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Review Article

Mitigating the Harmful Impacts of Industrial Effluents; The Potential of Biological Treatment Techniques

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ABSTRACT

The leather and chemical industries produce a large volume of effluents that contain harmful chemicals, heavy metals, and nutrients. These effluents contribute to pollution and have adverse effects on the environment, aquatic life, animals, and humans. To mitigate these effects, biological techniques such as degradation via algae, fungi, and bacteria have been implemented for the treatment of these effluents. The article discusses the harmful impacts of these industrial effluents and the potential of biological treatment methods to address them. The chemical industry generates effluent containing toxic, carcinogenic, and mostly non-biodegradable chemicals, leading to acute and chronic health effects. Similarly, leather industry generates heavy metals and toxic compounds in effluents that are discharged into aquatic life such as rivers, ponds and streams without further treatment. They have massive chronic effect on primarily them and ultimately up in the food chain. Various bioremediation techniques such as bio augmentation involving multiple microbes like bacteria, fungi and algae have and can be used to treat such effluents biologically and eco-friendly. Chromium (III) and chromium (VI) can be treated effectively only by such techniques. Furthermore, SBR technique and its multiple variants are applied for treatment of potentially toxic chemicals present in chemical industrial effluent. All such techniques provide strong biological substitution to prevalent physical or chemical methods of remediation.

INTRODUCTION

Effluents from the leather industry contain harmful chemicals and heavy metals that cause pollution and adverse effects on the environment, aquatic life, animals, and humans. Industrial effluent discharge has significantly increased, leading to rules and regulations on various chemical industries. Effluents from pharmaceutical and petrochemical industries contain a wide range of toxic, carcinogenic, and mutagenic chemicals, leading many physio-chemical and oxidative chemical procedures to be inefficient. Biological treatment methods, such as fungal and bacterial treatments, and activated sludge, are discussed as potential solutions for treating these effluents.

The Leather Industry

Leather making is a technique that involves the application of various chemicals (organic and inorganic) to a natural biological model, besides a significant amount of water. Around a hundred and thirty distinct types of chemicals are applied for the whole remedy of leather [1]. That wide variety of chemicals utilized in a tannery is drained out into streams, ponds, and rivers without treatment which causes groundwater pollution. A tannery can cause groundwater pollution in a range of about 7-8 km radius around it that has a devastating effect on aquatic lifestyles, birds, animals, and people[2].

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Detrimental Effects of Effluents

Effluents from tanneries produce quite significant by-products and wastes either in solid, liquid, or gaseous forms which take part in pollution by chemical oxygen demand (COD), total dissolved solids (TDS), chlorides, sulfates, and heavy metals. Chromium III a primary tanning agent applied in the leather industry has a deleterious impact on nature as well as on living creatures. The effluents from the leather industry also contain ammonium nitrogen and germanium. The increased percentage of nitrogen in drinking water near tanneries causes the condition of methemoglobinemia where transport of O2 (oxygen dioxide) is interrupted by nitrate in infants. Moreover, a slightly increased intake of germanium ions than the optimum requirement would immediately results in protein fixing and causes lung cancer, nose membrane shrinkage, and bleeding [2]. The heavy metal found in Leather industry effluent is Cd, Zn, Cr, Ni, Pb, and Mn, which when used to irrigate or discharge in nearby soil containing crops would result in phytotoxicity and groundwater pollution that causes deleterious impact not only on vegetation but also on human health. The increased amount of sodium and chloride ions in groundwater is the major cause of cardiac arrest, hypertension, and asthma. On the other hand, the presence of Sulphate ions causes dehydration and intestinal issue. Similarly, the consumption of Cr6 dissolved in groundwater results in serious health deterioration such as ulcers, genetic mutations, breathing problems, and organ damage (liver and kidney)[3].

Biological Treatment Techniques

Detoxification of Effluents by Microbes

Numerous chemical strategies have been followed for the treatment of those harmful chemicals present in the effluents of the leather industry although it is a less expensive approach, it generates harmful outcomes. For this reason, various biological techniques are implemented because of their ease of operation and eco-friendly results.

