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Bioremediation Application for Textile Effluent Treatment

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Abstract: Enormous volumes of effluent containing hazardous compounds are generated during textile dyeing and finishing processes. It is well known that many dyes are made from known carcinogens as benzidine. Thus the colored effluent if discharge without treatment pose a potential threat to human and wildlife. Moreover, it also affects the aesthetics, water transparency and gas solubility in receiving water. Therefore, the treatment of dyes in wastewater has become a matter of great concern. In recent years, efforts have been made to find the sustainable technique for the degradation of organic pollutant. Because of the recalcitrant nature of synthetic dyes, conventional biological treatment processes proved to be inefficient. But, some new studies have shown that many specific microorganisms are capable to remove or degrade several organic pollutants including dyes. However, the application of bioremediation for the treatment of toxic organics in aquatic environment has been limited. In this review, importance of microorganisms and the essential factors involved in textile effluent treatment using the biological treatment process is discussed and the areas in need of further investigation will be identified. The study may be valuable to scientists and engineers who are trying to develop methods for the treatment of toxic organics using bio mechanical system.

Key words: Hazardous Compounds · Colored Effluent · Microorganisms · Bioremediation

INTRODUCTION

Environmental problems and potential hazards caused by industrial wastewater has prompted many countries to limit the discharge of polluting effluent in receiving waters. Textile manufacturing yields a large quantity of colored and highly toxic wastewater. Many dyes and their intermediate aromatic amines are either toxic or mutagenic and carcinogenic [1, 2]. The presence of these toxic chemicals in the environment poses a serious threat to the health and safety of human and wildlife [3]. Moreover, colored effluent if discharged without proper treatment may provoke serious environmental impacts with resultant change in ecological balance [4]. The textile dyes in the water bodies cause an increased in biological oxygen demand chemical oxygen demand [5]. Moreover, the colored water affects photosynthetic organisms and consequently impact negatively on the food chain. Overall, the discharge of untreated textile dye effluent makes water unsuitable for its intend use [6].

The textile industry is one of the most important and largest industrial sectors in Pakistan. It has a high importance in terms of its environmental impact, as the large volume of wastewater generated during textile processing contains a wide variety of chemicals. Table 1 shows the characteristic of textile mills effluent in Karachi. The reported values lie beyond the permissible limits set by the National Environmental Quality Standard [7]. At present About 75% of wastewater generated from municipal and industrial sources are being discharged into the Arabian sea without treatment. Generally, the textile industries are contributing relatively high quantity of problematic compounds in the environment, as most of them have either no treatment facilities or have grossly inadequate arrangements. Among all pollutants, colour in textile effluent is the main pollutant that has to be

Table 1: Physicochemical Characterization of Textile Mills Effluents in Karachi [8].

S.No	Parameters	NEQS	Values
1	pH	6-9	8-11
2	Total Suspended Solids	200 mg/L	900-2000 mg/L
3	Total Dissolved Solids	3500 mg/L	2500-7000 mg/L
4	Oil and Grease	10 mg/L	10-45 mg/L
5	Biochemical Oxygen Demand (BOD_5)	80 mg/L	120-650 mg/L
6	Chemical Oxygen Demand (COD)	150 mg/L	300- 11000 mg/L

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removed before discharge into the water stream. As color is highly visible in the water bodies and affects aesthetics, water transparency and gas solubility and especially because many dyes are made from known carcinogens as benzidine that pose a potential health hazard to humankind [1]. Moreover, the heavy metals present in textile effluent such as cadmium chromium, copper, iron, nickle, magnese, zinc can bioaccumulate and through the food chain, led to toxic levels in higher trophic level. Any change in pH of water bodies as a result of influx of highly alkaline effluent, can cause serious change in water chemistry, that can affect the natural resources especially around the coastal areas. The discharge of textile waste water can cause serious environmental damages if not properly treated. Overall, the untreated effluent discharge not only affecting the environment but ultimately also having its toll on the country's health as well as economy, by polluting the water bodies. This renders them useless for human consumption, irrigation and industrial processing.

With new regulations and a greater environmental concern, an effective textile effluent treatment technology is therefore needed to prevent water pollution, to protect health and to achieve sustainability in the ecosystem. The purpose of this paper is to give an overview of bioremediation technique, that is environmentally sound, economical and sustainable. The importance of microorganisms and the essential factors involved in textile effluent treatment using the biological treatment process is discussed.

