer, where the demand for district heating is low. Often incineration plants consist of several separate 'boiler lines' (boilers and flue gas treatment plants), so that waste can continue to be received at one boiler line while the others are subject to revision.

### **Fixed grate**

The older and simpler kind of incinerator was a brick-lined cell with a fixed metal grate over a lower ash pit, with one opening in the top or side for loading and another opening in the side for removing incombustible solids called clinkers. Many small incinerators formerly found in apartment houses have now been replaced by waste compactors.

### **Rotary-kiln**

The rotary-kiln incinerator is used by municipalities and by large industrial plants. This design of incinerator has 2 chambers: a primary chamber and secondary chamber. The primary chamber in a rotary kiln incinerator consist of an inclined refractory lined cylindrical tube. Movement of the cylinder on its axis facilitates movement of waste. In the primary chamber, there is conversion of solid fraction to gases, through volatilization, destructive distillation and partial combustion reactions. The secondary chamber is necessary to complete gas phase combustion reactions.

The clinkers spill out at the end of the cylinder. A tall flue gas stack, fan, or steam jet supplies the needed draft. Ash drops through the grate, but many particles are carried along with the hot gases. The particles and any combustible gases may be combusted in an "afterburner".

### **Fluidized bed**

A strong airflow is forced through a sandbed. The air seeps through the sand until a point is reached where the sand particles separate to let the air through and mixing and churning occurs, thus a fluidised bed is created and fuel and waste can now be introduced.

The sand with the pre-treated waste and/or fuel is kept suspended on pumped air currents and takes on a fluid-like character. The bed is thereby violently mixed and agitated keeping small inert particles and air in a fluid-like state. This allows all of the mass of waste, fuel and sand to be fully circulated through the furnace.

### **Specialized incineration**

Furniture factory sawdust incinerators need much attention as these have to handle resin powder and many flammable substances. Controlled combustion, burn back prevention systems are essential as dust when suspended resembles the fire catch phenomenon of any liquid petroleum gas.

## **Use of heat**

The heat produced by an incinerator can be used to generate steam which may then be used to drive a turbine in order to produce electricity. The typical amount of net energy that can be produced per tonne municipal waste is about 2/3 MWh of electricity and 2 MWh of district heating. Thus, incinerating about 600 metric tons (660 short tons) per day of waste will produce about 400 MWh of electrical energy per day (17 MW of electrical power continuously for 24 hours) and 1200 MWh of district heating energy each day.

## **Pollution**

Incineration has a number of outputs such as the ash and the emission to the atmosphere of flue gas. Before the flue gas cleaning system, the flue gases may contain significant amounts of particulate matter, heavy metals, dioxins, furans, sulfur dioxide, and hydrochloric acid.

In a study from 1994, Delaware Solid Waste Authority found that, for same amount of produced energy, incineration plants emitted fewer particles, hydrocarbons and less SO<sub>2</sub>, HCl, CO and NO<sub>x</sub> than coal-fired power plants, but more than natural gas fired power plants. According to Germany's Ministry of the Environment, waste incinerators reduce the amount of some atmospheric pollutants by substituting power produced by coal-fired plants with power from waste-fired plants.

## **Gaseous emissions**

### **Dioxin and furans**

The most publicized concerns from environmentalists about the incineration of municipal solid wastes (MSW) involve the fear that it produces significant amounts of dioxin and furan emissions. Dioxins and furans are considered by many to be serious health hazards.

In 2005, The Ministry of the Environment of Germany, where there were 66 incinerators at that time, estimated that "...whereas in 1990 one third of all dioxin emissions in Germany came from incineration plants, for the year 2000 the figure was less than 1 %. Chimneys and tiled stoves in private households alone discharge approximately 20 times more dioxin into the environment than incineration plants."

According to the United States Environmental Protection Agency, incineration plants are no longer significant sources of dioxins and furans. In 1987, before the governmental regulations required the use of emission controls, there was a total of 10,000 grams (350 oz) of dioxin emissions from US incinerators. Today, the total emissions from the 87 plants are 10 grams (0.35 oz) annually, a reduction of 99.9 %.

Backyard barrel burning of household and garden wastes, still allowed in some rural areas, generates 580 grams (20 oz) of dioxins annually. Studies conducted by the US-

EPA demonstrate that the emissions from just one family using a burn barrel produces more emissions than an incineration plant disposing of 200 metric tons (220 short tons) of waste per day.

#### **Dioxin cracking methods and limitations**

Generally, the breakdown of dioxin requires exposure of the molecular ring to a sufficiently high temperature so as to trigger thermal breakdown of the strong molecular bonds holding it together. Small pieces of fly ash may be somewhat thick, and too brief an exposure to high temperature may only degrade dioxin on the surface of the ash. For a large volume air chamber, too brief an exposure may also result in only some of the exhaust gases reaching the full breakdown temperature. For this reason there is also a time element to the temperature exposure to ensure heating completely through the thickness of the fly ash and the volume of waste gases.

There are trade-offs between increasing either the temperature or exposure time. Generally where the molecular breakdown temperature is higher, the exposure time for heating can be shorter, but excessively high temperatures can also cause wear and damage to other parts of the incineration equipment. Likewise the breakdown temperature can be lowered to some degree but then the exhaust gases would require a greater lingering period of perhaps several minutes, which would require large/long treatment chambers that take up a great deal of treatment plant space.

A side effect of breaking the strong molecular bonds of dioxin is the potential for breaking the bonds of nitrogen gas ( $N_2$ ) and oxygen gas ( $O_2$ ) in the supply air. As the exhaust flow cools, these highly reactive detached atoms spontaneously reform bonds into reactive oxides such as  $NO_x$  in the flue gas, which can result in smog formation and acid rain if they were released directly into the local environment. These reactive oxides must be further neutralized with selective catalytic reduction (SCR) or selective non-catalytic reduction (see below).

#### **Dioxin cracking in practice**

The temperatures needed to break down dioxin are typically not reached when burning of plastics outdoors in a burn barrel or garbage pit, causing high dioxin emissions as mentioned above. While plastic does usually burn in an open-air fire, the dioxins remain after combustion and either float off into the atmosphere, or may remain in the ash where it can be leached down into groundwater when rain falls on the ash pile.

Modern municipal incinerator designs include a high temperature zone, where the flue gas is ensured to sustain a temperature above  $850\text{ }^\circ\text{C}$  ( $1,560\text{ }^\circ\text{F}$ ) for at least 2 seconds before it is cooled down. They are equipped with auxiliary heaters to ensure this at all times. These are often fueled by oil, and normally only active for a very small fraction of the time.

For very small municipal incinerators, the required temperature for thermal breakdown of dioxin may be reached using a high-temperature electrical heating element, plus a selective catalytic reduction stage.

## **CO<sub>2</sub>**

As for other complete combustion processes, nearly all of the carbon content in the waste is emitted as CO<sub>2</sub> to the atmosphere. MSW contains approximately the same mass fraction of carbon as CO<sub>2</sub> itself (27%), so incineration of 1 ton of MSW produces approximately 1 ton of CO<sub>2</sub>.

If the waste was landfilled, 1 ton of MSW would produce approximately 62 cubic metres (2,200 cu ft) methane via the anaerobic decomposition of the biodegradable part of the waste. This much methane has more than twice the global warming potential than the 1 ton of CO<sub>2</sub>, which would have been produced by incineration. In some countries, large amounts of landfill gas are collected, but still the global warming potential of the landfill gas emitted to atmosphere in the US in 1999 was approximately 32 % higher than the amount of CO<sub>2</sub> that would have been emitted by incineration.

In addition, nearly all biodegradable waste has biological origin. This material has been formed by plants using atmospheric CO<sub>2</sub> typically within the last growing season. If these plants are regrown the CO<sub>2</sub> emitted from their combustion will be taken out from the atmosphere once more.

Such considerations are the main reason why several countries administrate incineration of the biodegradable part of waste as renewable energy. The rest – mainly plastics and other oil and gas derived products – is generally treated as non-renewables.

Different results for the CO<sub>2</sub> footprint of incineration can be reached with different assumptions. Local conditions (such as limited local district heating demand, no fossil fuel generated electricity to replace or high levels of aluminum in the waste stream) can decrease the CO<sub>2</sub> benefits of incineration. The methodology and other assumptions may also influence the results significantly. For example the methane emissions from landfills occurring at a later date may be neglected or given less weight, or biodegradable waste may not be considered CO<sub>2</sub> neutral. A study by Eunomia Research and Consulting in 2008 on potential waste treatment technologies in London demonstrated that by applying several of these (according to the authors) unusual assumptions the average existing incineration plants performed poorly for CO<sub>2</sub> balance compared to the theoretical potential of other emerging waste treatment technologies.

## **Other emissions**

Other gaseous emissions in the flue gas from incinerator furnaces include sulfur dioxide, hydrochloric acid, heavy metals and fine particles.

The steam content in the flue may produce visible fume from the stack, which can be perceived as a visual pollution. It may be avoided by decreasing the steam content by flue gas condensation and reheating, or by increasing the flue gas exit temperature well above its dew point. Flue gas condensation allows the latent heat of vaporization of the water to be recovered, subsequently increasing the thermal efficiency of the plant.

## **Flue gas cleaning**

The quantity of pollutants in the flue gas from incineration plants is reduced by several processes.

Particulate is collected by particle filtration, most often electrostatic precipitators (ESP) and/or baghouse filters. The latter are generally very efficient for collecting fine particles. In an investigation by the Ministry of the Environment of Denmark in 2006, the average particulate emissions per energy content of incinerated waste from 16 Danish incinerators were below 2.02 g/GJ (grams per energy content of the incinerated waste). Detailed measurements of fine particles with sizes below 2.5 micrometres ( $PM_{2.5}$ ) were performed on three of the incinerators: One incinerator equipped with an ESP for particle filtration emitted 5.3 g/GJ fine particles, while two incinerators equipped with baghouse filters emitted 0.002 and 0.013 g/GJ  $PM_{2.5}$ . For ultra fine particles ( $PM_{1.0}$ ), the numbers were 4.889 g/GJ  $PM_{1.0}$  from the ESP plant, while emissions of 0.000 and 0.008 g/GJ  $PM_{1.0}$  were measured from the plants equipped with baghouse filters.

Acid gas scrubbers are used to remove hydrochloric acid, nitric acid, hydrofluoric acid, mercury, lead and other heavy metals. Basic scrubbers remove sulfur dioxide, forming gypsum by reaction with lime.

