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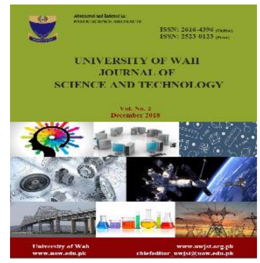

Bioremediation of Environmental Waste: A Review

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Abstract—Nearly 1.6 billion tons of waste produced annually poses several environmental and health threats and, therefore, efficient waste disposal and management programs require urgent attention. Biodegradation and bioremediation are environmental friendly methods with reference to reduced production of toxic residues and release of trapped nutrients in the process of mineralization. The so-called 'waste substances' have high calorific values and huge amount of energy that is often not utilized and is discarded. This waste matter can be utilized for energy, fuel and electricity production with the help of micro-organisms. Currently, 'Waste to Energy (WtE) Program' is being practiced by many countries for the production of clean fuels and electricity utilizing a number of methods e.g. fermentation, anaerobic digestion, landfill gas, bio-sparging, bio augmentation, microbial fuel cells, bioventing, dendro liquid energy, etc., with the latter being most efficient of all as it is based on zero waste technology and has high efficiency. Many bacterial, fungal and other species have been reported that efficiently degrade the waste matter. In addition, genetically modified organisms are being produced for the degradation of specific kinds of wastes e.g. polymers, hydrocarbons, plastics, industrial wastes, etc. Efficient system of waste collection, recycling and reuse along with active public participation are essential for any successful waste management program. This review aims to discuss few biological methods for waste management

***Index Terms*—Biodegradation, Bioremediation, Microbial fuel cells, Dendro liquid energy, WtE program**

I. Introduction

WASTE are the substances discarded as useless and are the byproducts of human activities that can be of solid, liquid and gas in nature. Annually, nearly 1.6 billion metric ton waste is produced globally and its management cost is expected to rise to US$50 billion by 2025 [1]. Solid wastes are most hazardous as they are source of many problems e.g. health-associated risks, ground water contamination, accumulation of particulate matter, soil and air contamination and difficulty in their management and disposal, especially in developing countries [2]. Because of ever-increasing pollution, health-associated risks and economic losses on the behalf of governments and public, waste management has gained worldwide attention. Waste management refers to collection, separation, handling and disposal of waste matter in an eco-friendly way [3]. Biodegradation refers to the reduced complexity of substrate (chemical compounds mostly), mediated biologically by the action of living microorganisms [4]. The process is termed as mineralization when microbes completely reduce the substrate in the form of smaller compounds [5]. Now-a-days, waste matter is regarded as a useful material that can be re-utilized for a lot of purposes including incineration, compost formation, fertilizers etc.

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II. Impacts of Inappropriate Waste Disposal

The major effect of inappropriate disposal of waste matter is soil pollution, surface and ground water contamination. Such waste disposal sites serve as a breeding place for several pathogens, vectors, pests and germs. Emission of toxic gases, air pollution by waste combustion, leachates, release of methane by decomposition of waste matter, etc. are most commonly encountered precarious effects. Landfills located near populated areas pose additional health risks [6].

Inappropriate dumping of wastes affects the number and kind of micro-organisms present in that area as well as their enzymatic activities and physiochemical properties thereby disturbing soil-environment homeostasis [7]. Several types of wastes and their sources are enlisted in Table I. Clogging of drains caused by municipal solid waste generates pools of stagnant water that provide brooding sites for insects and other pathogens transmitting several diseases such as cholera, dengue etc. and causes floods in rainy season. MSW-contaminated water used for drinking, irrigation, baths, etc. increases the risk of exposure to pathogens and contaminants. According to The U.S. Public Health Service, twenty two (22) diseases of human beings are related with inappropriate waste management including cancer, low birth weight, chemical poisoning caused by inhalation of toxic chemicals, neurological disorders, vomiting, nausea, congenital malformations, Hg toxicity, high algal populations, etc. Accumulation of heavy metals is increasing day by day in the food chains [8].

Exposure to waste matter increases the chances of cancer in liver, lung, soft tissues and testis [9]. Asthma, skin irritation, allergies, gastrointestinal diseases, are also found in people inhabiting areas near waste disposal sites [10].

