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Bioremediation of Leather Industrial Effluents: Prospects and Challenges

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ABSTRACT:

Bioremediation is the most recent and efficient method for treatment of various heavy metals and industrial wastes. One such industry where bioremediation is considered to be an attractive option is tanning industry. Although it is an industry which reaps profits, it has its own share of environmental concerns. Most of the tanning industries release potentially toxic heavy metals like Chromium, Aluminum, Iron, Zirconium and Titanium as effluents into the environment. Initially, phytoremediation was considered an attractive option for the treatment of effluents from tanning industry. However, the major disadvantage is that the leaching of the metals by the plants is efficient only when they reach certain age which is a time taking process. In these conditions microorganisms are considered an attractive option for the bioremediation. Several bacteria, algae and fungi have been considered as potent sources of bioremediation. The advantage in using microorganisms in bioremediation includeseasy disposal of biomass and lesser time for bioremediation due to the presence of various microbial enzymes. These advantages led to the preference of unicellular organisms over plants for the effluent bioremediation. The current review deals with the various prokaryotic and eukaryotic organisms involved in bioremediation process. We also focused on the various recent technological advancements that have occurred in this field.

Keywords: Tannery effluents; Bioremediations; Environmental concerns; Bacteria; Fungi

1. INTRODUCTION

Leather products are one of the most commonly traded commodities across the world. The trade value of leather products across the world have crossed 80 million US dollars annually and is still growing as per the data from International trade center [1]. China tops the leather production, import and export in the world and India shares about 7% of the global leather business and is currently holding the world's second position in leather footwear production.

India also boasts upon its abundance of raw materials with access to 20% of world's cattle and buffalo and 11% of the world's goat and sheep population [2]. The industry is known for its consistency in high export earnings and it is among the top ten foreign exchange earners for the country. Besides the leather industry is known to perform circular economy function to recycle the waste generated from slaughter houses and meat industries [3]. Leather industry is considered to be a sustainable industry but due to the nature of the effluents released, effects on environment are enormous. In this review we discuss the various bioremediation strategies being employed for treating leather industrial effluents in an ecofriendly manner.

1.0 TANNERY EFFLUENT DISPOSAL AND ENVIRONMENTAL CONCERNS

Although leather industry appears attractive and sustainable in terms of economy, it has its own pitfalls. The conversion of the animal hide into commercially valuable leather includes number of steps which incorporates many chemicals, energy and water. This makes leather industry less sustainable with respect to environment and social implications. Leather industry is in fact considered as the most polluting industries in the world contaminating both air and water resources in the ecosystem. The process of conversion of an animal hide into commercially valuable leather involves various steps like pretanning, tanning and post tanningoperations. The pretanning involves soaking, liming, deliming, bating,degreasing, and pickling unit operations.Tanning renders permanent stability to the skin/hide. Thepost tanning operations are retanning, dyeing and fat liquoringmainly to give color and to enhance physico-chemical properties ofleather. These steps require large quantities of water and the chemicals used in these steps are released into the water. The initial steps of processing the raw hides release enormous quantities of organic waste that includes protein and fat. Whereas, the later steps release very high concentration ofinorganic salts like chloride, ammonia, chromium, andsulfate, which may cause pollution [Table 1].Elements like chromium released into the water bodies can lead to death of aquatic life and phytoplankton in the aquatic ecosystem [5]. Similarly, the dichromates concentration builds up in the fishes and can lead to biomagnification [5]. The pH of the effluent is also acidic in nature which can lead to imbalances in the natural water bodies posing threat both to the environment and the aquatic life. Another study done in Bangladesh on the effect of tannery effluents on aquatic ecosystem in Buriganga revealed shocking results. It was observed in the study that the heavy metal concentration was significantly higher in the river water and also in the fish that were found in the waters. Among the heavy metals Chromium (Cr), Lead (Pb),Cadmium (Cd), Mercury (Hg), Manganese (Mn), And Aluminum (Al) were found to be in highest concentrations [6]. Various other organic and inorganic pollutants are released into the effluent during various steps of tanning. The chemicals released and their influence on the health of living organisms has been clearly tabulated in the Table 2. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) which measure the intensity of pollution in water bodies was estimated to be ranging between 500-7500mg/lit and1000-18000mg/lit respectively after the tannery effluents were tested after different stages of tanning procedures [4]. In addition to the chemical wastes tannery effluents are also rich in solid wastes that ranging between 10000-50000 mg/ml [4]. The inorganic chemical load including chlorides, sulphides, hydroxides, carbonates and bicarbonates also is quite high in the effluents [4].This huge amount of waste accumulation leads to clogging of the pipes in the tannery resulting in lowering of the treatment efficiency.

