Biological approaches to the purification of textile wastewater

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Abstract. The textile industry is one of the major sources of environmental pollution. This is due to the use of a wide range of dyes, surfactants, oxidizing agents and other chemical reagents in technological processes. Modern dyes are characterized by low biodegradability, resistance to chemical and temperature effects of the environment. Therefore, the development of cost-effective and effective measures to combat such pollution is necessary to protect ecosystems and natural resources. This review is a kind of compilation of the available information about the various technologies for the treatment of textile effluents, so that these technologies can be widely used.

1 Introduction

Nowadays, the problem is gaining more and more turnovers, related to production and using dyes [1, 2]. In progress of its work, textile manufacture uses about 8000 chemicals and water volume [3, 4]. Consequently, more than 280,000 tons of textile dyes [5-7] are dumped into wastewater every year. Part of the waste is dumped without any treatment, which results the enrichment of wastewater from the textile industry with mutagens and carcinogens, which leads to destruction of aquatic and soil ecosystems, also jeopardizes human health. Several scientists have reported about direct communication with developed a malignant tumors and influence on the reproductive and immune human system [7-9]. The main fraction of dyes are azodyes, which are complex aromatic compounds with one or several nitrogen groups. These compounds are highly persistent and hardly degradable [10, 11]. If not processed, they would remain in the wastewater for a long period of time.

The dyes disposal from textile wastewater is achieved due to the use of physical and chemical methods, as well as in the process of membrane filtration, oxidation, electrolysis and adsorption [12-14]. Nevertheless, these methods are characterized by high cost and dangerous by-products [7, 15]. The promising analogue is biological purification methods, ones are economical, less sediment formation, environmentally friendly, consume less water and develop safe metabolites [16, 17]. Biological methods are based on the phenomenon of bioremediation - the green method of removing dyes [4, 18]. The mechanism of biological purification consists in the decomposition of dyes to a less toxic
inorganic compound due to a bond break, which contributes to discoloration [19]. The main factors affecting the purification of textile wastewater are the ratio of the organic load of the dye and microorganisms, temperature and oxygen concentration in the system. In dependence on oxygen consumption biological purification methods can be aerobic, anaerobic, anoxic, optional or combined [17].

In recent years, attempts have been made to develop combined methods for the treatment of textile wastewater. Such methods include processes occurring in both physical and biological purification ways. The purpose of the development is obtaining the most effective cleaning technology. As a result, the latest advances in the removal of dyes using biological methods are considered in this review.

2 Main

2.1 Aerobic and anaerobic methods

Depending on the oxygen demand bacteria and biological approaches divide into anaerobic and aerobic. Anaerobic treatment carries out in sealed tanks using anaerobic bacteria. These bacteria can decompose organic substances under anaerobic conditions. Lots of anaerobic bacteria (Bacteroides sp., Eubacterium sp., Clostridium sp) and facultatively anaerobic bacteria (Proteus vulgaris, Streptococcus faecalis) can discolor azo dyes in anaerobic conditions by restoring azocondensation [20]. So, for the bleaching of a monoazodye in anaerobic conditions Morrison et al a strain Clostridium perfringens was used Sharma et al the discoloration of methyl red under anaerobic conditions using Aeromonas jandaei strain SCS5 [21, 22]. The reactive violet 5 was discolored under anaerobic conditions using Bacterial mixed culture-SB4, say [23]. A primary degradation and discoloration of azo dyes is carried out by restoring the azo bond using strong reducing agents (sodium hydrosulfite, thiourea dioxide, sodium formaldehyde sulfoxylate, sodium borohydride). The restoration of azobond is also achieved by the restoration prevailing in anaerobic bioreactors. Amines obtained by the reduction of azodyes are colorless. They are very resistant to further decomposition under anaerobic conditions. The discoloration rate or dyes depends on the structure of the one and an additional source of organic carbon. During the processing, biogas is formed and a considerable amount of heat is released [24].

Aerated lagoons, which seeping filters and stabilization lagoons, are used for aerobic cleaning [20]. The process of aerobic purification is carried out using processes occurring in active sludge and biofilm. The active sludge is a colony of microorganisms. These microorganisms have a high rate of decomposition and adsorption of organic compounds. This purification procedure works on the principle of microorganisms. Its grow up, accumulate together, settle to the bottom of the tank, form organic material and transparent liquid without suspended substances. The purification with activated sludge removes dissolved organic solids substances, besieged and not besieged suspended substances. Another common aerobic cleaning process is biofilm. The principle of cleaning is to attach microorganisms to the surface of a stationary object. At the same time, its forms a biofilm and cleans textile wastewater through contact [25].

