CHALLENGES IN TEXTILE WASTEWATER AND CURRENT PALLIATIVE METHODS: AN OVERVIEW

IBRAHIM ADEBAYO BELLO[1], NASSERELDEEN AHMED KABBASHI[1]*,
MD. ZAHANGIR ALAM[1], MA'AN FAHMI ALKHATIB[1], FATIN NABILAH MURAD[1]
AND ISSAM YASSIN QUDSIEH[2]

[1]Department of Biotechnology Engineering,
International Islamic University Malaysia,
Jalan Gombak, 53100 Kuala Lumpur, Malaysia.
[2]Chemical Engineering Department,
College of Engineering,Nanotechnology Research Unit (NTRU)
Jazan University
P.O.Box 706, Jazan 45142
Saudi Arabia

**Corresponding author: naserldin@iium.edu.my*

(Received: 15th Sept. 2017; Accepted: 20th Sept. 2017; Published on-line: 1st Dec. 2017)

ABSTRACT: Effluents from dye and textile industries are highly contaminated and toxic to the environment. High concentrations of non-biodegradable compounds contribute to increases in biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the wastewater bodies. Dyes found in wastewater from textile industries are carcinogenic, mutagenic, or teratogenic. Biological processes involving certain bacteria, fungi, activated carbon, and carbon nanotubes (CNTs) are promising methods for treating the wastewater. These methods are either inefficient or ineffective. These complexities necessitate a search for new approaches that will offset all the shortcomings of the present solutions to the challenges faced by textile wastewater management. This article reviews the past and recent methods used in the treatment of textile dye wastewater and future opportunities for efficient treatment of textile wastewaters.

ABSTRAK: Sisa daripada pewarna dan industri tekstil telah mengakibatkan pencemaran yang teruk dan pembuangan toksid kepada alam sekitar. Kepekatan tinggi pada kompaun bukan bio-kitar semula menyumbang kepada peningkatan permintaan bio-kimia oksigen (BOD) dan permintaan kimia oksigen (COD) pada sisa air buangan. Pewarna yang dijumpai daripada industri kain adalah karsinogenik, mutagenik atau teratogenik. Proses biologi melibatkan sesetengah bakteria, kulat, karbon diaktifkan dan karbon nanotiub (CNTs) merupakan kaedah-kaedah yang dijanjikan untuk merawat sisa air. Kaedah-kaedah ini samada tidak efisien ataupun tidak efektif. Ia memerlukan pencarian kepada pendekatan baru yang akan menghilangkan semua kekurangan pada solusi terkini kepada cabaran-cabaran yang dihadapi dalam pengurusan air sisa buangan kain. Artikel ini akan mengulas kaedah-kaedah terdahulu dan terkini yang telah digunakan dalam pengurusan air sisa buangan pewarna kain dan peluang akan datang bagi mendapatkan pengurusan yang cekap pada air buangan sisa tekstil.

KEYWORDS: *wastewater; dye; fungi; carbon nanotubes*

1. INTRODUCTION

Effluents (dye wastewaters) discharged from textile and dyestuff industries, as a result of the dye materials, are highly colored and contain a high level of non-biodegradable compounds, soaring up its biochemical and chemical oxygen demand [1]. The release of colored wastewater into the environment signifies a hazardous effect for aquatic life. Effluents from dye industries usually contain a high amount of chemicals that are known to be highly toxic, teratogenic and equally carcinogenic to the plant and animal community. Due to the complex molecular structure of the dyes [2], they have proven very difficult to treat by conventional biological and physico–chemical processes. Dye wastewater effluent, therefore, needs to be well treated (dye removal) before being released safely into the environment. Its impact on water bodies, and particularly on the growing public, is highly devastating. Therefore, there is a very urgent need for dye wastewaters to be treated. Due to their color, they significantly affect the activities of photosynthesis in aquatic life, bringing about turbidity and reduced light penetration.

