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Research Article

Advance in Environmental Waste Management & Recycling

Microbial Bioremediation Technology of Some Agro Industrial Wastes and Pesticides

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Abstract
Environmental pollution is the global sensitive issues currently resulting ecological crises, drastic climate change and biodiversity loss. Bioremediation is one of an ecofriendly and cost effective alternative strategy for removing different pollutant waste using microorganisms. Different types of ex-situ and in-situ bioremediation service these are biopiling, composting, Land farming, bioventing, biosparging, biostimulation, bioagumention are employed to treat heavy metal waste, Petroleum hydrocarbon, agro-industreal, dyestuff, agrochemicals, organic and volatile compound, lignocellulose biomass and nuclear waste. Several microorganisms (natural/exotic/ engineered) having specific metabolic capability and various enzyme production ability which fall under six main divisions include Oxidoreductases, Transferases, Hydrolases, Lyases, Isomerases and Ligases (synthetases) are used during bioremediation process. Understanding the mechanism, mode of action and role of microorgsnism in bioremediation process is essential to utilize microorganism potential and designe waste management strategy.

Keywords: Bioremdiation, Ex-Situ, Enzyme, In-Situ, Pollution, Sequestration, Waste

Introduction

Environmental pollution currently became one of the global sensitive issues. Recent decades witnessed of urbanization, unsafe agricultural practices, an accelerated population growth and unprecedented level of the industrial revolution which have not only improved the living standard but also compromised the quality of our environment [1, 2]. Municipal and domestic solid waste and swage, industrial effluent released to our environment containing thousands of potentially harmful pollutant containing of inorganic chemicals (NH_3, N_2, P,NO_3,NO_2), Organic chemicals and volatile organic compound (Benzene, Toluene, Xylenes, Dichloromethane), Agro waste (Coffee pulp, bagasse, rice bran etc.), Heavy metals (Cd, Hg, Cu, Pb, Cr), Xenobiotic, Agrochemicals (Pesticide, fertilizer), Chlorinated compounds, Dyes stuff (Azodye, vat dye, triphenylmethane, Anthraquione dye etc), Greenhouse gases, Hydrocarbons petroleum, Nuclear waste, Plastics, dioxins, furans, some food additives, hormones, and antibiotics Polychlorinated, biphenyls, detergents ,lubricants, nanoparticles, paints, disinfectants, particulate matter (PM) pollutants, nitrogen oxides [3, 4]. In developing countries discharge 90% of their wastewater into the water bodies without any treatment [5]. This wastewater may contain hazardous heavy metals, radionuclides, organic compounds, chemicals, and agricultural wastes. Reports show that approximately 730 megatons of sewage and other effluents are released into the water annually [6]. Industries alone discharge 300-400 million tons of waste into the streams every year [7].

At global scale, 140 billion metric tons of agriculture biomass waste is produced every year like fronds, husk, shell, coffee (hull, husk, ground), (cob, stover, stalks, leaves), cotton (stalks), nuts (hulls), peanuts (shells), rice (hull/husk, straw, stalks), sugarcane (leavings, bagasse, molasses), vegetable wastes, etc [8]. By 2015 humans had generated 8.3 billion metric tons of plastics, 6.3 billion tons of which had already become waste which only 9 % was recycled, 12 % was incinerated and 79 % accumulated in landfills or the natural environment [9]. The annual flow of plastic pollution to the world's oceans is estimated to be 4.8– 12.7 MT, a large proportion of which comes from sources on land and is transported by rivers or wind [10]. Worldwide over 10,000 different dyes and pigments are used in dyeing and printing industries. The total world colorant production is estimated to be 8,00, 000 tons per year and at least 10% of the used dyestuff enters the environment through waste [11-13]. In the last decade, consumption of synthetic dyes has been rapidly increasing, particularly in the textile industry. It has been estimated that more than 2×10^5 tons per year of textile dyes may be discharged worldwide [14].

Approximately 10–15% of the dyes employed in the textile, tanning, paper, plastic, food, cosmetic, and pharmaceutical industries are discharged in the wastewater during the dyeing maneuvers [15, 16]. Textile sector is responsible to create more pollution as they discharge colored wastewater. These wastewaters create aesthetically undesirable pollution effect if released untreated into water bodies. These wastes are non-recyclable, unavoidable and in very large volumes [17]. The excessive use of pesticides/chemical fertilizers in modern agriculture practices have led to contamination of different media including air, land, and water According to the Environmental Protection Agency, about, 45% of the whole pesticides utilized worldwide are organophosphorus insecticides that possess a significant potential to endanger the ecosystem [18-20]. Plastics have been identified as a potential agent of global change, altering the function of soils (water retention, microbial activity, soil structure and bulk density) and affecting their role in the function of the wider environment [21].

Due to the characteristics of difficult degradation, high toxicity, and biological accumulation, these pollutants not only can cause toxic, carcinogenic, teratogenic and mutagenic effects on humans or organisms but also pose a serious threat to the environmental sustainability [22]. Pesticides are also highly toxic and it can cause chronic abnormalities in humans, destroying the environment and biodiversity [23]. A number of previous studies have shown that exposure to environmental pollutants can alter the composition of the gut micro biome, leading to disorders of energy metabolism, nutrient absorption, and immune system function or the production of other toxic symptoms [24, 25]. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015. About 16% of all deaths worldwide are caused by pollution [26]. Recent data estimate that Cd, Cr, Hg, and Pb from various anthropogenic activities pose an outsized threat to collectively 66 million people from all over the world [27]. Pollutant carcinogenic effect and their bioaccumulation and bio-magnification upset human and animal health like respiratory, cardiovascular, renal effects(Cd), mental disturbance, cancer, ulcer, hypokerotosis (Cr), anemia and other toxicity effect includes indirectly through interaction with other nutrients (Cu), Neurotoxic (Pb), skin allergies, lung fibrosis, diseases of cardiovascular system(Ni), abdominal pain, nausea, vomiting and diarrhea, irritability, leathery, anemia (Zn) [28]. Physicochemical methods of pollution removal such as solidifications, filtration, incineration, evaporation, oxidation and reduction, reverse osmosis, chemical precipitation, electrochemical treatment, and ion-exchange approaches that have been practiced for several decades [29]. However, high processing costs, high reagent requirements, large volumes, and production of secondary environmental pollutants limit these conventional approaches. Limitation of these methods becomes more apparent in the case of mine tailings effluents, contaminated ground waters, and other industrial wastewaters [17]. There for cost effective and ecofriendly waste removal approach is timely important to reduce and avoid environmental pollution. Bioremediation is an optional and a modern concept for environmental pollution management highly involved in degradation, eradication, immobilization, or detoxification diverse chemical wastes and physical hazardous materials from the surrounding environment through the action of microorganisms and using their by product. Microorganisms use contaminant as a food and source of energy [30]. There are different bioremediation strategy these are bio mineralization, bio-sorbation, bio-stimulation, rhizoremediation, mycoremediation, bioventing, bioreactor, composting, bio-agumentation, land farming, soil vapor extraction, soil washing and land filling [31]. Bioremediation is mainly applied to matrices such as soil, sludges and several types of residual waters [1]. It can be applied in-situ or ex-situ in bioreactors. Its attractiveness is in its cost effectiveness and environmental friendliness, especially if applied insitu. In-situ attenuation can use strategies such as bio augmentation through inoculation and/or biostimulation by the addition of microbial growth-promoting formulations [32]. The major mechanism of microorganism in mode of action for catalytic role using degrading enzymes or mineralizing various contaminants and converting non-toxic by-products during soil bioremediation processes [33-35]. Various enzymes are produced by microorganisms fall under six main divisions include Oxidoreductases, Transferases, Hydrolases, Lyases, Isomerases and Ligases (synthetases) during bioremediation process [36]. The purpose of bioremediation is to stimulate the native microflora in contaminated site by providing more food and suitable growth conditions for thier full potential growth and produce more enzymes as secondary metabolites. These metabolites further efficiently break down the complex contaminant into simpler ones [37]. This paper reviews the mode, mechanism and role of microorganism in bioremediation process and microbial bioremediation technologies for some agro-industrial wastes treatment for environmental pollution control and detoxification of hazardous toxic compounds.

