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Biotechnological Approaches for Urban Solid Waste Management

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Review Article

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Abstract: The world reports show that the solid waste management in urban areas is the major challenge as more than 2 billion tons per annum of municipal solid wastes are released into the atmosphere. Dumping of municipal wastes such as rubber, plastics, agricultural refuse, and from the industries harm the environment and all the living being as well as reduction in biodiversity. The techniques used for solid waste bioremediation are: biosparging, bioaugmentaion, biopilling, and land farming. Biosparging is generally used in treatment of petroleum wastes at the underground storage tank (UST) sites for aerobic degradation and volatilization. The remediation is achieved by removal of the mass and discharge into groundwater. Bioaugmentation is used both for soil as well as treatment of ground water mainly contaminated with chlorinated ethanes, for degrading into non-toxic ethylene and chloride compounds by the compound-degrading microbes, into activated sludge or compost. Biopilling is a combination of the composting and land farming. Land farming is a natural degradation process and useful mainly against pesticides. Rubber is approximately 12% of the constituent in solid wastes but nondegradable and also nonrecyclable due to presence of polymers and also black carbon. Degradation of rubber is achieved by a fungus, Recinicium bicolourto to remove the toxic components. Rubber is recycled by devulcanization through reducing and oxidizing actinobacteria viz. Pyrococcus furiosus & Thiobacillus ferroxidans. The presentation will discuss various biotechnological ways and means for management of urban solid wastes.

Keywords: Biosparging, Bioaugmentaion, Biopilling, Pyrococcus furiosus, Thiobacillus ferroxidans

INTRODUCTION

Earth is rich in natural resources but urbanization and industrialization has caused generation of atmospheric pollutants resulting in contaminants leading to ecological imbalance. Dumping of municipal wastes like rubber, plastics, agricultural refuse and industrial waste damage the environment and harming living beings. Microorganisms are useful for degradation or removal of environmental pollutants; they provide economic and safe bioremediation methods than other physiochemical ones. They metabolize the contaminants for their growth and reproduction. Disposal of waste pollutants has created insufficiency of clean water and unsuitability of soils for agriculture that diminishing crop production and creating atmospheric pollution. The main cause of pollution is explosion of human population that is responsible for decrease in natural resources, rapid expansion of industries, intensive agricultural practices, poor health care, exponential growth of vehicles, etc.

World Network reports that 450 million kilograms of toxins from the wastes get released globally both in the air and water. Dumping of municipal, agricultural and industrial wastes creates harm all living beings into the environment (Fig-1). Management of solid-waste is an important challenge in all big cities of the world. Different industrial and urban wastes are discharged continuously in uncontrolled manner in the environment and that causes serious problem globally [1]. Similarly human and industrial activities create a great deal of contaminations to the agricultural lands. This also reduces the biodiversity. Pesticides, herbicides help the productivity of crop but certainly cause environment pollution [2]. Wastes are mainly of two types; inorganic and organic. Inorganic wastes include heavy metals while organic materials like agricultural refuse etc. These wastes having heavy metals are degraded by bioremediation process through microorganisms (Table-1).

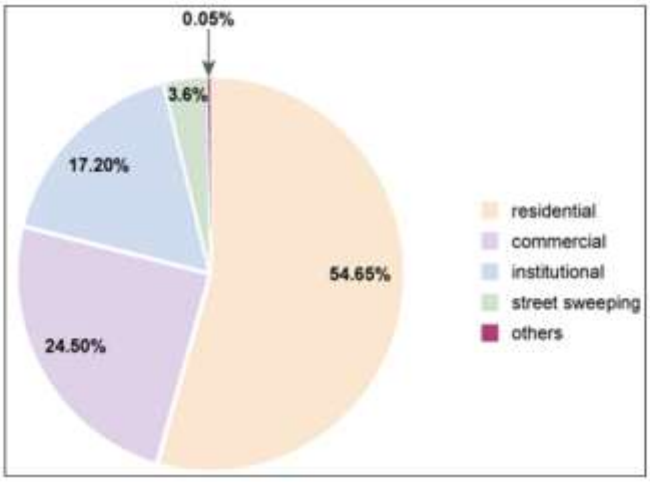

Fig-1: Solid wastes generated by different sources [3]

Table-1: Solid Waste and Sources

Solid wastes	**Sources**	**Types**
Industrial	Urban and rural dwellings	Food wastes, paper, plastic, textile mills, yard waste, glass, metals
Agricultural	Crops, orchards, vineyards, dairies	Livestock manure, agricultural wastes, pesticides
Municipal	Street cleaning, landscaping, parks, beaches, waste water treatment, other recreational areas	Wastes generated from trimming of trees, park, beaches, sweeping of roads, landscape,
Residential	Single and multifamily dwelling	Food wastes, consumer electronics, batteries, oil, tires, household, hazardous waste paper, plastic, textiles, leathers, yard wastes, wood glass

