Impact Of Biotechnology On Natural Resources

Abstract

In this review, we focus on the biotechnology approach towards the waste management in the wastewater treatment and also the hazardous industrial wastes. These two types of wastes are taken into consideration as the major pollutants are from the industrial wastes consisting of toxic constituents. The biological treatments involved in wastewater treatment as well the hazardous wastes are focused and to show that they can replace the physical and chemical treatments which pollute the environment and to reduce the human risks. Future research and developments are also explained to have a detail study of the waste management through biological treatments.

Introduction

Waste water treatment is essential to remove the harmful microbes, chemicals which pollute the environment. There are many effective treatments like physical, chemical and biological treatments out of which biological treatment is most widely to degrade the substances in wastewater and also being environmentally stable method. Wastewater consists of suspended, dissolved degradable organic material or colloidal particles which measured in terms of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Volatile Suspended Solids (VSS) (Cheremisinoff, 1997a).The biological treatment involves microorganisms like bacteria which play important role and the population dynamics of the bacteria depends on the temperature, pH, nutrient concentration and availability, concentration of substrate, osmotic pressure, degree of mixing and toxicity (Cheremisinoff, 1997a). Metabolic reactions which take place in biological treatment consist of the three phases like oxidation, synthesis and endogenous respiration. Oxidation- reduction reactions are either aerobic or anaerobic in process (Cheremisinoff, 1997a). The overall reactions are as follows:

Organic matter oxidation (respiration)

$C_xH_yO_z + O_2 \; CO_2 + H_2O$ + energy

Cell material synthesis

$C_6H_6O_3 + NH_3 + O_2 \; C_5H_7NO_2 + CO_2 + H_2O$

Cell material oxidation

$C_5H_7NO_2 \; NH_3 + 5CO_2 + 2H_2O$ + energy

Process	Treatment Agents	Wastes Treated
Activated sludge	Aerobic microorganisms suspended in wastewater	Refinery, petrochemical and biodegradable organic wastewater
Trickling filters	Packed bed covered by microbial film	Benzene, nylon, rocket fuel , chlorinated hydrocarbons and acetaldehyde
Water stabilization ponds	Shallow surface impoundments with aeration to promote algae growth and bacteria, algal symbiosis	Biodegradable organic chemicals
Aerated lagoons	Surface impoundments with mechanical aeration	Biodegradable organic chemicals

Table1: Methods of Biological Treatments for wastewater (Cheremisinoff, 1997a).

BOD Removal

In wastewater treatment microorganisms are present as biological floc called biomass treated by biological oxidation stabilization method where high rate of BOD can be removed by contact with active biomass and extends with the type of waste, loading rate and biomass. BOD is utilized with balance to cell growth and the particles on biomass surface are decomposed by enzymes of living cells which are synthesized and the end products decomposed into atmosphere (Cheremisinoff, 1997a). Biomass is converted into removable solids or settleable particles.

Application of Bioaugmentation

Bioaugmentation is introducing the group of natural microbial strains which can treat the water or soil contaminants(Stevens, 1989). Single species of bacteria which are selected and adapted using high technologies are harvested and freeze dried. These strains are blended for mixed culture inoculums by providing various advantages like increase in abnormal growth rate, increase in tolerance towards toxic chemicals, increase in concentration of desired bacteria and reducing the response time also increasing the spectrum of bacteria foe natural selection (Stevens, 1989). These advantages are also benefited for the aerobic wastewater treatment in plant start up, toxic shock/problematic wastewater, organic and hydraulic overloading and poor sludge treatment (Stevens, 1989).

Conventional aerobic and anaerobic biotechnologies in wastewater treatment

Conventional aerobic and anaerobic technologies have been used in the treatment of industrialized wastewaters. In these processes the organic waste is converted into biomass and metabolic end products such as methane, nitrates, carbon dioxide and inorganic constituents (Misra& Pandey, 2005). The waste constituents are metabolized by biological cells which form a solid mass and grow either in suspension or a biofilm which is fixed to inert medium which passes over the waste. Aerobic treatments shown in Figure1, are characterized by aerobic digesters, trickling filters, aerated lagoons, rotating biological contactors and activated sludge process (Peyton, 1984).

Figure1 : Aerobic treatment system (Vallero, 2011).

Activated sludge

Activated sludge process consists of a settler and reactor where flocculent slurry of microorganisms is used as biodegradable soluble organic matter in a reactor as shown in Figure2. Insoluble inorganic and organic matter is also treated in a reactor which is entrapped by microorganism floc (Vallero, 2011). The organisms from treated wastewater are separated by a settler and also to recycle to maintain cell reactor concentration. There are seven types of activated sludge process which are step aeration (SAAS), contact stabilization (CSAS), completely mixed (CMAS), extended aeration (EASS), pure oxygen (POAS)and conventional (CAS),tapered aeration (TAAS) (Vallero, 2011). This process is generally used in chemical plants, electric power plants, manufacturing facilities and petrochemical industries. Activated sludge has shown 95% destruction of nitrophenols, phenols, trichloroethylene, and chlorinated benzenes.