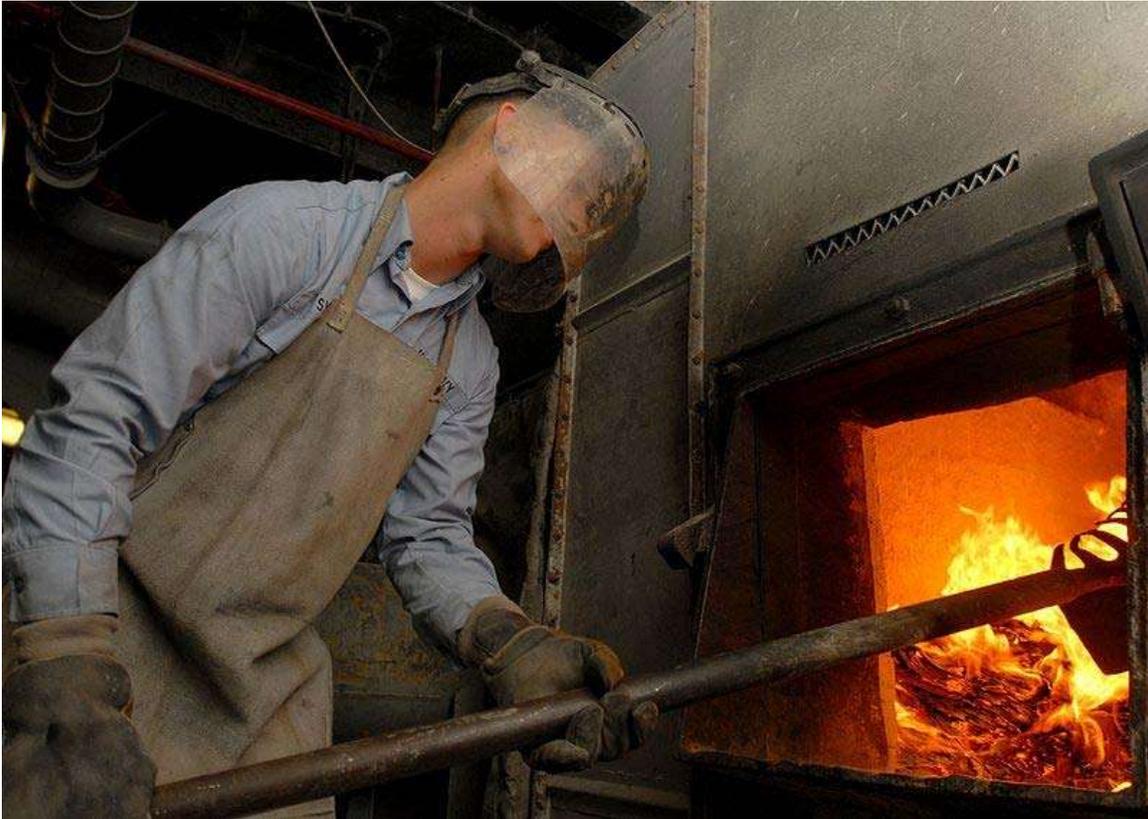
Waste water from scrubbers must subsequently pass through a waste water treatment plant.

Sulfur dioxide may also be removed by dry desulfurisation by injection limestone slurry into the flue gas before the particle filtration.

$NO_x$  is either reduced by catalytic reduction with ammonia in a catalytic converter (selective catalytic reduction, SCR) or by a high temperature reaction with ammonia in the furnace (selective non-catalytic reduction, SNCR). Urea may be substituted for ammonia as the reducing reagent but must be supplied earlier in the process so that it can hydrolyze into ammonia. Substitution of urea can reduce costs and potential hazards associated with storage of anhydrous ammonia.

Heavy metals are often adsorbed on injected active carbon powder, which is collected by the particle filtration.

## Solid outputs



Operation of an incinerator aboard an aircraft carrier

Incineration produces fly ash and bottom ash just as is the case when coal is combusted. The total amount of ash produced by municipal solid waste incineration ranges from 4 to 10 % by volume and 15-20 % by weight of the original quantity of waste, and the fly ash amounts to about 10-20 % of the total ash. The fly ash, by far, constitutes more of a potential health hazard than does the bottom ash because the fly ash often contain high concentrations of heavy metals such as lead, cadmium, copper and zinc as well as small amounts of dioxins and furans. The bottom ash seldom contain significant levels of heavy metals. In testing over the past decade, no ash from an incineration plant in the USA has ever been determined to be a hazardous waste. At present although some historic samples tested by the incinerator operators' group would meet the being ecotoxic criteria at present the EA say "we have agreed" to regard incinerator bottom ash as "non-hazardous" until the testing programme is complete.

## Other pollution issues

Odor pollution can be a problem with old-style incinerators, but odors and dust are extremely well controlled in newer incineration plants. They receive and store the waste in an enclosed area with a negative pressure with the airflow being routed through the boiler which prevents unpleasant odors from escaping into the atmosphere. However, not all plants are implemented this way, resulting in inconveniences in the locality.

An issue that affects community relationships is the increased road traffic of waste collection vehicles to transport municipal waste to the incinerator. Due to this reason, most incinerators are located in industrial areas. This problem can be avoided to an extent through the transport of waste by rail from transfer stations.

## ***Debate***

Use of incinerators for waste management is controversial. The debate over incinerators typically involves business interests (representing both waste generators and incinerator firms), government regulators, environmental activists and local citizens who must weigh the economic appeal of local industrial activity with their concerns over health and environmental risk.

People and organizations professionally involved in this issue include the U.S. Environmental Protection Agency and a great many local and national air quality regulatory agencies worldwide.

## **Arguments for incineration**



*Kehrichtverbrennungsanlage Zürcher Oberland (KEZO) in Hinwil, Switzerland*

- The concerns over the health effects of dioxin and furan emissions have been significantly lessened by advances in emission control designs and very stringent new governmental regulations that have resulted in large reductions in the amount of dioxins and furans emissions.

- The U.K. Health Protection Agency concluded in 2009 that "Modern, well managed incinerators make only a small contribution to local concentrations of air pollutants. It is possible that such small additions could have an impact on health but such effects, if they exist, are likely to be very small and not detectable."
- Incineration plants can generate electricity and heat that can substitute power plants powered by other fuels at the regional electric and district heating grid, and steam supply for industrial customers. Incinerators and other waste-to-energy plants generate at least partially biomass-based renewable energy that offsets greenhouse gas pollution from coal-, oil- and gas-fired power plants. The E.U. considers energy generated from biogenic waste (waste with biological origin) by incinerators as non-fossil renewable energy under its emissions caps. These greenhouse gas reductions are in addition to those generated by the avoidance of landfill methane.
- The bottom ash residue remaining after combustion has been shown to be a non-hazardous solid waste that can be safely put into landfills or recycled as construction aggregate. Samples are tested for ecotoxic metals.
- In densely populated areas, finding space for additional landfills is becoming increasingly difficult.



The Maishima waste treatment center in Osaka, designed by Friedensreich Hundertwasser, uses heat for power generation.

Fine particles can be efficiently removed from the flue gases with baghouse filters. Even though approximately 40 % of the incinerated waste in Denmark was incinerated at plants with no baghouse filters, estimates based on measurements by the Danish Environmental Research Institute showed that incinerators were only responsible for approximately 0.3 % of the total domestic emissions of particulate smaller than 2.5 micrometres (PM<sub>2.5</sub>) to the atmosphere in 2006.

- Incineration of municipal solid waste avoids the release of methane. Every ton of MSW incinerated, prevents about one ton of carbon dioxide equivalents from being released to the atmosphere.
- Incineration of medical waste and sewage sludge produces an end product ash that is sterile and non-hazardous.
- Most municipalities that operate incineration facilities have higher recycling rates than neighboring cities and counties that do not send their waste to incinerators. This is in part due to enhanced recovery of ceramic materials reused in construction, as well as ferrous and in some cases non-ferrous metals that can be recovered from combustion residue. Metals recovered from ash would typically be difficult or impossible to recycle through conventional means, as the removal of attached combustible material through incineration provides an alternative to labor- or energy-intensive mechanical separation methods.
- Volume of combusted waste is reduced by approximately 90%, increasing the life of landfills. Ash from modern incinerators is vitrified at temperatures of 1,000 °C (1,830 °F) to 1,100 °C (2,010 °F), reducing the leachability and toxicity of residue. As a result, special landfills are generally no longer required for incinerator ash from municipal waste streams, and existing landfills can see their life dramatically increased by combusting waste, reducing the need for municipalities to site and construct new landfills.

## Arguments against incineration



Decommissioned Kwai Chung Incineration Plant from 1978. As of late February 2009, it has been demolished.

- The Scottish Protection Agency's (SEPA) comprehensive health effects research concluded "inconclusively" on health effects in Oct. 2009. The authors stress, that even though no conclusive evidence of non-occupational health effects from incinerators were found in the existing literature, "small but important effects might be virtually impossible to detect". The report highlights epidemiological deficiencies in previous UK health studies and suggests areas for future studies. The U.K. Health Protection Agency produced a lesser summary in September 2009. Many toxicologists criticise and dispute this report as not being

comprehensive epidemiologically, thin on peer review and the effects of fine particle effects on health.

- The highly toxic fly ash must be safely disposed of. This usually involves additional waste miles and the need for specialist toxic waste landfill elsewhere. If not done properly, it may cause concerns for local residents.
- Some people are still concerned about the health effects of dioxin and furan emissions into the atmosphere from old incinerators; especially during start up and shut down, or where filter bypass is required.
- Incinerators emit varying levels of heavy metals such as vanadium, manganese, chromium, nickel, arsenic, mercury, lead, and cadmium, which can be toxic at very minute levels.
- Incinerator Bottom Ash (IBA) has elevated levels of heavy metals with ecotoxicity concerns if not reused properly. Some people have the opinion that IBA reuse is still in its infancy and is still not considered to be a mature or desirable product, despite additional engineering treatments. Concerns of IBA use in foam concrete have been expressed by the UK Health and Safety Executive in 2010 following several construction and demolition explosions. In its guidance document, IBA is currently banned from use by the UK Highway Authority in concrete work until these incidents have been investigated.
- Alternative technologies are available or in development such as Mechanical Biological Treatment, Anaerobic Digestion (MBT/AD), Autoclaving or Mechanical Heat Treatment (MHT) using steam or plasma arc gasification PGP, or combinations of these treatments. Erection of incinerators compete with the development and introduction of other emerging technologies. A UK government WRAP report, August 2008 found that in the UK median incinerator costs per ton were generally higher than those for MBT treatments by £18 per metric ton; and £27 per metric ton most for modern (post 2000) incinerators.
- Building and operating waste processing plants such as incinerators requires long contract periods to recover initial investment costs, causing a long term lock-in. Incinerator lifetimes normally range 25–30 years. This was highlighted by Peter Jones, OBE, the Mayor of London's waste representative in April 2009.
- Incinerators produce fine particles in the furnace. Even with modern particle filtering of the flue gases, a small part of these is emitted to the atmosphere. PM<sub>2.5</sub> is not separately regulated in the European Waste Incineration Directive, even though they are repeatedly correlated spatially to infant mortality in the UK (M.Ryan's ONS data based maps around the EfW/CHP waste incinerators at Edmonton, Coventry, Chineham, Kirklees and Sheffield). Under WID there is no requirement to monitor stack top or downwind incinerator PM<sub>2.5</sub> levels. Several European doctors associations (including cross discipline experts such as physicians, environmental chemists and toxicologists) in June 2008 representing over 33,000 doctors wrote a keynote statement directly to the European Parliament citing widespread concerns on incinerator particle emissions and the absence of specific fine and ultrafine particle size monitoring or in depth industry/ government epidemiological studies of these minute and invisible incinerator particle size emissions.

- Local communities are often opposed to the idea of locating waste processing plants such as incinerators in their vicinity (the Not In My Back Yard phenomenon). Studies in Andover, Massachusetts strongly correlated 10% property devaluations with close incinerator proximity.
- Prevention, waste minimisation, reuse and recycling of waste should all be preferred to incineration according to the waste hierarchy. Supporters of zero waste consider incinerators and other waste treatment technologies as barriers to recycling and separation beyond particular levels, and that waste resources are sacrificed for energy production.
- A 2008 Eunomia report found that under some circumstances and assumptions, incineration causes less CO<sub>2</sub> reduction than other emerging EfW and CHP technology combinations for treating residual mixed waste. The authors found that CHP incinerator technology without waste recycling ranked 19 out of 24 combinations (where all alternatives to incineration were combined with advanced waste recycling plants); being 228% less efficient than the ranked 1 Advanced MBT maturation technology; or 211% less efficient than plasma gasification/autoclaving combination ranked 2.
- Some incinerators are visually undesirable. In many countries they require a visually intrusive chimney stack.
- If reusable waste fractions are handled in waste processing plants such as incinerators in developing nations, it would cut out viable work for local economies. It is estimated that there are 1 million people making a livelihood off collecting waste.