Microbial bioremediation

Many groups of microorganisms from bacteria species, yeast, filamentous fungi, actinomycetes, microalgae are involved in bioremediation activities in different mode of action and mechanisms to treat polluted environment. Microbial bioremediation largely grouped as mycoremediation, bacterial bioremediation. Mycoremediation is a biological process of recovering from polluted environments by using the metabolic potential of natural fungal inhabitants in contaminated areas [38]. Mycoremediation it can be an economical, eco-friendly, and effective strategy to combat the ever-increasing problem of soil and water pollution. Robust growth of fungus, vast hyphal network, production of versatile extracellular ligninolytic enzymes, high surface area to volume ratio, resistance to heavy metals, adaptability to fluctuating pH and temperature and presence of metal-binding proteins; fungi are an ideal candidate for the remediation of various pollutants [39-41]. Fungi can be used for the in-situ remediation of various pollutants such as various recalcitrant, persistent and harmful pollutants like polycyclic aromatic hydrocarbon, pesticides, herbicides, insecticides, antifungal drugs, antibiotics, heavy metals, detergents, cyanotoxins, dyes, pharmaceuticals, and phthalates released by various industries. Alternatively, it can also be used in bioreactors. Fungal extracellular ligninolytic enzymes such as dioxygenase, dehydrogenases, FAD-dependent monooxygenases, glutathione transferase and epoxide hydrolases catalyze the oxidation of PAH into quinones [42]. Biosorption, bioaccumulation, and biovolatilization are the principles often used by fungi to transform heavy metals and metalloids [43]. Some fungi species are involved degradation of aromatic compounds including toluene and polycyclic aromatic hydrocarbons (PAHs) by *Cladophialophora, Schizopora, and Dentipellis* [44, 42]. Fuel oils by *Punctularia and Scedosporium* [45, 46]. And even to radioactive wastes by *Rhodotorula* [47]. Bacterial bioremediation is now gradually gaining global attention as a potential, less harmful, ecofriendly and economically viable method to decontaminate/detoxify polluted environments. Soil, the naturally occurring critical zone of the earth's surface made up of various unconsolidated mineral and organic materials, is a niche for the inhabiting diverse group of bacteria. The use of bacteria for the degradation and detoxification of numerous toxic chemicals such as pesticides, hydrocarbon, organic waste etc is an effective tool to decontaminate the polluted sites. Due to bacterial potential biofilm formation, sidrophore production, strong hydrolytic enzyme secretion, their cell wall binding potential and living in any extreme environment serve for bioremediation tool. Isolation of indigenous bacteria capable of metabolizing pollutant provides environmentally friendly means of in situ and ex situ detoxification [48].

Microbial bioremediation strategies

Ex-situ bioremediation strategy

In cases where soils cannot be treated in the contaminated site due to regulatory reasons or the unavailability of sufficient land, risk to ground water or air pollution. These techniques involve excavating pollutants from polluted sites and subsequently transporting them to another site for treatment. Ex situ bioremediation techniques are usually considered based on the cost of treatment, depth of pollution, type of pollutant, degree of pollution, geographical location and geology of the polluted site, performance criteria. Ex -situ bioremediation methods consisting of solid phase system (composting, land farming, and bio piling) and slurry phase system (bioreactors) [30] (Figure 1).

Bio piling

Bio-piles also known as bio-cells, bio-heaps, bio-mounds, and compost piles are used to reduce concentrations of petroleum pollutants in excavated soils contaminated with aerobically remediable hydrocarbons. Bio pile-mediated bioremediation involves above-ground piling of excavated polluted soil, followed by nutrient amendment, and sometimes aeration to enhance bioremediation by basically increasing microbial activities. The components of this technique are aeration, irrigation, nutrient and leachate collection systems and a treatment bed. The application of biopile to polluted sites can help limit volatilization of low molecular weight (LMW) pollutants; it can also be used effectively to remediate polluted extreme environments such as the very cold regions [49, 50].

Composting

Composting is an ancient technology, practiced today at every scale from the backyard compost pile to large commercial operations. Composting represents a widely used and effective method for converting organic wastes into relatively stable humus-like product that can be used as soil amendment or organic fertilizer [51]. Composting is applied for the cleaning of heavy metals, pesticide, hydro carbon and chlorinated compound from tannery wastes, green wastes, municipal solid wastes (bio solid), sewage sludges, mine spoils, brownfields, storm water runoff, etc [52]. Composting is most effective technique to remove PAH, TNT, and RDX [30]. Composting occurs through the activity of microorganisms naturally found in soils. Under natural conditions earthworms, nematodes and soil insects such as mites, sow bugs, springtails, ants, and beetles do most of the initial mechanical breakdown of organic materials into smaller particles. Microorganism degrades the waste at elevated temperature that is ranges from 55- 65oC. Enzymatic activities provide important role on the conversion of complex organic compounds into more easily assimilable substances. Hence, enzymes are important stabilization throughout waste biodegradation [53]. Compost product can be safely applied to soil as organic fertilizer or conditioner depending on products containing high content of organic matter and nutrients, being mature or stable and without toxicity to plant growth [54]. Compost amendments stimulated the growth of alkane degrading microorganisms and thus the degradation of alkane [54].

Land farming

Land farming is one of the simplest ex-situ methods of remediation. When land farming, polluted soil is excavated and then spread in thick (0.3m) layers in a lined treatment area. This process can be enhanced by periodically turning the bed and adding more nutrients. Although, land farming is a feasible technique but, it is slow and not much effective in comparison to the other ex- situ bioremediation treatments. The goal is to stimulate indigenous bio derivative microorganisms and facilitate their aerobic degradation of contaminants in general the practice is limited to the treatment of superficial 10–35 cm of soil. Land farming is usually used for remediation of hydrocarbon-polluted sites including polyaromatic hydrocarbons [56, 57].

