TECHNOLOGIES TO IMPROVE WASTE DISPOSAL

C.N. Mulligan
Department of Building, Civil and Environmental Engineering, Concordia University, Canada

Keywords: Solid waste, hazardous waste, landfill, incineration, recycling, composting, digestion, landfill mining, landfill bioreactor, waste management , deep well injection, landfarming

Contents

Summary

The current trend for waste disposal has been out of sight –out of mind. Future generations should not be burdened by leaking landfills and other such problems. Health, the environment and non-renewable resources should be protected. Loss of valuable land, and decrease in groundwater, surface water and atmospheric quality will continue unless changes are made. Land, groundwater and water resources must be conserved. New approaches in waste disposal are necessary to minimize the impact on future generations. Current practice is as follows: landfill disposal, recycling, reduction at source and incineration. Reduction at source is practised very little. The United States and Canada produce more garbage per person than other countries and also has reduced the amount of waste going to landfills. Recycling must be increased for metals, paper and plastics. Organic wastes can be treated be composting or digestion. Incineration could function with recycling since it would recover energy from waste that cannot be recycled. Incineration can be employed to reduce the amount of waste for disposal, to convert organic wastes to the more stable ash and produce electricity. Since landfills will continue to play a major role in waste management, landfills should be designed so that they will be as leak resistant as possible. Paper, metals and plastics occupy large amounts of space in landfills. They thus should be recovered for recycling, and gas collection systems should be installed. Where liners and barriers are not defective, the landfill can be operated as a bioreactor to enhance gas production and degradation rates. This can be done by recirculation of leachates. Attitudes must change regarding the generation and handling of waste via education, governmental policies, taxes and penalties.

1. Introduction

Currently, 20% of municipal waste is recycled in North America. This includes metal cans, glass, plastics, and paper . In the future this could increase to 50%. Approximately, only 18% of the waste in the U.S. and 5% in Canada is incinerated. This increases up to 34% in Japan.

This leaves most of the waste for landfill which has been believed to be the best way to handle waste. It is not the perfect solution, however. Due to population growth, the amount of available land is decreases. For example in New York, the landfill occupies 1000 hectares and is 150 m high. The largest in Europe is located in Marseilles, France and occupies 84 hectares.

Canada has the second largest area but only 0.8% is useful for agriculture and most of this is located close to cities. Therefore, this land could potentially be used for landfills. Current landfills cannot be used for commercial purposes due to methane gas production, settling of the landfill and the potential for contaminant leakage. New strategies are needed to deal with the increasing amounts of waste. More than 93 cities have populations more than 5 million.

According to the USEPA, 75% of landfills are leaking and causing groundwater pollution. The contaminants include polychlorobiphenyls (PCBs), solvents, lead, and many other toxic compounds. Atmospheric pollution is caused by methane, carbon dioxide, vinyl chloride and others. Many of these are greenhouse gases and thus lead to global warming.

The concept of landfill is against sustainable development. The United Nations World Commission on the Environment and Development (1992) says that sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. The current trend for waste disposal has been out of sight –out of mind. Future generations should not be burdened by leaking landfills and other such problems. Health, the environment and non-renewable resources should be protected. Therefore, strategies need to be developed to encompass these requirements for future generations.

2. Sources and characteristics of waste

Wastes are often classified as municipal, industrial, hazardous and radioactive. Mining and agricultural are other sources. Municipal solid waste (MSW) was generated at a rate 208 million tonnes annually according to the US EPA in 1995-96. For every person per day, 2 kg of waste is produced in North America. State and federal requirements in the U.S. control treatment, storage and disposal of waste. Wastes can be classified as organic, inorganic or microbiological.