Degradation via Algae

The algal genera i.e., the Spirulina sp., the Scenedesmus sp., the Chlorella sp., and the Scenedesmus sp. have the potential to extract the heavy metals from the effluents. These genera contain polysaccharides in their cell wall which facilitate the adsorption of heavy metals. Marine algae are also widely utilized nowadays for treating various kinds of industrial effluents. They also work as an adsorbent for treating effluent. Following a test finished, the result suggests that discrete extracts of 4 marine algae i.e., the Grateluopia lithophile, the Ulva Lactuca, the Enteromorpha flexuosa, and lastly the Centroceras clavulatum have been used to deal with leather industry effluents. Amongst all, extracts of Ulva Lactuca reduced extra amounts of chemicals existing in the effluent. Benzene extract of Ulva Lactuca also proves useful in decreasing the TDS (85%), sulfate (82%), and nitrate (91%). Also, the Hardness of water (81%) and chloride ions (91%) content has decreased significantly with the help of methanolic residue of the Ulva Lactuca. Chloroform extract of Ulva Lactuca decreased more amount of chromium (91%) existing in the effluent [4].

Degradation via Fungi

Similarly, fungi have the potential to entice and adsorb harmful material by using their specialized organs i.e., hyphae and help in the metabolic process. Two researchers have examined and finished the biosorption of chromium from effluent of leather tannery, using Aspergillus sp. 85% of Cr was eliminated at optimum pH of 6 within a bioreactor. Others also suggested a brand-new mechanism of chromium (VI) elimination by employing the use of dead biomass of Aspergillus niger obtained from synthetic wastewater. The process of chromium (VI) becomes a redox reaction between chromium (VI) and the deceased biomass of Aspergillus niger [5].

Degradation via Bacteria

Numerous bacterial species were used to detoxify tannery effluents. For example, Burkholderia spp., Acinetobacter spp. Bacillus spp., and Pseudomonas spp., are used as microorganisms in one-of-a-kind research for Cr elimination [6]. While, hexavalent Cr is being bio-remediated at a neutral pH variety, it generates a chemical sludge in a small quantity. During the bioremediation process, Cr (VI) is highly soluble in bacteria and toward the finish of the cycle, it is shifted by means of the sulfate pathway all around the cell membrane and is reduced inside the cytoplasm to Cr (III). The Cr (III) further interconnects with protein and nucleic acids and is unable to go through the cell membrane. Two researchers have inspected the biosorption of Cr through the Staphylococcus spp. and the Bacillus spp. from tannery wastewater whose preliminary consideration becomes 100 mg/L. Underneath the ideal conditions (i.e., 37 °C and a 7.0 pH for Bacillus spp., and 37 °C and an 8.0 pH for Staphylococcus spp.), the highest chromium uptake by bacterial species was recorded to be 94.5 mg/L and 72.6 mg/L, respectively [7].

Bio-augmentation by BM-S-1

It is the method used to speed up the degradation of contaminants within the tannery effluents and for this motive a unique microbial consortium, BM-S-1, became effectively applied, at a full-scale tannery wastewater treatment plant, to cast off the scent and notably reduce sludge without the involvement of any chemical. Microbial groups that occupy a distinctive area of interest facilitated using the augmented BM-S-1 appeared to play important roles in the biological and eco-friendly treatment of the

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tannery wastewater. The elimination efficiencies of COD, TN, TP, and Cr have been predicted to be 98.3%, 98.6%, 93.6%, and 88.5%, respectively. The pyrosequencing evaluation confirmed Brachymonas denitrificans to be the most dominant microbial population in the buffering tank (B; 37.5%). The polymer degraders (the Clostridia), sulfate diminisher (the Desulfuromonas palmitatis), and sulfur oxidant (uncultured Thiobacillus) were prepotent in (SD) tank[8].

Bioremediation by GS-TE1310

A unique bacterial consortium GS-TE1310 is developed for the degradation and detoxification of leather tannery effluents and its phytotoxicity assessment for environmental protection. Three pollution degrading bacterial strains recognized through gene sequencing are Ochrobactrum intermedium (GS1), Micrococcus lylae (GS3), and Stenotrophomonas acidaminiphila (GS10) were separated from leather-based tannery effluents + sludge, which had been able to tolerate up to 6, 4, and 8% salt (NaCl) concentration and capable to degrade COD up to 61.12, 54.28, and 66.32 % from actual leather tannery effluents, respectively, and subsequently, used inside the improvement of a new bacterial consortium GS-TE1310. However, the newly modified bacterial consortium GS-TE1310 was extraordinarily beneficial in degrading all of the pollution parameters (BOD: 85.32 %, COD: 76.12 %, TDS: 71.89 %, phenol: 88.70 %, and general chromium: 71.22 %) simultaneously from actual leather-based tannery effluents within 120 h and therefore, compellingly showed a significant capacity for tannery effluents remedy and cleansing. The optimum pH is 7, temperature 35.5°C, inoculum conc. 20 mL, and agitation rate was 120 rpm[9].