TABLE I
DIFFERENT TYPES OF WASTES AND THEIR SOURCES [13]

Source/Type		Composition
Municipal Solid Waste	Residential	Food waste, paper, cardboards, plastics, textiles, leather, yard wastes, wood, glass, metal, ashes, special wastes (e.g. bulky items, consumer electronics, white goods, batteries, oils, tyres), household hazardous wastes, e-wastes.
	Industrial	Housekeeping wastes, packaging, food wastes, wood, steel, concrete, bricks, ashes, hazardous wastes.
	Commercial and Institutional	Paper, cardboards, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes, e-wastes.
	Construction and Demolition	Wood, concrete, steel, soil, bricks, tiles, glass, plastics, insulation, hazardous wastes.
	Municipal Services	Street sweepings, landscape and tree trimmings, sludge, wastes from recreational areas.
Process Waste		Scrap materials, off-specification products, slag, tailings, top soil, waste rock, process water and chemicals.
Medical Waste		Infectious wastes (bandages, gloves, cultures, swabs, blood and bodily fluids), hazardous wastes (sharps, instruments, chemicals), radioactive wastes, pharmaceutical wastes.
Agricultural Waste		Spoiled food wastes, rice husks, cotton stalks, coconut shells, pesticides, animal excreta, soiled water, silage effluent, plastic, scrap machinery, veterinary medicines.

III. Waste Management Strategies

In order to devise efficient waste management strategies, accurate assessment of quantity of different categories of waste production is the foremost necessity.

A. Waste to Energy Program

A rapidly developing waste management approach is waste to energy transformation strategy in which waste matter is utilized to produce energy and is being rapidly adopted by many countries around the globe. In 2013, the global market of waste to energy was evaluated at about \$25.32 billion with a profound increase in successive years [11]. India, Thailand and Philippines have started this program for the generation of electricity [12].

Direct combustion of waste substances generate heat that is used to drive a turbine, with 15-27% efficiency. Gasification of solid waste involves the generation of 'Syngas' i.e. combustible synthetic gas that can either be used to drive a steam turbine for the generation of electricity or direct generation in gas turbines or engines after further refining. This Syngas can be converted further into methane for domestic utilization and can be used as transport fuel e.g. diesel, ethanol, hydrogen, biodiesel, jet fuel, etc. after being upgraded to bio-methane and various others substances [13].

Many waste to energy plants use combined heat and power units to increase the efficiency of energy production up to 40%. Heat generated during the process of electricity production is captured and then utilized for industrial, domestic or commercial purposes [13].

B. Biological Management of Waste Matter

Using living organisms for the management, recycling or decomposition of waste substances is an efficient method often combined with other chemical or physical procedures. This method can be used for several materials but is most suited for management of domestic, municipal and agricultural wastes. Bioremediation can be carried out by in-situ and ex-situ means. In in situ remediation, nutrients and oxygen are supplied in the form of a solution to contaminated soil that stimulate biodegradation by naturally found bacteria. This method is generally used for soil and ground water. Intrinsic bioremediation and engineered in situ bioremediation are two types of in situ remediation. In ex situ remediation, soil excavation and ground water pumping activities facilitate biodegradation by microbes. This technique can involve solid and slurry phase systems, sub-categorized into land farming, composting, biopiles - hybrids of land farming and composting; and bioreactors, bioventing i.e. indigenous bacteria are stimulated by using wells to supply nutrients and oxygen to contaminated soil; bio-sparging i.e. rate of biological degradation is enhanced by injecting air under pressure below ground water table in order to increase oxygen concentrations; bioaugmentation-importing microbes to the site of contamination in order to enhance degradation; respectively [14]. Some of the bioremediation strategies are enlisted in Table II.

Anaerobic digestion involves the degradation of wastes in the absence of oxygen resulting in the release of 'biogas' which is rich in methane and can be used as fuel for electricity production and contains many nutrients that are employed in fertilizers as shown in *Fig.1*. The duration of this procedure varies from 15 to 30 days. Bio-fertilizer can efficiently replace conventional chemical fertilizers after they have been made pathogen free. Waste water treatment is an example of this type of bioremediation [13]. The fertilizer or compost is beneficial with reference to a number of crops. Tea waste and tea bark composts were experimentally proven to enhance the yield in 'Great Lakes 118' lettuce [16].

Fermentation involves anaerobic conversion of organic wastes to produce acids or alcohols, leaving behind a residue rich in a number of useful nutrients. Production of bioethanol using various yeast strain and substrates is an excellent example of fermentation. This process can provide an annual production of about 2-3 lac tons of bioethanol which is regarded as clean fuel [13].

Landfill gas (LFG) emitted from landfills as a result of decomposition of organic wastes, is mainly composed of 50% of CO_2 and CH_4 each. It is an eco-friendly method as methane has 25% greater global warming capacity as compared to CO_2. LFG is used mainly in thermal kilns, boilers, infrared heaters, sludge dryers, forgers, electricity generations, leachate evaporations, blacksmithing forges, etc. [13].