Table 1: Methods employed for treatment of leather and the resultant pollutants released into the tannery effluent.

S.No	Steps in Leather Treatment	Chemicals employed	Pollutants Released
1.	Treatment of raw hides and skin	Water, Calcium Carbonate, Sodium sulphide, Sodium bicarbonate, Sodium Chloride, Proteases, Acids,	Salts, dirt, organic substances, Hydrogen sulphide, Interfibrillar material, pH changes, excess salinity
2.	Deliming	Ammonia salts and water	Ammonia
3.	Pickling	Sodium chloride, acid and water	Increased salinity and pH variations due to acids
4.	Tanning	Chromium tanning agent, Bicarbonate and water	Chromium salts and pH variations due to bicarbonate
5.	Retanning	Phenol, Aldehydes, Resin, vegetable tannins	Salts, Phenol, Resins and Aldehyde
6.	Dyeing	Different natural and synthetic dyes	Dyes and heavy metals like Hg, As, Cr, Pb, Cu, Co, Se, Sb etc.
7.	Fat Liquoring	Different oils and fats	Oils and Fats
8.	Fixing	Formic acid	pH variations due to acids

Table 2: Various pollutants from tannery effluents and their role on the human health

S.No	Component present in tannery effluent	Effect on Human health
1.	Chlorinated phenols	Affects the cellular components of organisms along with histopathological changes these causes mutagenic and carcinogenic effects, genotoxicity in human and animals [59].
2.	Chromium	Nose irritation (breathing effect/respiratory problems) or bleeds, skin rashes, upset stomach and ulcers, weakened immune system, kidney- liver damage [60, 61]. Mutagenic, carcinogenic, teratogenic effects on human, many plants, animals and microorganisms inhabiting aquatic environment. Temporary effects (dizziness, head ache, irritation of eyes, skin/lungs [62]. Inhibit seed germination, seedling growth and deleterious to plant growth (effects amylase). Shows negative effect on the environment due to its eminent solubility, mobility, and responsiveness [63].

3.	Sulphides	Inhibition of the cytochrome oxidase and other oxidative enzymes resulting in cellular hypoxia/anoxia. 50- 100mg/L exposure/moderate level results in keratoconjunctivitis, respiratory tract irritation and olfactory fatigue. 250-500mg/L or prolonged exposure will result in olfactory paralysis and unconsciousness in human [64].
4.	Antimony	Nausea, vomiting, and diarrhoea, human carcinogen, flame retardant [65].
5.	Cadmium	Renal disfunction, high exposure led to obstructive lung disease, bone defects (osteomalacia, osteoporosis) in human and animals. Increased blood pressure, effects myocardium in animals [66].
6.	Copper	High doses cause anaemia, liver and kidney damage, and stomach/ intestinal irritation [67].
7.	Lead	Effects on the kidneys, gastrointestinal tract, joints, reproductive system, synthesis of haemoglobin and damage to the nervous system [68].
8.	Mercury	Tremors, gingivitis, spontaneous abortion and congenital malformation [69].
9.	Nickel	Long term exposure can cause decreased body weight, heart and liver damage and skin irritation [70].
10.	Selenium	Larger amounts can cause damage to nervous system, fatigue and irritability. Damage liver, kidney and circulatory tissues [71].
11.	Cobalt	Radioactive cobalt cause trouble breathing, effects lungs, including asthma and pneumonia [72].
12.	Arsenic	Bronchitis, dermatitis and poisoning, internal cancer and death [73].
13.	Manganese	Damages central nervous system [74].
14.	Dyes and Azo dyes	Carcinogenic, alter physical, chemical properties of soil, deterioration of water bodies, death to the soil inhabiting microorganisms which in turn effects the agricultural productivity. Skin irritation, chemosis, lacrimation, permanent blindness, hypertension and oedema [75].
15.	Formaldehyde Resins	Easily reacts with cellular components and cause cytotoxicity, inflammatory reaction, necrosis, allergy, mutagenic effects by denaturation of proteins [76].
16.	Pesticide residues	Genetic disorders, physiological alterations, muscarinic syndrome, disrupts the gastrointestinal tone (nausea, vomiting and diarrhoea), bronchospasm, mitosis, bradycardia; Nicotine syndrome- causes tremors, hypertonicity, hyper flexia, paralysis and effects CNS, respiratory depression and coma [77].