At the moment, there are many strains of bacteria are selecting, had the ability to discolor azo dyes in aerobic environments [4]. The strain Klebsiella sp. was used for discoloring an acid blue 25 was used Enterococcus durans GM13 for discolor a reactive green 19, a dark blue, a reactive rad 198 in aerobic condition [26, 27]. Saratale et al said that reactive orange has been discolored by strain a Lysinibacillus sp [28]. Z. Ibrahim et al. investigated the cleansing potential of microbial flakes in the treatment of textile wastewater. Flakes form in a reactor system with an aerobic biofilm. The results of
investigating show the removal of the dye (by 70%) and COC (Chemical oxygen consumption) (by 55%) after 6 days of treatment [29]. The best way to cleaning textile wastewater from dyes is to combine aerobic and anaerobic purification processes [20]. In this case, bacterial purification of azodyes will be occurring in two stages. At the beginning, the reductive cleavage of azo bonds occurs with the formation of aromatic amines. These bonds are toxic and impervious to anaerobic treatment. The second stage includes an aerobic degradation of aromatic amines Rajaguru et al. inform about sulfonated dyes degradation (CI Acid Orange 10, CI Acid Black 1, CI Direct Red 2, CI Direct Red 28) combined situation with helping by glucose . Results demonstrate the reduction of azo dyes into aromatic amines, which hereinafter are mineralized during aerobic treatment shows the work of the anaerobic-aerobic system. This system was used for the treatment of simulated textile wastewater with a reactive azo dye CI Reactive Red 141. The research demonstrates developing aromatic amines after anaerobic degradation with subsequent degradation in anaerobic stage in polar, non-aromatic co-product. Removing pigment, COD, BOD, is 75%, 84,8% and 95,5% respectively [30].

2.2 Bacterial method

Bacterial method is used for the purification to textile wastewater from dyes. Bacteria propagate rapidly and cultivate easily, which is the most advantage using this way. So, bacteria are great for discolor, breaking down and mineralizing textile pigments in anaerobic, aerobic and mixed environments [31, 32]. At the same time, the bacterial activity process in aerobic and anaerobic conditionals are too different [33, 34].

A lot of works were dedicated to researches on the purification of textile wastewater using bacteria. So, [35] was discolored 95% CI Reactive Red 180 at 36 hours used Citrobacter sp. CK3. In Wu ea al. [36] work, Schervanella oxeidensis WL-7 was used to purification from CI Reactive Black 5. Results demonstrated the full purification during 12 hours. Potential Pseudomonas putida SKG-1 was explored by [37]. Results of the work demonstrated the purification about 92,8% of dye at the concentration of 100 mg/l at 96 hours (the temperature is 30°C, pH 8). In its work, Jadhav et al. explores the discoloration of red Remazol by Pseudomonas aeruginosa during at 20 minutes with pigment concentration of 50 mg/l, pH 7, the temperature is 40°C, in static state. Results of the research demonstrate 97% discoloration [38].

The removal of the dye in aerobic conditions is usually complicated. Consequently, in the presence of oxygen, the reconstruction of azo-bond seems to be a hard process [39]. However, there are bacteria with the ability to metabolize azo-dyes by reducing processes in aerobic conditions. These bacteria produce oxygen-sensitive azo-reductase, which uses Nicotinamide adenine dinucleotide (NADH). Azo-reductases are also emits, which are not sensitive to oxygen. Its use reducing processes to break down azo-compounds and produce aromatic amines in aerobic conditions.

An interesting example of the discoloration of chemically active dyes in aerobic conditions is using Micrococcus sp. Complete discoloration of the dye is achieved at 6 hours. However, the time increased at 24 hours in anaerobic conditions [40]. Olukanni OD et al. reports 98.4% discoloration with Micrococcus R3 methyl red in aerobic conditions at 6 hours at pH 7, the temperature is 37°C [41]. Ayed L et al. reported that also about discoloration (98%) in aerobic conditions of methyl red has being used Micrococcus R3 strain (the concentration is 850 mg/l, pH 9, the temperatures 30°C, at 10 hours) [42].