Bioremediation

Bioremediation is the natural process for removing the pollutants to detoxify the environment by using microorganisms or plants which destroy them or transform into some biodegradable substances [4]. This is an environment friendly technology, with low cost, having high efficiency and safer. It has selectivity for specific metals without additional nutrient requirement. Bioremediation helps in metal recovery and also for regeneration of biosorbents. Major benefit in bioremediation is that it can be carried out at any site [5]. It includes burning, catalytic devastation, the use of adsorbents and also physical elimination which help in reducing mass and form of the pollutants. Bioremediation processes depend on many factors such as microbes, contaminants and environmental factors. In microbes it depend on biomass concentration, diversity of microbes, growth pattern, nutrients required for the growth of microbes, primary and secondary metabolites production. As a contaminants, physico-chemical bioavailability of pollutants (equilibrium sorption, irreversible sorption, incorporation into humic matters), chemical structure of contaminants level of toxicity, solubility. As a environmental factors depletion of preferential substrates, electron acceptor/donor, oxygen content, pH(5.5 – 8.8), type of nutrients such as Carbon, Nitrogen, Phosphorus, soil type, low % of clay or silt content, temperature (15–45^{0}C), moisture content(45 – 85%), water holding capacity (25–28%), mass transfer limitations (oxygen diffusion and solubility, diffusion of nutrients, solubility or in miscibility with water). Bioremediation can be grouped in two categories viz. *in-situ* bioremediation and *ex-situ* bioremediation (Fig-2).

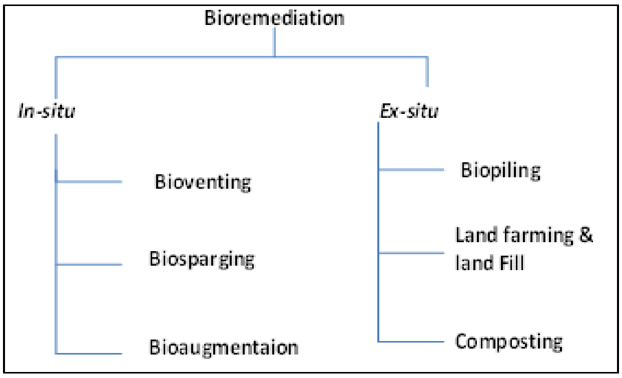

Fig-2: Types of Bioremediation

In situ bioremediation

In situ bioremediation achieved by the addition of nutrients in the soil. This biological treatment removes the hazardous substances from contaminated sites (soil and groundwater) and avoids the need of excavation and transport of soil. The microbes metabolically used these toxic compounds by degrading the pollutants over a period. The microbes use oxygen and nutrients at the contaminated site. It can be used for detoxifying soil and ground water. It is a cheaper, safer method using harmless microorganisms, through chemotaxis for removing the contaminants. The whole process has minimal site disruption, treatment of contaminated soil and groundwater simultaneous and a minimal exposure of public and site personnel. The major disadvantages of this treatment viz consuming of long time and depending on seasonal variations for microbial activity as well as lack of control on environmental factors. Different techniques are used for *in-situ* bio- remediation as:

(i)Bioventing (ii) Biosparging (iii) Bioaugmentaion

(i)Bioventing

This method is used for degradation of aerobically degradable compounds. For this oxygen and nutrients are injected to remove the contamination from the sites (Fig-3). Major limitation for this process is that microbes provide very low air exchange. The air is pumped into the soil above the water level through wells in periphery. This technique is suitable for the surface having deep water level and when temperature is high. This help in removing gasoline, oil, petroleum etc. Different soils have varying rates of pollutant removal based on the soil texture and composition of hydrocarbons.

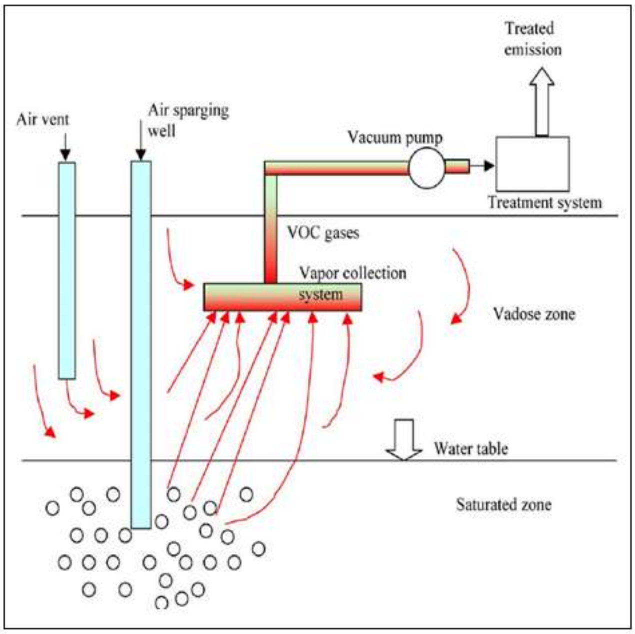

Fig-3: Schematic of a Bioventing System [6]