2.0 EFFECT OF TANNERY EFFLUENTS ON THE BACTERIAL DIVERSITY

The organic waste present in the tannery effluents might influence few bacteria whereas the toxic metal components might result in anti-bacterial effect. Not many studies have been done in terms of bacterial diversity and the influence of effluents on various bacterial genera in water ecosystem.Bangladesh which is the hub of tanning industries has conducted few studies in the eco-toxicological aspects of tannery effluents and had come up with interesting findings. Tests were performed to analyze the effects of tannery effluent released into various water bodies [13]. The results showed that the raw tannery effluents were highly contaminated with coliform bacteria indicating risk of water borne diseases. The study results also suggested possible disturbance of ecosystem around the river basin [13]. Similar study conducted in a river in Dhaka that was surrounded by tanneries showed very interesting findings in terms of bacterial diversity [12]. It was observed that higher bacterial diversity was associated with tannery floor where there was a constant supply of organic nutrients from the effluent which was also associated with low concentration of toxic elements. However, in the sites like retention tank where the concentration of nutrients is relatively low and concentration of toxic elements are high the bacterial numbers dwindled [12].Another study from Bangladesh itself reported similar findings related to microbial patterns through molecular techniques [6]. High throughput MiSeq studies performed on tannery effluents showed that effluents suppressed the growth of certain bacterial genera in the streams whereas few of the genera were unaffected. However, this effect was short lived and the bacterial diversity increased after 24 hours [6]. One of the study conducted in India tried to study the impact of tannery effluent on Ganges River [14]. The results showed that lower concentration of tannery effluents were useful in irrigation and seed germination of *Vignaradiata* (Green gram). The reason could be that higher concentrations of inorganic ions like chloride, sulphate,calcium, phosphate, magnesium, potassium, sodium,copper and other heavy metals could be detrimental for plant germination and growth [14].

3.0. BIOREMEDIATION TREATMENT STRATEGIES FOR EFFICIENT DISPOSAL OF TANNERY EFFLUENTS

Efficient methods are required for the remediation of the waste water and reducing the BOD and COD of the effluents. The tannery effluents are known to pose very high risk both to the environment and water bodies if the effluents are contaminating the surrounding water bodies. Initially few plants capable of leaching the heavy metals were grown around the treatment plants where tannery effluents were treated. One such study was conducted in India with plants like *Typhaan gustifolia L*. and *Cyperus esculentus L*. Among them *Typha* species was found to be more tolerant under stress conditions and accumulated more heavy metals in their roots compared to *Cyperus* species [15]. This indicates that these plants can be used to leach potentially harmful heavy metals and later the effluents can be treated for organic matter. Advantage of this method is that *Typha*is a weed that has been extensively studied to be used as a source of biomass or can be used as an efficient biofuel [16]. Although phytoremediation using the weeds like Typha seems a promising strategy for chelating various heavy metals the disadvantages like time consuming process, and the process of chelation depends on the age of the plant and might diminish as the plant ages. Similarly, high concentration of contaminants might lead to toxicity in plants. Disposal of the plants that has quenched the heavy metals is also a very important task as there are chances of contaminants entering the food chain through insects and animals that might accidentally eat them.Therefore, phytoremediation is largely used as option in places where there is no immediate response required [17].