The textile wastewater treatment in anaerobic conditions with the help of bacterial approach provided by simple and viable process. Cytoplasmic azo-reductases reconnect bonds in dye molecules. This process lead to formation toneless aromatic amines. Such compounds are impervious to mineralization in anaerobic conditions and are dangerous to
human [34]. At the same time a source of carbon and energy is required to remove dyes. The removal rate depends on the structure of the dye and the added carbon source.

Wang H et al. inform about 92% purification of reactive black 5 in aerobic conditions for 120 hours. About decay of the anthraquinione-based reactive blue 19 by Enterobacter sp.F NCIM 5545 is reported by Holkar et al and Yu et al indicate the discoloration of orange methyl with the Klebsiella oxytoca strain for 48 hours at pH 7 and temperature 30°C [44, 45].

The formation of toxic aromatic amines or metabolites during the treatment of textile wastewater causes a problem. The process of decomposition of such compounds more difficult than the initial dyes. One of the solutions to the problem of decomposition of toxic aromatic amines is the use of mixed bacterial cultures. This approach has many advantages. Variants bacteria during decomposition of azo dyes attack to molecules in different position and use metabolites produced by other strain to promote decomposition and in some cases for mineral dye [40, 46].

Thus, in their work report on microaerophilic processing of orange II using a consortium of E. casselilavus and E. cloacae (NAR-1). The results show the formation of sulfanilic acid [40]. Such an acid is susceptible to decomposition by the same consortium under aerobic conditions. About 97% decomposition within 24 hours of direct blue dye 15 with a concentration of 250 mg/l (98 COD) is reported by Jain et al. and Ruiz-Arias et al. worked on the discoloration of acid orange with the help of a bacterial consortium [47, 48]. Ruiz-Arias et al. worked on the discoloration of acid orange with the help of a bacterial consortium Pseudomonas, Arthrobacter and Rhizobium. The results showed complete discoloration at a concentration of 200 mg/l, pH 7[48].

2.3 Wetlands

The direction of wastewater treatment is gaining increasing relevance including textile, with the use of wetlands. Wetland (CW) is an efficient, easy-to-use, inexpensive and eco-friendly system by. Such a system filters the runoff, helping to remove sediments, nutrients and pollutants, slow it down and help control flooding downstream. Like natural wetlands, they look attractive and serve a home and refuge for wildlife [49, 50]. The main functions of the wetlands system are: preservation or storage of water for a long period; prevention of floods and soil erosion; increase of biological productivity; improvement of water quality; restoration of groundwater quality [51]. CW is a shallow basin, filled some kind of filter material (substrate), usually sand or gravel, and planted with vegetation, resistant to saturated conditions. Wastewater is introduced into the basin and flows through the structure or through the substrate, and then is leaked out from the basin through a structure that controls the depth of wastewater in wetlands. Purification processes occur in contact with the substrate surface and rhizospheres of plants. Therefore, for CW designing the most important is the selection of suitable substrates, namely type and size, hydraulic conductivity, porosity, filtering property, sorption, ion exchange and Reed complexation. The design of the system of artificially created CWS is generally divided into horizontal surface or underground flow, vertical flow and a system of floating rafts. [52].

Currently, many scientific studies have been conducted on the treatment of waste water from the textile industry from dyes using CW. Thus, Alenka Ojstrsek et al. conduct a study on the purification of CWs on three laboratory prepared residual dyes - C. I. Reactive Red 22, C. I. Jet Black 5 and C. I. Vat Red 13 e. The results show a 53% reduction in color (after 1 h) to 70% (after 24 h) for C. I. Reactive Black 5.2% after 1 h and up to 40% (after 24 h) for C. I. Reactive Red 22 [53]. Cleaning efficiency artificially created wetlands (CW) for dye-rich textile wastewater with special emphasis on color reduction were carried out by [54]. The results obtained indicate that the applied CW model decline the color to 70%, and
COD and CBT to 45%. Zahid et al. in their work, CW was used to purify dye-rich real textile wastewater. The results of the study show an increase in dissolved oxygen up to 188% and a significant decrease in chemical oxygen demand (81%), biochemical oxygen demand (72%), total dissolved solids (32%), color (74%), nitrogen (84%), phosphorus (79%) and heavy metals: Cr (97%), Fe (89%), Ni (88%), Cd (72%) [55]. Soon-An et al. evaluated the treatment of Acid Orange 7 azo dye and nutrients using five laboratory wetlands with an updraft (UFCW) with and without additional aeration, as well as with various surface plants. The removal efficiency of Acid Orange 7 was above 95% in all UFCW reactors, and most of the color was removed in the anaerobic region of the UFCW layers. Removal of TN and TP was 60-6% and 26-37%, respectively, COD - 86% [56].