### ***Trends in incinerator use***

The history of municipal solid waste (MSW) incineration is linked intimately to the history of landfills and other waste treatment technology. The merits of incineration are inevitably judged in relation to the alternatives available. Since the 1970s, recycling and other prevention measures have changed the context for such judgements. Since the 1990s alternative waste treatment technologies have been maturing and becoming viable.

Incineration is a key process in the treatment of hazardous wastes and clinical wastes. It is often imperative that medical waste be subjected to the high temperatures of incineration to destroy pathogens and toxic contamination it contains.

### **Incineration in North America**

The first incinerator in the U.S. was built in 1885 on Governors Island in New York. In 1949, Robert C. Ross founded one of the first hazardous waste management companies in the U.S. He began Robert Ross Industrial Disposal because he saw an opportunity to meet the hazardous waste management needs of companies in northern Ohio. In 1958, the company built one of the first hazardous waste incinerators in the U.S. The first full-scale, municipally operated incineration facility in the U.S. was the Arnold O. Chantland Resource Recovery Plant, built in 1975 and located in Ames, Iowa. This plant is still in operation and produces refuse-derived fuel that is sent to local power plants for fuel. The

first commercially successful incineration plant in the U.S. was built in Saugus, Massachusetts in October 1975 by Wheelabrator Technologies, and is still in operation today.

There are several environmental or waste management corporations that transport ultimately to an incinerator or cement kiln treatment center. Currently (2009), there are three main businesses that incinerate waste: Clean Harbours, WTI-Heritage, and Ross Incineration Services. Clean Harbours has acquired many of the smaller, independently run facilities, accumulating 5–7 incinerators in the process across the U.S. WTI-Heritage has one incinerator, located in the southeastern corner of Ohio (across the Ohio River from West Virginia).

Several old generation incinerators have been closed; of the 186 MSW incinerators in 1990, only 89 remained by 2007, and of the 6200 medical waste incinerators in 1988, only 115 remained in 2003. No new incinerators were built between 1996 and 2007. The main reasons for lack of activity have been:

- Economics. With the increase in the number of large inexpensive regional landfills and, up until recently, the relatively low price of electricity, incinerators were not able to compete for the 'fuel', i.e., waste in the U.S.
- Tax policies. Tax credits for plants producing electricity from waste were rescinded in the U.S. between 1990 and 2004.

There has been renewed interest in incineration and other waste-to-energy technologies in the U.S. and Canada. In the U.S., incineration was granted qualification for renewable energy production tax credits in 2004. Projects to add capacity to existing plants are underway, and municipalities are once again evaluating the option of building incineration plants rather than continue landfilling municipal wastes. However, many of these projects have faced continued political opposition in spite of renewed arguments for the greenhouse gas benefits of incineration and improved air pollution control and ash recycling.

## **Incineration in Europe**

In Europe, with the ban on landfilling untreated waste, scores of incinerators have been built in the last decade, with more under construction. Recently, a number of municipal governments have begun the process of contracting for the construction and operation of incinerators. In Europe, some of the electricity generated from waste is deemed to be from a 'Renewable Energy Source (RES)' and is thus eligible for tax credits if privately operated. Also, some incinerators in Europe are equipped with waste recovery, allowing the reuse of ferrous and non-ferrous materials found in landfills. A prominent example is the AEB Waste Fired Power Plant.

## Incineration in the United Kingdom

The technology employed in the UK waste management industry has been greatly lagging behind that of Europe due to the wide availability of landfills. The Landfill Directive set down by the European Union led to the Government of the United Kingdom imposing waste legislation including the landfill tax and Landfill Allowance Trading Scheme. This legislation is designed to reduce the release of greenhouse gases produced by landfills through the use of alternative methods of waste treatment. It is the UK Government's position that incineration will play an increasingly large role in the treatment of municipal waste and supply of energy in the UK.

In the UK in 2008, plans for potential incinerator locations exists for approximately 100 sites. These have been interactively mapped by UK NGO's.

### Small incinerator units



An example of a low capacity, mobile incinerator

Small scale incinerators exist for special purposes. For example, the small scale incinerators are aimed for hygienically safe destruction of medical waste in developing countries. Small incinerators can be quickly deployed to remote areas where an outbreak has occurred to dispose of infected animals quickly and without the risk of cross contamination.

## Chapter- 6

# Gasification

**Gasification** is a process that converts carbonaceous materials, such as coal, petroleum, biofuel, or biomass, into carbon monoxide and hydrogen by reacting the raw material at high temperatures with a controlled amount of oxygen and/or steam. The resulting gas mixture is called synthesis gas or syngas and is itself a fuel. Gasification is a method for extracting energy from many different types of organic materials.

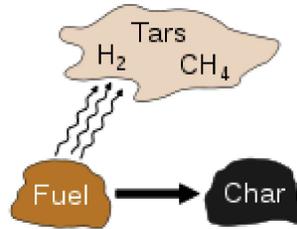
The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperatures or even in fuel cells, so that the thermodynamic upper limit to the efficiency defined by Carnot's rule is higher or not applicable. Syngas may be burned directly in internal combustion engines, used to produce methanol and hydrogen, or converted via the Fischer-Tropsch process into synthetic fuel. Gasification can also begin with materials that are not otherwise useful fuels, such as biomass or organic waste. In addition, the high-temperature combustion refines out corrosive ash elements such as chloride and potassium, allowing clean gas production from otherwise problematic fuels.

Gasification of fossil fuels is currently widely used on industrial scales to generate electricity. However, almost any type of organic material can be used as the raw material for gasification, such as wood, biomass, or even plastic waste.

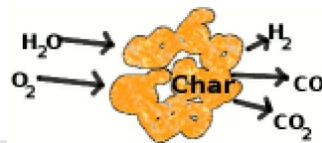
Gasification relies on chemical processes at elevated temperatures  $>700^{\circ}\text{C}$ , which distinguishes it from biological processes such as anaerobic digestion that produce biogas.

## Chemistry

In a gasifier, the carbonaceous material undergoes several different processes:



Pyrolysis of carbonaceous fuels



Gasification of char

1. The *pyrolysis* (or devolatilization) process occurs as the carbonaceous particle heats up. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.
2. The *combustion* process occurs as the volatile products and some of the char reacts with oxygen to form carbon dioxide and carbon monoxide, which provides heat for the subsequent gasification reactions. Letting **C** represent a carbon-containing organic compound, the basic reaction here is 
$$\text{C} + \frac{1}{2}\text{O}_2 \rightarrow \text{CO}$$
3. The *gasification* process occurs as the char reacts with carbon dioxide and steam to produce carbon monoxide and hydrogen, via the reaction 
$$\text{C} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{CO}$$
4. In addition, the reversible gas phase water gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen. 
$$\text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2$$

In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide. Further reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide. This third reaction occurs more abundantly in reactors that increase the residence time of the reactive gases and organic materials, as well as heat and pressure. Catalysts are used in

more sophisticated reactors to improve reaction rates, thus moving the system closer to the reaction equilibrium for a fixed residence time.

## ***History***



Adler Diplomat 3 with gas generator (1941)

The Process of producing energy using the gasification method has been in use for more than 180 years. During that time coal and peat were used to power these plants. Initially developed to produce town gas for lighting & cooking in 1800s, this was replaced by electricity and natural gas, it was also used in blast furnaces but the bigger role was played in the production of synthetic chemicals where it has been in use since the 1920s.

During both world wars especially the Second World War the need of gasification produced fuel reemerged due to the shortage of petroleum. Wood gas generators, called Gasogene or Gazogène, were used to power motor vehicles in Europe. By 1945 there were trucks, buses and agricultural machines that were powered by gasification. It is estimated that there were close to 9,000,000 vehicles running on producer gas all over the world.

## ***Gasification processes***

Four types of gasifier are currently available for commercial use: counter-current fixed bed, co-current fixed bed, fluidized bed and entrained flow.

The **counter-current fixed bed ("up draft") gasifier** consists of a fixed bed of carbonaceous fuel (e.g. coal or biomass) through which the "gasification agent" (steam, oxygen and/or air) flows in counter-current configuration. The ash is either removed dry or as a slag. The slagging gasifiers have a lower ratio of steam to carbon, achieving temperatures higher than the ash fusion temperature. The nature of the gasifier means that the fuel must have high mechanical strength and must ideally be non-caking so that it will form a permeable bed, although recent developments have reduced these restrictions to some extent. The throughput for this type of gasifier is relatively low. Thermal efficiency is high as the gas exit temperatures are relatively low. However, this means that tar and methane production is significant at typical operation temperatures, so product gas must be extensively cleaned before use. The tar can be recycled to the reactor.

The **co-current fixed bed ("down draft") gasifier** is similar to the counter-current type, but the gasification agent gas flows in co-current configuration with the fuel (downwards, hence the name "down draft gasifier"). Heat needs to be added to the upper part of the bed, either by combusting small amounts of the fuel or from external heat sources. The produced gas leaves the gasifier at a high temperature, and most of this heat is often transferred to the gasification agent added in the top of the bed, resulting in an energy efficiency on level with the counter-current type. Since all tars must pass through a hot bed of char in this configuration, tar levels are much lower than the counter-current type.

In the **fluidized bed reactor**, the fuel is fluidized in oxygen and steam or air. The ash is removed dry or as heavy agglomerates that defluidize. The temperatures are relatively low in dry ash gasifiers, so the fuel must be highly reactive; low-grade coals are particularly suitable. The agglomerating gasifiers have slightly higher temperatures, and are suitable for higher rank coals. Fuel throughput is higher than for the fixed bed, but not as high as for the entrained flow gasifier. The conversion efficiency can be rather low due to elutriation of carbonaceous material. Recycle or subsequent combustion of solids can be used to increase conversion. Fluidized bed gasifiers are most useful for fuels that form highly corrosive ash that would damage the walls of slagging gasifiers. Biomass fuels generally contain high levels of corrosive ash.

In the **entrained flow gasifier** a dry pulverized solid, an atomized liquid fuel or a fuel slurry is gasified with oxygen (much less frequent: air) in co-current flow. The gasification reactions take place in a dense cloud of very fine particles. Most coals are suitable for this type of gasifier because of the high operating temperatures and because the coal particles are well separated from one another. The high temperatures and pressures also mean that a higher throughput can be achieved, however thermal efficiency is somewhat lower as the gas must be cooled before it can be cleaned with existing technology. The high temperatures also mean that tar and methane are not present in the product gas; however the oxygen requirement is higher than for the other types of gasifiers. All entrained flow gasifiers remove the major part of the ash as a slag as the operating temperature is well above the ash fusion temperature. A smaller fraction of the ash is produced either as a very fine dry fly ash or as a black colored fly ash slurry. Some fuels, in particular certain types of biomasses, can form slag that is corrosive for ceramic inner walls that serve to protect the gasifier outer wall. However some entrained

bed type of gasifiers do not possess a ceramic inner wall but have an inner water or steam cooled wall covered with partially solidified slag. These types of gasifiers do not suffer from corrosive slags. Some fuels have ashes with very high ash fusion temperatures. In this case mostly limestone is mixed with the fuel prior to gasification. Addition of a little limestone will usually suffice for the lowering the fusion temperatures. The fuel particles must be much smaller than for other types of gasifiers. This means the fuel must be pulverized, which requires somewhat more energy than for the other types of gasifiers. By far the most energy consumption related to entrained bed gasification is not the milling of the fuel but the production of oxygen used for the gasification.