The composition of municipal solid waste (MSW) delivered to a landfill can vary considerably by country. In general, food wastes make up 10% of domestic waste, 35 to 50% is paper and cardboard, 20% is construction debris, tires, and other materials, 8 to 10% are plastics, 5 to 6% are metals, 1% is glass, 1% is hazardous materials, and ash content decreases as the gross domestic product increases. Approximately 16% of all landfills are also used for the disposal of sludge from sewage plants that are often run by the same authorities. Food includes meat, fat, vegetables, oils, fruit, and bones. Sources include residential (apartments and houses), commercial (restaurants, office buildings, stores, service stations), institutional (schools, hospitals, courthouses, etc.), construction and demolition sites, municipal services (wastewater treatment, street-cleaning, garden and park landscaping). The types of commercial establishments in an area influence the composition of the waste. Offices, restaurants, schools, hospitals and retail outlets all generate different percentages of food, paper, plastics, glass, metal and other materials.

Various manufacturing and chemical processes produce various solid wastes. The amount is usually about four times that of municipal wastes. This does not include that produced by mining, oil and gas and agriculture sectors. Each type of industry produces a particular type of waste. Some examples are distillation column bottoms from chlorobenzene production, sludges and emission control dust from coal burning and residues from the decolorization of pharmaceuticals. The wastes are often incinerated or placed in landfills for industrial wastes.

Hazardous wastes are separated from industrial and municipal wastes. According to the U.S. Resource Conservation and Recovery Act (RCRA), waste is considered hazardous if it is ignitable, corrosive, reactive or toxic. Approximately 15% of industrial waste and 1% of municipal waste is hazardous. Industrial wastes include organic sludges, oil and greases, solvents, heavy metal solutions, pesticides and herbicide wastes, PCBs and others wastes such as contaminated soils. Varnishes, paints, turpentines, motor oil, herbicides, pesticides, batteries and fertilizers are examples of household hazardous wastes. Annually, 40 million tonnes are produced in the U.S , 22 million tonnes in the European Union (EC, State of the Environment, 1993) and 2.3 million tonnes in Canada. Disposal must be in specially designed landfills. Liquid wastes often end up in sewage plants.

Radioactive wastes are generated by specific industries. Examples are nuclear reactors, research labs, medical procedures and others. In most countries, disposal of high level wastes is by burial in deep, stable geologic formations. Low level wastes are disposed of in a variety of ways but mainly by burial in caverns or clay formations and thus will not be considered furthered in this chapter. They become less radio-active over time due to radioactive decay.

Several technologies for waste management will be discussed. They include landfill disposal, recycling, incineration, composting, digestion, landfill mining, and landfill bioreactors. Finally, these processes will be compared to traditional ones that have been used for many years. Biological processes are less costly and require less energy than traditional processes and can produce highly useful products such as methane, soil conditioners and feeds. Extensive experience in the design and operation has been obtained for numerous biological processes including anaerobic and aerobic digestion and composting. Public acceptance of processes such as composting is increasing.

3. Technologies for waste management

3.1 Land disposal

3.1.1 Landfill

In 1995, 56.9% of municipal solid waste was sent for land disposal in the U.S. Landfills are necessary since waste management cannot totally reduce the wastes produced and other treatment processes such as incineration and biological treatment produce residues. Despite all design considerations, leakage is inevitable and must be designed for. Biodegradation rates are much higher in municipal landfills than hazardous waste landfills due to the higher organic matter contents. Covers are required for emission control and liners and leachate collection systems to minimize contaminant migration. Even after closure, monitoring of emissions and groundwater quality must take place. Landfills will always be necessary but efforts should be made to minimize their use as much as possible by recycling and conversion of wastes into useful products such as compost and energy.

Landfills can be located in ravines, canyons, abandoned quarries and open pits since these are easily filled. As much as possible, they are located where natural attenuation of contaminants can take place. The choice is based on surface and groundwater locations, soil conditions, transportation routes, presence of endangered species, contaminant transport routes, citizen's groups concerns, politics and adjacent land use. Other considerations are subsoil permeability, soil cation exchange capacity (CEC), steepness, seismic activity, proximity to transport, depth to water table and proximity to groundwater wells. Faults in the pits underneath the pits can act as conduits for the leachate. Pits have been used mainly for tailings disposal or radioactive waste.