Options for Textile Effluent Treatment: In the textile industry, every production process goes with waste generation. The textile dyeing process yields a large quantity of colored and highly toxic wastewater. No single treatment system is adequate for degrading the various dye structures. Currently, much research has been focused on chemically and physically degrading azo dyes in wastewaters. These methods include chemical oxidation, which uses strong oxidizers such as hydrogen peroxide or chlorine dioxide. Chemical oxidation is sometimes coupled with UV light exposure to increase the color removal. Other techniques involve electrochemical or wet oxidation, activated carbon adsorption, reverse osmosis, or coagulation/ flocculation. These processes, in spite of costs, do not always ensure that the contaminants are completely removed [9] and thus not a viable option for the treatment of large volumes of waste streams.

Of all the technologies that have been investigated, bioremediation technology has been found to be the most cost-effective and environmentally friendly method used for the treatment of many pollutants including dyes. According to Nicholas and Giamporcaro [10], the cost of *in situ* bioremediation can be as little as 1 percent of off-site incineration. In bioremediation, microorganisms are used to destroy or immobilize waste materials [11], usually as contaminants of soils, water or sediments that otherwise threaten public health. This process of detoxification, targets the harmful chemicals by mineralization, transformation, or alteration [12]. For centuries, civilizations have used natural bioremediation in wastewater treatment [13- 16], but intended use for the reduction of hazardous wastes is a more recent development.

Microorganisms Involveld in Bioremediation: Pollution of soil and water through the discharge of domestic and manufacturing waste cause an immense environmental problems. Although microorganisms represent half of the biomass of our planet, but very little (5%) is known about the microbial diversity in the biosphere [17]. The great versatility of microbes offers a simpler, economical and more environmental friendly strategy to reduce environmental pollutant and to help in biodegradation of many xenobiotic compounds. Continuing research with the persistent organic compounds has often been successful in isolating and identifying some microorganisms, or consortium of microorganisms, that can degrade not only simpler compounds like benzene, phenols, toulene, atrazine etc. but also the complex ones like polychlorinated biphenyl (PCBs), dichlorodiphenyltrichloroeth ane (DDT) and hexacholorocyclohexane (HCH) [18- 24].

According to the literature, the microbial strains used for enhancing the degradation of specific chemicals are generally isolated from environmental samples (wastewater, sludge, compost, soil) and selected by conventional enrichment techniques [25- 27]. Soil microorganisms that have been isolated on the basis of their ability to degrade natural or man-made organic substrates including dyes belong mainly to genus *Aeromonas, Alcaligenes, Pseudomonas, Nocardia, Flavobacterium, Arthrobacter and Corynebacterium*, without forgetting the relevant role of fungi and other eukaryotic microorganisms in biodegradation and biotransformation processes [28- 37]. In particular, *Pseudomonas* species are known to metabolize a broad

Table 2: Microorganisms involved in biodegradation of organic pollutant.

Organic pollutants	Organisms
Phenolic compounds	*Achromobacter,Alcaligenes,Acinetobacter,Arthrobacter, Azotobacter, Bacilluscereus,Flavobacterium,Pseudomonas putida, P. aeruginosa and Nocardia Candida tropicalis, Debaromyces subglobosus and Trichosporon Cutaneoum Aspergillus, Penicillium and Neurospora*
Benzoates and Related compounds	*Arthrobacter, Bacillus spp., Micrococcus, Moraxella, Mycobacterium, P. putida and P. fluorescens*
Hydrocarbons	*Eschericia coli, P.putida, P. aeroginosa and Candida*
Surfactants	*Alcaligene, Achromobacter Bacillus, Citrobacter,Clostridium resinae, Corynebacterium, Flavobacterium, Nocardia, Pseudomonas, Candia and Cladosporium*
Pesticides	
DDT	*P.aeruginosa*
Linurin	*B.sphaerius*
2,4-D	*Arthrobacter, P.cepacia*
2,4,5-T	*P.cepacia*
Parathion	*Pseudomonas spp and E.coli,; P. stutzeri and , P. Aeruginosa*
Azo dyes	*Bacillus* sp., *Pseudomonas* sp., *Sphingomonas* sp., *Xanthomonas* sp.

range of organic compounds and therefore are an ideal choice as the bacteria to be used for degradative biotechnologies. They have, in fact, an extraordinary range of catabolic plasmids [38]; a single species such as *P. cepacia* utilizes more than 100 different substrates as the only C, N, or S source [39, 40]. Although a wide range of new microorganisms have been discovered that are able to degrade highly stable, toxic organic xenobiotics, still many pollutants persist in the environment. A list of microbial species [41- 44] involved in biodegradation of xenobiotic chemical is shown in Table 2.