Figure2: Activated Sludge treatment (Vallero, 2011).

Aerated lagoons

Aerated lagoons are used to convert the soluble organic matter into microbial cells as a pretreatment and to oxidize organic matter for the primary waste treatment (Borowitzka, 1994).

Aerobic digestion

Aerobic digestion is mainly used for the degradation of organic matter and for microbial sludge which has undergone primary waste treatment (Peyton, 1984).

Trickling filters

Trickling filters are used for degrading soluble organic matter by aerobic conversion of microbial cells which is attached to a fixed medium. It consists of filter media, enclosure, and distribution system and under drain system(Peyton, 1984)

Rotating biological contactors

A rotating biological contactor consists of parallel circular discs which are attached perpendicularly to a horizontal shaft that passes through their centre. This assembly is placed in a tank so that the discs are only half immersed where microbes grow on the discs and the shaft rotation brings them in contact with the liquid to absorb organic matter (Misra& Pandey, 2005).

Hazardous Waste

Hazardous waste which consists of toxic chemicals from various industries can be treated effectively using biotechnology treatments as shown in Table2. Biotreatment processes include conventional aerobic and anaerobic technologies, land treatments similar to composting and novel technologies for ground and surface waters(Peyton, 1984). Novel technologies include enzymes in batch and continuous fermentors, high rate fermentations also free and immobilized cells. Disposal of hazardous waste can also be treated biologically by considering environmental issues .Toxic chemicals consists of inorganic heavy metals like lead, cadmium and mercury or organic like isomers of dioxin, biphenyls, aromatic and aliphatic hydrocarbons (Misra& Pandey, 2005). In biotechnology, microorganisms play an important role as they quickly regenerate in environment can be used as enzymes for breakdown of toxic substances.

Industries

Potentially hazardous waste generated

Pesticides

Organic chlorine compounds, organic phosphate compounds

Plastic

Organic chlorine compounds

Paints

Heavy metals pigments, solvents, organic residues

Medicines

Organic solvents and residue, heavy metals like mercury and zinc

Oils, gasoline and other petroleum products

Phenols, oils, heavy metals, ammonia, salts, acids, caustics and other organic compounds

Textiles

Heavy metals ,dyes, organic chlorine compounds, solvents

Leather

Heavy metals, organic solvent

Heavy metals, fluorides, cyanides, acid and alkaline cleaners solvents, pigments, phenols, abrasives salts

Table2:Major group of industries generating hazardous wastes (Misra& Pandey, 2005).

In United States, a number of federal legislations were developed under three major environmental concerns laws: the Resource Conservation and Recovery Act (RCRA); the Toxic Substances Control Act (TSCA); and the Comprehensive Environmental Response, Compensation and Liabilities Act (CERCLA) (Peyton, 1984).The regulations of hazardous waste are explained in Table3.

Legislation

Regulation

Resource Conservation and Recovery Act(RCRA)

Identification and listing Manifest system for tracking waste

Standards for treatment, storage and disposal

Comprehensive Environmental Response, Compensation and Liabilities Act (CERCLA)

Government response to spills of hazardous materials into the environment

Funds for compensation and authority to impose liability on clean- up- cost

Toxic Substances Control Act (TSCA)

Evaluation of risk of all chemicals in commerce and testing of new chemicals

Contribution manufacture, processing, distribution, use and disposal of commercial substances posing unreasonable risks

Table3: Major US Federal legislation and regulations concerning hazardous waste control(Peyton, 1984)

Biotreatment

The main objectives of Biotreatment are recycling; containment and destruction which are intended to reduce the risk of human and ecological exposures of toxic constituents to levels that are safe and acceptable. This can be achieved by reducing rate of waste generated by recycling or conversion into usable by-product, removal and permanently isolating the toxic chemicals from waste stream and by destroying the toxic components(Peyton, 1984).

Recycling

Toxic metals can be removed using microorganisms which are mesophilic and thermophilic aerobes and anaerobes in the process of mineral leaching either by a direct microbial attack or by chemical solubilization. In microbial attack, energy is obtained from chemolithotrophs which oxidize inorganic elements like sulphur, ferrous iron and insoluble sulphides. Sulphur with bacterial oxidation forms sulphuric acid by leaching process (Beolchini et al, 2012). Toxic organic chemicals can be converted into usable by-products like methane through anaerobic fermentation and co oxidation process, methylotrophic bacteria with biochemical conversions converts methane into methanol, which is a valuable chemical product (Beolchini et al, 2012).

Separation

The toxic substances can be treated biologically when the toxic substances along with the waste is adsorbed in intracellular matrix using hydrophobic polychlorinated biphenyls and also biochemical’s extracted from cells to remove toxic substances like emulsans where high molecular weight lippolysaccharide on gram positive bacteria with anionic and cationic binding sites suitable for various chemicals to remove them(Peyton, 1984). Enzymes like horseradish peroxidase can be used o separate phenols as solid from aqueous stream.