The Chemical Industry

Water rendered to the living organisms is approximately 0.03% thus its contamination must be avoided at all costs. Due to industrial revolution effluent discharge increased a lot, as a result uncompromised rules and regulations have been implemented on various chemical industries. The chemical industry comprises mainly of pharmaceutical, petrochemical, oleo-chemical, polymer, organic and inorganic chemicals etc. Chemical industrial effluents thus contain a wide range of chemicals that are toxic, carcinogenic, mutagenic and mostly non-biodegradable due to combined effects. Such enormous numbers of substances cause many physio-chemical and oxidative chemical procedures inefficient[10].

Harmful Effects of Effluents

Harmful effects of pharmaceutical industrial effluent are mostly dependent on the concentration of APIs in the effluent. Local discharge from the excretion of humans has very small number of APIs present as compared to discharge from the pharmaceutical industries. For example, in 2007 effluents from plants in Patacncheru near Hyderabad India, which are considered as a hub for worldwide production of drugs, were analyzed. The effluent of treatment plant which was receiving waste water from 90 manufacturing plants contained lethal number of APIs. For instance, ciprofloxacin (a broad spectrum-antibiotic) was present in 31mg/L; highly toxic to many organisms. This is nearly one million times more than treated municipal sewage effluents [10]. These uncontrolled discharges have led to deterioration of river sediments, pollution of drinking water and adulteration of irrigated lands. Additionally, high amounts of penicillin (mg/L) and ethyniloestradiol (51ng/L) were found [11]. Other countries include Pakistan, Taiwan, Korea, USA and Europe where all effluents had mg/L of APIs. Lethal harms of discharge include phosphoric acid that kill fish, gene expression thereby enzymatic action changes, antibiotic resistance, intersex fish production in France due to steroidal discharge, relatively highly toxic to aquatic life forms than terrestrial, bad effect on overall metabolism, sperm production (especially in mice) and behavioral changes. The risks associated with discharge particularly in context of epidemic are concerned more often with antibiotic resistance and spread from localized areas which gets intensified by bad sewerage and wastewater management systems more often in developing areas [12, 13].

Harmful impacts of petrochemical or hydrocarbon industrial effluents include acute health effects like eye irritation, nausea, vomiting, diarrhea, and confusion. Additionally, skin irritation, allergic reactions or inflammation may also occur. Embryotoxic effects like low IQ level, behavioral problems and childhood asthma. Chronic effects include breathing defects, kidney and liver problems, eye cataract and blood cell breakdown. Genotoxic and immunotoxic effects may also persist. Major sources of toxicity are PAHs (Polycyclic Aromatic Hydrocarbons). They are also potent cause of cancer in many organisms.

BIOLOGICAL TREATMENT TECHNIQUES

Fungal Treatment

Treatment of pharmaceutical industrial effluent includes fungal treatment but it has setbacks due to extended life cycles and spore production. A fungal strain Bjerkandera adusta MUT 2295 was used to achieve 91 % COD reduction as compared to activated sludge process which gives 78 % results. Aspergillus niger, Aspergillus fumigatus and Aspergillus niveus were used at different concentration to show COD reduction of diluted industrial wastes. Fungi group called as Ascomycetes which include Penicillium decumbens and Penicillium lignorum cause significant COD reduction, phenol treatment and color improvement

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[14].