Bioreactor

Bioreactor is a specific container or vessel in which contaminated soil and other raw materials are feed to produce the desired remediated products following a series of biological reactions. Bioreactors can be operated in different ways, which include, batch, fed-batch, sequencing batch, continuous and multistage, airlift and bubble columns, immobilized reactors for Cr(VI) bio- sorption [58]. The choice of mode can be decided only on the financial basis. Polluted soil with pesticides can be fed into a bioreactor either in solid powder or in slurry form. The conditions inside the bioreactors can be modified as per our need like, oxygen content, bacterial strain, and nutrients for enhancement of the bioremediation process.

In-situ bioremediation strategies

In situ bioremediation is the application of a biological treatment to clean up hazardous compounds present in the environment or contaminated site. The optimization and control of microbial transformations of organic contaminants requires the integration of many scientific and engineering disciplines. The success of onsite bioremediation employing native microbial populations could be majorly inhibited by imbalanced nutrients and/or unfavorable factors like temperature, moisture content, pH, availability of electron donor and/or acceptor, high pollutant concentration, etc. prevailing within the contaminated sites. Shortage of important nutrients such as nitrogen, phosphorous and terminal electron acceptors (TEAs) has been recognized as crucial factors that hinder microbial bioremediation performance [59]. Bio-augmentation, bioventing, biosparging, bio stimulation are main in situ bioremediation methods [30].

Bio augmentation

Microorganisms (natural/exotic/ engineered) having specific metabolic capability are introduced to the contaminated site for enhancing the degradation of waste. Therefore, bio augmentation corresponds to an increase in the gene pool and thus the genetic diversity of the site. In principle, this genetic diversity could be increased by augmenting the microbial diversity and increase microbial catabolic activities. [60, 61]. The use of agar, agarose, alginate, gelatin, gellan gum and polyurethaneas the carrier materials will help solve some of the challenges associated with bioagumentation [62]. Under optimal environmental conditions, indigenous microbes at polluted site would likely degrade pollutant better than allochthonous microbes [63].

Bio stimulation

This kind of strategic is the addition of specific nutrients usually sources of carbon, nitrogen, and phosphorus, oxygen or other electron donors or acceptors at the site (soil/ground water) to stimulate the activity of indigenous microorganisms [64]. Amendments can be added in either liquid or gaseous form, via injection. Liquids can be injected into shallow or deep aquifers to stimulate the growth of microorganisms involved in the bioremediation. It is focus with in the stimulation of indigenous or naturally existing bacteria and fungus community. Firstly, by supplying fertilizers, growth supplements and traces minerals. By providing other environmental requirements like pH, temperature and oxygen to speed up their metabolism rate and pathway [65, 66]. The presence of small amount of pollutant can also act as stimulant by turning on the operons for bioremediation enzymes. This type of strategic path is most of the time continued in the addition of nutrients and oxygen to help indigenous microorganisms. These nutrients are the basic building blocks of life and allow microbes to create the basic requirement for example, energy, cell biomass and enzymes to degrade the pollutant. All of them will need nitrogen, phosphorous and carbon [67]. The major contaminants that can be successfully remediated through bio stimulation are petroleum hydrocarbons, sulphate and polyester polyurethanes [68, 69]. Indigenous microorganisms present in polluted environments hold the key to solving most of the challenges associated with biodegradation and bioremediation of polluting substances [70].

Biosparging

In biosparging air is injected below the ground water under pressure to increase the concentration of oxygen for microbial degradation of pollutant. Biosparging increase the aerobic degradation and volatilization [71]. This technique is very similar to bioventing in that air is injected into soil subsurface to stimulate microbial activities in order to promote pollutant removal from polluted sites. Unlike bioventing, air is injected at the saturated zone, which can cause upward movement of volatile organic compounds to the unsaturated zone to promote biodegradation. The effectiveness of biosparging depends on two major factors namely soil permeability, which determines pollutant bioavailability to microorganisms, and pollutant biodegradability [72].

Bioventing

It characteristically applies low air flow so that sufficient amount of oxygen can be supplied to microorganisms. This method shows substantial potential of stabilizing or removing pesticides from soil. In traditional bioventing systems, oxygen is transported by an electric blower to subsurface soil to flourish microbial activity. In passive bioventing technique natural air is used transport oxygen to the subsoil via bioventing wells. Single way valve, is used to permit air to enter in sub soil. When atmospheric pressure falls below the subsurface pressure, the valve is closed down, and traps the air in the sub surface that results in the increase concentration of oxygen at this place [73].

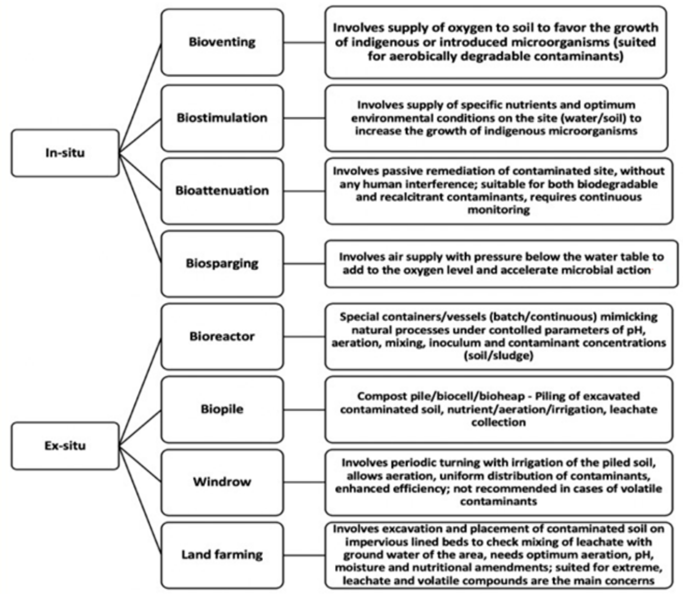

Figure 1: Bioremediation strategies

Pollution from some agro-industrial wastes and Microbial bioremediation service

Heavy metal waste from Tannery, Textile and other industry in environmental pollution

Tannery wastewater is considered to be a severe pollutant source due to its high concentration of dyes, surfactants, sulfonated oils, chromium salts, solid waste fragments, and waste skin trimmings [74, 75]. Chromium-containing tannery sludge (Cr-TS) produced during the tannery waste water treatment has become a major heavy metal pollutant resource threatening the environment [76]. Heavy metals are critical pollutants due to their wide spread application in tannery, textile, paint and various industries. Trivalent chromium and hexavalent chromium heavy metal are one of the known sever toxic pollutant from tannery effluent waste. Heavy metal pollution has the characteristics of the long residual period, irreversibility, small transfer amount, severe toxicity, concealment, complex chemical properties, and ecological response, so it becomes the most serious problem in soil pollution, ground water, surface water and air [77]. The three classes of heavy metals classified the metals as toxic metals (such as Zn, Ni, Hg, Cr, Pb, Cu, Cd, As, Co, Sn, etc.), precious metals (such as Au, Pd, Pt, Ag, Ru etc.), and radionuclides (such as Th, U, Am, Ra, etc.).There is more than 20 heavy metals, is considered due to their toxicity potential in trace amount [78]. Heavy metal concentrations above the threshold and its bioaccumulation or bio magnifications intimidating ecosystem and affect human health severely, generally neurological disorders, Parkinson, Alzheimer, depression, schizophrenia, cancer, poor nutrition, lack of hormones balance, obesity, abortion, respiratory and cardiovascular disease, damage in organs (liver, kidneys and brain), anorexia , arthritis, hair loss, osteoporosis and death(in severe cases) are adverse effects of heavy metals in the human body [79]. It also evoke our ecology severely and biodiversity loss in general.