In addition to the several biological methods employing plants several physical and chemical methods have been studied for effective treatment of the tannery effluents. The physical methods include sedimentation, electrofloatation, filtration, membrane filtration, precipitation and coagulation are the most important. The major problem with the tannery effluent is the organic compound concentration in the effluent which are resistant to degradation by chemical or biological treatments [18]. Other important factors that influence the treatment of the effluents include efficiency, cost and environmental capability. Although there are many methods developed to treat the effluents efficiently they are not being implemented due to cost constraints. Chemical methods include treatment of effluents with alum, ozone, peroxide and lime. Lime is used to make the acidic pH of the effluent alkaline [19].Various oxidizing agents like potassium permanganate, potassium dichromate, hydrogen peroxide, hypochlorite and ozone are known to be very efficient in oxidizing various pollutants present in the effluents and convert them into relatively less toxic forms [20,21, 22, and 23]. Advanced oxidation process employing the hydroxyl radicals as oxidizing chemicals gained prominence known as solar Fenton method [24]. However, it was discontinued due to cost constraints. Later combining electricity with chemical oxidation process called electrochemical treatment was introduced but it was found to be ineffective in raw effluent without prior treatment and therefore restricted only to pretreated effluents to greater extent [25]. Electrocoagulation and Electrooxidation are other methods that make use of combination of the electricity and various physical and chemical methods for effluent treatment [26, 27]. Physical effluent treatment processes include filtration, sedimentation using gravity and mechanical treatment includes skimming of grease, oil and fats [28]. Biological treatment involves living organisms and is usually secondary treatment option after the major wastes have been removed through various physical methods. Biological treatment happens both aerobically and anaerobically. In aerobic biological treatmentmicrobial derived enzymes like oxygenases and peroxidases are involved in the degradation of organic pollutants. Recent years have seen development of membrane bioreactors which act like filters and retain most of the microbial biomass for the degradation of the pollutants in effluents [29]. Anaerobic digestion of organic matter and produces various gases like methane, carbondioxide and hydrogen which can be used as biofuels. However, the disadvantages include the process being highly time consuming compared to aerobic respiration. Anaerobic sludge digestors and Upflow anaerobic sludge blanket reactor fall under the category of anaerobic digestion. After studying about these methods question arises as to that which method is most recommended for the treatment of tannery effluent? It was observed that combined method involving both chemical and biological treatment was most efficient compared to single strategy [30].

Recent years have seen a deep rise in various technologies for the treatment of tannery effluents. One such method is the Dual Biological Aerated tower Filter (DBAF). DBAF method claims to have reduced the BOD by 16.0 -23.6 % and COD values by 26.7 -39.4% [7]. It also removed the chromium by formation of flocs. Although this method has reduced the cost by more than 50% compared to other technologies it still requires large space and dedicated plant to establish and run this equipment. Since tannery effluents also have certain hue to them recent technologies have focused on the removal of color along with reducing the COD of the effluents. One such technology is hybrid membrane bioreactor [8]. This method makes use of electrocoagulation process integrated with activated sludge process and microfiltration for efficient treatment of tannery effluents. The reduction in COD was estimated to be 73-76%, whereas the color was reduced by 90-93% which was quite remarkable compared to other technologies [8].However, the method has certain disadvantages like the pretreatment of the effluent to remove various pollutants to increase the life of the membrane from getting fouled within short period of time. Similarly the method was found highly effective when the pH of the effluent was near to neutral pH which again requires treatment of the effluent which is both time taking and also costly [8]. The study assures that by reducing the pollutant concentration the life of the membrane can be extended by few hours to days depending on the amount of effluent being handled by the treatment plant, but still this method is not economically feasible as the membranes used in this technique are costly.