### ***Current applications***

In small business and building applications, where the wood source is sustainable, 250-1000 kWe and new zero carbon biomass gasification plants have been installed in Europe that produce tar free syngas from wood and burn it in reciprocating engines connected to a generator with heat recovery. This type of plant is often referred to as a wood biomass CHP unit but is a plant with seven different processes: biomass processing, fuel delivery, gasification, gas cleaning, waste disposal, electricity generation and heat recovery.

Industrial-scale gasification is currently mostly used to produce electricity from fossil fuels such as coal, where the syngas is burned in a gas turbine.

Gasification is also used industrially in the production of electricity, ammonia and liquid fuels (oil) using Integrated Gasification Combined Cycles (IGCC), with the possibility of producing methane and hydrogen for fuel cells. IGCC is also a more efficient method of CO<sub>2</sub> capture as compared to conventional technologies. IGCC demonstration plants have been operating since the early 1970s and some of the plants constructed in the 1990s are now entering commercial service.

Gasification technologies have been developed in recent years that use plastic-rich waste as a feed.

Syngas can be used for heat production and for generation of mechanical and electrical power. Like other gaseous fuels, producer gas gives greater control over power levels when compared to solid fuels, leading to more efficient and cleaner operation.

Gasifiers offer a flexible option for thermal applications, as they can be retrofitted into existing gas fueled devices such as ovens, furnaces, boilers, etc., where syngas may replace fossil fuels. Heating values of syngas are generally around 4-10 MJ/m<sup>3</sup>.

Diesel engines can be operated on dual fuel mode using producer gas. Diesel substitution of over 80% at high loads and 70-80% under normal load variations can easily be achieved. Spark ignition engines and SOFC fuel cells can operate on 100% gasification gas. Mechanical energy from the engines may be used for e.g. driving water pumps for irrigation or for coupling with an alternator for electrical power generation.

Small-scale rural biomass gasifiers have been applied in India to a large extent, especially in the state of Tamil-Nadu in South India. Most of the applications are 9 kWe systems used for water pumping and street lighting operated by the local panchayat government. Although technically applicable the systems face political, financial and maintenance problems. Most of the systems are no longer running after 1–3 years.

While small scale gasifiers have existed for well over 100 years, there have been few sources to obtain a ready to use machine. Small scale devices are typically DIY projects. However, currently in the United States, several companies offer gasifiers to operate small engines.

### ***Potential for renewable energy***



Gasification plant Güssing, Austria (2006)

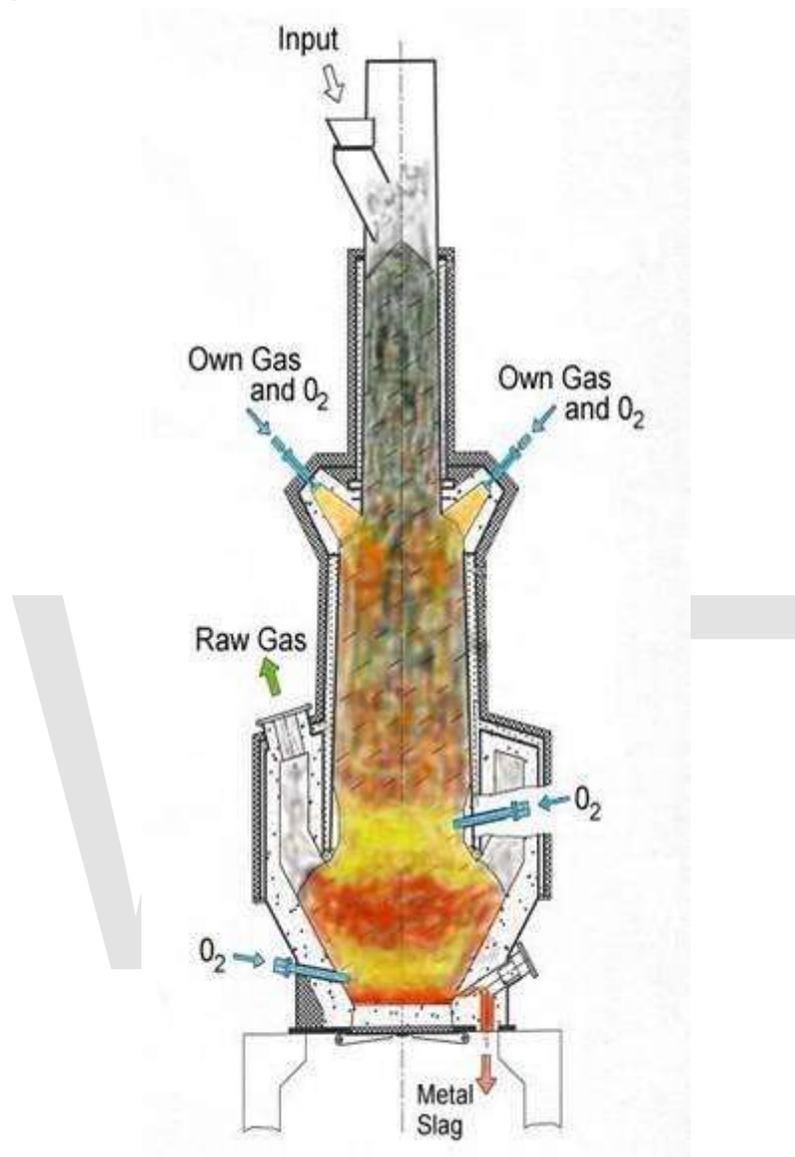
In principle, gasification can proceed from just about any organic material, including biomass and plastic waste. The resulting syngas can be combusted. Alternatively, if the syngas is clean enough, it may be used for power production in gas engines, gas turbines or even fuel cells, or converted efficiently to dimethyl ether (DME) by methanol dehydration, methane via the Sabatier reaction, or diesel-like synthetic fuel via the Fischer-Tropsch process. In many gasification processes most of the inorganic components of the input material, such as metals and minerals, are retained in the ash. In some gasification processes (slagging gasification) this ash has the form of a glassy solid with low leaching properties, but the net power production in slagging gasification is low (sometimes negative) and costs are higher.

Regardless of the final fuel form, gasification itself and subsequent processing neither directly emits nor traps greenhouse gasses such as carbon dioxide. Power consumption in the gasification and syngas conversion processes may be significant though, and may indirectly cause CO<sub>2</sub> emissions; in slagging and plasma gasification, the electricity consumption may even exceed any power production from the syngas. Combustion of syngas or derived fuels emits exactly the same amount of carbon dioxide as would have been emitted from direct combustion of the initial fuel. Biomass gasification and combustion could play a significant role in a renewable energy economy, because biomass production removes the same amount of CO<sub>2</sub> from the atmosphere as is emitted from gasification and combustion. While other biofuel technologies such as biogas and biodiesel are carbon neutral, gasification in principle may run on a wider variety of input materials and can be used to produce a wider variety of output fuels.

There is at present very little industrial scale biomass gasification being done. Examples of demonstration projects include

- Those of the Renewable Energy Network Austria, including a plant using dual fluidized bed gasification that has supplied the town of Güssing with 2 MW of electricity and 4 MW of heat, generated from wood chips, since 2003.
- Chemrec's pilot plant in Piteå that has produced 3 MW of clean syngas since 2006, generated from entrained flow gasification of black liquor.

## ***Waste disposal***



HTCW reactor, one of several proposed waste gasification processes. According to the sales and sales management consultants *KBI Group* a pilot plant in Arnstadt implementing this process has completed initial tests.

Waste gasification has several principal advantages over incineration:

- The necessary extensive flue gas cleaning may be performed on the syngas instead of the much larger volume of flue gas after combustion.
- Electric power may be generated in engines and gas turbines, which are much cheaper and more efficient than the steam cycle used in incineration. Even fuel cells may potentially be used, but these have rather severe requirements regarding the purity of the gas.

- Chemical processing of the syngas may produce other synthetic fuels instead of electricity.
- Some gasification processes treat ash containing heavy metals at very high temperatures so that it is released in a glassy and chemically stable form.

A major challenge for waste gasification technologies is to reach an acceptable (positive) gross electric efficiency. The high efficiency of converting syngas to electric power is counteracted by significant power consumption in the waste preprocessing, the consumption of large amounts of pure oxygen (which is often used as gasification agent), and gas cleaning. Another challenge becoming apparent when implementing the processes in real life is to obtain long service intervals in the plants, so that it is not necessary to close down the plant every few months for cleaning the reactor.

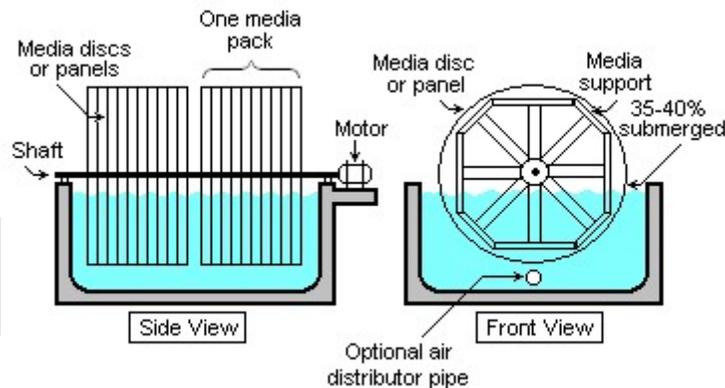
Several waste gasification processes have been proposed, but few have yet been built and tested, and only a handful have been implemented as plants processing real waste, and always in combination with fossil fuels.

One plant (in Chiba, Japan using the Thermoselect process) has been processing industrial waste since year 2000, but has not yet documented positive net energy production from the process.

Ze-gen is operating a waste gasification demonstration facility in New Bedford, Massachusetts. The facility was designed to demonstrate gasification of specific non-MSW waste streams using *liquid metal gasification*

## Chapter- 7

# Rotating Biological Contactor



Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram.

A **rotating biological contactor** or **RBC** is a biological treatment process used in the treatment of wastewater following primary treatment. The primary treatment process removes the grit and other solids through a screening process followed by a period of settlement. The RBC process involves allowing the wastewater to come in contact with a biological medium in order to remove pollutants in the wastewater before discharge of the treated wastewater to the environment, usually a body of water (river, lake or ocean). A rotating biological contactor is a type of secondary treatment process. It consists of a series of closely spaced, parallel discs mounted on a rotating shaft which is supported just above the surface of the waste water. Microorganisms grow on the surface of the discs where biological degradation of the wastewater pollutants takes place.