Mode of action, mechanism and role of microbes in heavy metal bioremediation

Conventional methods like adsorption processes, chemical oxidation or reduction reactions, chemical precipitation, electrochemical techniques, evaporative recovery, ion exchange, reverse osmosis, and sludge filtration to get rid of heavy metal burden of the environment, have their own shortcomings. These methods offer limitations like slow metal precipitation and incomplete removal generation of contaminated sludge requiring careful disposal, high cost involved in the processes [80]. The microbial bioremediation method for heavy metal removal is an excellent strategy and having important features like economic viability, repeated use of biomass, selective metal binding, effective desorption and recycling of desorbents [81]. Different microorganisms from algae, bacteria, fungi, yeast species have been employed to carry out heavy metals remediation from polluted site (Table.1). Fungi have chitin in their walls which can tolerate high concentrations of metals and are capable of growing on medium at low pH and temperature exhibiting excellent mycoremediation potential. These are *Aspergillus fumigatus, Aspergillus tereus, Aspergillus versicolor, Gloeophyllum sepiarium, Penicillium chrysogenum, Rhizopus oryzae (MPRO), Candida utilis, Hansenula anomala, Rhodotorula mucilaginosa, Rhodotorula rubra GVa5, Saccharomyces cerevisiae* [28]. Mushrooms belonging to the genera including *Agaricus, Boletus, Armillaria, Polyporus, Russula, Pleurotus, Termitomyces* have been investigated by some researchers for the uptake of heavy metals [82]. Bacteria species like *Arthrobacter sp., Bacillus cereus, Bacillus cereus strain XMCr-6, Bacillus subtilis, Citrobacter sp., Cupriavidus metallidurans, Cyanobacteria sp., Enterobacter cloacae, Enterobacter cloacae B2-DHA, Kocuria flava, Pseudomonas aeruginosa, Pseudomonas putida, Pseudomonas veronii, Sporosarcina ginsengisoli, Streptomyces sp, Zoogloea ramigera* [28].

Microorganism do have several mechanisms to remediate heavy metal and continued existence in metal polluted environment. The microbial bioremediation of heavy metal can be carried out by mobilization or immobilization processes, which can be accomplished by following mechanisms, i.e., chelation, oxidation-reduction, pH change, biosorption, bioaccumulation, immobilization, biomethylation [28]. The uptake of heavy metals by microbial cells through bio-sorption mechanisms can be classified into metabolism-independent bio-sorption, which mostly occurs on the cells exterior part and metabolism-dependent bioaccumulation, which comprises sequestration, redox reaction, and species-transformation methods [83, 84]. Bio-sorption mechanism consists of several processes including electrostatic interaction, ion exchange, precipitation, the redox process, and surface complexation [51]. Every biosorbant organism has specificity for a particular metal ion [85]. It is seen that certain extracellular polymeric substances (EPS), a complex mixture of polysaccharide, mucopolysaccharides, and proteins are capable to bind a significant amount of toxic metal ions. In case of Gram-positive and -negative bacterial species, peptidoglycans and phosphate groups are main cationic and anionic binding sites respectively. Whereas, in fungal biomass, the chitin, phenolic polymers and melanin are the most important structural components which effectively act as heavy metal and radionuclide biosorbent [28]. The bioaccumulation is also a beneficial microbial mechanism like bio sorption for heavy metal remediation. The microorganism normally accumulates these metals by ion pumps, ion channels, endocytosis, and lipid permeation [86]. Chelation is another of central mechanism of microorganism for detoxification heavy metals, via formation of complexes, particularly with glutathione, metallothioneins. Microorganism produce low molecular weight organic acids (citric acid, tricarboxylic acids, and alcohols) and (ii) high molecular weight ligands, siderophores, and toxic metal-binding compounds capable enough in binding metal ions to form complex ring-like structure called ‘chelates [81]. Microorganisms can also detoxify metals by valence transformation (e.g., Cr (VI) to Cr (III), $SeO_4^{2-}$to Se). Many bacteria (e.g., *Bacillus subtilis, Torulopsis bombicola*) could produce biosurfactants such as surfactin, rhamnolipids, sophorolipids, aescin, and saponin to solubilize metals in soils [37]. Certain rhizosphere microbes promote the tolerance of plants to heavy metals and enhance their growth in contaminated soils [75]. In-situ soil bioremediation to remove Hg via microbial enhanced volatilization is feasible, in which bacteria transform methyl mercury into Hg (II) and reduce it to Hg (0) [87].

Current microbial bioremediation technology for heavy metal treatment in Tannary, Textile, Paint industry

Biosurfactant technology is one of currently applied method to extract the heavy metals from soil, sludge, and sediment. Biosurfactants active chemical species, frequently polymers produced by bacteria or fungi assist in the solubilisation and desorption of metals from polluted soils or sediments. Rhamnolipids as biosurfactants active chemical species produced by *P. aeruginosa* have been extensively produced commercially and applied for heavy metal treatment [88]. Biobead technology with the transformed Ecoli-TB1 cells with T4MBP and HMP genes, respectively, having CaMV 35S promoter were encapsulated in 1% and 1.5% w/v sodium alginate solutions in 100 mM $CaCl_2$ solution for biosorbation of heavy metal [89]. Bioreactors treatment technology comprises detoxification/removal of heavy metals using biological organism especially genetically engineered microorganisms by improving microbial lipopolysaccharides cell wall, Synthesis of novel metal ligands and chelating efficiency [90]. Composting technology is also a decomposition process of organic matters by microorganisms, which is also likely to contribute in heavy metal bioremediation. Microbial-assisted phytoremediation technology is a novle technology currently applied via using different plant species having a capacity to harbor or symbiotic association with plant growth promoting microbs (PGPM) which indirectly have great role in biosorbation of heavy metal [91].