(ii) **Biosparging**

It is used for aerobic degradation and volatilization to help reducing petroleum products at underground storage tank (UST) sites mainly for mid weight petroleum products (diesel fuel/jet fuel) and also for lighter products (e.g., gasoline etc) (Fig-4). Applitcation of his technology is successfully for removing the contamination of gasoline and to check percent remediation achieved by estimating mass removed and discharge to the groundwater. The concentration of air is increased by injecting air into the ground water under pressure for microbial degradation of pollutant [7].

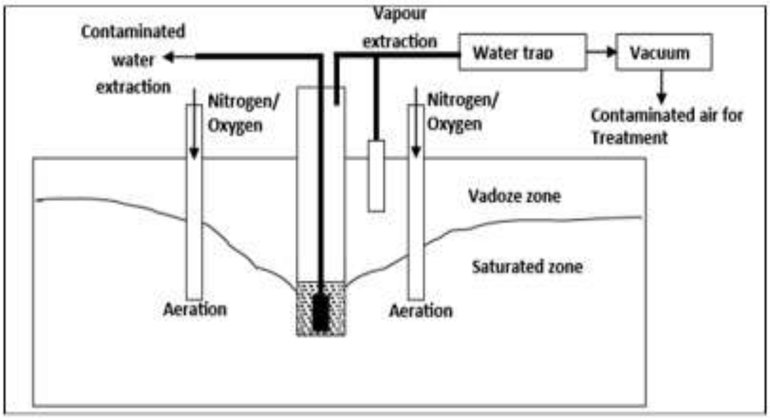

Fig-4: A schematic diagram for vacuum extraction procedure [8].

(iii) **Bioaugmentation**

This is used by addition of compound-degrading microbes or organic amendments containing active microorganisms e.g. activated sludge or compost. These microorganisms have specific metabolic activity to degrade the wastes. It is used for soil as well as ground water that are mainly contaminated with chlorinated ethanes as tetrachloroethylene and trichloroethylene, being degrading into non-toxic ethylene and chloride compounds [9].

***Ex-situ* Remediation**

This remediation is applied at other sites. By the excavating the soil and transporting to a suitable location nearby. Different techniques used for *ex-situ* remediation are as;
(i) Biopiling (ii) Land Farming and land fill (iii) Compositing

(i) Biopiling

Is a combination of composting and land farming where bed is a treated by a irrigation/nutrient and supply of nutrition as well as collecting leachates. Adequate biodegradation occurs by controlling various factors like moisture, heat, nutrients, oxygen and pH etc. The air and nutrients are provided under the soil through vacuum pump. Soil is covered with plastics to prevent volatization/evaporation. The whole process of biopiling is completed in 20 days to three months.

(ii) Land Farming and land fill

Land farming is a natural bioremediation process with specially enhanced microbes, with soil aeration. This process is simple, inexpensive, self-heating, and cost efficient [10]. It is useful mainly for pesticides and petroleum-impacted soil and water. This is followed by irrigation and tailing. It is generally for Non-hazardous materials. It makes sandwich of excavated soil is made with clean soil and clay, concrete where garbage is thinly spread and covered with clay or plastic foam. Thus clean soil is at bottom while concrete is at the top. In this method oxygen, nutrition have to be provided and with desired moisture and pH near neutral (pH 7) with the help of lime. Plastic liner is used to prevent leaching the contaminations. The liner protects the ground water from being contaminated due to percolation of leachate. By this anaerobic decomposition occurs that produces methane and is used to produce electricity.

Landfill is the traditional storage disposal site for hazardous and non-hazardous wastes. It does not conserve our natural resources. Land fill process depositing in low- lying areas, low value sites in land fill process. Every day a new layer of soil is deposited on the waste. These areas have a wide range of microorganisms suitable for degrading various wastes which however takes long time to degrade.

It is important to pump away the leachates for treatment. Many wells are drilled around the sites to keep checking leakage of the contaminants. And methane produce used for generation of heat.

The Landfills Sites for sanitary purposes are too selected on the following grounds:

1. Need to above the water table so that minimum interaction with ground water.

2. To avoid leaching it must be having clay or silt so that there is no leaching.
3. It is never done in sand or gravel pits and also in flood plains.