Bacterial Treatment

Bacterial treatment includes species Pseudomonas, Enterobactor, Streptomonas, Aeromonas, Acinetobactor and Klebsiella which show 44% COD reduction. 15 isolated rhizosphere bacteria showed color reduction of 76% and 85-86% of COD and BOD reduction in a period of 30 days [15]. E. coli and methanogenic consortium are used to detoxify phenol and related compounds. Their removal is undoubtedly needed as they are potent sources of many toxic effects as discussed above, bacterial strain used should completely mineralize these contents. Bacterial species from genera Arthrobacter, Comamonas, Rhodococcus and Ralstonia can degrade phenolic and organic matter; some Clostridium species (fermenting bacteria) can degrade resorcinol. Pseudomonas; a rhizospheric soil bacteria can biodegrade phenolic compounds. A thermophilic bacteria Bacillus thermoglucosidasius A7 can breakdown phenolic and cresolic compounds at 64° C by utilizing meta-cleavage pathway. Pseudomonas putida MTCC 1194 highly-acclimatized culture could degrade phenol (100mg/L) in 162 hours and catechol (500mg/L) in 94 hours. Fluorescence can degrade phenols and chlorophenols (table 1) [16].

Table 1: Reduction of Pharmaceutical Industrial Effluents by Bacterial Consortia

Effluent	Concentration Before Treatment	Concentration After Treatment
Sulphates	44–1,527 mg/L	6–65.8 mg/L
Total Dissolved Solids (TDS)	484–1,452 mg/L	68–540 mg/L
Total Suspended Solids (TSS)	4–84 mg/L	12–56 mg/L
Chemical Oxygen Demand (COD)	1,257.9–1,542.9 mg/L	113.2–377.6 mg/L

A phototrophic Rhodobactor spheroids reduced COD by 80%. A mixed bacterial culture showed COD reduction of 62 % at 30° C and 38 % at 60° C [17].

Petrochemical and Hydrocarbon Industrial Effluent Treatment by SBR Technique

SBR (Sequencing Batch Reactor) technique is employed to treat the effluent from petrochemical industries that primarily consists of hydrocarbons, for example Xylene, styrene, methyl styrene, indene, methylidene, alkylated naphthalene, phenol, cyclooctadiene, isopropyl benzene, ethyl toluene, butoxyethanol, acetophenone, terpineol, acenaphthene, fluorene, diphenyl propanol, cresol, acenaphthylene etc. and some oils as well. SBR is applied at second stage treatment processes which utilize microorganisms to remove oil and other waste hydrocarbons producing carbon dioxide, water and methane [18]. SBR can be employed for both aerobic and anaerobic and treatment of wastewater. SBR is run as a single batch reactor that may be modified as sequential batch reactor. It has following main steps: fill, react, settle, draw and idle. Wastewater treatment installed SBR have flow rates of 22L/s. SBR technology is flexible and can also be used for denitrifying purposes. Modified SBR include continuous flow SBR sequencing batch biofilm reactor (SBBR), anaerobic sequencing batch reactor (ASBR), anaerobic-aerobic SBR, and membrane sequencing batch reactor (MSBR) (table 2).

Table 2: Bacterial Species and Their Functions in the Treatment of Industrial Effluents

Function	Species	Reference
Bacteria used in treating Nitrogen (Nitrite reducing)	Rhodobacter (Nitrate reductase enzyme)	[19]
Bacteria used in treating Sulphur (Sulphur oxidizing)	Acinetobacte	[20]
Bacteria used in treating Nitrogen (Nitrogen fixation)	Xanthobacter	[19]
Bacteria used in treating Nitrogen (Denitrification)	Agrobacterium	[21]

Beside SBR microbes employed to treat industrial effluents include bacteria such as Pseudomonas, Achromobacter, Azoarcus, Arthrobacter, Brevibacterium, Micrococcus, Flavobacterium, Corynebacterium, Cellulomonas, Nocardia, Marinobacter, Acinetobacter, Ochrobactrum, Vibrio, Stenotrophomaonas, etc. to degrade hydrocarbons. Fungal species include Candida, Saccharomyces, Fusarium, Aspergillus, Neosartorya, Amorphoteca, Talaromyces, Penicillium, Paecilomyces, Graphium. Rhodotorula, Pichia, Sporobolomyces, Pseudozyma, Yarrowia, etc. that breakdown petroleum and related compounds [22].

CONCLUSIONS

Effluents from leather and other chemical industries are harmful to the environment and living organisms. Biological treatment methods such as those done by algae, fungi, and bacteria have shown promise in reducing the concentration of heavy metals and toxic chemicals in these effluents. Bacterial species like Pseudomonas, Enterobacter, and Acinetobacter have been effective in COD reduction.

Authors Contribution

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Writing-review and editing: HN, RY, MDM, MAZ, ZN, JA
All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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