Table 1: Some microorganisms involved in heavy metal detoxification

Heavy metals	Sources	Microorganism in Heavy metal Bioremdation
Cr	Tanneries, steel industries, flying ash from the burning of coal	*Pantoea sp., Bacillus circulans, Bacillus megaterium, Bacillus coaglans, Zoogloea ramigera, Streptomyces nouresei, Aeromonas caviae, Pseudomonas sp., and Staphylococcus xylosu, Methylococcus capulants, Aspergillus sp, Saccharomyces cerevisiae (Y)*
Pb	Herbicides, batteries, insecticides, aerial emissions from petrol	*Aspergillusniger,Aspergillus terrus, Aspergillus versicolor, Neurospora crassa, Penicillium canescens, Penicillium chrysogenum, Penicillium decumbens, Penicillium simplicissimum,and Saccharomyces cerevisiae*
Hg	Medical waste, coal burning, and Au-Ag mining	*Trichoderma viride, Humicola insolensSaccharomyces cerevisiae Penicillium canescens, Rhizopus arrhizus, Shewanella oneidensis, Geobacter sulfurreducens, Geobacter metallireducens, Enterobacter cloacae, Klebsiellap neumoniae, Pseudomonas aeruginosa*
Ni	Battery manufacturing, steel alloys, kitchenappliances, surgical instruments, industrial effluents	*Pseudomonas aeruginosa, Oedogonium rivulare, Aspergillus versicolor, Aspergillusniger, spergillus versicolor*
Cu	Pesticides and fertilizers usage	*Desulfovibrio desulfuricans (KCTC5768) (immobilize onzeolite), Flavobacterium sp., Bacillus firmus, Micrococcussp, Pseudomonassp, Acinetobacter sp. B9*
Cd	Electroplating, plastic burning, phosphate fertilizer, paints and pigments	*Bascillus species, Pseudomonas aeruginosa, Micrococus roseus*
As	Wood storage and pesticides	*Acinetobacter sp., Brevundimonas sp., Pseudomonas sp., Rhizobium sp., Aeromonas sp., Penicillium canescens, Alcaligenes, Achromobacter, Variovorax chemolithotrophs like Agrobacterium, Azoarcus, Sinorhizobium, and diazotroph*
Zn	Priming paints for metals, varnishes and pigments in aerospace paints.	*Bacillus firmus, Pseudomonas sp.*

Source: - (Pratush *et al*., 2018, Medfu Tarekegn *et al*., 2020)

Dye waste from Tannery, Textile and other industries in environmental pollution

Worldwide over 10,000 types of dyestuff and pigments are produced with their annual production over 7 × 10^5tons and used in dyeing and printing activities in textile, tannery, paper, plastic, detergent, food, cosmetic, bleaching and pharmaceutical industries etc. [11]. The total world colorant production is estimated to be 8,00, 000 tons per year and approximately 10–15% dyes are discharged in the wastewater during the dyeing process and enters into the environment as a waste. [15, 16,1213]. In the last decade, consumption of synthetic dyes has been rapidly increasing, particularly in the textile industry. It has been estimated that more than 2 × 10^5 tons per year of textile dyes may be discharged worldwide [14]. Dyes can be grouped on the basis of their origin (natural and synthetic), chemical structures (acridine, anthraquinone, chromophoric, azin, and nitroso dyes), and applications (vat dyes, dispersive dyes, and azoic colors). Broadly, dyes may be nonionic (disperse dyes), anionic (direct, acid and reactive dyes), and cationic forms (basic dyes). The chromophoric groups in anionic and nonionic dyes generally consist of azo groups or anthraquinone types. Of all the different types of dyes, azo dyes are the most useful and widely used colorants which account more than50% of the global industrial demand [95]. Owing to their genotoxic/carcinogenic potential, the annual disposal of ~4,500,000 tons of dyes and/or degraded products is an environmental and socio-economic concern [126]. Many azo dyes have one or more sulfonate groups linked to aromatic rings and exist as sodium salts. Azo dyes are recalcitrant pollutants, which are toxic, carcinogenic, mutagenic and teratogenic, that constitute a significant burden to the environment and human as well as animal health [96]. A prolonged intake of azo dyes can result in the formation of tumors, allergies, respiratory problems and birth defects. Dye wastewater from textile and dyestuff industries is characterized by high alkalinity, biologicaloxidation demand, chemical oxidation demand, total dissolved solids with dye concentrations generally below 1 g/dm [109]. Due to high COD level, the presence of dye reduces the water transparency and solubility of oxygen, which in turn potentially interferes with the evolution and development of aquatic biota and the ecological equilibrium of water [97].

Mode of action, mechanism and role of microbes in dye bioremediation

Recently, the development of inexpensive and environmentally friendly methods for the treatment of wastewater containing pollutants becomes important [125]. Physical and chemical treatment methods such as membrane filtration, electro kinetic coagulation, electrochemical destruction, ion-exchange, irradiation, precipitation, ozonation, and katox treatment are too expensive and not ecofriendly but microbial bioremediation of dye waste water treatment is cost-effective and eco-friendly [103]. The first step in the mode of action in microbial degradation of azo dye in either aerobic or anaerobic condition reduction of –N=N– bond. Reduction may be due to enzymes, redox mediator, and chemical reduction by reductants like sulfide or combination. This reaction involving enzyme-mediated azo dye reduction may be either specific or nonspecific to dye. There are different mechanism like deamination, Reduction, oxidation, desulfonation, Asymmetric cleavage, demethylation and hydroxylation involved in dye microbial dye degradation methods. Enzymes play the key role in the biotransformation mechanisms. Oxidizing enzymes such as LiP, veratryl alcohol oxidase, laccase, and tyrosinase are well known to degrade textile dyes. However, reducing enzymes such as azo reductase, riboflavin reductases, DCIP reductase, and Green HE4B reductase also break the complex dye structures [2]. Peroxidases in particular, catalyze phenolic substrates result in radical formation by using hydrogen peroxide as the electron donor. Versatile peroxidases (VP) can oxidize not only Mn but also phenolic and nonphenolic aromatic compounds including dyes. Laccases have very broad substrate specificities and can oxidize a variety of dye substrates, such as di- and polyphenols, aromatic amines, and a considerable range of other compounds. Laccase is effective in dye decolorization [4]. Hao *et al*., 2016), and it can be combined with other enzymes in the bioremediation of reactive dye [41]. Laccase couples the oxidation of substituted phenolic and nonphenolic chemical moieties with oxygen as an electron acceptor to form free radicals. These free radicals further undergo demethylation, depolymerization, repolymerization or quinoneformation [61]. Microbial biodegradation of azodye has different mechanism by living and dead cells involves several complex mechanisms such as surface adsorption, ion-exchange, complexation (coordination), complexation chelation and micro-precipitation [99]. Cell walls consisting mainly of polysaccharides, proteins and lipids offer many functional groups. The dyes can interact with these active groups on the cell surface in a different manner. Adsorption is increased by the presence of hydroxyl, nitro and azo groups in the dye molecule but decreased by sulfonic acid groups. Different species of fungi, bacteria, actinomycts, and microalgae are excellent in detoxification, decolorization and degradation of different dye waste effluent (Table 2).

Table 2: Dye degrader microorganisms.