Microbial Fuel Cell (MFC) are systems that involve the production of electricity from bacteria or enzymes from the oxidation of organic wastes. In MFC chambers, proton exchange membranes separate the anode and cathode chambers; the former chamber is maintained under anaerobic conditions and latter submerged in aerobic solutions or is exposed to air as shown in *Fig.2*. External circuit regulates the flow of electrons from anode to cathode [17]. MFC systems find applications in many areas ranging from power sensors in devices used to monitor corrosion and those that measure pressure levels in deep sea gas and oil pipelines; electricity generation on small scale; waste water treatment; production of bio-hydrogen; bioremediation and biosensors for monitoring of various processes and analysis of many pollutants. This technique is not yet being used commercially because of expensive electrode materials, inadequate manufacturing capabilities for producing reactor cathodes etc. [18].

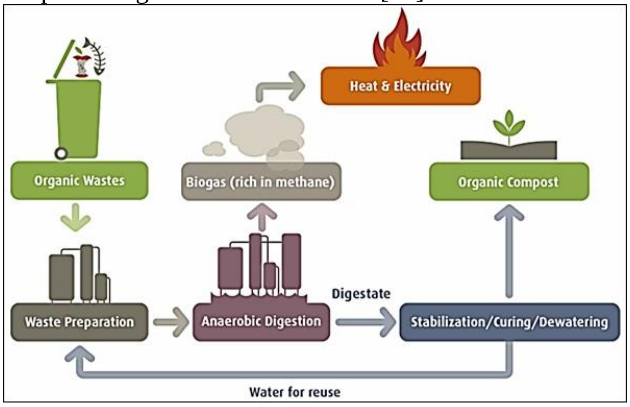

Fig. 1. Anaerobic digestion of waste matter.

Recently, a German innovation named Dendro Liquid Energy (DLE) involves bio-processing of mixed wastes e.g. plastics, wood logs etc. to produce clean fuels e.g. CO, H_2, etc.; needed for electricity production. The system is based on 'zero waste technology' and is 4 times more efficient as compared to anaerobic digestion involving no combustion, effluents, emissions discharges or nuisance [19].

Insects driven Bioremediation is gaining popularity now days. Many insets like black soldier fly, Hermetia illucens L, can actively degrade the waste matter for example, can reduce kitchen waste, poultry feed, fruits and vegetables, pig liver, rendered fish and pig manure, that can be used in animal feed [20]. In addition, bioremediation of organic wastes can be promoted by using earthworms due to their physical, chemical, and biological activities.

TABLE II
BIOREMEDIATION STRATEGIES [15]

Technology	Examples	Benefits	Limitations	Factors to Consider
In situ	In situ bioremediation Bio-sparging Bioventing Bio augmentation	Most cost efficient Non-invasive Relatively passive Natural attenuation processes Treats soil and water	Environmental constraints Extended treatment time Monitoring difficulties	Bio degradative abilities of microorganisms Presence of metals and other inorganics Environmental parameters Biodegradability of pollutants Chemical solubility Geological factors Distribution of pollutants
Ex situ	Land farming Composting Bio piles	Cost Efficient Low Cost Can be done on site	Space requirements Extended treatment time control abiotic loss Mass transfer issues Bioavailability limitations	See Above
Bioreactors	Slurry reactors Aqueous reactors	Rapid degradation kinetic Optimized environmental parameters Enhance mass transfer Effective use of inoculants and surfactants	Soil requires excavation Relatively high cost capital Relatively high operating cost	See above Bio augmentation Toxicity of amendments Toxicity concentrations of contaminants

Earthworms are reported to improve the aeration, fertility and nutritional status of the soil. These factors are often thought to be limiting the process of biodegradation. Earthworms decreases the binding of organic chemicals and soil; release any formerly bound soil contaminants followed by subsequent degradation; disperse and promote other organic contaminant-degrading microbes [21].

C. Biodegradation of Polymers and Xenobiotic

With the advancements of science and technology, nearly 140 millions of polymers are produced every year [22]. These polymers are increasingly polluting surface and ground water sources and are hindrance to waste treatment plants. Many such synthetic chemicals are resistant to physical and chemical degradation, and hence they are hard to dispose off. Therefore, there has been an increasing trend towards the production of biodegradable polymers and plastics [23].

Xenobiotic are synthetics, often halogenated, difficult to degrade by microbial species. Saturated, long chain and straight alkanes are more prone to aerobic degradation as compared to unsaturated aliphatic hydrocarbons. Most common mechanism for the degradation is the oxidation of terminal methyl group into a carboxylic acid through an alcohol intermediate, and eventually complete mineralization through β-oxidation [24]. Aromatic compounds are mostly degraded under anaerobic, iron-reducing, nitrate-reducing, methanogenic and sulfate-reducing conditions. Oxidation of aromatic compounds produces molecular intermediates that enter metabolic pathways e.g. β-oxidation and Krebs Cycle [25].

