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Bioremediation of industrial wastewater: A synergistic approach

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Abstract
The sustainability of the ecosystem is threatened by the hazardous inorganic and organic contaminants found in industrial effluent. In comparison to inorganic pollutants, organic pollutants pose a greater threat to the environment and life forms. They are teratogenic, mutagenic, carcinogenic, and have other seriously harmful effects on living things. In addition, they have an impact on the fertility and quality of the soil. It is difficult to remove different effluents with resistant pollutants using traditional treatment procedures. Biological treatment techniques differ from physical and chemical ones in that they are technically possible, adaptable, effective, and have minimal operational costs and energy footprints. An ex-situ technique for bioremediation, biological treatment in bioreactors has the advantages of continuous monitoring under regulated limits. Environmental pollution, heavy metal contamination, and microbial adaptation mechanisms have all been linked to significant alterations in the microbial diversity that can be remedied by bacteria. Microbes are useful for cleaning up the contaminated environment; in-situ bioremediation is suggested as a remedy for emerging contamination issues. This essay aims to present a survey of bioremediation methods, focusing on widely used bioreactors and developments utilized for various industrial effluents, along with their relative benefits and drawbacks.

Keywords: Bioremediation, industrial wastewater, synergistic approach

Introduction
Over the last several decades, the globe has faced a wide range of environmental pollution issues as a result of excessive human activity. The world's population boom has expanded the area of contaminated water. The quantity and quality of trash produced and released into natural water sources has therefore been studied, as has the necessity for alternative ways to address water quality issues in the locations. Modernising economies, intensive industrial development, urban expansion, and massive population increase are the primary drivers of deteriorating water quality [Kshirsagar, 2013; Coelho *et al*., 2015; Azubuike *et al*., 2016] [10, 5, 3]. Recent advances in bioremediation approaches have been undertaken with the goal of effectively recovering damaged areas. Several research have been undertaken employing diverse microbes as an alternative to traditional treatments for the removal of heavy metals found in contaminated streams. Bioremediation is a natural alternative procedure to incineration, catalytic degradation, adsorbent usage, physical removal, and ultimately pollutant annihilation. Microorganisms are a biological technique for metal removal because they may be utilized to remove, concentrate, and extract heavy metals from contaminated aquatic ecosystems. The bioremediation technique is based on biological agents' strong metal binding capacity, which aids in the extraction of heavy metals from contaminated environments [Amin, 2013; Abatenh *et al*., 2017; Gupta *et al*., 2017] [2, 1, 8].

Causes of water pollution
Water pollution is a multidimensional hazard to aquatic ecosystems and human health, and it is caused by a wide range of contaminants. Pathogens, which include bacteria, viruses, and protozoa, stand out as powerful foes. These pathogenic microbes enter water bodies mostly through sewage and sanitation systems, generating a chain reaction of health problems such as diarrhoea and gastrointestinal diseases.

Organic waste is another type of polluter that contributes to water contamination. These contaminants cover a wide range of substances, including food waste, detergents, leaves, and grass.

They come from a variety of sources, including home sewage, discharge from food processing plants, and agricultural runoff. When organic waste enters water sources, it is decomposed by bacteria, which consumes the dissolved oxygen in the water. The number of decomposers rises as the organic load in water increases, further lowering oxygen levels. This oxygen deprivation has serious consequences for aquatic species, creating negative impacts and threatening their survival [Srivastav *et al*., 2020; Masindi *et al*., 2018; Verma *et al*., 2013] [18, 12, 20].

Another important type of water contamination is chemical pollution. Heavy metals such as mercury, lead, and cadmium are included in this category, as are solvents from industrial operations, pesticide run-off, and ship oil spills. These chemicals are extremely harmful to aquatic living forms and can cause infertility and death. Furthermore, when absorbed into the body, they represent a major risk to human health, perhaps causing damage to the brain system and kidneys. Heavy metal pollution caused by human and industrial activity is especially harmful since these pollutants are non-biodegradable and can cause irreversible damage to marine habitats, impacting both flora and wildlife [Masindi *et al*., 2018; Verma *et al*., 2013] [12, 20].