Classification of Dye	Dye degrader
Based on chemical structure	
Azodye dye	*P. rettgeri, Pseudomonas sp, Paenibacillus polymyxa, Micrococcusluteus, Micrococcussp. as Bacillus vallismortis, Bacillus pumilus, Bacillus cereus, Bacillus subtilis and Bacillus megaterium, Daphnia magna, Exiguobacterium indicum, Exiguobacterium aurantiacums, Bacillus cereus andAcinetobacter baumanii.*
Metal complex azo dye	
Anthraquione dye	*Pseudomonassp, Shewanellasp., Aeromonas sp. Rhodococcus sp.Klebsiella sp.*
Phthalocyamine dye	*Phanerochaete chrysosporium*
Triphenodioxazine	*Trametes hir suta , Pleur otus pulmonarius ECS-0190, Bjerkander aadusta*
Formazon dye	*Bjerkander a adusta , Pleur otusostr eatus*
Based on usage/application	
Disperse dye	*P. chrysosporium*
Direct dye	*P. chrysosporium*
Sulphure dye	*Acidithiobacillus thiooxidans*
Acid dye	*T. versicolor, Coriolopsis polyzona; Perenniporia ochroleuca; Perenniporia tephropora, Pycnoporus sanguineus.*
Vat dye	*Bacillus firmus, Bacillus macerans, Staphylococcus aureus and Klebsiella oxytoca*

Source: (Jadhav *et al*., 2016) Microorganism-Based Treatment of Azo Dyes

Current Microbial bioremediation technology for dye waste treatment in Tannary, Textile, paint industry

Ex-situ and in-situ bioremediation strategies employed particularly using Aerobic granular sludge (AGS) sequencing batch reactors have shown their utility in the treatment of Tannary, Textile, paint industry and others. Bio augmentation with aggregating bacterial strains was recommended for promoting AGS formation. Currently Aerobic granular sludge (AGS) reactors is a novel microbial community which allows simultaneous removal of carbon, nitrogen, phosphorus, various xenobiotic compounds such as phenol, para-nitrophenol, chlorinated phenols, pentachlorophenol, pyridine, phthalic acids and esters, tert-butyl alcohol, methyl tert-butyl ether, chloroanilines, metal chelating agents, textile dyes, 2,4-dinitrotoluene, azo dyes and organophosphorous esters and other pollutants in a single sludge system. AGS is distinct from activated sludge in physical, chemical and microbiological properties and offers compact and cost-effective treatment for removing oxidized and reduced contaminants from wastewater. AGS technology is of potential use for treating textile wastewaters because of the following: maintenance of aerobic and anaerobic regions within the granules, enhanced tolerance to toxic pollutants, and superior biodegradation of toxic and recalcitrant compounds [123]. *Aeromonas sp., Pseudomonas sp., and Acinetobacter sp* quorum quenching (QQ) enzymes in producing aerobic granule microorganisms. Bio augmentation of AGS with algal cultures (*Chlorella and Scenedesmus*) improved the total N and P removal efficiencies [112]. Aerobic Treatment technology is most generally employed aerobic treatment system for dye wastewater is activated sludge. The conventional aerobic treatment systems are stabilization ponds, aerated lagoons, trickling filters (packed bed reactors), and activated sludge. Where microorganisms are suspended in aerated wastewater in the presence of oxygen synthesize an azoreductase enzyme, specific for azo group. Anaerobic treatment technology is conducted in sealed tanks and the waste is mineralized into methane and CO_2. Coupled Anaerobic–Aerobic Treatment technology is another system in decolorization of azo dyes during biological effluent treatment can involve both adsorption to the cell biomass and degradation through azo-bond reduction during anaerobic digestion. Decolorization is expected to form aromatic amines, which may be toxic and recalcitrant to anaerobic treatment but degradable aerobically [132]. Biofilm and membrane bioreactors, hybrid/integrated bioreactors, microbial fuel cells (MFCs), plant-microbial fuel cells (P-MFCs) technology are employed for dye stuff degradation in general.

Pesticide pollution, role& mechanism of microorganisms in pesticide bioremediation

Pesticide is organic and inorganic chemical substance deliberately applied in to the environment for controlling any pest including unwanted species of microorganism, plants and animals during production, storage, transport, distribution and processing of food, agricultural commodities or animal feeds or which may be administered to the animals for the control of ectoparasites. It is used in areas of agriculture, horticulture, fish farming, forestry, homes, gardens, food and commodity storage, animal husbandry, etc for pest control. The pesticides can be classified in many ways on the basis of use, toxicity, mode of entry, mode of action, chemistry and formulations. Pesticides may be grouped according to the pest to be controlled (algicides, bactericides, fungicides, herbicides, insecticides, nematicides, and rodenticides). Also grouped depending on chemical classes of organic pesticides which includes organochlorine, organophosphorus, acetamides, carbamates, triazoles and triazines, neonicotinoids and pyrethroids [130]. Currently, there are more than 1000 active ingredients of pesticide which are distributed among insecticides, herbicides and fungicides and, although considered worldwide as one of the main factors involved in environmental contamination, pesticides are one of the few classes of toxic substances that are deliberately available for use in the control of pests and vectors of diseases[120]. to ever-increasing world population and their corresponding food commodities also need to be enhanced [98]. Worldwide approximately 9,000 species of insects and mites; 50,000 species of plant pathogens and 8,000 species of weeds damage crops [113]. With over 50% of the world food supply lost by pests. Globally, the use of synthetic pesticides has increased rapidly in the last fifty years due to intensification of farming in order to obtain higher yields [139]. According to an estimate, about 5.2 billion pounds of pesticides are used worldwide per year [150]. Society benefits from pesticides because they improve agricultural productivity and help fight disease. However due to their unplanned and indiscriminate use only 10% of applied pesticides reach the target organism and the remaining 90% is deposited on non-target areas such as soil, groundwater, surface water, sediments, atmosphere, biomass and causes serious environmental pollution. Similarly they also cause impacts on to non-target organism such as wild life, besides affecting public health [130]. Human health is also affected following inhalation, ingestion, and dermal contact with contaminated air, soil, food, and water. According to World Health Organization, each year, about 3,000,000 cases of pesticide poisoning and 220, 000 deaths are reported in developing countries [110]. About 2.2 million people, mainly belonging to developing countries are at increased risk of exposure to pesticides [64]. Meanwhile, it was estimated that about 25 million agricultural workers suffering from poisoning every year in the third world countries [25]. Chlorpyrifos, malathion and methyl parathion pesticides of the organophosphorus class, which cause a significant increase in markers of DNA damage, such as the presence of protein adducts and micronuclei [94, 105].

Environment must be free from hazardous pesticide contamination for healthy ecosystem functioning and its inhabitants. There are different physico- chemical methods to treat pesticide waste; its cost and other related limitation are not widely utilized. However the biological degradation is promising. Various studies suggested that a wide range of microorganisms are capable of degrading pesticides (Table.3). Microbes which were commonly reported in pesticides bioremediation include *Pseudomonas sp., Bacillus sp, Klebsiella sp, Pandoraea sp, Phanerochaete Chrysosporium, Mycobacterium sp., Agrocybesemiorbicularis, Auricularia auricula, Coriolus versicolor, Dichomitus squalens, Flammulina velupites, Hypholoma fasciculare, Pleurotus ostreatus, Stereum hirsutum, and Avatha discolor* have shown their ability to degrade various pesticide groups like phenylamide, triazine, phenylurea, dicarboximide, chlorinated and organophosphorus compounds [158, 93]. Microorganisms use different mechanisms in pesticide degradation via enzymes (Cytochrome P450s, peroxidases, phenoloxidases, oxidoreductases, hydrolytic). (a) Biodegradation in which the pesticide can serve as a substrate for growth. (b) co-metabolism, in which the pesticide is transformed by metabolic reactions, but microorganisms do not use it as an energy source; (c) polymerization or conjugation, in which pesticide molecules are linked together with other pesticides, or with naturally occurring compounds; (d) accumulation, in which the pesticide is incorporated into the microorganism; and (e) secondary effects of microbial activity, in which the pesticide is transformed because of changes in the pH, redox conditions, reactive products, etc., in terrestrial or aquatic environments, brought about by microorganisms. The microbial conversion of a pesticide may involve more than one type of mechanism, and under different conditions, different products can be derived from the same initial compound depending on the environmental characteristics [133].