2.4 Fungal method

Fungi are one of the most important living organisms. They are able to decompose dyes, thereby purifying textile waste water. There are many types of fungi that biosorb or discolor various dyes. Thus, Kumar et al. explored the removal of the bright green dye Aspergillus sp. at pH 5, temperature 35 °C, concentration 10 mg/l and stirring. The result was the removal of 99.2% of the dye within 72 hours. This method is called inexpensive and easy to use [57]. The red azo dye in aqueous solutions (1000 mg/l) was discolored by Mahmoud et al. at pH 9 using Aspergillus Niger [58].

The main purpose of fungal cleaning is to purify the waste water of the textile industry. Achieving the goal is the consumption of organic substances by funges to reduce COD and BOD. The purification of dyes occurs due to the coding of fungi laccase, manganese peroxidase and lignin peroxidase by fungi. These enzymes are able to carry high concentrations of harmful substances and allow fungi to decompose dyes [31]. However, some researchers claim that it is more effective to use bacteria remove dyes rather than fungi, due to the most rapid discoloration of [59].

There are several types of fungi capable to decomposing dyes. The main ones are white rot mushrooms and filamentous mushrooms. White rot fungi represent a class of microorganisms that decomposes synthetic Ali dyes most effectively [59]. So, one of the most common is Phanerochaete chrysosporium.

This fungus is capable of decomposing many persistent pollutants (chlorophenols, nitrotoluenes and polycyclic aromatic hydrocarbons) and discoloring a wide range of different dyes, including azo dyes (Orange II, Congo Red and Tropeolin) under aerobic conditions [60-62].

Thus, Enayatizamir N et al. degradation of the Azo Black dye was observed Reactive 5 in processing with Phanerochaete chrysosporium and achieved 92% discoloration after 3 days [63]. Lee et al. white rot fungi Coriolus versicolor and Schizophyllum commune were used in the work to purify textile wastewater with a color of 1000 Pt/Co and COD 4000 mg/l. Coriolus versicolor showed an 80% reduction in COD (after 9 days) and 68% color removal (after 5 days) [64].

However, the decomposition of dyes in textile wastewater by white rot fungi has its disadvantages: a long growth phase, the need for restrictive environments with nitrogen, unreliable enzyme production and a large reactor size [65, 66].

The use of filamentous fungi in the process of discoloration of textile wastewater is an attractive alternative due to the low cost and the possibility of complete mineralization of the dye [67]. Filamentous fungi have a lower sensitivity to changes in temperature, pH, nutrients, and aeration by. Also, this type of fungi has a lower content of nucleic acids in the biomass and the ability to exist with dyes as a single source of carbon when cultivated under two different conditions - aerobic and anaerobic [68].
Many works are devoted to the study of wastewater treatment of the textile industry with the help of filamentous fungi. Thus, in their study, Joutey et al. work with filamentous fungi. The results show that filamentous fungi are an effective in decomposing [69]. Because its have a high surface-to-cell ratio. Trametes versicolor was investigated by Cano et al. for discoloration of direct brown dye at a concentration of 100 mg/kg, 2 COD [70]. The results show 100% discoloration. Ali et al. discolored Acid Red 151 and Orange II (at concentrations of 20 mg/kg) with Aspergillus flavus. In the course of the work Ali et al. achieved 98% discoloration of Acid Red 151 and 58% Orange II [71]. Majeau et al. report that the oxidation of azo dyes by filamentous fungi occurs through peroxidases and phenol oxidases, which solves problems with the formation of amine during the reduction of azo dye [72].

2.5 Enzymatic decomposition

Enzymes promote the sequential cleavage and decomposition of complex compounds. The most effective enzymes in removing dyes from textile wastewater are: azoreductase, laccase and peroxidase [73].