Landfill operation has changed little over the years. The waste is placed daily as lifts in the vertical and horizontal direction. The landfill can be built in trenches where the land is excavated, the waste is place and the soil used for the excavation is used as the cover. In this case the soil must be flat and be at least 2 m deep and the groundwater table deep. The area method involves spreading the waste on the ground followed by compacting. Soil from another area is used as the cover. This method is used for large quantities of waste over variable topography. Currently, the trench method is often used for developing the base and the area method for building the height of the landfill.

Landfills now include a significant amount of engineering. Soil is used as a daily thin cover (about 0.3 m) to minimize odor, to reduce transport of contaminants due to wind and is more aesthetically pleasing. The disadvantage of using soil as a daily cover is that soil takes up space in the landfill and seepage can occur through the cover and out the side slopes. Upon closure, an impermeable cover is used on the landfill. An impermeable liner is placed under the landfill. Leachate and gas collection systems are installed. The environment around the landfill must also be monitored.

A filter zone is the first encountered under the landfill and removes particulates from the leachate. This zone can contain a geotextile with or without a geogrid for support or well-graded sand or gravel. The leachate collection system removes the filtered leachate from the waste to the treatment system. Flow depends on the hydraulic head and this is minimized by an appropriately designed system based on the size and spacing of the pipes, the drainage material, and the slope. Clogging of the collection system is a major problem due to microbial growth and chemical precipitation. Sometimes geonets are used instead with geotextiles to minimize the amount of particulates in the leachates.

In the case of hazardous waste landfills, a double liner and leachate collection system is used (Figure 1). The secondary system is below the primary and is designed to handle much lower quantities of leachate. Theoretically, there should be no need for secondary system. However, all liners leak. The current definition of leakage rate is based on hydraulic head on the bottom liner. The EPA says that response is not needed if the leachate collection system can remove the leachate so that it does not exceed a head on the final liner of 30 cm.

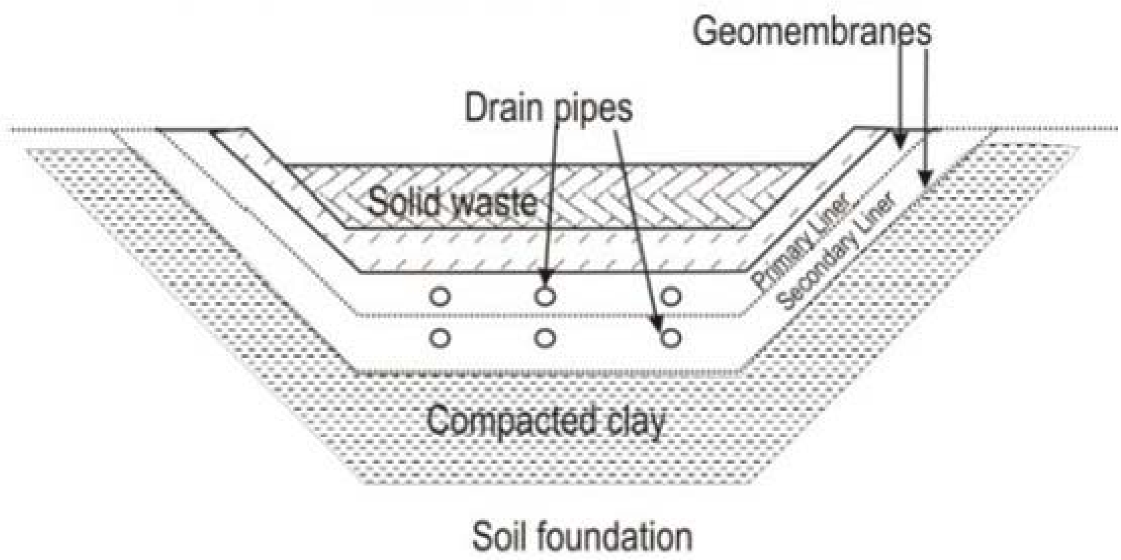

Figure 1. Design of a hazardous waste landfill liner and leachate collection system

Membranes made of polymers are known as geomembranes and are used as cover and bottom liners in a landfill. A wide variety of materials can be used including polyvinyl chloride, (PVC), chlorinated polyethylene, high-density polyethylene (HDPE) and butyl rubber. They are resistant to chemicals, are of low permeability and take up less volume than clay liners. The most common type of membrane is HDPE since it has a wide range of chemical resistance. Thicknesses range from 30 to 120 mils (0.75 to 3.0 mm).