Destruction

Destruction is performed when the toxic substances are of no economic use generally biodegradation which is a biological method using heterotrophic microorganisms which use organic waste as food source. In fermentation, organic compounds are used as both electron acceptors and electron donors (Cheremisinoff, 1997b). In respiration, free oxygen is used as electron acceptor in aerobic process. The organic compounds are oxidized and reduced to water and carbon dioxide. In this way the toxic compounds can be destructed.

Biotechnologies to treat hazardous waste

Anaerobic treatments.

Anaerobic treatments are generally applicable for reductive dehalogenation of aliphatics and fermentation of high organic loading which is carried out in three stages. The first stage consists of liquefaction, where hydrolysis of insoluble material to soluble organics takes place. In the second stage, acidogenesis, converts organic compounds into simple organic acids like sulphur to sulphuric acid (Vallero, 2011). The third stage is methanogenic bacteria converts organic acids into methane and carbon dioxide. The methanogens are rate limiting as well as sensitive, so acidogenesis is generally used (Vallero, 2011).

Figure3: Anaerobic Treatment (Vallero, 2011).

Anaerobic contact

Anaerobic contact is an effective method which improves the degradation of high strength soluble organic waste. The anaerobic biomass is separated and recycled to achieve high cell mass-to-substrate using bioreactor.

Anaerobic fixed film

Anaerobic fixed-film treatment is anaerobic filter, used for the treatment of soluble and high strength waste. The anaerobic filter consists of a column filled with solid medium which is used for treating the organic matter(Peyton, 1984). The waste which is to be treated flows upward through the column.

Land farming and composting

Land farming and composting is used for biologically treating sludges and solids contaminated with hazardous waste. Land farming is biological decomposition of organic compounds through soil, where a crop of microorganisms utilizes the waste as carbon and energy source. In United States, 150 land operations are conducted in 1500 acres of land(Peyton, 1984). The petroleum industry uses these sites for the disposal of refinery wastes like API separator sludge. The considerations for land farming are maintenance of soil pH, rate of application of waste to soil, avoidance of soil compaction, appropriate Bioaugmentation and the climatic cycles(Peyton, 1984).

Composting

Composting is similar to land farming and it can employed by blended organic/soil matrix. It is a well aerated and mixed process on soft surface or in contained systems. It is like dry aerobic or anaerobic treatment with lignin based particles serving as supporting medium for biological growth where blending of dry organic material like sludge or biological disposal hazardous waste, allowing saprophytic organisms to degrade the matrix over several weeks (Vallero, 2011). There is a technique called vermial- composting where the virucidal activity of the Earthworms responsible for the disposal of hazardous waste (Amaravadi et al, 1990).

Areas for future research and development

There have been many biological treatments conducted against the hazardous waste and waste water treatment in the field of biotechnology with strong regulatory legislations. In 1990, a capital equipment market was US$5-10 billion and has grown huge in the next 10 years(Peyton, 1984). This market includes the use of genetically tailored microbial formulations for Bioaugmentation and by expanding from the present level of US$6-11 million to US$25-50 million. Technical achievement has been promising based upon public and private sector research and development which showed a market development. Research and development is recommended in two major areas which are microbiology and genetic engineering also system design and testing.

Microbiology and genetic engineering

Both substrates (chemical)-specific and waste-specific research strategies can be developed in combination with the bio-system (Cheremisinoff, 1997b) .A substrate-specific approach focuses on developing the genetic component to degrade a specific toxin like isomer of dioxin. A waste specific approach focuses on the development of mixed cultures that can degrade the actual waste matrix which can be like superbugs that can be programmed for biocatalysis of all organic toxic pollutants(Peyton, 1984)

System design and testing

Biotreatment systems need design and testing based upon the performance of pure and mixed cultures. These systems should be considered for both immobilized and suspended cell processes in the waste treatment and enzyme production. Test systems should be applied to the various types of solid or liquid waste matrices, and successful processes need development for scale-up and process optimization(Peyton, 1984). As there are approaches (physical or chemical) alternative to biotechnologies, they should be used and viewed in combination with Biotreatment.

Conclusion

Biotechnology has seen many technological treatments in waste management. Wastewater treatment and hazardous industrial wastes have been considered, the major pollutants in the atmosphere. The industrial wastes especially a chemical industry from which toxic compounds have been released can be balanced by the Biotreatments following the principle of treat, recycle and reuse. There have been many applications where the by- products. In detailed studies, we can consider Bioprocessing as the major asset for biotechnology in production of biofuels as by-product also in pharmaceutical sector. Agriculture and food biotechnology from these sectors the waste produced are treated using the advanced technologies and eco-friendly manner. However, eliminating the wastes before they are released is the best means of reducing hazards and the associated risks, especially by applying the principles of green chemistry and sustainable design.