Moreover, due to the presence of aromatics, metals, chlorides, etc. in these effluents, aquatic plants and animals may become toxic and unsafe for human consumption. Usually having synthetic origins and complex aromatic molecular structures, dye components are hardly degradable and their concentration (of as low as 1.0 mg/l) could contaminate water, making it unfit for drinking and other domestic usage [3]. The main objective of this article is not only to create awareness on the current trend of dye wastewater treatment but also to recommend the application of the latest treatment methods to solve the problem.

2. PAST, PRESENT AND FUTURE OPPORTUNITIES

In the past, so many methods have been employed in the removal of dye from industrial effluents. The various methods that have been employed can be broadly categorized into three: physical, chemical, and biological methods. These methods include removal of debris, filtration, flocculation, precipitation, adsorption, ion exchange membrane, electro chemical technologies, sedimentation and then use of processes such as the activated sludge process wherein microbes are introduced into wastewater to remove biodegradable material, that may then be followed by some chemical additions for the best treatment. However, literature studies have shown that these technologies are not without some major setbacks such as low efficiency, high cost, and a non-environmentally-friendly nature, amongst others [4]. The methods have been extensively reviewed [5] and due to the complex molecular structure of dyes, it has proven very difficult to treat by the conventional biological and physico-chemical processes [2]. Recently, several researchers have shown that biosorption (adsorption) can be a better substitute to the physicochemical, microbial and or enzymatic biodegradation methods. Among treatment technologies, adsorption has been shown to be the most promising option for the removal of non-biodegradable organics from aqueous effluents. So many adsorbent materials, such as activated carbon, cotton, velvet, sponge, clay, and carbon nanotubes (CNTs), are in existence. CNTs have gained a high popularity due to their large specific surface area and nano structure, outstanding thermal and chemical stability, excellent adsorption efficiency, environmental friendly nature and high flux membranes, high reactivity, porosity, surface functional groups, binding strength, high affinity between sites and the particular pollutant of interest, high adsorptive capacities etc. From various research conducted, CNTs have been excellent in the treatment of heavy-metal-contaminated aqueous solutions [7]. They are, however, very expensive [8] and they have some disadvantages when used in high concentration for removal of pollutants.

Apart from CNTs, other adsorbents have also been used in textile dye removal. Recently, a number of studies have focused on low-cost adsorbent that is capable of degrading and adsorbing dyes from wastewater. A material could be assumed to be low cost if it is abundant in nature, inexpensive, requires little processing, and is effective in the treatment process [9]. Low-cost adsorbents could be obtained from any agriculture and industrial by-products, natural materials, and biosorbents that contain high surface area and porosity [10]. Adsorption of dyes onto low-cost adsorbents is largely dependent on dye properties such as molecular structure and type, number and position of substituent in the dye molecule [11], source of raw materials used, preparation and treatment conditions such as pyrolysis temperature and activation time, surface chemistry, surface charge, pore structure and surface area of the adsorbent [12].

Nowadays, the adsorbents mostly investigated for different effluent treatment are dead plants and animal residues, known as biomass, which includes charcoals, activated carbons, activated sludge, compost, and various plants.

2.1 Activated sludge

The most widely used adsorbent is activated sludge. Important factors affecting the optimum adsorption of color with activated sludge are its quality and concentration, the hardness of the water and the duration of the treatment. Research by [13] investigated the application of activated sludge for the removal of water-soluble acid and reactive dyes and water insoluble disperse dyes. They found that the concentration of sludge, water-hardness and time for optimum removal of color were 3 g/l, 80 mg/l, Ca^{2+} and 1–2 days, respectively. Although activated sludge is suitable for removal of various textile dyes, it alone cannot satisfy modern day's tight consent limits.