Vulcanization is sometimes used to treat the polymer to give it more strength and chemical resistance. However, thermoplastic (unvulcanized form) is more common since seaming repair is easier in the field. Additives can also be incorporated to increase resistance to fungicides and biocides, ultraviolet light and ozone or to enhance flexibility and stiffness.

The primary liners are geomembranes that are available as sheets about 4.5 m wide and are joined by extrusion welding, or with thermal or solvent fusion or adhesives. To prevent leaks through the geomembranes, punctures and tears must not be made. This is difficult to avoid due to pinholes from grit, and procedures during the laying of the geomembranes including dropping of tools, trucks on the liner, high winds and problems during the joining of the membranes. Mathematical methods have been developed to calculate the flow from flaws in the membrane. In addition, roots, animals, shifts in the landfill mass, chemical and microbial attack all can lead to the degradation of the membrane over time. It has been suggested the lifetime of the membranes would be about 25 years. Therefore, other barriers must also be used.

Clays have a high capacity to adsorb contaminants. Low hydraulic conductivity materials are preferable for liners. Kaolinite, illite and montmorillonite (bentonite). Hydraulic conductivities of 10^{-8} cm/sec are possible. Chemical interactions between pollutants and the clays are highly complex and must be understood to design liners properly. Replacement of calcium by sodium in bentonite increases shrinking and cracking. Organic contaminants such as benzene, xylene or others can increase conductivities by 100 to 1000. Monitoring the behavior of the liners is essential. Cracks can form due to wetting/drying and freeze/thaw cycles, root penetration, animal burrowing, waste settlement, gas penetration and change in the chemistry of pore water. The use of clays can cause liner failures since it is difficult estimate field hydraulic conductivities and long term performance of the liner.

Recently, clays and synthetic materials have been combined and are named "geosynthetic clay liners". A 4 to 6 mm layer of bentonite is placed between two geotextiles or bonded to a geomembrane. There are several advantages to this type of liner. It is very impermeable, quality control is good since it is made in the factory , and less space is used. However, shear strength is low, care must be taken in installing the geomembrane to avoid damaging it and it can be used for flat areas with slopes of less than 5%. Hydraulic conductivities of less than 10^{-7} cm/sec are achievable. Other materials include carbon, zeolite and organically modified clays.

Final covers must be designed for numerous aspects. Their purpose is to maintain health and safety, to eliminate moisture in landfill, to enable the site to be used for other purposes, and look pleasing. It has to maintain permeability for compressibility and strength for more than 30 years. Numerous layers are thus used (Figure 2). The vegetative layer (0.3 m) is a topsoil consisting of an organic sandy loam for the growth of vegetation. This keeps erosion to a minimum, reduces infiltration of precipitation which reduces leachate formation and the chance of groundwater contamination and allows moisture to evaporate. A geotextile filter can be used to separate the vegetative support layer and lateral drainage layer and reduce fines going into the drainage layer. A biotic barrier is sometimes used to prevent roots growing into hydraulic layer in humid regions or to prevent destruction of the lower layers by burrowing animals in arid regions. The drainage layer provides flow to perforated pipes for collection and consists of gravel, a geonet or geocomposite. Barrier layers are below the drainage layers and consist of clays, geomembranes or combinations of various types of liners. This layer prevents movement of water into the landfill. Composite liners of geomembrane and low hydraulic conductivity soil serve as a foundation. The gas collection layer (coarse gravel layer) to allow gases to go to surface via gas collection piping. Recovery wells are installed for gas collection and vacuum is used to draw gas. Finally the subgrade layer enables the uneven waste to be leveled. It also enhances lateral drainage and reduces hydraulic head.