In bioremediation of textile effluent, many microorganisms have been found that are capable of degrading dyes including bacteria [45-47], fungi [48-50] and algae [51]. However, the long growth cycle and moderate decolorization rate limit the performance of the fungal system [48]. In contrast, bacteria could reduce the color intensity more satisfactorily, but individual bacterial strain cannot degrade azo dyes completely and the intermediate products are carcinogenic aromatic amines, which needs further decomposition [52, 53]. Mixed culture studies may be more appropriate for decolorization of azo dyes. It has been observed that by using mixed bacterial culture about 80% of the color removed in an effluent containing mixture of azo and diazo-reactive dyes [54]. Moreover, an isolated microbial consortium were able to remove 67-84% of color from textile dye effluent after 44 hours of cultivation [55].

In recent years, the use of microalgae in bioremediation of colored wastewater has attracted great interest due to their central role in carbon dioxide fixation. In addition, the algae biomass generated has great potential as feedstock for biofuel production [56]. These bioremediation capabilities of microalgae are useful for environmental sustainability [57, 58]. These studies suggest that cultures of bacteria with the ability to degrade specific compounds can be used for bioremediation of polluted waste streams.

Essential Factors Involved in Bioremediation: The recalcitrant organic contamination in soils and water lead to the great need of remediation. In some cases it has been found that intrinsic bioremediation work. At these sites, the microbes needed for bioremediation are already present in the soil or water. However, for synthetic chemical degradation, an engineered treatment system is needed. The treatment of such chemicals can occur via bioaugmented activated sludge, a trickling filter, rotating biological contactors and ion exchange, among other possible systems [59].

Research studies have shown that many microorganisms are capable to degrade chlorinated and other organic contaminants such as oil and mineral chemicals, making biological treatment a technically feasible alternative for many environmental problems [60-65]. However, in some cases the specific compounds have either resisted biodegradation, or their degradation occurs so slowly as to make the biological treatment ineffective. Therefore it is essential for the biological treatment processes; to promote and maintain a microbial population that can metabolize the target wastes. According to literature reports, bioremediation success depends upon the physical and chemical characteristics of the substrate, such as nutrient status and pH and is influenced by environmental factors such as temperature, dissolved oxygen and biotic factors such as inoculum density [66- 69]. In order to influence the effectiveness of biological treatment process, a number of essential factors that are required to be maintained are briefly discussed below:

Microbes: To speed up the bioremediation process, seeding of contaminated wastewater with competent microflora that are capable to degrade hazardous waste is used in the treatment. The inoculated microorganisms either may be naturally occurring types or prepared in the laboratory to attack the target waste. Thomas and ward [70] found that the treatment of chlorinated aliphatic compounds (e.g. carbon tetrachloride. Chloroform, tetrachloroethylene) generally requires mixed cultures. However, Murthy *et al*. [71] have shown that the right consortium or organisms is central to optimizing the degradation activity.

In the laboratory (and theoretically in the field) it is possible to acclimate the naturally occurring soil microbes to specific chemicals and eventually select the strains that can utilize hazardous chemicals as a carbon source. This process usually takes time during which increasing concentrations of the chemical are added slowly. At the end of the process an enriched culture of microbes results. These enriched cultures would be useful to destroy target chemicals in contaminated soil and water.

According to the literature, Nicolas and Giamporcaro state that about 42 different pollutants can be biodegraded by using *Pseudomonas* organisms. These organisms have been isolated, identified and studied by many researcher. One specie *i.e., Pseudomonas putida* was found to remediate PCB in the soil, another specie *Pseudomonas aerogenosa was able to detoxify chlorinated aliphatic solvents. Whereas, Corynebacterium sp. mineralizes p-nitrophenyl in lake water and Arthobacter spp. decontaminate the chlorinated aromatics.*

Nutrients: Cell mass is composed of water, organic compounds and inorganic materials. The inorganic cellular material contains numerous elements including phosphorus, sodium, sulfur, potassium, calcium, magnesium, iron and various trace metals. Metabolism requires these elements as nutrients in addition to organic carbon as substrate. Phosphorus and nitrogen is referred to as macronutrients because the synthesis of cellular tissue requires much more of these than other nutrients. Frequently, nitrogen and phosphorus are not available in sufficient amounts in hazardous waste and must be added, usually as ammonia and orthophosphate. However, no carbon source is required to be added to the culture in the presence of hazardous waste. But in some cases the toxic molecules may be so resistant that their carbon is only easily available to the organisms. Under such circumstance, it may be necessary to add carbon to the extent that an active population can remain sufficiently large.

In addition to nitrogen and phosphorus, many other inorganic nutrients are needed at lower concentrations to ensure unhindered metabolism. These micronutrients include sulfur, potassium, calcium, magnesium, iron, nickel, copper, zinc, various vitamins and others. The micronutrients should have a minimum concentration of 1 to 100 μg/L [72]. In most cases, all micronutrients can be obtained by bacteria from the environment and do not have to be added, particularly if the waste is a contaminated soil or one that has been in contact with soil (e.g. ground water). However, the biological treatment of an industrial process wastewater may require the addition of micronutrients.