D. Biodegradation of Industrial Effluents

Industrial effluents are the most important source of toxic waste accumulation in the environment. Several species of cyanobacteria have been reported to show efficient potential in the bioremediation of terrestrial and aquatic habitats, waste water treatment, biodegradation of toxic components in industrial effluents, etc. Species mainly cyanothece, Oscillatoria, Nodularia and Synechococcus have high biosorption and biodegradation capability [26]. For the bioremediation of pulp and paper mill effluents, Alteromonas species can be efficiently utilized because of their alkali tolerant and osmophilic characteristics [27]. For the biodegradation of textile effluents, several Bacillus species e.g. Bacillus cereus, B. subtilus, B. mycoides, Micrococcus sp. and Pseudomonas sp. are considered to be best microbial organisms [28].

Moderate heavy metal concentrations in domestic and industrial effluents can be remediated by the action of Bacillus licheniformes and Pseudomonas putida [29]. 95% BOD and COD can be reduced by naturally found consortia of microbes including Bacillus, Arthrobacter, Micrococcus and Pseudomonas in industrial effluents from steel mills [30]. Effluents from sugar mills can be remediated biologically by the action of Bacillus cereus, Staphylococcus aureus, Klebsiella pneumonia, Escherichia coli, and Enterobacter aeruginosa, with Staphylococcus aureus having maximum degradation potential [31]. In the biodegradation of municipal sewage water, Pseudomonas, Alcaligenes Flavobacterium, Acinetobacter, Enterobacteriaceae and Zooglea sp. are the dominant bacterial species as shown in Table III [32].

TABLE III
VARIOUS SPECIECES OF MICRO-ORGANISM THAT UTILIZE DIFFERENT HEAVY METALSV

Micro-organisms	Elements
Bacillus spp., Pseudomonas, aeruginosa	Cu, Zn
Zooglea spp.	U, Cu, Ni
Citrobacter spp.	Co, Ni, Cd
Chlorella	Cd, U, Pb, Au, Cu, Ni
Aspergillus niger	Hg, Zn, Cd, Ag, Th
Pleurotus ostreatus	U, Cd, Cu, Zn
Rhizopus arrhizus	Ag, Hg, P, Cd, Pb, Ca
Stereum hirsutum	Cd, Co, Cu, Ni
Phormidium valderium	Cd, Pb
Ganoderma applantus	Cu, Hg, Pb
Volvariella	Zn, Pb, Cu

E. Biodegradation of Waste Papers

Because of the cellulose-digestion abilities of bacteria, they can be efficiently used in the degradation of waste papers. Using bacterial species namely E. coli, Pseudomonas florescence and Bacillus subtillus isolated from soil, 1 gram paper waste was incubated at 35°C for 90 days resulting in a zone of clearance of about 13.3mm diameter with Pseudomonas florescence most actively hydrolyzing the paper [33]. Microbial and fungal consortia including Bacillus cereus, A. niger etc. can actively degrade waste papers [34]. Macroalgae from the genus Oedogonium has the potential to lower the concentration of a number of heavy metals e.g. Cd, Ni, Al, Zn, Cu, As, Cr, etc. in the ash water from coal-fired power plants [35].

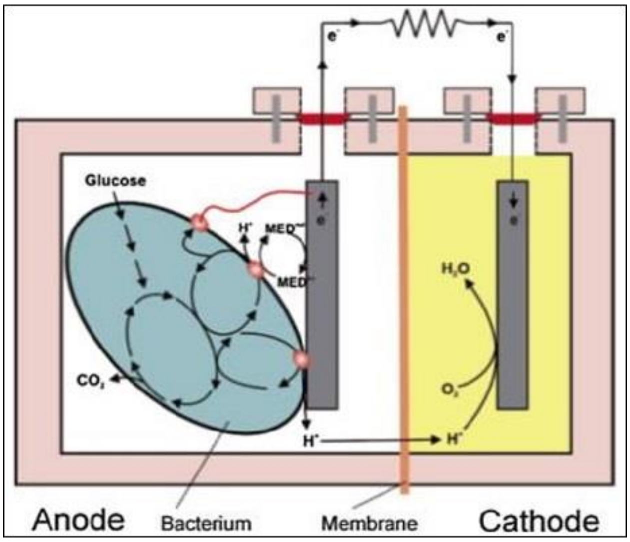

Fig. 2. Components of a two-chambered MFC system [17].