As the search for efficient method for effluent treatment continued researchers came up with the idea of bioremediation. Bioremediation involves usage of live microorganisms for the degradation of various pollutants in the effluents. The advantage of bioremediation is that the biomass obtained after the treatment can be used as biofuel. Several researchers have been focusing their efforts in this direction. Initially, organisms especially fungi isolated from spoiled foods were used to treat the effluents [37]. Later the focus was shifted towards green algae *Pseudochlorella pringsheimii* (VIT_SDSS)which was tested for its ability to degrade the pollutants present in tannery effluents. The results obtained were promising and showed about COD (63%) and Cr (80%) at higher dilution of the tannery effluent [9].However, the disadvantage of this method was that the effluent had to be diluted to reduce the toxicity it carries because of presence of various pollutants. In a quest to overcome this problem, few researchers experimented with methods involving pretreatment of effluent and later employing the algae for bioremediation of the effluent. The pretreatment was ozonization or treatment of the effluent with ozone for a time period to oxidize few components of the effluent.The advantage of ozonization was that it was economical and used very low concentrations of ozone at the lab reactor level i.e. 1.5gm/90 minutes. Similarly the efficiency was equally good with removal of 60% COD within 90 minutes of exposure to ozone at pH 7.6 [10]. However, when synergistic support from marine microalgae *Nannochloropsis oculata* was involved the treatment efficiency further improved and COD was reduced by 84%. In addition to this the inorganic ion levels and chromium levels were reduced by 97% [10]. The above technique was performed in two steps wherein first step, highly toxic tannery effluents were detoxified to certain extent through ozonization and then later the marine microalgae was capable of surviving in the effluent that was relatively less toxic and could completely quench the pollutants from the effluent. This synergistic effect had advantages like reduced consumption of ozone compared to the methods involving only ozonization process. The disadvantages of this method includes the selection of favorable conditions for better efficiency and thereby screening and optimization of various biotic and abiotic factors associated with the effluent is the need of the future.More focus and efforts were put to overcome the problems of effluent pretreatment and also to cut down the cost of effluent bioremediation which resulted in usage of microbial consortia rather than a single organism. In recent years, consortia of microorganisms have been considered for better treatment of the tannery wastewater in Korea through a process termed as "Bioaugmentation" [31]. In this method, group of bacteria belonging to consortium BM-S-1 including *Proteobacteria, Firmicutes, Bacteroidetes, Planctomycetes and Deinococcus-Thermus* species were used for treating the tannery effluents.It was observed that this consortium helped in reducing the COD by 91%, Total Nitrogen by 79% and Total Phosphorous by 90%. Due to this high efficiency it is being proposed that consortia of microbes can be used for treatment of effluents from several sources like food processing industries, waste water plants etc. Large-scale waste water treatment showed similar results using the consortium BM-S-1 resulting in lowering of COD by98.3%, Total Nitrogen by 98.6%, Total Phosphorous by 93.6%, and Chromium by 88.5% [32]. The advantage of this method was that pretreatment was not necessary to treat the effluent thereby saving lot of effort and money. These findings triggered the hunt for various indigenous bacteria found within the waste waters that can be used for the treatment of the effluents effectively without the need for pretreatment. Another study from Kanpur and Chennai in India showed similar findings [33]. *Citrobacter freundii* a species of bacteria isolated from sludge was proven to reduce the COD by 80% and BOD by 86%. Also the heavy metals like Cr and inorganic chemicals like sulphates were reduced by 73% and 68% respectively which met the Bureau of Indian Standards for safer disposal of effluents. Similar studies reported from various countries showed bacteria to be an efficient option for the treatment of tannery effluents with improved results [34, 35]. The term "Microremediation" is being proposed to describe the use of various microorganisms for treatment of various effluents. A very recent study conducted by a group of researchers on marine bacteria isolated from Arabian Sea and from Indian Ocean tried to compare the efficiency of nine isolates for their ability to treat the tannery effluents [36]. This study for the first time focused on marine bacteria capable of producing the siderophores and thereby quenches the various metal pollutants both under aerobic and anaerobic conditions. More studies are underway which focuses exclusively on cost-effective treatment of the tannery effluents across the world in all environmental conditions.