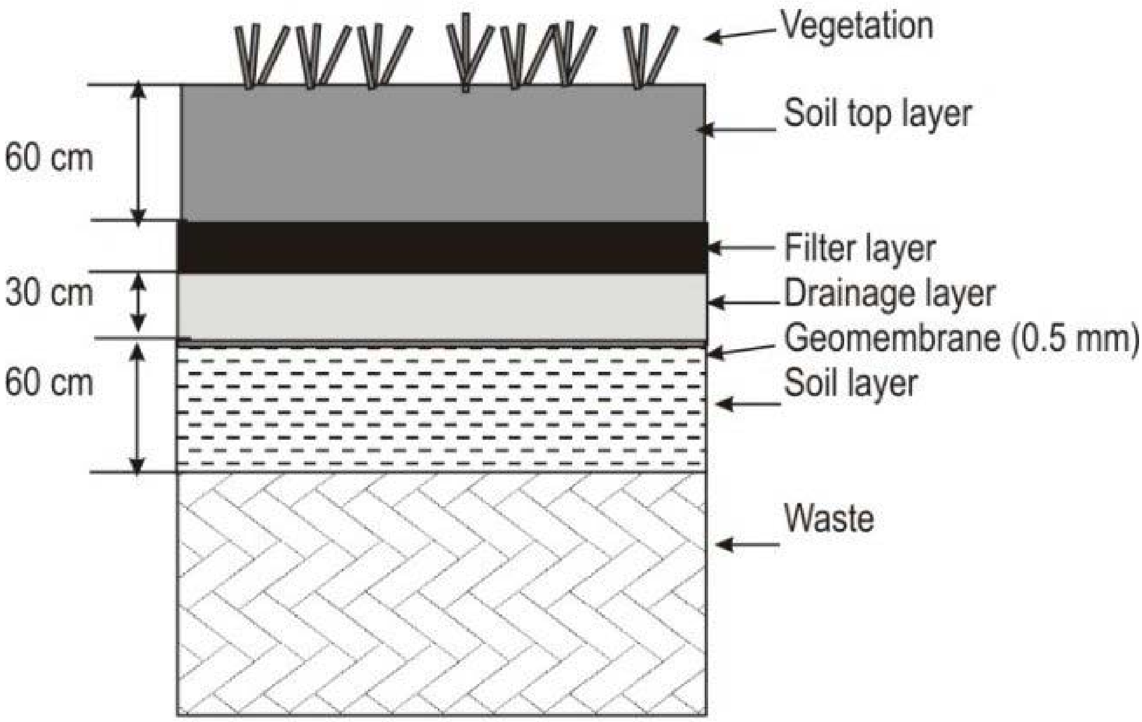

Figure 2. Design of a cover system for a landfill

In the landfill, complex decomposition reactions of organic material occurs. This leads to acid leachate production, methane gas formation and landfill settlement that can lead to cracking of the cover. Moisture content is usually less than 20% which is not optimal for biodegradation. Contents have been preserved. Refuse is typically 40 to 50% cellulose, 12% hemicellulose, 10 to 15% lignin. Rubber and plastic are fairly resistant to biodegradation. Only food and yard wastes are totally degraded. Approximately 17% of biosolids are landfilled acording to the USEPA in 1999.

In traditional landfills, there are four sequential steps in the decomposition of organic matter (Figure 3) . They include an initial aerobic phase, first transition phase, second transition phase and methane phase. The aerobic phase lasts only a few days to weeks until the oxygen is depleted. At the first transition phase, anaerobic conditions will start to develop and the pH will decrease to between 4 and 6. Organic matter decomposes to organic fatty acids then to volatile fatty acids such as acetic acid. This stage lasts from weeks to months. In the next stage, methanogenic bacteria start to grow and produce methane from acetic and formic acids. Optimal pH is between 6 and 7. This stage can take from 3 to 5 years before stability is obtained. Once stability is obtained, the last stage of methanogenisis is obtained. Methane and carbon dioxide form 45 to 65% of the gas. Gas production from MSW is in the range of 150 to 250 m^3 per tonne of wet waste.