F. Biodegradation of Plastic

Annually, about 300 million metric tons of plastic is produced, 50% of which is discarded within one (1) year of purchase. Plastics usually have high molecular weight and have high demand in various fields. They pose several health and environmental hazards because of their non-degradable nature. Therefore, there has been an increased concern about the proper management of plastic wastes. The calorific value of plastics is high therefore they can be used as an alternative fuel with lesser CO_2 emissions. Plastic wastes can be managed by recycling, incineration, reuse, landfills, utilization in the construction of roads and can be co-processed in cement kilns [36]. *Fig. 3* explains the microbial action of biodegradation.

G. Waste Management in Pakistan

Waste management strategies are currently inefficient in Pakistan as 51-69% of waste remains uncollected [38]. Solid waste management (SWM) approaches include open dumping of waste matter and landfills, posing serious environmental and health threats. Burning of solid wastes releases a number of highly toxic gases posing further environmental risks and causing ground water contamination. According to a study conducted in Peshawar, Pakistan, 43% of respondents were willing to pay for the betterment of solid waste management techniques and the remaining 57% were content with existing SWM strategies [39]. Waste generation in Pakistan ranges from 1.896-4.29Kg per house per day [40].

Waste generated in Pakistan can be broadly categorized as biodegradable, e.g. food and animal wastes, plant-based wastes etc.; non-biodegradable, e.g. rubber, plastic, metals, textile waste, stones; and recyclable material e.g. paper, rags, cardboards etc. [37].

In Islamabad, open dumping of waste material has resulted in deteriorated quality of water, reduced abundance and diversity of vegetation along with significant alterations in the quality and properties of soil, e.g. elevated pH levels; increased concentration of heavy metals, mainly lead, chromium, nickel, copper and zinc; EC regime and TDS [41]. Rate of waste generation and collection in five (5) major cities of Pakistan is shown in *Fig. 4*.

The adaptability of above-mentioned waste management techniques depends upon the efficiency of waste collection system and the infrastructure available for extraction of energy from so-called waste matter. Waste to energy programs can be immensely helpful in eco-friendly production of energy and clean fuel for domestic and commercial usage. These programs can also be helpful in lessening the burden on already-diminishing water resources of Pakistan for electricity production.

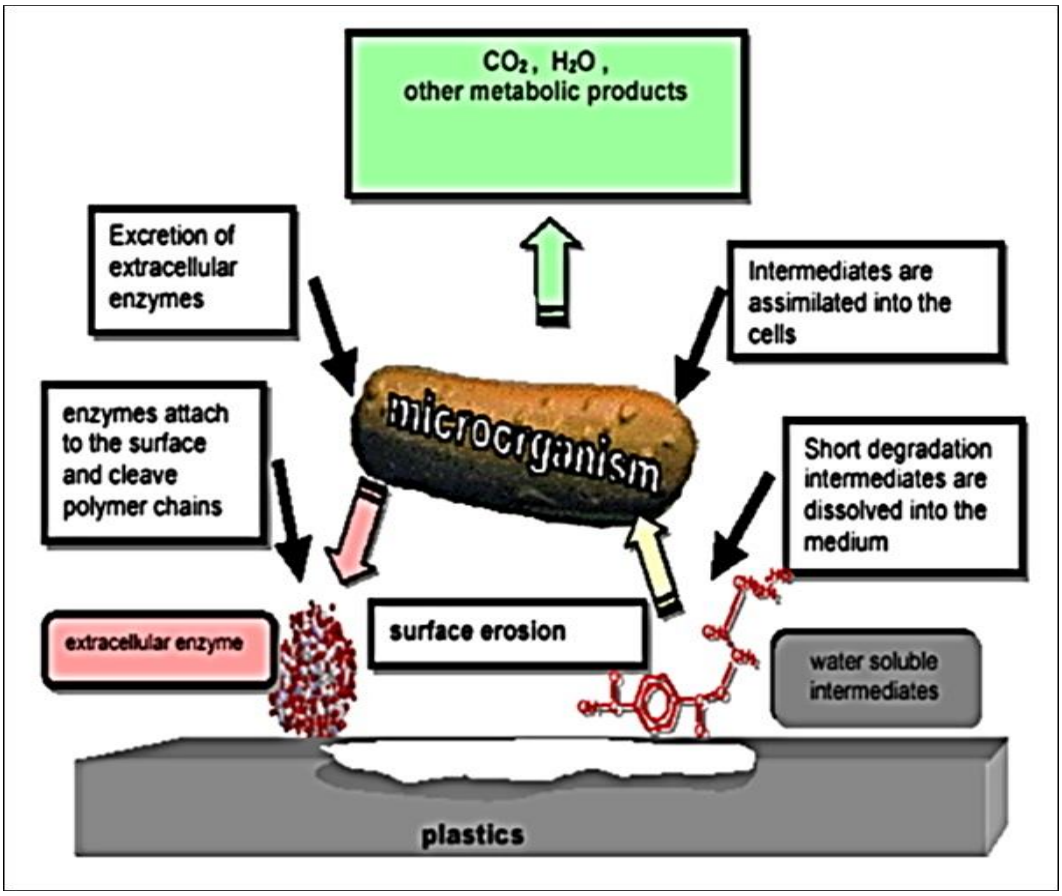

Fig. 3. Mechanism of plastic biodegradation under aerobic conditions [37].