Table 3: Pesticide degrading microorganisms

	Degrading Microorganisms	Organic compound or pesticide
Bacteria	*Alcaligenes denitrificans*	Fluoranthene (PAH)
	Alcaligenes faecalis	Arylacetonitrils
	Arthrobacter sp	Carbofuran, Parathion
	Arthrobacter sp.	EPTC,Pentachlorophenol, glyphosate
	Bacillus sphaericus	Urea herbicides, Parathion
	Brevibacterium oxydans DH35A	Cyclohexylamine
	Burkholderia sp. P514	1,2,4,5-Te CB
	Clostridium sp.	Quinoline, Glyphosate
	Corynebacterium nitrophilus	Acetonitril, Carboxylic acid
	Dehalococcoides ethanogenes)	Trichloroethylene (TCE
	Desulfovibrio sp.	Nitroaromatic compounds
	Flavobacterium sp.	Pentachlorophenol, Parathion
	Geobacter sp.	Aromatic compounds
	Klebsiella pneumoniae	3&4 Hydrobenzoate
	Methylococcus capsulatus	Trichloroethylene
	Nitrosomonas europaea	1,1,1-Trichloroethane
	Nocardia	Quinoline
	Pseudomonas stutzeri	Parathion, Methyl parathion
	Pseudomonas capaciea	2,4,5-T Diazinon
	Pseudomonas sp.	2,4,5-T Diazinon
	Rhodococcus chlorophenolicus	Pentachlorophenol (PCP)
Fungi and Yeast	*Aspergillus flavus*	DDT
	Aspergillus paraceticus	DDT
	Aspergillus niger	2,4-D
	Candida tropicalis	Phenol
	Chrysosporium lignorum	3,4-Dichloroaniline
	Fusarium oxysporum	DDT
	Phaenerochaete chrysosporium	Lindane, DDT, Pentachlorophenol,
	Pleurotus ostreatus	DDT
	Trichoderma viride	DDT
Ectomycorrhizal Fung	*Paxillus involutus*	Mefluidide
	Scillus luteus	Mefluidide

Source: Mateen *et al*., 1994; Encyclopedia of Pest Management, 2002

Current Microbial bioremediation technology for pesticide waste treatment

However still conventional ex-situ and in-situ bioremediation technology including bio stimulation, bioagumentation, land farming, sullry and solid phase bioreactor technology is applied for pesticide waste treatment. Composting is also conventional treatment technology employed in remediation of pesticide [122,137]. Currently advanced microencapsulation technology has been widely applied in bioremediation of groundwater polluted by pesticide or herbicides. Various micro-carriers grouped as alginates, gums, polymers have also been used as encapsulating materials providing protection as well as nutrition source in suitable environment allowing the release and growth of microbial cells. bioagumentation &bio-stimulation assisted microencapsulation technology also applied in different country for pesticide bioremediation where the use of microencapsulated microorganisms offers a great potential in degrading pollutants bring more advantages over the free cell bio-augmentation [134].

Petroleum hydrocarbons and chlorinated compound pollution & microbial bioremediation

Petroleum hydrocarbons composed of aliphatics, aromatics, resins (carbazoles, sulfoxides, pyridines, quinolines and amides) and asphaltenes (phenols, ketones, esters, porphyrins and fatty acids,) groups [135]. its products have become a major energy source in the century, its use in industry and daily life have increased tenfold to that used previously leading to hydrocarbon contamination of both soil and water. Every year about 35 million barrels of oil is ferried across the oceans, making the aquatic environment vulnerable to pollution from oil spills, leakages that threaten the aquatic or marine life all over [114]. Contamination of soil with oil spills is another major concern, contaminated soil is a serious, often lethal hazard to the health of humans, and it causes pollution of ground water, environmental problems, decreases overall productivity of agricultural land [136]. Mono and poly nuclear aromatic hydro carbons (PAHs) pollutants commonly found near coal conversion facilities and petroleum plants It is considered the main energy source and materials for different industries [142]. Oil spillage in sea since the years 1970–2015 which shows more than 700 tonnes of oil spillage which occurred in year 2015 itself [107]. Another group of pollutant is Chlorinated hydrocarbons are also known as chlorocarbons and can be viewed as formed from an organic radical (alkyl, cycloalkyl, aryl, etc.) and one or more chlorine functional groups. Chlorinated aliphatic and aromatic compounds such as chlorinated ethenes, dichloroethene, vinyl chloride make up an important group of organic pollutants that are both ubiquitous and relatively persistent in aquifers. Particularly is the generation of dioxins, furans, and PCBs. Some of these compounds are carcinogens, highly toxic substances, and persistent pollutants with high propensity for bioaccumulation [119].

Biodegradation of petroleum hydrocarbons is a complex process that depends on the nature and on the amount of the hydrocarbons present. The continuous development and improvement of microbial remediation technology has also provided a new method for the remediation of petroleum hydrocarbon pollution, which has attracted much attention [100, 102]. Recent studies have identified bacteria from more than 79 genera that are capable of degrading petroleum hydrocarbons [137]. Several of these bacteria such as *Achromobacter, Acinetobacter, Alkanindiges, Alteromonas, Arthrobacter, Burkholderia, Dietzia, Enterobacter, Kocuria, Marinobacter, Mycobacterium, Pandoraea, Pseudomonas, Staphylococcus, Streptobacillus, Streptococcus and Rhodococcus* have been found to play vital roles in petroleum hydrocarbon degradation [131, 142, 143, 140]. Different Fungi species like *Trichoderma harzianum, Aspergillus fumigatus,Aspergillus spp, Cunninghamella elegans, Aspergillus niger, Penicillium sp, Cunninghamella elegans, Aspergillus ochraceus, Trametes versicolorAspergillus sp. RFC-1Penicillium sp. RMA1 and RMA2* produce major lignolytic enzymes including lignin peroxidases, manganese-dependent peroxidases, phenol oxidases (laccases and tyrosinases) and H_2O_2 have been proved to degrade PAHs [92, 111]. In general diverse group of microorganisms are involved in Hydrocarbon degradation (Table.4). Microbial degradation mechanism of Petroleum hydrocarbon (PH) of most organic contaminants occurs under aerobic conditions. The first intra-cellular organic pollutant attack takes the form of oxidation and activation, and also the integration of oxygen is the key enzymatic catalyst via peroxidases and oxygenase enzyme. Pathways of peripheral degradation transform organic contaminants step by step in intermediates of the central intermediary metabolism, for instance, the tricarboxylic acid cycle. The cell biomass biosynthesis happens from the metabolites of the central precursors, like the acetyl-CoA, pyruvate and succinate. The saccharides necessary for different biosynthesis and growth are synthesized via gluconeogenesis. PH degradation could be possible via a specific enzyme system. Other mechanisms are also implicated, such as microbial cell attachment to substrates and biosurfactant production (proteins, exopolysaccharides, fatty acids, amino acids, glycolipids, etc. with hydrophobic and hydrophilic components) [91]. PHs can be selectively metabolized from an individual strain of microorganisms or a microbial consortium of strains pertinence to the same or dissimilar genera. The consortium had showed to be more possibility than the individual cultures to metabolizing or degrading of PHs [142].