In terms of heavy metal concentration in the leachate, pH is a major factor in mobility. Mobility increases as the pH decreases. In addition, organic and inorganic agents can serve as ligands, promoting metal transport. However, the mechanisms of precipitation, encapsulation and sorption ensure that the heavy metals remain in the waste. Therefore, heavy metal content must be verified in the leachate.

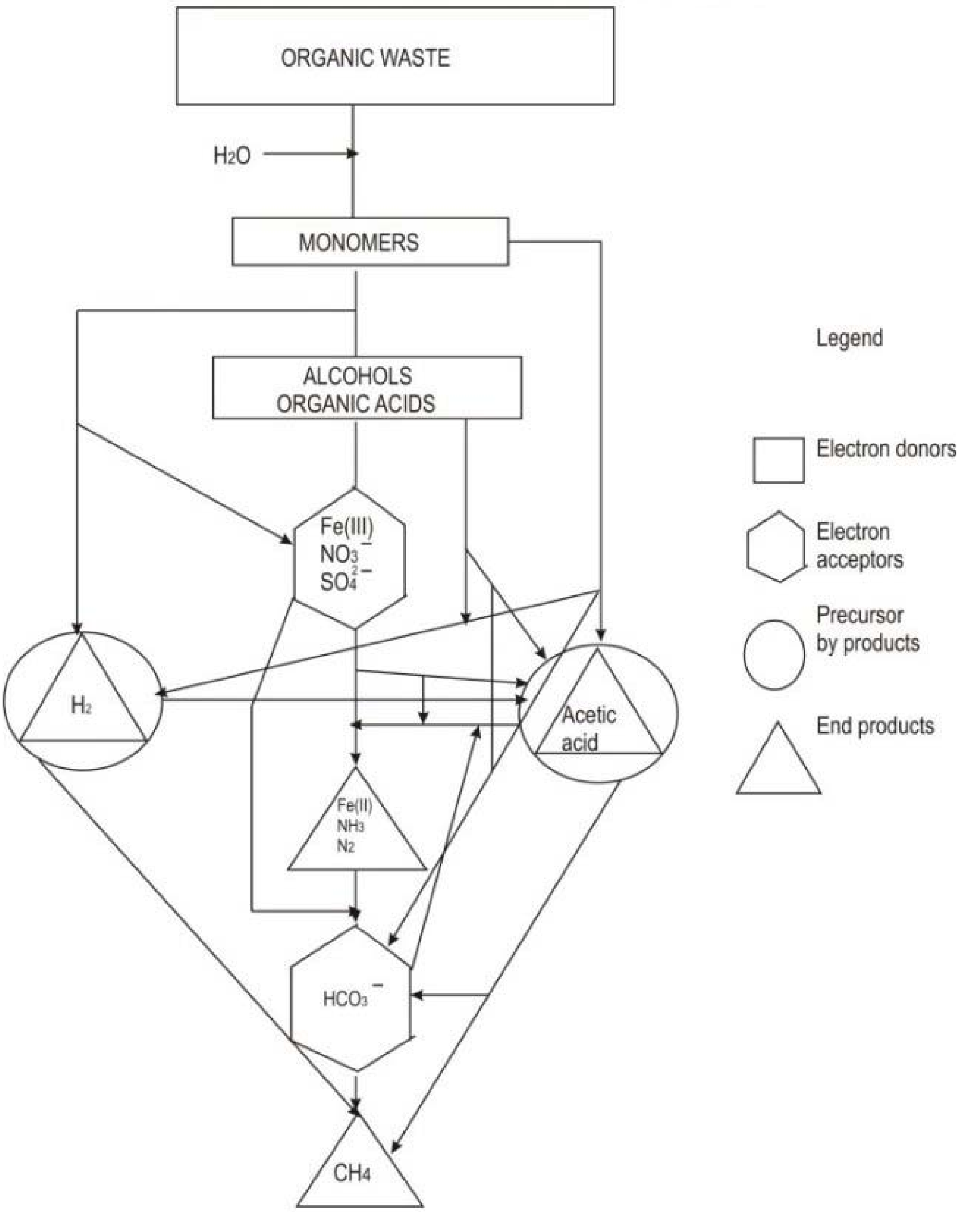

Figure 3. Complex reactions occurring within a landfill

Solubility, volatility, hydrophobicity (K_{ow}), biodegradability, and toxicity influence the behavior of organic contaminants in the landfill. Compounds such as dibromomethane, trichloroethylene (TCE), 2- nitrophenol , nitrobenzene, pentachlorophenol (PCP) and dichlorophenol tend to be highly mobile and thus are found in the leachate and gas .

-

-

Bibliography

Bilitewski, B., Härdtle, G. and Marek, K. (1997) *Waste Management,* Berlin: Springer-Verlag,.[This book provides information on the technologies used and developed in Europe for waste management]

Biocycle, Web site, www.biocycle.com [This journal provides up to date information of installations and practical information for practising engineers on digestion and composting of organic wastes]

LaGrega, M.D., Buckingham, P.L. and Evans, J.C. (2001) *Hazardous Waste Management*, New York: McGraw-Hill [This book is useful as a textbook providing information hazardous waste management and the various technologies for hazardous waste treatment]

Mulligan, C.N. (2001) *Environmental Biotreatment*, Government Institutes.[This book provides information on the design and operation, case studies and vendor lists on the biological treatmzent processes for waste including digestion, landfarming, composting, and landfill bioreactors]

Reinhart, D.R. and Townsend, T.G. (1998) *Landfill Bioreactor Design and Operation*, Boca Raton: Lewis Publishers [A complete book on the design and operation of a landfill bioreactor].

Tammemagi, H. (1999*) The Waste Crisis: Landfills, Incinerators, and the Search for a Sustainable Future,* NewYork: Oxford University Press.[This book is an excellent resource on the status of waste management in the U.S. and Canada]

United States Protection Agency's Municipal Solid Waste Factbook (2001) Internet Version, www.epa.gov/epaoswer/non-hw/muncpl/factbook/internet/intro/how5.htm [This is a helpful guide to the characterization of waste and the technologies for waste management in the U.S., in particular, and in other countries]