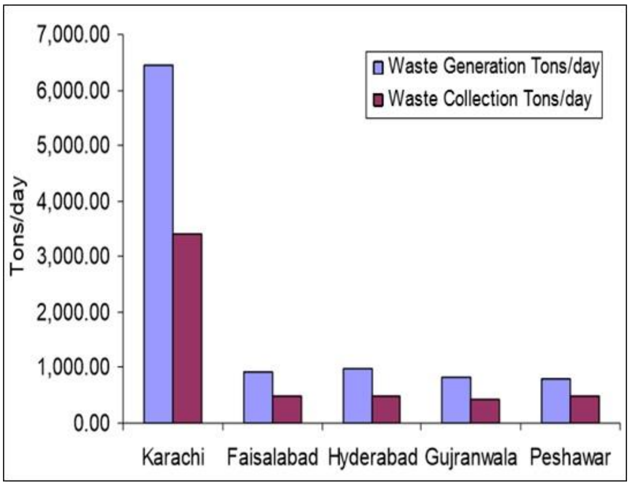

Fig. 4. Rate of waste generation and collection in five (5) major cities of Pakistan.

IV. Limitations of Bioremediation and Waste Management

Although bioremediation is an environmental friendly process, it has certain limiting factors as well. In case of in situ remediation, several additives are added for the enhancement of degradation activities of microbes. These additives can be disruptive or damaging for many other microbes inhabiting the same environment [15]. The removal of these organisms from that particular environment becomes difficult with the passage of time even if genetically modified organisms are used. Bioremediation is labor intensive, costly and time consuming in order to reach a prescribed level of remediation. In addition, neither all compounds are biodegradable nor can be degraded quickly and completely as shown in Table IV. Nature of contaminants and waste can vary in accordance with their physical state e.g. solid, liquid, gas etc.

Several compounds formed as a result of bioremediation and degradation are more toxic or persistent than their parent compound. These toxins can inhibit the growth of microbes and can even kill them. In addition, biodegradation requires specific types of microbes for particular contaminants or toxins; optimum environmental conditions for the degradation to take place; and optimum levels of contaminants or nutrients; etc. Large scale bioremediation operations are difficult to carry out as compared to laboratory or pilot scale projects [42].

The foremost limiting factor for efficient waste matter management is lack of awareness about the gravity of this matter among general public. In addition, lack of adequate legislations, infrastructure and institutional deficiencies, limited financial and human resources, inadequate short and long-term planning, etc. exacerbate the problem leading to waste accumulation [6].

V. Conclusion

Bioremediation provides an efficient way to tackle different categories and types of wastes with the help of microbes. Not only can bioremediation discard waste materials, but it can also be used for the removal of unwanted substances from soil, water, air and raw materials from industrial wastes. Recovery of recyclable and reusable materials is crucial in a world that is quickly running out of resources. Inappropriate waste management practices could result in the loss of huge amount of energy that could be recovered from these wasted materials. Waste to energy program is beneficial in this regard for the generation of electricity and fuels producing less toxic gases and environmental hazards. Increasing the efficiency of these processes can lead to huge economic and social benefit in terms of reduced health risks and incidence of diseases; reduced costs of fuel and electricity; cleaner environments; reduced public and government cost being spent on waste management; and creating new chances for employments.

TABLE IV
FACTORS LIMITING BIOREMEDIATION [43]

Types of Limitations	Effects
Microbial	Growth until critical biomass is reached Mutation and horizontal gene transfer Enzyme induction Enrichment of the capable microbial populations Production of toxic metabolites
Environmental	Depletion of preferential substrates Lack of nutrients Inhibitory environmental conditions
Substrate	Too low concentrations of contaminants Chemical structure of contaminants Toxicity of contaminants Solubility of contaminants
Biological aerobic vs anaerobic process	Oxidation/reduction potential Availability of electron acceptors Microbial population present in site
Growth rate vs co-metabolism	Type of contaminants Concentration Alternate Carbon source present
Physico-chemical bioavailability of pollutants	Equilibrium sorption Irreversible sorption Incorporation into humic matters
Mass transfer limitations	Oxygen diffusion and solubility Diffusion of nutrients Solubility/miscibility in/with water

References

[1] D. Hoornweg and L. Thomas. What a waste: solid waste management in asia, World Bank Urban Waste Management Working paper series, Vol. 1, 1999.