(iii) Composting

It is an anaerobic solid substrate fermentation process generally using white rot fungi. This is a technique of recycling organic matter. It helps in recycling of wastes from agricultural, domestic/ food wastes. Compositing helps organic wastes into sanitary humus without requiring much moisture which can be reload into agricultural field for high productivity. This material can then be safely returned to the natural environment. The biochemical reaction of composting results into production produce carbondioxide, water and other organic by products.

Therefore the composting is a controlled biological exothermic process. In this microbes release heat that increases the temperature which in turn increases wastes solubility. Firstly the oxidation of organic matter occurs followed by a dynamic and rapid succession of microbial population to maturing phase. It is followed by mineralization and humification process in which the volatile solids are converted into CO_2 and H_2O. The overall reaction for the composting is given below:

Organic Biodegradable Matter + O_2 +Microorganisms Stabilized organic residuals + Microbial biomass + CO_2+ H_2O + Heat

Domestic solid waste when composted give organic matter that help improve the soil quality besides agricultural refuse can be particularly treated for the production of mushroom.

Bioremediation of Heavy Metals

There are approximately 20 heavy metals having the toxicity due to their high atomic weight and density then other elements. These contaminants cause serious problems in the environment, especially soil, because these are not biodegradable. Bioremediation is related to the composition, complexity, physiological and ecological components, species, solubility and concentration of metals and the characteristics of the effluent, such as pH, as well as presence and concentration of other cations and/or molecules and also suspended solids [11]. Metal contaminants cause harmful effects on human/ animal health and creates ecological damage [12] by altering the conformation structure of nucleic acids, proteins and interference with oxidative phosphorylation [13]. There are different sources of heavy metals (Table-2).

Table-2: Sources of Heavy Metals in the Environment [14]

Heavy Metals	
Natural Sources	**Anthropogenic Sources**
Weathering of minerals	Pesticides, wood preservatives, biosolids, ore mining and smelting
Erosion and volcanic activities	Cd: Paints and pigments, plastic stabilizers, electroplating, phosphate fertilizers
Biosolids (e.g., livestock manures, composts, and municipal sewage sludge)	Cr: Tanneries, steel industries, fly ash
Forest fires and biogenic source	Cu: Pesticides, fertilizers, ore mining and smelting Hg: Mining for Au-Ag, coal combustion, medical waste
Particles released by vegetation	Ni: Mining, electroplating, kitchen appliances, surgical instruments, automobile batteries
	Pb: Aerial emission from combustion of leaded fuel, battery wastes, insecticides and herbicides.

Different biological agents as yeast, fungi, bacteria, algae etc act as biosorbents for sequestering the metals and are employed for removing theses metals (Table-3) Gikas, 2008. This is a very quick, more effective and efficient way for removal of metal elements from the soil.

Table-3: Showing the name of microbial species & removal elements

Name of the species	Removal of elements	Reference
Cellulosmicrobium cellulans	Cr	Chatterjee *et al.*, [15]
Pseudomonas aeruginosa	Cd, Pb, Fe, Cu, U, Ra, Ni, Ag	Jayashree R, [16]
Saccharomyces cerevisiae	Ur	Wang *et al.*, [17]
Aspergillus niger	Cd, Zn, Th, Ur, Ag, Cu	Gunasekaran *et al.*, [18]
Trichoderma Viride, And Humicola Insolens	Hg	Javed *et al.*, [19]

CONCLUSION

Heavy metals, nuclear wastes, pesticides, green house gases, and hydrocarbons are amongest the pollutants causing highest level of toxicities and create a major concern for environment and public health. Bioremediation is the most effective and eco-friendly process for remediation of theses polluted sites. It is possible both ex-situ and in-situ depending on site characteristics, type and concentration of pollutants. Therefore, choosing an appropriate bioremediation technique, to effectively reduce pollutant concentration to an innocuous state, is crucial for a successful bioremediation project. Recently biotechnology method has employed useful bacteria for degrading various solid waste /municipal waste. Many efficient bacterial strain geneticlaylly modified for bioremediation of specific sites in a less time. This ensures rapid degradation of the waste material. It was reported that emission of ammonia is reduced by composting of chicken manure [20].

Rubber is approximately 12% of constituent in the solid wastes. Rubber is nondegradable and nonrecyclable based on the physical composition [21]. The strength of the rubber depends on the vehicles tires that are made of synthetic polymers with a high grade black carbon generating a large amount of toxic fumes and carbon monoxide [22]. 65% decomposing rubber from vehicles, having zinc oxide can inhibit the sulfur oxidizing and other naturally occurring bacteria [23]. The fungus Recinicium bicolourto devulcanized rubber. Sulfur reducing or oxidizing actinobacteria like Pyrococcus furiosus & Thiobacillus ferroxidans for recycling [24, 21] and energy generation

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