Furthermore, some water-borne pollutants, such as colours and medications, have direct negative impacts on marine species, plants, and people. They obstruct sunlight penetration in bodies of water, lowering dissolved oxygen levels and harming photosynthetic organisms and other marine life. Certain chemicals, such as dyes, are mutagenic and carcinogenic. Pharmaceutical residues in water can cause immediate and chronic injury to marine species, whereas endocrine-disrupting chemicals (EDCs) can cause endocrine abnormalities in aquatic life and raise the risk of cancer in people. These contaminants have a significant influence on aquatic creatures' reproductive and developmental processes.

Mechanism of bioremediation by microorganisms

Bacteria: Bacteria have a wide spectrum of bioremediation capabilities. *Desulfovibrio vulgaris, Arthrobacter, Pseudomonas* sp., Serratia marcescens, *Ochrobactrum* sp., *Bacillus* sp., *Cellulomonas* spp., Acinetobacter, and Ochrobactrum are just a few of the microbes that have been documented to convert highly soluble and poisonous Cr (VI) to less soluble and less dangerous Cr (III). Arthrobacter Psychrolactophilus Sp. 313 lowered the protein content of wastewater. They are utilized for the sewage from industrial facilities. Other bacteria utilized in the treatment process as possible bio remediating agents include endophytes, pseudomonas, and B. subtilis [Das *et al*., 2014; Zahoor *et al*., 2009; Gratia *et al*., 2009; Shah *et al*., 2020] [6, 21, 9, 16].

Algae: Algae are crucial to the process of naturally purifying water. They can be utilised for recovering valuable metal ions like gold and silver as well as for the sorption of toxic and radioactive metal ions. They contribute to the cleanup of nutrients by growing quickly and assimilating C, N, and P from wastewater. It is an alternate method of treating sewage effluent that is also cost-effective and environmentally friendly. Textile wastewater (TWW) includes organic dyes that act as a carbon source and nutrients including phosphate, nitrates, and micronutrients that are essential for algal development. Chlorella vulgaris and Scenedesmus quadricauda are two examples of microalgae that may efficiently bioremediate TWW by using both dyes and nutrients for growth. *S. Quadricauda* effectively eliminates phosphate, whereas *C. Vulgaris* effectively produces ethanol and citric acid from wastewater, lowering both BOD and COD levels.

Additionally, the *C. vulgaris* strain UMACC 001 is used in the TWW bioremediation process, which uses both live and non-living algae in two different ways: bioconversion, where colours are converted into metabolites, and biosorption, where colours are adsorbed to the surface of the algae [Sharma *et al*., 2013; Fazal *et al*., 2018; Lim *et al*., 2010] [17, 7, 11].

Fungi: Filamentous fungus eat heavy metals such as Zn, Cd, Pb, Fe, Ni, Ag, Th, Ra, and U. Penicillium, Aspergillus, Rizopus, Mucor, Saccharomyces, and Fusarium all absorb metal ions. Penicillium is employed in the biosorption of heavy metals (Cr, Ni, Zn, Pb, and As). Penicillium, Rizopus, and Saccharomyces may biosorb radionuclides (U, Th, and Sr). Trametes pubescens MB 89, Ceriporiopsis subvermispora, Pycnoporus cinnabarinus, and UD4 were employed in the bioremediation of distillery effluent. White rot fungus may decompose high-intensity phenolic waste. White rot fungus (Including Lentinula and Pleurotus edible mushrooms), Aspergillus sp., and many other varieties of yeast may be utilized to remediate olive oil mill effluent (OMWW). They reduce COD, phenolics, and the colour of OMWW. White rot fungi such as Coriolus versicolor and Funalia trogii, Geotrichum candidum, Lentinula (Lentinus) edodes, and *Phanerochaete* sp were utilized to treat OMWW. White-rot fungi, in particular, have a number of environmental contaminants degrading benefits. Fungi from the class zygomycetes including Aspergillus, mucor, and penicillium were employed to decompose and detoxify textile effluent and crude oil. Polychlorinated biphenyls (PCB) are degraded by Penicillium chrysogenum, Scedosporium apiospermum, Penicillium digitatum, and Fusarium solani [Ojha *et al*., 2021; Bishnoi *et al*., 2005; Strong *et al*., 2007] [15, 4, 19].