Role of Algae in Bioremediation of tannery effluents

Algae majorly contribute to the tannery effluent treatment processes. They are capable of quenching majority of the contaminants and heavy metals discharge into the tannery effluents. Besides larger surface area/volume ratio for better absorption of pollutants their cellular composition greatly enhances their capacity to remediate the pollutants. Their cell walls are usually made up of polysaccharides which are highly efficient in absorbing the heavy metals. *Spirulina*(blue- green algae) and *Chlorella* spp. are known to be the best choices used in bioremediation of tannery effluents [78, 79]. It was observed that algae are the most resistant towards pollutants [80].However, the disadvantage of employing algae for bioremediation is that algae can just convert the liquid waste into solid waste by quenching the heavy metal ions. Further studies are required as to how this solid waste can be completely eliminated from the environment. Algae are also used in the treatment of effluents as their preferred environment for growth discourages the growth of pathogenic organisms like *Salmonella* and *Shigella*, viruses and protozoa [81]. Microalgae are known to quench heavy metals and several authors have concluded that using algae is the cheapest method for eliminating the heavy metals from various industrial effluents [82, 83, and 84]. Arranging a proper treatment system is also very important for the algae to cleanse the ecosystem in which they are growing. Hyperconcentrated cultures of algae having biomass greater than 1.5g/lit are considered best. However, the major problem in usage of algae as biodegrading agent is their recovery from the effluent after treatment. This problem can be overcome by immobilization process where the algae are immobilized onto an inert support and can be reused for many batches of effluent treatment [85, 86]. Algal mat system is another effective method in removal of nutrients from effluents [87].The algal biomass thus used in the bioremediation can be used for biogas production [88].

Role of Fungi in Bioremediation of tannery effluents

Fungi are multicellular eukaryotes abundantly found in the waste water system. Fungal species like *Aspergillus, Penicillium, Fusarium*are reported to be found in the sectional waste stream.Fungi play a critical role in the tannery waste water treatment at very high acidic pH.

Although acidresistancebacteria exist, there is still a challenge for the bacterial treatment at low pH.Fungal species like *Peacilomycessp, Trichodermainhamatum, Candidamaltose* have been isolated from tannery effluents [89, 90, 91 and 92]. Research done by Juvera-Espinosa *et al* in 2006 showed *Candida spp.* was capable of growing and removing Cr(VI) with greater efficiency [93]. Metal resistant fungi belonging to *Fusarium chlamydosporium, Aspergillus, Rhizopus sp.* were isolated from crop lands contaminated with waste water from tanneries[94-99]. *Fusarium sp*. was found to have better tolerance to the Cr(VI) with 5000 μg/mL compared to *Aspergillus sp*. which had tolerance level of 1000 μg/mL [100, 101]. On the other hand, *Penicillium* species has been reported to have a tolerance of approximately 1040–7000 mg/mL of total chromium [100]. At a lower proportion, fungi such as the *Rhizopus* genus have been reported to have a tolerance to total chromium concentrationof 400 μg/mL and higher limit was found to be 7000 μg/mL [100- 110]. Waste water treatment can employ both dead biomass or live, biomass. However, they have their own advantages and disadvantages. The use of dead biomass does not require preparation of culture media and they can even be employed in the waste waters that were having high concentrations of Cr (VI). Recycling the dead fungal biomass is also relatively easier [109, 110]. However, the disadvantage of using the dead fungal biomass is that the fungal metabolism and biochemical activity is zero [111]. However, when the fungal biomass is alive then biosorption of Cr (VI) happens during the growth of fungi omitting the steps like growth, drying and storage, which are unavoidable in case of dead fungal biomass. However, the disadvantage of using the live biomass is that it is highly dependent on the environmental factors. [112-117]. Contact time between the fungal biomass and the metal ions is also crucial for the biosorption. Biosorption happens in three stages wherein the first stage maximum concentration of the toxic metals is absorbed by the mycelium. Contact time of two hours was known to reduce the concentration of Cr (VI) by more than 50% according using the fungal mycelium of *Rhizopus. arrhizus* [118]. Higher temperatures support biosorption of toxic metals, increase in temperature by 10^0C led to increase in biosorption by 90% in *Trichoderma harzianum* [119]. However, the increase in temperatures although increases the active sites of absorption it can also damage them [120].

Role of Protozoa in Bioremediaton of tannery effluent:

The role of protozoa in treatment of tannery effluent is very interesting. It was observed that protozoa besides absorbing the heavy metals like Cr, Hg, Zn, Cd etc also improved the water quality by feeding upon the bacteria existing in the effluent [121]. Protozoa are known to sequester the toxic elements as granules inside the cell. These granules are known to be generated due to metallothionein [122]. *Euglena proxima, Vorticella microstoma and Solonvchianotilus* were known to be commonly associated with effluents and were found to be relatively resistant to the toxic metal ions that are commonly resent in industrial and tannery effluents [123]. Although protozoa are not potent detoxifiers of Cr (VI) it was observed that they can tolerate the presence of toxic metals along with bacteria and yeast. This indicates that protozoa can remediate the effluents in combination with other microorganisms like bacteria, yeast and algae in the ecosystem through cooperative action. The study also confirmed that protozoans can survive under the stress of heavy metals for years [123].