2.2 Clays

Clay is one of the biosorbents that can be used in the treatment of dye wastewater. Clay minerals are important inorganic components in soil. Their sorption capabilities come from the high surface area and exchange capacities. The negative charge on the structure of clay minerals gives clay the capability to be modified by the surfactant. Different types of clays and diatomaceous earth, including activated bleaching earth, montmorillonite, bauxite, alumina pillared clays, mesoporous alumina, aluminum phosphates and bentonitic or kaolinitic clays were investigated for wastewater treatment [14]. Their use encourages flocculation of organic impurities. The feasibility of using peat and lignite as adsorbents for the removal of basic dyes was studied by [15]. A two resistance model based on external mass transfer and pore diffusion was developed to predict the performance of agitated-batch adsorbers, but the validity of the model was not tested against a real industrial effluent.

2.3 Activated Carbon

Activated carbon is the most widely used for the removal of a variety of organics from water [16], but the disadvantage associated with it is the high regeneration cost and the generation of carbon fines, due to the brittle nature of the carbon used for the removal of organic species. Carbon nanotubes are also quite expensive (the higher the quality, the greater the cost), non-selective, and ineffective against dispersing and vat dyes. One of the main disadvantages of activated carbon is also fouling by natural organic matter (NOM) [17]. It competes with other organic pollutants for adsorption sites and prevents them from entering the micro-pores by blocking them. They also showed the possibilities of using activated carbon fiber (ACF) as an alternative to granular activated carbon and claimed it to be less affected by the presence of NOM. The use of alternative cheaper carbonaceous adsorbents, including coconut husk charcoal and pyrolyzed bagasse char was also investigated for decolorization and reduction of COD and found to be as efficient as activated carbon [18]. This has thus simulated research into specialty absorbents using synthetic resins that may facilitate a cheap and effective chemical regeneration process.

The last three decades have witnessed an extensive study of biomass being a perfect replacement for activated carbon. Microbial decolorization is now given much attention for textile dye wastewater treatment because of its cost-effectiveness [19]. Different researches have been conducted to see the effects of microbes on the adsorption of various pollutants ranging from heavy metals to organic materials. Such research works have demonstrated the capacity of various microbial biomass (bacteria yeast, fungi, and algae) and agricultural waste materials to adsorb or accumulate dyes [20]. Among the various types of biomass, the fungal biomass has proven to be particularly suitable [21]. *Aspergillus niger* has been experimented and found to be important in the biodegradation of toxic chemicals, treatment of waste beet molasses, olive mill waste, and bioconversion of wastewater sludge. A waste fungal biomass containing killed cells of *A. niger* has been efficiently utilized for the removal of toxic metal ions such as nickel, calcium, iron and chromium from aqueous solution. Fungi have advantages over bacteria because fungi are able to degrade more complex substances and a variety of substrates. The advantages of fungal treatment are cost-effectiveness, environmental-friendly, toxic compound removal, and sludge reduction [22]. Table 1 shows the adsorption capacities for some microorganisms and materials and from the table, it is shown that dead macro fungi, *Rhizopus nigricans* (fungi) and jute fiber carbon (JFC) all have very high adsorption capacities.

Table 1: Adsorption capacities for some natural materials

Dye	**Material used**	**Adsorbent capacity (mg/g)**	**Working Isotherm**	**References**
Reactive dye RY-145; RB-B	Sorel's cement	RY-145 D 107.67 RB-B D 103.14	Langmuir isotherm	[23]
Congo red	Australian kaolin	More than 85% colour removal	Langmuir isotherm; pseudo-firstorder kinetic model	[24]
MB(Basic dye)	Dead macro fungi	232.73	Langmuir isotherm	[25]
Reactive Dye Reactive Black 8; Brown 9; Green 19; Blue 38	*Rhizopus nigricans*	90–96% adsorption of the selected dyes	Langmuir and Freundlich isotherm	[26]
MB	Glass wool	2.24	Langmuir and Freundlich isotherms	[27]

MB	The brown alga *Cystoseira barbatula*	38.61	Langmuir isotherm; pseudosecond-order kinetic model	[28]
Reactive red	Jute fiber carbon (JFC)	200	Langmuir isotherm; pseudosecond-order kinetic model	[29]

The main reasons why biosorption remains the best method for dye removal from industrial effluents are its high selectivity and efficiency, good removal from large volumes, and the potential cost effectiveness. The majority of the physico-chemical technological processes such as ion-exchange, dilution, coagulation and flocculation, adsorption, chemical precipitation, oxidation, reverse osmosis and ultra-filtration are presently employed for color removal from the aquatic media. However, due to high cost, formation of hazardous by-products, intensive energy requirements and inefficient reusability of adsorbents, limitations have been encountered during the application of these techniques [30].