### ***Biotechnology for wastewater***

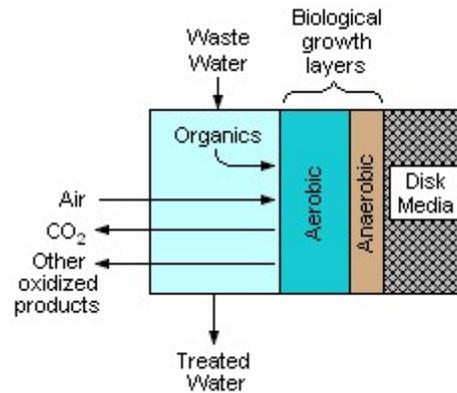
Environmental consciousness and concern sustainable society have driven the society to the direction of re-organization of the infrastructures and the urban systems. To build an environmental management system that satisfies various social needs simultaneously in the water environment, it is essential to optimize environmental control technologies by comprehensive and systematic approaches. In this course, we critically discuss several key issues that are important in achieving desirable environmental technology systems. Biochemistry to understand the technology of wastewater treatment technologies using

microorganisms is the main topic. The characteristics of complex microbial community and mathematical design modeling for Rotating Biological Contactors are discussed in this project. Biotechnology for wastewater treatment is needed so that we can use our rivers and stream for fishing, swimming and drinking water. For the first half of the 20th century, population in the Nation's urban waterways resulted in frequent occurrences of low dissolved oxygen, fish kills, algal blooms and bacterial contamination. Early efforts in water pollution control prevented human waste from reaching water supplies or reduced floating debris that obstructed shipping. Pollution problems and their control were primarily local, not national, concerns. Since then, population and industrial growth have increased demand on our natural resources, altering the situation dramatically. Progress in abating pollution has barely kept ahead of population growth, changes in industrial processes, technological developments, and changes in land use, business innovations, and many other factors. Increases in both the quantity and variety of goods produced can greatly alter the amount and complexity of industrial wastes and challenge traditional treatment technology. The application of commercial fertilizers and pesticides, combined with sediment from growing development activities, continue to be source of significant pollution as runoff washes off the land. Water pollution issues now dominate public concerns about national water quality and maintaining healthy ecosystems. Although a large investment in water pollution control has helped to reduce the problems, many miles of streams are still impacted by variety of different pollutants. This, in turn, affects the ability of people to use the water for beneficial purpose. Past approaches used to control must be modified to accommodate current and emerging issues. Hence the appropriate biotechnology should be used for wastewater treatment plant.

## ***Operation***

The rotating packs of disks (known as the media) are contained in a tank or trough and rotate at between 2 and 5 revolutions per minute. Commonly used plastics for the media are polythene, PVC and expanded polystyrene. The shaft is aligned with the flow of wastewater so that the discs rotate at right angles to the flow with several packs usually combined to make up a treatment train. About 40% of the disc area is immersed in the wastewater. RBC's are closely packed circular discs submerged in wastewater and rotated slowly. Biological growth is attached to the surface of the disc and forms a slime layer. The disc contact wastewater and air for oxidation as it rotates. Helps to slough off excess solids. About one third of the disc is submerged. The disc system can be staged in series to obtain nearly any detention time or degree of removal required. Since the systems are staged, the culture of the later stages can be acclimated to the slowly degraded materials. RBC media in the form of large, flat disc mounted on common shaft are rotated through specially contoured tanks in which waste water flow on a continuous basis. The medium consists of plastic sheets ranging from 2 to 4 m in dia and up to 10 mm thick. Several modules may be arranged in parallel and / or in series to meet the flow and treatment requirements. The discs are submerged in waste water to about 40% of there diameter and are rotated by power supplied to the shaft. Approximately 95% of the surface area is thus alternately immersed in waste water in then exposed to the atmosphere above the liquid under normal operating conditions; carbonaceous substrate is removed in the initial stage of RBC. Carbon conversion may be completed in the first

stage of a series of modules, with nitrification being completed after the 5th stage. Most design of RBC systems will include a minimum of 4 or 5 modules in series to obtain nitrification of waste water.



A schematic cross-section of the contact face of the bed media in a rotating biological contactor (RBC)

Biofilms, which are biological growths that become attached to the discs, assimilate the organic materials in the wastewater. Aeration is provided by the rotating action, which exposes the media to the air after contacting them with the wastewater, facilitating the degradation of the pollutants being removed. The degree of wastewater treatment is related to the amount of media surface area and the quality and volume of the inflowing wastewater. RBC's were first installed in West Germany in 1960 and were later introduced in U.S and Canada, 70% of the RBC systems installed are used for carbonaceous BOD removal only, 25% for combined carbonaceous BOD removal and nitrification, and 5% for the nitrification of secondary effluent.

## Construction

Rotating Biological contactor is the attached growth process. Rotating biological consist of 3-4m diameter plastic sheet of thickness 10mm attached to a shaft which is connected to a motor power 40kW, rotate at 1-2 rpm. 1 module contains 4-6 discs. And 5-6 module in series to assure complete nitrification Process-in this process the disc rotate in the tank at 1-2 rpm to assure proper growth of bio logical film on the disc. The disc is submerged in the waste water about 45% to 90% of it dia according to the characteristic of waste water. When the disc rotates outside the tank the air enters the voids of the disc and water inside the disc trickles out the surface of the disc on the biological growth. During the submergence period the microbes present in the waste water get attached to the disc and form a bio-logical film. T film is around 3-4mm thick. This film when enter in to the waste water it consumes the organic waste by breaking the complex organic matter into the compound organic matter. Again when the disc surface faces the open atmosphere to receive enough oxygen to sustain and carry out their metabolic activities. Since the bio film is oxygenated externally from the wastewater, aerobic condition may develop in the liquid. Under normal operating condition the carbonaceous sustain in the initial stage of

RBC. The carbon conversion may be completed in the first stage of a series of modules with nitrification being completed after the fifth stage. Nitrification proceeds only after carbon concentration is substantially reduced. Most design of RBC system will include minimum of four to five module in series to obtain nitrification of wastewater. The sloughed bio mass is relatively dense and settles well in secondary clarifier. Since it is continuous process it has no detention time.

## **Details**

### **History**

RBC was first installed in Germany in 1960 later it was introduced in U.S.A. In U.S.A RBC is used for industries producing high B.O.D. i.e. for industries producing high B.O.D i.e. for petroleum industry dairy industries etc.

Detail:- size of disc- 3 to 3.7m

Length of shaft- 8 to 8.5m

Length of module- 7.6 to 8m

PVC or plastic media is used for disc.

Thickness of plastic media is 10mm.

Submergence of disc in wastewater 45 - 95% as pre design.

Speed of disc -: 1-2rpm (revolution per minute)

NO. Of disc in module -: 4 - 6 as per design.

Hydraulic loading -: 40 - 60 lit/day/m<sup>2</sup>

Organic loading -: 0.05to0.06 lit/day/m<sup>2</sup>

Film of micro organism on disc -: 3-4mm as per characteristic of waste water.

Power of motor -: 40 kW.

Detention time -: it is a continuous process.

The rotating biological contactor reactor is a unique adaptation of the attached-growth process. Media in the form of large, flat disks mounted on a common shaft are rotated through specially contoured tanks in which waste water flows on a continuous basis. The medium consist of plastic sheets ranging from 2 to 4 m in diameter and upto 10mm thick. Spacing between flat disks is approximately 30 to 40 mm. the disk are mounted through the center on a shaft in width up to 8 m. Each shaftful of medium, along with its tanks and rotating device, become a reactor module.

The disk are submerged in waste water to about 40 percent of their diameter and are rotated by power supplied to the shaft. Approximately 95% of the surface area is thus alternately immersed in the waste water and then exposed to atmosphere above the liquid. Rotational speed of the unit ranges from 1 to 2 r/min. Micro-organism growing on the medium surface remove food from the waste water and oxygen from the air to sustain their metabolic process. Growth and sloughing of the bio-film reach 2 to 4 mm. since the bio-film is oxygenated externally from the wastewater, an anaerobic condition may develop in the liquid. Provision for air injection near the bottom of the tank is usually provided when multiple modules in series are used. Under normal operating conditions, carbonaceous substrate is removed in the initial stages of the R.B.C. carbon

conversion may be completed in the first stage of a series of modules with nitrification being completed after fifth stage.

Most designs of R.B.C include minimum of 4 to 5 module in series to obtain nitrification of the wastewater. One module of 3.7 m in diameter by 7.6 m long contains approximately 10,000 m<sup>2</sup> of surface area for bio-film growth. A 40-kw motor is sufficient to turn the 3.7 by 7.6 m unit.

## Secondary clarification

The unit of secondary clarifier are quite similar in appearance to those used in primary clarification I wastewater treatment. Difference in different sludge-removal mechanisms. Sludge should be removed as rapidly as possible to ensure that the aeration unit. A rapid sludge return also prevent anaerobic condition from developing, with subsequent sludge floatation due to the release of gases. The sludge-return system must be capable of handling a wide range of flow. Underflow rates may exceed 100% of wastewater flow of wastewater flow under upset conditions, wt conditions, while normal underflow rates range from 20 to 40 % of the wastewater flow.

## Disinfection of effluents

Disinfection of effluent includes:

1. Disinfection of wastewater.
2. Sludge treatment.

## Disinfection of wastewater

The wastewater after from secondary clarifier is allow to pass through chlorine contact tank for reducing harmful bacteria. The dosage are comparatively much higher than which was require for chlorination of potable water since wastewater contain ammonium and other substance and free residual. The use of chlorine for disinfection of water effluent has come under close scrutiny due to formation of halo-form by contact of chlorine in wastewater with certain constituent.

Wastewater type (mg/l)to yield 0.2 mg/l After 15-min contact time	Chlorine dosage free residual
Raw:	
Fresh to stale	6 - 12
Septic	12 - 25
Settled:	
Fresh to stale	5 - 10
Septic	12 - 40
Effluent chemical precipitation	3 - 6
Trickling filter:	

Normal	3 - 5	
Poor		5 - 10
Activated sludge:		
Normal	2 - 4	
Poor		3 - 8
Intermittent sand filter:		
Normal	1 - 3	
Poor		3 - 5

After chlorination then the water is disposed off.

## Sludge treatment

After the secondary clarifier the sludge which is removed from clarifier some part of sludge is again re circulate to biological process and some part is treated. The sludge first thickened with gravity thickner and then sludge digestion is done. In sludge digestion organic-matter of sewage is aerobically decomposed under condition of adequate operational control. The sludge is broken in three different from. 1. Digested sludge which is stable humus like solid matter with reduced moisture content. 2. Supernatant liquor which include liquefied and finely divided solid matter. 3. Gases of decomosition Methane, Carbon dioxide, Nitrogen etc. Digested sludge is dewatered, dried and used as fertilizer. Gases produced is used as fuel. And the supernatant liquor is retreated by treatment plant along with raw sludge.

## Typical design information for rotating biological contactors

Item	Treatment level		
	Secondary	Combined	
nitrification	Separate		
nitrification			
Hydraulic loading, m <sup>3</sup> /m <sup>2</sup> .d	0.08 - 0.16	0.03 - 0.08	0.04 - 0.10
Organic loading			
kg SBOD <sub>5</sub> /m <sup>2</sup> .da,b			
kg TBOD <sub>5</sub> /m <sup>2</sup> .da, c			
	3.68x10 <sup>-3</sup> - 9.8x10 <sup>-3</sup>		
	9.8x10 <sup>-3</sup> - 0.017		
	2.45x10 <sup>-3</sup> - 7.35x10 <sup>-3</sup>		
	7.35x10 <sup>-3</sup> - 0.015		
	4.9x10 <sup>-4</sup> - 1.47x10 <sup>-3</sup>		
	9.8x10 <sup>-4</sup> - 2.94x10 <sup>-3</sup>		

Maximum loading on first stage

kg SBOD5 /m2 .da,b

kg TBOD5/m2 .da,c

0.02 - 0.03

0.04 - 0.06

0.02 - 0.03

0.04 - 0.06

NH3 loading, kg/m2 .d                    7.35x10<sup>-4</sup> - 1.47x10<sup>-3</sup>    9.8x10<sup>-4</sup> -  
1.96x10<sup>-3</sup>

Hydraulic retention time ,  $\theta$ , h            0.7 - 1.5                    1.5 - 4    1.2 - 2.9

Effluent BOD5, mg/l            15 - 30    7 - 15    7 - 15

Effluent NH3, mg/l                    <2            1 - 2

Note:

a Wastewater temperature above 13°C

b SBOD = Soluble BOD.

c TBOD = Total BOD.