Azoreductases are called enzymes that initiate a catalytic reduction reaction. This reaction leads to the destruction of the azo group bond (–N=N-) and converts the aromatic amine into colorless water. Azoreductase can also be called one of the rare primary amino acids [74]. Azoreductase is suitable for the destruction of acidic red and reactive blue. Thus, Ramya et al. report the participation of azoreductase in wastewater treatment from textile dyes, namely acid red [75]. The biological source of azoreductase is the bacterium Acinetobacter radiotolerans. Also in Pandey and Dubey the reactive red is purified using an azoreductase enzyme obtained from the bacterium Alcaligenes sp. AA09 [76]. Khan and Malik the reactive black was bleached using azoreductase at pH 5-9 and temperature 37°C for 120 hours. The enzyme is isolated from the strain Pseudomonas entomophila BS1. The results show 93% discoloration [77]. Decomposition of orange II at a concentration of 6 mg/l under static conditions c using the azoreductase enzyme. Discoloration occurred at a temperature of 37°C for 48 hours. The results showed 76% discoloration [78].

Laccases are multicomponent enzymes from the group of oxidases with four copper atoms at their catalytic level [79]. These enzymes catalyze one-electron oxidation of substituted aromatic compounds to the corresponding radicals with concomitant reduction of molecular oxygen to water by [80]. Laccases also have the ability to oxidize a wide range of substrates. This ability gives a high potential for the treatment of textile wastewater [81]. The ability to decompose phenolic compounds makes laccases suitable for decomposition xenobiotic compounds in the process of purification of textile wastewater [81, 82]. Laccases are most suitable for the discoloration of amaranth dye, direct blue 14, methyl orange, new crown red.

Thus, Bibi and Bhatti report discoloration of the active black dye by 43% in textile wastewater for 30 minutes using laccase. The enzyme was obtained from a strain of Trametes versicolor bacteria [83]. Another example of the discoloration of dyes in textile wastewater is the work of Ilyas et al [84]. Results of research demonstrated 96% discoloration for 24 days using laccases from the strain Pleurotus ostreatus. Kurade et al. reports about the full discoloration of the scarlet R azo-dyes in concentration about 30 mg/l by ferment laccase. The discoloration occurred in a static, oxygen-free state and the temperature is 30°C, pH 6.6 for 48 hours. The ferment was obtained by Microbial consortium DAS strain [85]. Kalme et al. also explored the dyes discolored in textile wastewater. At their work, they explored the discoloration of CI Direct Blue 6 dye due to the oxidative laccase ferments activity from the strain Pseudomonas desmolyticum NCIM 2112. Results demonstrated the full discoloration after 72 hours on a statistical status [86].
Peroxidases are classified as non-specific extracellular ligninolytic ferments [82]. These ferments are most effective for removing synthetic dyes. As a rule, the removal of synthetic dyes occurs by depolymerization, demethylation, decarboxylation, hydroxylation and aromatic ring opening reactions [87]. There are many types of peroxidase ferments. As an example, manganese peroxidases and lignin peroxidases can be distinguished. The first group consists of the oxidoreductase class ferments. These peroxidases group acts on phenolic compounds by an intermediate redox reaction with the help of ions $\text{Mn}^{2+} / \text{Mn}^{3+}$. While lignin peroxidases attack methoxy substituted lignin subunits, which behave like a substrate [88].

Verma and Madamwar explored the biodegradation of dyes in textile wastewater. Blue and brilliant blue are considered as a dye. Ferments are manganese peroxidases obtained from the Serratia marcescens. Results demonstrated 90% of the discoloration pigments for 8 days (for blue) and for 5 days (for brilliant-blue) [89]. In the Bholay et al. work explored the discoloration of textile wastewater using lignin peroxidase. The ferment was obtained from Pseudomonas aeruginosa and Serratiamarcescens. Research results demonstrated 50-58% of the discoloration (information about the time and specific dyes is not provided) [90]. Vishwakarma et al. was experienced on the discoloration azo dye Direct blue; CI 23850 in aerobic environment. In the Vishwakarma et al. work used the manganese peroxidases. Results demonstrated 99% of the discoloration for 18 hours [91].

3 Conclusion

The removal of dyes from textile wastewater is achieved by physical and chemical methods, as well as through membrane filtration, oxidation, electrolysis and adsorption processes. However, these methods are expensive and have dangerous by-products. This review reviewed recent advances in dye removal using biological methods that are economical, less sludge-producing, environmentally friendly, use less water and produce safe metabolites. Depending on oxygen consumption, biological treatment methods can be classified as aerobic, anaerobic, anoxic, facultative or combined. When choosing a biological method for a particular composition of wastewater, it is necessary to take into account a number of factors that affect the ability of the dye to decompose (the ratio of the organic load of the dye and microorganisms, the dye class, pH, temperature and oxygen concentration in the system).

References