Table 4: Petroleum hydrocarbon pollutants degrading microorganisms.

Petroleum hydrocarbon	Degrader Microorganisms
Aliphatics	*Acinetobacter sp., Alcanivorax sp., Azoarcus sp., Bacillus sp, Brevibacterium, Desulfosarcina sp.,Desulfococcus sp, Marinobacter sp., Micrococcus sp. Ochrobactrum sp,Oleispira sp.,Pseudomonas sp., Rhodococcus sp. Stenotrophomonas sp., Thalassolituus sp., Aspergillus sp., Candida sp.Pseudozyma sp,,Penicillium sp.*
Monoaromatics	*Acinetobacter sp., Archaeoglobus fulgidus., Aromatoleum aromaticum.,Bacillus sp. Halomonas sp.., Pseudomonas sp.,Rhodococcus sp..,Sphingobacterium sp.*
Polyaromatics	*Chromobacter insolitus.,Bacillus sp.,Cycloclasticus sp.,Phanaerochaete chrysporium Pseudomonas sp.,Vibrio sp.,Penicillium janthinellum*
Resins	*Pseudomonas sp.,Member of family Vibrionaceae, Family Enterobacteriaceae, Moraxella sp.*

Source: Varjani., S.J., 2017

Microbial bioremediation technology for Petroleum hydrocarbon& chlorinated compound waste treatment

Composting, biosparging, bioventing technology and solid and slurry bioreactor technology are applied currently for Petroleum hydrocarbon& chlorinated compound microbial waste treatment [58]. During in Situ sorption and Biodegradation processes different enhanced remediation device are used currently like Waterloo Emitter technology, TersOx™ Powder and Granular, Nutrisulfate, NutriBind .The Waterloo Emitter technology is a simple, low cost device designed for the controlled and uniform release of oxygen, or other bio-enhancing amendments, to encourage and sustain the growth of microorganisms required for in situ bioremediation of Petroleum hydrocarbon contaminated groundwater. Micro Boost is a concentrated and stabilized nutrient package that promotes and accelerates reproduction and growth of microorganisms, shortening the time required for hydrocarbon degradation. Micro Boost™ is a specially formulated product for bio-remediation of soils contaminated by petroleum hydrocarbons. Modulated TersOx™ Liquid it is a liquid is formulated to slowly generate hydroxyl free radicals that exhausts oxygen demand, eliminates high contaminant inhibition and enhances bioremediation performance by reducing lag times and directs biological activity towards contaminant breakdown [138].

The role of microbes in domestic and agricultural lignocellulos wastes remediation

In nature, lignocellulose is derived from wood, grass, agricultural residues, forestry wastes, and solid municipal wastes. Lignocellulosic complex contains three types of polymers approximately 40 to 60% cellulose, 20 to 40% hemicellulose, and 10 to 25% lignin. Each year, human, livestock, and crops by product produce approximately 38 billion metric tons of organic waste worldwide [104]. Composting is one of the bioremediation method where the compost generated by bioconversion of agro residues offers several benefits such as enhanced soil fertility and soil health which can lead to increased agricultural productivity, improved soil biodiversity, reducing ecological risks and a healthier environment. Composting microorganisms degrade organic waste through the mechanism of producing hydrolytic enzyme especially cellulase, lacase, lignin peroxidase, manganese peroxidase, hemicellulose degradation of cellulose, hemicellulose and lignin containing agricultural and domestic organic waste. Compost amendments stimulated the growth of alkane degrading microorganisms and thus the degradation of alkane [55]. During composting diverse microorganisms are involved in three succession temperature phase where mesophilic initiate the process, at elevated temperature the thermopilic decompose complex lignocellulose biomass and finaly phychrophilic end the process of composting at low temperature (Table 5).

Table 5: Composting Microorganisms

	Composting phase	Composting Microorganisms
1	Thermophilic phase(day 45)	*Curtobacteriumcitreum,Stenotrophomonas rhizophila,Stenotrophomonas maltophilia, Microbacteriumfoliorum,Xanthomonas oryzae,Pseudoxanthomonas taiwanensis,Bacillus ginsengihumi,Serratia marcescens, Serratia odorifera Rhabditidae spp, Panagolamidae sp.Diplogasteridae Sp, Cephalobidae sp., Mononchoides sp., Ditylenchus filimus.*
2	Mesophilic phase(day 139)	*Xenophilus azovorans,Bacillus licheniformis, Pseudomonas mendocina, Rhodococcus rhodochrous Bacillus sp., Paenibacillius sp, Actinomycetes, Aspergillus fumigatus , Feacal coliforms,Pseudomonas Sp,Streptococcus sp, Proteus Sp,Serratia Sp.*
3	Psychophilic phase	*Asprgillus fumigatus, Emericella Sp,Aspergillus ochraceus,Aspergillus terreus, Penicillium oxalicum, Thermoactinomyces sp. Cladosporium sp, Mycotypha sp, Scopulariopsis sp, Coprinus sp,Cephalosporium sp,Trichotheclum sp.,*

Source: Ryckeboer *et al*., 2003 (In Chater 3, Microbiology of the Composting Process: Compost Science and Technology 8: 1-364).

Microbial development in emerging technologies in environmental Bioremediation

The recent advances and breakthroughs in genomics, metatranscriptomics, metaproteomics metabolomics, and fluxomics along with in silico (bioinformatics) analysis play their part by providing key in-sights in understanding and exploring the microbial communities and their mechanisms in the bioremediation of environmental contaminants. These approaches have made it practically possible and economically feasible to explore the metagenomes of contaminated environmental samples, harboring diverse microbial communities. This has not only provided an insight regarding the diversity, but also putative information about the meta-functionality of the microbial populations inhabiting the contaminated environments. Even the combination of data generated via different omic-approaches may be used to study the microbial metabolism during the bioremediation processes. In order to expedite the complete remediation of contaminated environments a comprehensive understanding of the physiology, biochemistry, ecology, and phylogeny of the indigenous microbial consortia of contaminated sites is warranted [117]. Emerging technologies in environmental bioremediation for the treatment and management of industrial wastes and other environmental pollutants for the sake of environmental sustainability. Emerging bioremediation approaches such as nano-bioremediation technology, electro-bioremediation technology, microbial fuel cell technology, Modified Ludzack-Ettinger Process, Modified Activated Sludge Process, and phytotechnologies for the remediation of industrial wastes and pollutants.

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