WWT

## Chapter- 8

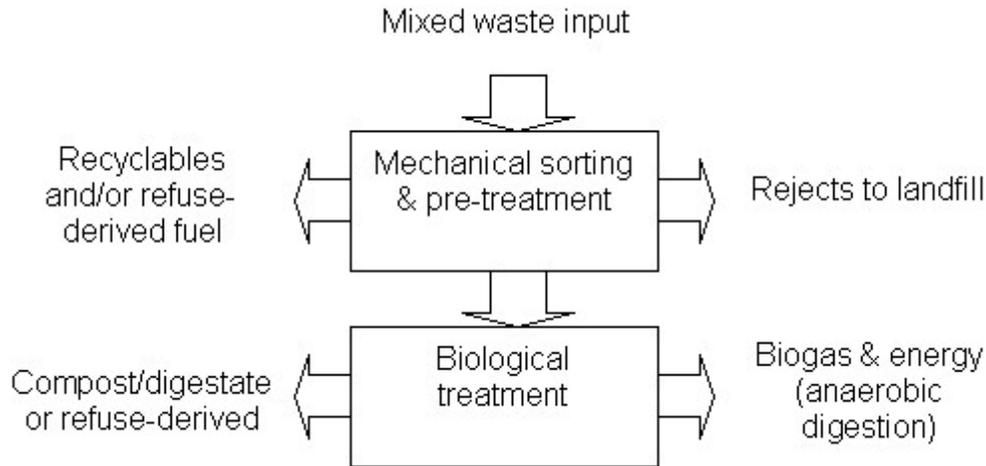
# Mechanical Biological Treatment



Anaerobic digestion and air processing components of Lübeck mechanical biological treatment plant in Germany

A **mechanical biological treatment** system is a form of waste processing facility that combines a sorting facility with a form of biological treatment such as composting or anaerobic digestion. MBT plants are designed to process mixed household waste as well as commercial and industrial wastes.

## Process



Process flow chart

The terms 'mechanical biological treatment' or 'mechanical biological pre-treatment' relate to a group of solid waste treatment systems. These systems enable the recovery of materials contained within and the stabilisation of the biodegradable component of the material.

The sorting component of the plants resemble a materials recovery facility. This component is either configured to recover the individual elements of the waste or produce a refuse-derived fuel that can be used for the generation of power.

The components of the mixed waste stream that can be recovered include:

- Metals
- Plastics
- Glass

## Terminology

MBT is also sometimes termed BMT – biological mechanical treatment – however this simply refers to the order of processing, i.e. the biological phase of the system precedes the mechanical sorting. MBT should not be confused with MHT – *mechanical heat treatment* - which does not include any form of biological degradation or stabilisation.

## ***Mechanical sorting***



Wet material recovery facility, Hiriya, Israel

The "mechanical" element is usually an automated mechanical sorting stage. This either removes recyclable elements from a mixed waste stream (such as metals, plastics, glass and paper) or processes them. It typically involves factory style conveyors, industrial magnets, eddy current separators, trommels, shredders and other tailor made systems, or the sorting is made by hand. The mechanical element has a number of similarities to a materials recovery facility (MRF).

Some systems integrate a wet MRF to recover & wash the recyclable elements of the waste in a form that can be sent for recycling. MBT can alternatively process the waste to produce a high calorific fuel given the term refuse derived fuel (RDF). RDF can be used in cement kilns or power plants and is generally made up from plastics and biodegradable organic waste. Systems which are configured to produce RDF include the Herhof and Ecodeco Processes. It is a common misconception that all MBT processes produce RDF. This is not the case and depends strictly on system configuration and suitable local markets for MBT outputs.

## ***Biological processing***



Twin stage & UASB anaerobic digesters

The "biological" element refers to either:

- Anaerobic digestion
- Composting
- Biodrying

Anaerobic digestion breaks down the biodegradable component of the waste to produce biogas and soil improver. The biogas can be used to generate electricity and heat.

Biological can also refer to a composting stage. Here the organic component is treated with aerobic microorganisms. They break down the waste into carbon dioxide and compost. There is no green energy produced by systems employing only composting treatment for the biodegradable waste.

In the case of biodrying, the waste material undergoes a period of rapid heating through the action of aerobic microbes. During this partial composting stage the heat generated by the microbes result in rapid drying of the waste. These systems are often configured to produce a refuse-derived fuel where a dry, light material is advantageous for later transport combustion.

Some systems incorporate both anaerobic digestion and composting. This may either take the form of a full anaerobic digestion phase, followed by the maturation (composting) of the digestate. Alternatively a partial anaerobic digestion phase can be induced on water that is percolated through the raw waste, dissolving the readily available sugars, with the remaining material being sent to a windrow composting facility.

By processing the biodegradable waste either by anaerobic digestion or by composting MBT technologies help to reduce the contribution of greenhouse gases to global warming.

Usable wastes for this system:

- Municipal solid waste
- Sewage sludge

Products of this system:

- Recyclable materials such as metals, paper, plastics, glass etc.
- Organic fertilizer (separate collection of organic waste)
- Unusable materials prepared for their unarmful final deposit (compaction  $> 1.3$  t/m<sup>3</sup>)
- Carbon credits – additional revenues
- High calorific fraction (refuse derived fuel – RDF) – additional revenues

Further advantages:

- The finally deposited waste is inert
- Reduction of the waste volume to be deposited to at least a half (density  $> 1.3$  t/m<sup>3</sup>), thus the lifetime of the landfill is at least twice as long as usually
- Utilization of the leachate in the process
- No unbidden guests such as birds, dogs, vermin, rats on site
- No additional facilities for the collection and combustion of biogas as there is no biogas
- Daily covering not necessary
- Aftercare 3 to 5 years

### ***Consideration of applications***

MBT systems can form an integral part of a region's waste treatment infrastructure. These systems are typically integrated with curbside collection schemes. In the event that a refuse-derived fuel is produced as a by-product then a combustion facility would be required.

Alternatively MBT solutions can diminish the need for home separation and curbside collection of recyclable elements of waste. This gives the ability of local authorities and councils to reduce the use of waste vehicles on the roads and keep recycling rates high.

### ***Position of Environmental Groups***

Friends of the Earth suggests that the best environmental route for residual waste is to firstly maximise removal of remaining recyclable materials from the waste stream (such as metals, plastics and paper). The amount of waste remaining should be composted or

anaerobically digested and disposed of to landfill, unless sufficiently clean to be used as compost.

A report by Eunomia undertook a detailed analysis of the climate impacts of different residual waste technologies. It found that an MBT process that extracts both the metals and plastics prior to landfilling is one of the best options for dealing with our residual waste, and has a lower impact than either MBT processes producing RDF for incineration or incineration of waste without MBT.

Friends of the Earth does not support MBT plants that produce refuse derived fuel (RDF), and believes MBT processes should occur in small, localised treatment plants.

WWT

## Chapter- 9

# Anaerobic Digestion



Anaerobic digestion and regenerative thermal oxidiser component of Lübeck mechanical biological treatment plant in Germany, 2007

**Anaerobic digestion** is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste and/or to release energy.

It is used as part of the process to treat wastewater. As part of an integrated waste management system, anaerobic digestion reduces the emission of landfill gas into the atmosphere.

Anaerobic digestion is widely used as a renewable energy source because the process produces a methane and carbon dioxide rich biogas suitable for energy production, helping to replace fossil fuels. The nutrient-rich digestate which is also produced can be used as fertilizer.

The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available

for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide.

The technical expertise required to maintain industrial scale anaerobic digesters coupled with high capital costs and low process efficiencies had limited the level of its industrial application as a waste treatment technology. Anaerobic digestion facilities have, however, been recognized by the United Nations Development Programme as one of the most useful decentralized sources of energy supply, as they are less capital intensive than large power plants.

### ***History***



Gas street lamp

Scientific interest in the manufacturing of gas produced by the natural decomposition of organic matter, was first reported in the seventeenth century by Robert Boyle and Stephen Hale, who noted that flammable gas was released by disturbing the sediment of streams and lakes. In 1808, Sir Humphry Davy determined that methane was present in the gases produced by cattle manure. The first anaerobic digester was built by a leper colony in Bombay, India in 1859. In 1895 the technology was developed in Exeter, England, where a septic tank was used to generate gas for the sewer gas destructor lamp, a type of gas lighting. Also in England, in 1904, the first dual purpose tank for both sedimentation and sludge treatment was installed in Hampton. In 1907, in Germany, a patent was issued for the Imhoff tank, an early form of digester.

Through scientific research anaerobic digestion gained academic recognition in the 1930s. This research led to the discovery of anaerobic bacteria, the microorganisms that facilitate the process. Further research was carried out to investigate the conditions under which methanogenic bacteria were able to grow and reproduce. This work was developed during World War II where in both Germany and France there was an increase in the application of anaerobic digestion for the treatment of manure.

## **Applications**

Anaerobic digestion is particularly suited to organic material and is commonly used for effluent and sewage treatment. Anaerobic digestion is a simple process that can greatly reduce the amount of organic matter which might otherwise be destined to be dumped at sea, landfilled or burnt in an incinerator.

Almost any organic material can be processed with anaerobic digestion. This includes biodegradable waste materials such as waste paper, grass clippings, leftover food, sewage and animal waste. The exception to this is woody wastes that are largely unaffected by digestion as most anaerobes are unable to degrade lignin. The exception being xylophalgeous anaerobes (lignin consumers), as used in the process for organic breakdown of cellulosic material by a cellulosic ethanol start-up company in the U.S. Anaerobic digesters can also be fed with specially grown energy crops such as silage for dedicated biogas production. In Germany and continental Europe these facilities are referred to as *biogas plants*. A *co-digestion* or *co-fermentation* plant is typically an agricultural anaerobic digester that accepts two or more input materials for simultaneous digestion.

In developing countries simple home and farm-based anaerobic digestion systems offer the potential for cheap, low-cost energy for cooking and lighting. Anaerobic digestion facilities have been recognized by the United Nations Development Programme as one of the most useful decentralized sources of energy supply. From 1975, China and India have both had large government-backed schemes for adaptation of small biogas plants for use in the household for cooking and lighting. Presently, projects for anaerobic digestion in the developing world can gain financial support through the United Nations Clean Development Mechanism if they are able to show they provide reduced carbon emissions.

Pressure from environmentally related legislation on solid waste disposal methods in developed countries has increased the application of anaerobic digestion as a process for reducing waste volumes and generating useful by-products. Anaerobic digestion may either be used to process the source separated fraction of municipal waste, or alternatively combined with mechanical sorting systems, to process residual mixed municipal waste. These facilities are called mechanical biological treatment plants.

Utilising anaerobic digestion technologies can help to reduce the emission of greenhouse gasses in a number of key ways:

- Replacement of fossil fuels
- Reducing or eliminating the energy footprint of waste treatment plants
- Reducing methane emission from landfills
- Displacing industrially produced chemical fertilizers
- Reducing vehicle movements
- Reducing electrical grid transportation losses

Methane and power produced in anaerobic digestion facilities can be utilized to replace energy derived from fossil fuels, and hence reduce emissions of greenhouse gasses. This is due to the fact that the carbon in biodegradable material is part of a carbon cycle. The carbon released into the atmosphere from the combustion of biogas has been removed by plants in order for them to grow in the recent past. This can have occurred within the last decade, but more typically within the last growing season. If the plants are re-grown, taking the carbon out of the atmosphere once more, the system will be carbon neutral. This contrasts to carbon in fossil fuels that has been sequestered in the earth for many millions of years, the combustion of which increases the overall levels of carbon dioxide in the atmosphere.