Environmental Conditions: Temperature has a major influence on the microbial growth rate. Cellular activity, particularly enzyme systems, responds to heat so that the rate of cell growth increases sharply with increasing temperature until the optimum growth temperature is reached. Increase in temperature only a few degrees above an organism's optimum temperature can slow the growth dramatically. Continued exposure to high temperature may result in cell death.

Unlike high temperatures, low growth temperatures are usually not lethal. Instead, many cells have the ability to become dormant. Metabolic activity decreases at temperatures below the optimum because of reduced enzyme activity and a loss of the fluidity of the cell membranes. These changes may restrict the transport of substrate molecules [73]. A rapid change in low-temperature conditions produces a much greater reduction in cell activity than a corresponding gradual decrease to the same temperature. Gradual decreases may enable the microorganisms to acclimate. Each species of microorganism has a distinct optimum growth temperature and microorganisms have been isolated that are able to survive and grow across a wide range of temperatures.

Oxygen [O_2] availability is an important environmental factor, because most microbes that are able to degrade toxic waste are either obligate or facultative aerobes. Usually, facultative aerobes function more efficiently under aerobic conditions. Consequently most biological systems for treating toxic wastes are designed to operate under aerobic conditions. However, during past decade it has been observed that certain wastes (e.g., halogenated hydrocarbons, some pesticides) can be broken down under a combination of the two conditions, namely, an aerobic and an anaerobic phase in series.

The end product of aerobic processes usually are increased microbial mass, carbon dioxide and various intermediates. Aerobic processes generally are assumed to be more efficient than anaerobic processes. Further, much higher temperatures are also attainable with the aerobic processes. In contrast, certain anaerobic processes have the advantage of producing useful end products, e.g., methane, ethanol, lactic acid; whereas, the utility of aerobic processes usually is limited in effective treatment.

The microbial growth and metabolism also depends on the pH of the surrounding environment. Most bacteria grow best in a relatively narrow pH range around neutrality (i.e., in a range of pH 6 to 8). Die-off typically occurs below a pH of 4 to 5 and above a pH of 9 to 9.5. In the treatment system the microbial activity can alter the pH. Examples include an anaerobic fermentation process, in which bacteria convert the organic compounds to organic acids and thus depressing the pH. Nitrification also lowers pH, as does the carbon dioxide produced by aerobic degradation. The breakdown of organic nitrogen compound can raise pH by releasing NH_4. If the pH changes are significant and not buffered, the altered pH can create a environment that is inhibitory to microbial growth or toxic to the microbial populations present in the treatment system [74].

Bioremediation Advantages: Biological means i.e. microbial metabolism provide an excellent alternative to various conventional physical/chemical treatment methods used for the decontamination of toxic wastes. Generally the off-site biological treatment system for hazardous waste management provide an excellent alternative to this problem. This is the only means to completely mineralize many toxic compounds [75] and have the following advantages:

- They are ecologically sound, a natural process
- The target chemicals are completely destroyed or detoxified into harmless intermediates finally assimilating them forming carbon dioxide and water.
- Biologically-based treatment is reported to be less costly as it employs growing the microorganisms at the expense of the toxic chemicals whereas conventional methods may use costly chemicals/manpower etc.
- Operating conditions are less extreme, elaborated equipment and controls are not needed.
- Bioremediation can often be accomplished where the problem is located, eliminating the need to transport large quantities of contaminated wastes off site.

Bioremediation Limitations: Bioremediation has some limitation as described below and need to be investigated:

- Due to the complex structure of dyes, they are not as easily biodegraded [76]. Therefore, further research needs to be conducted in order to improve current biodegradation methods.
- Bioremediation of dyes are also limited by oxygen availability.
- During biodegradation, partial degradation may result in toxic and potentially volatile products [77].
- As bioremediation work under natural environment, all conditions cannot be strictly regulated. Therefore the treatment results are variable with differing environmental conditions. To ensure acceptable results, extensive monitoring is required throughout the process [59].
- Finally, bioremediation of dyes requires a longer treatment time than other possible detoxifying processes [77].

CONCLUSIONS

To sum up, the following points may be concluded:

- The study may be helpful in understanding the role of microorganisms and the essential factors involved in the operation of bioremediation processes.
- As bioremediation is a slow process, the use of combined processes may overcome many of the disadvantages associated with individual unit processes.
- The study may be valuable to improve the design and operation of biomechanical treatment system used for the degradation of toxic compounds which

are resistant otherwise to conventional biological treatment.

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