[2] M. Rafiq, S. H. Gillani, M. Khan and M. Atiq. Health and economic implication of solid waste dumpsites: A case study hazar khwani peshawar, Fedral Works Union Journal of Social Sciences, Vol. 9(2), pp. 40-52, 2015.

[3] A. A. Khan, Z. Ahmed and M. A. Siddiqui. Issues with solid waste management in South Asian countries: A situational analysis of

pakistan, Journal of Environmental and Occupational Sciences, Vol. 1(2), pp. 129-131, 2012.
[4] J. J. Ortega-Calvo and M. Alexander. Roles of bacterial attachment and spontaneous partitioning in the biodegradation of naphthalene initially present in non-aqueous-phase liquids, Apple Environment Microbiology, Vol. 60, pp. 2643–2646, 1994.
[5] M. Marinscu, M. Dumitru and A. Lacatusu. Biodegradation of Petroleum Hydrocarbons in artificial polluted soil, Research Journal of Agricultural Science, Vol. 41(2), 2009.
[6] C. Visvanathan and U. Glawe. Domestic solid waste management in south asian countries – A comparative analysis, 3-R South Asia Expert Workshop, 2006.
[7] B. Breza-Boruta, J. Lemanowicz and A. Bartkowiak. Variation in biological and physicochemical parameters of the soil affected by uncontrolled landfill sites, Environment. Earth Science, Vol. 75(201), pp. 1-13, 2016.
[8] P. Alam and K. Ahmade. Impact of solid waste on health and the environment, International Journal of Sustainable Development and Green Economics, Vol. 2(2), pp. 165-168, 2013.
[9] N. Gouveia and R. R. D. Prado. Health risks in areas close to urban solid waste landfill sites, Revista de Saúde Pública, Vol. 44, pp. 859-866, 2010.
[10] S. De and B. Debnath. Prevalence of health hazards associated with solid waste disposal - A case study of kolkata, India, Procedia Environmental Sciences, Vol. 35, pp. 201–208, 2016.
[11] Global news wire. Waste to energy (wte) market will be worth $37.64 billion by 2020, Grand View Research, Inc, 2015.
[12] S. Udomsri, M. P. Petrov, A. R. Martin and T. H. Fransson. Clean energy conversion from municipal solid waste and climate change mitigation in Thailand: Waste management and thermodynamic evaluation, Energy for Sustainable Development, Vol. 15, pp. 355-364, 2011.
[13] World Energy Council Report. World energy resources: waste to energy, 2016.
[14] A. Kumar, B. S. Bisht, V. D. Joshhi and T. Dhewa. Review on bioremediation of polluted environment: A management tool, International Journal of Environmental Sciences, Vol. 1(6), pp. 1079-1093, 2011.
[15] M. Vidali. Bioremediation: An overview, Pure Applied Chemistry, Vol. 73(7), pp. 1163–1172, 2001.
[16] F. Mastouri, R. M. Hassandokht and P. N. M. Dehkaei. The effect of application of agricultural waste compost on growing media and greenhouse lettuce yield, International Symposium on Soilless Culture and Hydroponics, Acta Hort, Vol. 697, pp. 153-158, 2005.
[17] M. Rahimnejad, A. A. Ghoreyshi, G. Najafpour and T. Jafary, Power generation from organic substrate in batch and continuous flow microbial fuel cell operations, Applied Energy, Vol. 88, pp. 3999–4004, 2011.
[18] B. E. Logan. Assessment of microbial fuel cell configurations and power densities, Environmental Science and Technology Letters, Vol. 2, pp. 206-214, 2015.
[19] B. Ghougassian. Waste to energy technologies, Arab Forum for Environment and Development, 2012.
[20] X. T. T. Nguyen, K. J. Tomberlin and S. Vanlaerhoven. Ability of black soldier fly (diptera: stratiomyidae) larvae to recycle food waste, Environment Entomol, pp. 1–5, 2015.
[21] A. Z. Hickman and J. B. Reid. Earthworm assisted bioremediation of organic contaminants, Environment International, Vol. 34(7), pp. 1072–1081, 2008.
[22] M. Shimao. Biodegradation of plastics, Current Opinion Biotechnology, Vol. 12, pp. 242, 2001.
[23] P. White, M. Franke and P. Hindle. Integrated solid waste management: A lifecycle inventory, Chapmann and Hall, Vol. 368, 1994.
[24] C. Zhang and G. N. Bennett. Biodegradation of xenobiotic by anaerobic bacteria, Applied Microbiology Biotechnology, Vol. 67, pp. 600, 2005.