If the putrescible waste processed in anaerobic digesters was disposed of in a landfill, it would break down naturally and often anaerobically. In this case the gas will eventually escape into the atmosphere. As methane is about twenty times more potent as a greenhouse gas than carbon dioxide this has significant negative environmental effects.

Digester liquor can be used as a fertiliser supplying vital nutrients to soils. The solid, fibrous component of the digested material can be used as a soil conditioner to increase the organic content of soils. The liquor can be used instead of chemical fertilisers which require large amounts of energy to produce and transport. The use of manufactured fertilisers is therefore more carbon intensive than the use of anaerobic digester liquor fertiliser. In countries, such as Spain where there are many organically depleted soils the markets for the digested solids can be equally as important as the biogas.

In countries that collect household waste, the utilization of local anaerobic digestion facilities can help to reduce the amount of waste that requires transportation to centralized landfill sites or incineration facilities. This reduced burden on transportation reduces carbon emissions from the collection vehicles. If localized anaerobic digestion

facilities are embedded within an electrical distribution network, they can help reduce the electrical losses that are associated with transporting electricity over a national grid.

In Oakland, California at the East Bay Municipal Utility District's (EBMUD) Main Wastewater Treatment Plant(MWWTP), food waste is currently co-digested with primary and secondary municipal wastewater solids and other high-strength wastes. Compared to municipal wastewater solids digestion, food waste digestion has many benefits. Anaerobic digestion of food waste pulp from the EBMUD food waste process provides a higher normalized energy benefit, compared to municipal wastewater solids:

- 730 to 1,300 kWh per dry ton of food waste applied.
- 560 to 940 kWh per dry ton of municipal wastewater solids applied.

### ***Power generation***

Biogas from sewage works is sometimes used to run a gas engine to produce electrical power; some or all of which can be used to run the sewage works. Some waste heat from the engine is then used to heat the digester. It turns out that the waste heat is generally enough to heat the digester to the required temperatures. The power potential from sewage works is limited – in the UK there are about 80 MW total of such generation, with potential to increase to 150 MW, which is insignificant compared to the average power demand in the UK of about 35,000 MW. The scope for biogas generation from non-sewage waste biological matter – energy crops, food waste, abattoir waste etc. is much higher, estimated to be capable of about 3,000 MW. Farm biogas plants using animal waste and energy crops are expected to contribute to reducing CO<sub>2</sub> emissions and strengthen the grid while providing UK farmers with additional revenues.

Some countries offer incentives in the form of, for example, Feed-in Tariffs for feeding electricity onto the power grid in order to subsidize green energy production.

### ***Grid injection***

Biogas grid-injection is the injection of biogas into the natural gas grid. As an alternative, the electricity and the heat can be used for on-site generation, resulting in a reduction of losses in the transportation of energy. Typical energy losses in natural gas transmission systems range from 1–2%, whereas the current energy losses on a large electrical system range from 5–8%.

In October 2010, Didcot Sewage Works became the first in the UK to produce biomethane gas supplied to the national grid, for use in up to 200 homes in Oxfordshire.

### ***The process***

There are a number of microorganisms that are involved in the process of anaerobic digestion including acetic acid-forming bacteria (acetogens) and methane-forming archaea (methanogens). These organisms feed upon the initial feedstock, which

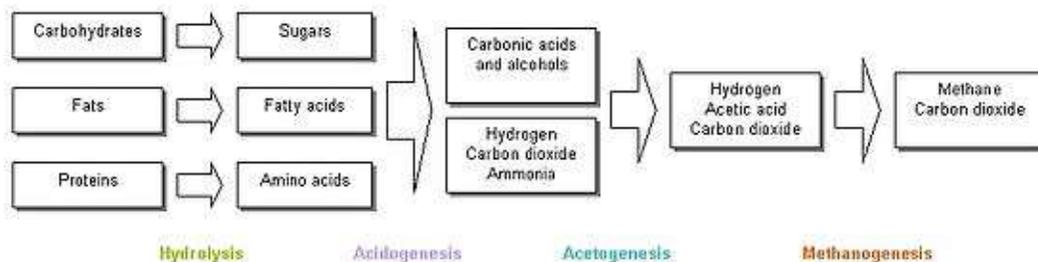
undergoes a number of different processes converting it to intermediate molecules including sugars, hydrogen, and acetic acid, before finally being converted to biogas.

Different species of bacteria are able to survive at different temperature ranges. Ones living optimally at temperatures between 35–40 °C are called mesophiles or mesophilic bacteria. Some of the bacteria can survive at the hotter and more hostile conditions of 55–60 °C, these are called thermophiles or thermophilic bacteria. Methanogens come from the domain of archaea. This family includes species that can grow in the hostile conditions of hydrothermal vents. These species are more resistant to heat and can therefore operate at high temperatures, a property that is unique to thermophiles.

As with aerobic systems the bacteria in anaerobic systems the growing and reproducing microorganisms within them require a source of elemental oxygen to survive. In an anaerobic system there is an absence of gaseous oxygen. Gaseous oxygen is prevented from entering the system through physical containment in sealed tanks. Anaerobes access oxygen from sources other than the surrounding air. The oxygen source for these microorganisms can be the organic material itself or alternatively may be supplied by inorganic oxides from within the input material. When the oxygen source in an anaerobic system is derived from the organic material itself, then the 'intermediate' end products are primarily alcohols, aldehydes, and organic acids plus carbon dioxide. In the presence of specialised methanogens, the intermediates are converted to the 'final' end products of methane, carbon dioxide with trace levels of hydrogen sulfide. In an anaerobic system the majority of the chemical energy contained within the starting material is released by methanogenic bacteria as methane.

Populations of anaerobic microorganisms typically take a significant period of time to establish themselves to be fully effective. It is therefore common practice to introduce anaerobic microorganisms from materials with existing populations, a process known as "seeding" the digesters, and typically takes place with the addition of sewage sludge or cattle slurry.

## Stages



The key process stages of anaerobic digestion

There are four key biological and chemical stages of anaerobic digestion:

1. Hydrolysis

2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

In most cases biomass is made up of large organic polymers. In order for the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts or monomers such as sugars are readily available by other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore hydrolysis of these high molecular weight polymeric components is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids.

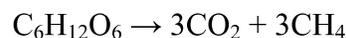
Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules such as volatile fatty acids (VFA's) with a chain length that is greater than acetate must first be catabolised into compounds that can be directly utilised by methanogens.

The biological process of acidogenesis is where there is further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here VFAs are created along with ammonia, carbon dioxide and hydrogen sulfide as well as other by-products. The process of acidogenesis is similar to the way that milk sours.

The third stage anaerobic digestion is acetogenesis. Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as carbon dioxide and hydrogen.

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here methanogens utilise the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. It is these components that makes up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8. The remaining, non-digestible material which the microbes cannot feed upon, along with any dead bacterial remains constitutes the digestate.

A simplified generic chemical equation for the overall processes outlined above is as follows:



## Configuration



Farm-based maize silage digester located near Neumünster in Germany, 2007. Green inflatable biogas holder is shown on top of the digester

Anaerobic digesters can be designed and engineered to operate using a number of different process configurations:

- Batch or continuous
- Temperature: Mesophilic or thermophilic
- Solids content: High solids or low solids
- Complexity: Single stage or multistage

### **Batch or continuous**

A batch system is the simplest form of digestion. Biomass is added to the reactor at the start of the process in a batch and is sealed for the duration of the process. Batch reactors suffer from odour issues that can be a severe problem when they are emptied. Typically biogas production will be formed with a normal distribution pattern over time. The operator can use this fact to determine when they believe the process of digestion of the organic matter has completed. As the batch digestion is simple and requires less equipment and lower levels of design work it is typically a cheaper form of digestion.

In continuous digestion processes organic matter is constantly added (continuous complete mixed) or added in stages to the reactor (continuous plug flow; first in – first out). Here the end products are constantly or periodically removed, resulting in constant production of biogas. A single or multiple digesters in sequence may be used. Examples of this form of anaerobic digestion include continuous stirred-tank reactors (CSTRs), Upflow anaerobic sludge blanket (UASB), Expanded granular sludge bed (EGSB) and Internal circulation reactors (IC).

## Temperature

There are two conventional operational temperature levels for anaerobic digesters, which are determined by the species of methanogens in the digesters:

- *Mesophilic* which takes place optimally around 30-38 °C or at ambient temperatures between 20-45 °C where mesophiles are the primary microorganism present
- *Thermophilic* which takes place optimally around 49-57 °C at elevated temperatures up to 70 °C where thermophiles are the primary microorganisms present

A limit case has been reached in Bolivia, with anaerobic digestion in temperature working conditions less than 10 °C. The anaerobic process is very slow, taking more than three times the normal mesophilic time process.

There are a greater number of species of mesophiles than thermophiles. These bacteria are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are therefore considered to be more stable than thermophilic digestion systems.

As mentioned above, thermophilic digestion systems are considered to be less stable, the energy input is higher, and more energy is removed from the organic matter. However, the increased temperatures facilitate faster reaction rates and hence faster gas yields. Operation at higher temperatures facilitates greater sterilization of the end digestate. In countries where legislation, such as the Animal By-Products Regulations in the European Union, requires end products to meet certain levels of reduction in the amount of bacteria in the output material, this may be a benefit.

Certain processes shred the waste finely and use a short high temperature and pressure pre-treatment (pasteurization / hygienisation) stage that significantly enhances the gas output of the following standard mesophilic stage. The hygienisation process is also applied in order to reduce the pathogenic micro-organisms in the feedstock. Hygienisation / pasteurization may be achieved by using a Landia BioChop hygienisation unit or similar method of combined heat treatment and solids maceration.

A drawback of operating at thermophilic temperatures is that more heat energy input is required to achieve the correct operational temperatures. This increase in energy may not

be outweighed by the increase in the outputs of biogas from the systems. It is therefore important to consider an energy balance for these systems.

## **Solids**

Typically there are three different operational parameters associated with the solids content of the feedstock to the digesters:

- High-solids (dry—stackable substrate)
- High-solids (wet—pumpable substrate)
- Low-solids (wet—pumpable substrate)

High-solids (dry) digesters are designed to process materials with a high-solids content between ~25-40%. Unlike wet digesters that process pumpable slurries, high solids (dry – stackable substrate) digesters are designed to process solid substrates deposited in tunnel-like chambers with a gas-tight door. They typically have few moving parts, require minimal or no pre-grinding or shredding, and do not use water addition.

Wet digesters can either be designed to operate in a high solids content, with a total suspended solids (TSS) concentration greater than ~20%, or a low solids concentration less than ~15%.

High-solids (wet) digesters process a thick slurry that requires more energy input to move and process the feedstock. The thickness of the material may also lead to associated problems with abrasion. High-solids digesters will typically have a lower land requirement due to the lower volumes associated with the moisture.

Low-solids (wet) digesters can transport material through the system using standard pumps that require significantly lower energy input. Low-solids digesters require a larger amount of land than high-solids due to the increase volumes associated with the increased liquid-to-feedstock ratio of the digesters. There are benefits associated with operation in a liquid environment as it enables more thorough circulation of materials and contact between the bacteria and their food. This enables the bacteria to more readily access the substances they are feeding off and increases the speed of gas yields.