United States Environmental Protection Agency. Office of Solid Waste and Emergency Response. Web site. www.epa.gov/oswer [This office of the USEPA provides literature to the public and scientists on solid and hazardous waste management and technologies]

Waste Age, Web site, www.wasteage.com [This journal provides up to date information of installations and practical information for practising engineers on waste management]

Water Environment Federation. Web site. www.wef.org [This federation distributes literature on the management of wastes such as biosolids in particular].

Biographical Sketch

Dr. Catherine Mulligan has worked for the past 15 years in the field of biotechnology in research, industrial and academic environments. After six (6) years in the production of biosurfactants by fermentation at McGill University and the Biotechnology Research Institute, she joined the SNC Research Corporation in 1989, a subsidiary of SNC-Lavalin Group where she has conducted various projects in the development of environmental processes, bioconversions, fermentation, process evaluation, and technico-economic studies. She was involved in the development of the anaerobic treatment of various types of industrial wastewater and air, in addition to the bioleaching of mining residues. She has recently joined Concordia University, Department of Building Civil and Environmental Engineering, as a professor where her research interests include biosurfactant-washing of contaminated oils, treatment of metal-contaminated soils and wastes, bioremediation, the biological treatment of wastewater and the biological treatment of air. She has taught courses in Site Remediation, Environmental Engineering, Fate and Transport of Contaminants in the Environment and Geoenvironmental Engineering. She earned B.Eng. and M.Eng. degrees in Chemical Engineering and a Ph.D. in Civil Engineering at McGill University, Montreal, Canada. She is a member of Order of Engineers of Québec, Canadian Society of Chemical Engineering, American Institute of Chemical Engineering, Air and Waste Management Association, Association for the Environmental Health of Soils, Canadian Society of Civil Engineering, American Chemical Society and the Canadian Geotechnical Society. She has authored over 30 articles and presented at numerous conferences.