Role of Bacteria in the Bioremediation of tannery effluents:

Bacteria are known to have highest ability to bioremediate various industrial effluents because of their capacity to produce wide range of metabolites and enzymes which can quench various toxic metal ions. Recent study conducted in Pakistan tested the efficacy of eleven bacterial strains for their abilities to bioremediate the tannery effluent[124]. Another bacterium which was found to be effective in reducing the COD and BOD was *Rhodopseudomonas blastica*[125]. Consortia of bacteria were known to reduce the COD by 80% at salinity concentration of 8%. The bacteria in the consortium were found to be *Bacillus flexus, Exiguobacterium homiense, Pseudomonas aeruginosa* and *Staphylococcus aureus* [126]. Using indigenous bacteria for treating the tannery effluent was studied by Vijayraj et al., and it was found that indigenous microbes like *Citrobacter freundii* is useful [127]. Besides this bacteria help in reducing the total solids in the effluent by using the waste for their growth and development. These advantages make bacteria the most conducible organisms for being employed in bioremediation of tannery effluents.

5.0. FACTORS AFFECTING MICROBIAL BIOREMEDIATION

Microbial bioremediation is a natural process involving aerobic and anaerobic microorganisms. Microbial bioreactors are the controlled environments which are highly employed for the microbial bioremediation as they provide ambient conditions for the microbes to act upon the substrates and degrade them. Several biotic and abiotic factors are responsible for the efficient microbial remediation. *Bacillus.galactosidilyti*APBS5-3 was capable of tolerating highly toxictannery effluent and 63.1 and 41.8% reduction in COD and Cr(VI)after 72 hr indicated a potential application of this bacterial strain in bioremediation [45]. APBS5-3 for bioremediation of tannery effluent Minimum inhibitory concentration (MIC) forCr(VI) was found to be 800 ppm for the *Bacillus galactosidilyti.* The study showed that the pH -7 was ideal for the optimum growth and functioning of the bacteria. Similarly, other parameters like carbon source, nitrogen source, temperature and agitation was optimized to 0.2% glucose, 0.2% ammonium chloride, 37^0C and 150rpm respectively. The parameters were optimized based on various studies that gave supporting data. It was observed in many studies that pH-7 was the most preferred pH for the bioremediation process [46, 47, 48 and 49]. When it comes to the preference of various sugars as carbon source it was observed that glucose was effective in Cr(VI) reduction and attributed itto the chemical structure of glucose as an electron donor, whiledisaccharides (sucrose) and sodium acetate exhibited low valuesof Cr(VI) reduction [48,50]. Another parameter that has to be taken into consideration for the efficient bioremediation is inoculums load. Studies showed that higher inoculums concentrations failed to cause any changes in Cr(VI)reduction, suggesting that competition for limited nutritionalresources restricts the bacterial metabolic activity [51]. Similar results were observed when the agitation was increased above 150rpm as higher agitation led to change incell morphology and damage to bacterial cells caused byshearing effect, which reduced metabolic activities, and hencebioremediation efficiency [52]. High temperature in synergism with high salt concentration has alsobeen reported to induce cell lysis, resulting into reduced biomass growth [53]. It was observed that higher concentrations of polyphenols and sulphates in the tannery effluent [54, 55]. Thereby sulphate reducing bacteria are employed to reduce the sulphate into sulphide during the effluent treatment process. However, the sulphide resulting due to the reduction process is known to be highly toxic to both methanogens and sulphate reducing bacteria themselves. Therefore, to overcome the toxicity a twostageanaerobic treatment and the in-situ removal ofsulphide has been proposed in various studies [56, 57, and 58].

2. Conclusion

To reduce inorganic pollutants like nitrogen and phosphorous the effluent should be subjected to the combination of treatments. With the recent studies focusing on the usage of various bacteria for the bioremediation tanneries can definitely flourish as sustainable industries in India and also globally without polluting the environment.

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