## Number of stages



Two-stage, low-solids, UASB digestion component of a mechanical biological treatment system near Tel Aviv, process water is seen in balance tank and sequencing batch reactor, 2005

Digestion systems can be configured with different levels of complexity:

- One-stage or single-stage
- Two-stage or multistage

A single-stage digestion system is one in which all of the biological reactions occur within a single sealed reactor or holding tank. Utilising a single stage reduces construction costs, however facilitates less control of the reactions occurring within the system. Acidogenic bacteria, through the production of acids, reduce the pH of the tank. Methanogenic bacteria, as outlined earlier, operate in a strictly defined pH range. Therefore the biological reactions of the different species in a single stage reactor can be in direct competition with each other. Another one-stage reaction system is an anaerobic lagoon. These lagoons are pond-like earthen basins used for the treatment and long-term storage of manures. Here the anaerobic reactions are contained within the natural anaerobic sludge contained in the pool.

In a two-stage or multi-stage digestion system different digestion vessels are optimised to bring maximum control over the bacterial communities living within the digesters. Acidogenic bacteria produce organic acids and more quickly grow and reproduce than methanogenic bacteria. Methanogenic bacteria require stable pH and temperature in order to optimise their performance.

Typically hydrolysis, acetogenesis and acidogenesis occur within the first reaction vessel. The organic material is then heated to the required operational temperature (either mesophilic or thermophilic) prior to being pumped into a methanogenic reactor. The initial hydrolysis or acidogenesis tanks prior to the methanogenic reactor can provide a buffer to the rate at which feedstock is added. Some European countries require a degree of elevated heat treatment in order to kill harmful bacteria in the input waste. In this instance there may be a pasteurisation or sterilisation stage prior to digestion or between the two digestion tanks. It should be noted that it is not possible to completely isolate the different reaction phases and often there is some biogas that is produced in the hydrolysis or acidogenesis tanks.

## **Residence**

The residence time in a digester varies with the amount and type of feed material, the configuration of the digestion system and whether it be one-stage or two-stage.

In the case of single-stage thermophilic digestion residence times may be in the region of 14 days, which comparatively to mesophilic digestion is relatively fast. The plug-flow nature of some of these systems will mean that the full degradation of the material may not have been realised in this timescale. In this event digestate exiting the system will be darker in colour and will typically have more odour.

In two-stage mesophilic digestion, residence time may vary between 15 and 40 days.

In the case of mesophilic UASB digestion hydraulic residence times can be (1 hour-1 day) and solid retention times can be up to 90 days. In this manner the UASB system is able to separate solid a hydraulic retention times with the utilisation of a sludge blanket.

Continuous digesters have mechanical or hydraulic devices, depending on the level of solids in the material, to mix the contents enabling the bacteria and the food to be in contact. They also allow excess material to be continuously extracted to maintain a reasonably constant volume within the digestion tanks.

## ***Feedstocks***



Anaerobic lagoon & generators at the Cal Poly Dairy, United States 2003

The most important initial issue when considering the application of anaerobic digestion systems is the feedstock to the process. Digesters typically can accept any biodegradable material, however if biogas production is the aim, the level of putrescibility is the key factor in its successful application. The more putrescible the material the higher the gas yields possible from the system.

Substrate composition is a major factor in determining the methane yield and methane production rates from the digestion of biomass. Techniques are available to determine the compositional characteristics of the feedstock, whilst parameters such as solids, elemental and organic analyses are important for digester design and operation.

Anaerobes can breakdown material to varying degrees of success from readily in the case of short chain hydrocarbons such as sugars, to over longer periods of time in the case of cellulose and hemicellulose. Anaerobic microorganisms are unable to break down long chain woody molecules such as lignin. Anaerobic digesters were originally designed for operation using sewage sludge and manures. Sewage and manure are not, however, the material with the most potential for anaerobic digestion as the biodegradable material has already had much of the energy content taken out by the animal that produced it. Therefore, many digesters operate with *co-digestion* of two or more types of feedstock.

For example, in a farm-based digester that uses dairy manure as the primary feedstock the gas production may be significantly increased by adding a second feedstock; e.g. *grass* and *corn* (typical on-site feedstock), or various organic byproducts, such as *slaughterhouse waste, fats oils and grease* from restaurants, *organic household waste*, etc. (typical off-site feedstock).

A second consideration related to the feedstock is moisture content. Dryer, stackable substrates, such as food- and yard- waste, are suitable for digestion in tunnel-like chambers. Tunnel style systems typically have near zero wastewater discharge as well so this style system has advantages where the discharge of digester liquids are a liability. The wetter the material the more suitable it will be to handling with standard pumps instead of energy intensive concrete pumps and physical means of movement. Also the wetter the material, the more volume and area it takes up relative to the levels of gas that are produced. The moisture content of the target feedstock will also affect what type of system is applied to its treatment. In order to use a high solids anaerobic digester for dilute feedstocks, bulking agents such as compost should be applied to increase the solid content of the input material. Another key consideration is the carbon:nitrogen ratio of the input material. This ratio is the balance of food a microbe requires in order to grow. The optimal C:N ratio for the 'food' a microbe is 20–30:1. Excess N can lead to ammonia inhibition of digestion.

The level of contamination of the feedstock material is a key consideration. If the feedstock to the digesters has significant levels of physical contaminants such as plastic, glass or metals then pre-processing will be required in order for the material to be used. If it is not removed then the digesters can be blocked and will not function efficiently. It is with this that mechanical biological treatment plants are designed. The higher the level of pre-treatment a feedstock requires, the more processing machinery will be required and hence the project will have higher capital costs.

After sorting or screening to remove any physical contaminants, such as metals and plastics, from the feedstock the material is often shredded, minced and mechanically or hydraulically pulped to increase the surface area available to microbes in the digesters and hence increase the speed of digestion. The maceration of solids can be achieved by using a chopper pump to transfer the feedstock material into the airtight digester where anaerobic treatment takes place.

## **Products**

There are three principal products of anaerobic digestion: biogas, digestate and water.

## Biogas



Biogas holder with lightning protection rods and back-up gas flare

### Typical composition of biogas

Matter	%
Methane, CH <sub>4</sub>	50–75
Carbon dioxide, CO <sub>2</sub>	25–50
Nitrogen, N <sub>2</sub>	0–10
Hydrogen, H <sub>2</sub>	0–1
Hydrogen sulfide, H <sub>2</sub> S	0–3
Oxygen, O <sub>2</sub>	0–2



Biogas carrying pipes

Biogas is the ultimate waste product of the bacteria feeding off the input biodegradable feedstock (the methanogenesis stage of anaerobic digestion is performed by archaea - a micro-organism on a distinctly different branch of the phylogenetic tree of life to bacteria), and is mostly methane and carbon dioxide, with a small amount hydrogen and trace hydrogen sulfide. (As-produced, biogas also contains water vapor, with the fractional water vapor volume a function of biogas temperature). Most of the biogas is produced during the middle of the digestion, after the bacterial population has grown, and tapers off as the putrescible material is exhausted. The gas is normally stored on top of the digester in an inflatable gas bubble or extracted and stored next to the facility in a gas holder.

The methane in biogas can be burned to produce both heat and electricity, usually with a reciprocating engine or microturbine often in a cogeneration arrangement where the electricity and waste heat generated are used to warm the digesters or to heat buildings. Excess electricity can be sold to suppliers or put into the local grid. Electricity produced by anaerobic digesters is considered to be renewable energy and may attract subsidies. Biogas does not contribute to increasing atmospheric carbon dioxide concentrations because the gas is not released directly into the atmosphere and the carbon dioxide comes from an organic source with a short carbon cycle.

Biogas may require treatment or 'scrubbing' to refine it for use as a fuel. Hydrogen sulfide is a toxic product formed from sulfates in the feedstock and is released as a trace component of the biogas. National environmental enforcement agencies such as the U.S. Environmental Protection Agency or the English and Welsh Environment Agency put strict limits on the levels of gasses containing hydrogen sulfide, and if the levels of hydrogen sulfide in the gas are high, gas scrubbing and cleaning equipment (such as amine gas treating) will be needed to process the biogas to within regionally accepted levels. An alternative method to this is by the addition of ferrous chloride  $\text{FeCl}_2$  to the digestion tanks in order to inhibit hydrogen sulfide production.

Volatile siloxanes can also contaminate the biogas; such compounds are frequently found in household waste and wastewater. In digestion facilities accepting these materials as a component of the feedstock, low molecular weight siloxanes volatilise into biogas. When this gas is combusted in a gas engine, turbine or boiler, siloxanes are converted into silicon dioxide ( $\text{SiO}_2$ ) which deposits internally in the machine, increasing wear and tear. Practical and cost-effective technologies to remove siloxanes and other biogas contaminants are available at the present time. In certain applications, *in situ* treatment can be used to increase the methane purity by reducing the carbon dioxide content.

In countries such as Switzerland, Germany and Sweden the methane in the biogas may be concentrated in order for it to be used as a vehicle transportation fuel or alternatively input directly into the gas mains. In countries where the driver for the utilisation of anaerobic digestion are renewable electricity subsidies, this route of treatment is less likely as energy is required in this processing stage and reduces the over all levels available to sell.

## **Digestate**

Digestate is the solid remnants of the original input material to the digesters that the microbes cannot use. It also consists of the mineralised remains of the dead bacteria from within the digesters. Digestate can come in three forms; fibrous, liquor or a sludge-based combination of the two fractions. In two-stage systems the different forms of digestate come from different digestion tanks. In single stage digestion systems the two fractions will be combined and if desired separated by further processing.



Acidogenic anaerobic digestate

The second by-product (acidogenic digestate) is a stable organic material consisting largely of lignin and cellulose, but also of a variety of mineral components in a matrix of dead bacterial cells; some plastic may be present. The material resembles domestic compost and can be used as compost or to make low grade building products such as fibreboard. The solid digestate can also be utilized as feedstock for ethanol production.

The third by-product is a liquid (methanogenic digestate) that is rich in nutrients and can be used as a fertiliser dependent on the quality of the material being digested. Levels of potentially toxic elements (PTEs) should be chemically assessed. This will be dependent upon the quality of the original feedstock. In the case of most clean and source-separated biodegradable waste streams the levels of PTEs will be low. In the case of wastes originating from industry the levels of PTEs may be higher and will need to be taken into consideration when determining a suitable end use for the material.

Digestate typically contains elements such as lignin that cannot be broken down by the anaerobic microorganisms. Also the digestate may contain ammonia that is phytotoxic and will hamper the growth of plants if it is used as a soil improving material. For these two reasons a maturation or composting stage may be employed after digestion. Lignin and other materials are available for degradation by aerobic microorganisms such as fungi helping reduce the overall volume of the material for transport. During this maturation the ammonia will be broken down into nitrates, improving the fertility of the material and making it more suitable as a soil improver. Large composting stages are typically used by dry anaerobic digestion technologies.

## **Wastewater**

The final output from anaerobic digestion systems is water. This water originates both from the moisture content of the original waste that was treated but also includes water produced during the microbial reactions in the digestion systems. This water may be released from the dewatering of the digestate or may be implicitly separate from the digestate.

The wastewater exiting the anaerobic digestion facility will typically have elevated levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), these are measures of the reactivity of the effluent and show an ability to pollute. Some of this material is termed 'hard COD' meaning it cannot be accessed by the anaerobic bacteria for conversion into biogas. If this effluent was put directly into watercourses it would negatively affect them by causing eutrophication. As such further treatment of the wastewater is often required. This treatment will typically be an oxidation stage where air is passed through the water in a sequencing batch reactors or reverse osmosis unit.

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