[25] L. P. Wilson and E. J. Bouwer. Biodegradation of aromatic compounds under mixed oxygen/denitrifying conditions: A review, Journal of Industrial Microbiology and Biotechnology, Vol. 18, pp. 116, 1997.
[26] S. K. Dubey, J. Dubey, S. Mehra, P. Tiwari and A. J. Bishwas. Potential use of cyanobacterial species in bioremediation of industrial effluents, African Journal of Biotechnology, Vol. 10(7), pp. 1125-1132, 2011.
[27] K. Murugesan. Bioremediation of paper and pulp mill effluents, International Journal of Experimental Biology, Vol. 41, pp. 1239-1248, 2003.
[28] R. Mahmood, R. Shariff, S. Ali and M. U. Hayyat. Bioremediation of textile effluents by indigenous bacterial consortia and its effects on zea mays L.CVC 1415, Journal of Animal and Plant Sciences, Vol. 23(4), pp. 1193-1199, 2013.
[29] L. Kamika, and M. N. B. Momba. Comparing tolerance limits of selected bacterial and protozoan species to vanadium in waste water systems, Water, Air and Soil pollution, Vol. 223(5), pp. 2525-2539, 2012.
[30] R. Krishnaveni, Y. Pramiladevi and R. S. Ramgopal. Bioremediation of steel industrial effluents using soil microorganisms, International Journal of Advanced Biotechnology and Research, Vol. 4(1), pp. 51-56, 2013.
[31] S. Buvaneswari, M. Muthukumaran, S. Damodarkumar, and S. Murugesan. Isolation and identification of predominant bacteria to evaluate the bioremediation in sugar mill effluent, International Journal of Current Science, Vol. 5, pp. 123-132, 2013.
[32] S. Kappesser, E. Rude and H. J. Kutzner. Microbiological studies of selected bacterial cultures for aerobic treatment of waste water, Proc. Dechema Biotechnology Conference, Vol. 3, pp. 855-858, 1989.
[33] M. D. Jabir, and M. M. Jabir. A study of biodegradation of paper wastes by using bacteria isolated from the soil, Asian Journal of Microbiology and Biotechnology Environmental Sciences, Vol. 18(3), pp. 225-229, 2016.
[34] I. A. Adeyemo, O. E. Adetoyi, M. O. Oni, M. J. Ayodele and A. B. Olayemi. Studies on degradation of waste papers using microflora/microbial consortia isolated from refuse dumpsites in Ilorin metropolis, International Journal of Biotechnology and Food Science, Vol. 1(1), pp. 13-22, 2013.
[35] A. D. Roberts, A. N. Paul, I. M. Bird, and D. N. Rocky. Bioremediation of coal-fired power stations using macro algae, Journal of Environmental Management, Vol. 153, pp. 25-32, 2015.
[36] P. Singh and P. V. Sharma. Integrated plastic waste management: environmental and improved health approaches, Procedia Environmental Sciences, Vol. 35, pp. 692–700, 2015.
[37] R. J. Mueller. Biodegradability of polymers: regulations and methods for testing, Biopolymers, Vol. 10, 2003.
[38] A. Mahar, R. N. Malik, A. Qadir, T. Ahmed, Z. Khan and M. A. Khan. Review and analysis of current solid waste management situation in urban areas of Pakistan, International Conference on Sustainable Solid Waste Management, India, 2007, pp. 34-41.
[39] R. U. M. Khattak, J. Khan. and I. Ahmad. An analysis of willingness to pay for better solid waste management services in urban areas of district Peshawar, Sarhad Journal of Agriculture., Vol. 25(3), pp. 529-535. 2009.
[40] Pakistan environmental protection agency. Guidelines for solid waste management, Ministry of Environment, PEP and United Nation Developed Program, 2005.
[41] M. S. Ali, A. Pervaiz, B. Afzal, N. Hamid and A. Yasmin. Open dumping of municipal solid wastes and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city, Journal of King Saud University of Science, Vol. 26, pp. 59-65, 2014.
[42] M. D. Zeyaullah, M. D. Atif, B. Islam, S. Azza, S. P. Abdelkafel, M. A. ElSaady and A. Ali. Bioremediation: A tool for environmental cleaning, African Journal of Microbiology Research, Vol. 3(6), pp. 10-14, 2009.
[43] R. Boopathy. Factors limiting bioremediation technologies, Bio Resource Technology, Vol. 74, pp. 63-67, 2000.

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