Yeast: Yeast absorbs heavy metals such as Zn, Cd, Pb, Fe, Ni, Ag, Th, Ra, and U. Yeasts employed in OMWW bioremediation include Trichosporon cutaneum, Candida tropicalis, and Saccharomyces sp. Yeasts are also effective at eliminating mono- and polyphenols and decreasing COD levels. They are utilised in textile wastewater treatment because they are capable of collecting, aggregating, and decomposing harmful chromophores into simpler molecules. They are biosorbents for dye biosorption and contain enzymes for dye breakdown. Candida krusei, Trichosporon beigelii, Galactomyces geotrichum, S. Cerevisiae, and other yeasts are employed to biodegrade colours, among other things [McNamara *et al*., 2008; Mullai *et al*., 2017] [13, 14].

Anaerobic degradation: Anaerobic degradation is a method in which biodegradable content is broken down by microorganisms in the absence of oxygen. The anaerobic degradation theory entails the following steps: first, insoluble organic pollutants are broken down into soluble substances and made available to other bacteria; second, acidic bacteria convert sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acid; and third, organic acids are converted into acetic acid, ammonia, and hydrogen. Anaerobic degradation processes, in contrast to aerobic degradation, are slow and inefficient. Furthermore, some organic pollutants, such as lignin and high molecular weight PAH, have the potential to degrade anaerobic microorganisms. They can successfully treat wastewater with high organic pollutant loads from the sugar industry, slaughterhouses, food industry, paper industry, and so on [Ojha *et al*., 2021] [15].

Table 1 Represents different bioremediation agents responsible for bioremediation different type of contaminants and the ultimate outcome.

Table 1: Different bioremediation agents, types of industrial waste, & their outcomes [Ojha *et al*., 2021] [15]

Bioremediation agents	Type of Industrial waste	Outcomes
Bacteria	Textile Pharmaceuticals	Removal of heavy metals like Hg, Cr, Cu, Cd, Zn, dyes, color, pesticides, dyes
Algae	Sewage wastewater Textile wastewater	Used for sorption of poisonous, heavy metals, and radioactive metal ion. Gold and Silver metal ion recovery. Reduction of N, P, and COD by microalgae. 68.4% BOD and 67.2% COD removal
Fungi	Olive mill wastewater	Reduction of heavy metals like Pb, Fe, Ni, U, Zn, Cd, Ag, Th, & Ra Used to remove radionuclides from polluted waters.
Yeast	Textile	Helps in reducing COD levels and removing mono- and polyphenols, organic matter, heavy metals, & degrade dyes. They remove 98% of oils and 94% of COD.

Future prospects and Conclusion

Water pollution is a worldwide problem as a result of increased human activity, such as unsustainable agriculture and fast industrialization. Microorganisms are critical in tackling these concerns via bioremediation, a natural and effective technique of clearing contaminated regions. Bioremediation uses live microorganisms such as bacteria, yeast, fungus, algae, and plants to accelerate biological decomposition, making it a long-term option for pollution control. This method converts diverse contaminants into innocuous molecules, lowering the dangers associated with hazardous material handling and transportation. Bioremediation is a low- cost, safe, and environmentally friendly technology that may be used with other technologies to improve overall effectiveness.

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