Various classifications of fungi exist. Microscopic fungi include yeasts with spherical budding cells and molds with elongated filamentous hyphae in mycelia. The molds are filamentous fungi, such as *Pencillium, Aspergillus,* etc. The body or vegetative structure of a fungus is called thallus (pl., thalli), which varies in complexity and size from a single cell microscopic yeast to multicellular molds. A single filament is called a hypha. Hyphae usually grow together, collectively to form mycelium. Most fungi are sturdy organisms and can generally tolerate more levels of pollutants and contaminants than bacteria. Bioremediation capabilities of fungi in the tropical forest may not be as effective as those in the temperate regions.

Many genera, either in living or dead form, of fungi have been employed for the removal of dye in aqueous solutions, as shown in Table 1. The use of microorganisms in dye treatment such as the use of bacteria to degrade azo dyes started in the 1970s with reports of *Bacillus subtilis*, followed by *Aeromonas hydrophila*, and *Bacillus cereus* [31].

The use of fungi as adsorbents in wastewater treatment is known as bioadsorption or biosorption. Use of bioadsorbent in the adsorption process can reduce dye concentration to parts-per-billion (ppb) levels. Bio-adsorption is a novel, cheap, and effective process [32].

Different types of dyes have also been used in the textile industries. Dyes can be defined as soluble colored substances that can be applied mainly to textile materials from a water solution. Dye molecules comprise two main components: chromophores and auxochromes. Chromophores are known as a group of atoms principally responsible for the colour of the dye. The most important chromophores are the azo (–NDN–), carbonyl (CDO), methine (–CHD), and nitro (–NO_2) groups. Auxochromes are useful in providing an essential "enhancement" of the colour [33]. Common auxochrome groups (include hydroxyl (OH) and amino (NR_2) groups) normally increase the intensity of the colour and shift the absorption to longer wavelengths of light [33, 34].

Synthetic dyes are solely recalcitrant organic compounds that are extensively used in various branches of textile industries [35], pulp and paper industries [36], leather tanning industries [37], food industries [38], agricultural research [39], hair colorings [40], light-harvesting arrays [41], etc.

However, nowadays, scientists have started looking into genetic manipulations of microorganisms to aid the production of biological agents whose efficiency will be more than the existing ones and also with an option of using purified enzymes for decolorization [42]. According to the literature, fungal decolorization has great potential to be further developed as a solution to the dye wastewater treatment problem in the near future [42].

3. CONCLUSION

The review shows that different methods have been employed in treating wastewater. However, the methods are either ineffective or inefficient. The ineffectiveness of the previous methods of dye wastewater treatment, therefore necessitates the search for new approaches that would help to offset all the short comings of the past and present methods.

Based on the characteristics of CNTs and fungal biomass presented, it will be interesting to develop a biosorbent where a matrix of carbon nanotubes immobilizes a biomass, such a biosorbent would be able to combine the powerful adsorptive abilities found in both for a very effective dye wastewater treatment.

4. RECOMMENDATION

Although, its application in the removal of textile dyes is yet to be ascertained, CNTs have been investigated as the best adsorbent for industrial pollutants even from dilute solutions [6]. Fungal biomass has also proved to be particularly suitable for the adsorption processes [11]. Therefore, a low-cost immobilization technique using CNTs and fungal biomass could be an effective alternative to overcome the current problems, with an added advantage of helping to remove very low concentration pollutants. This will bring about the development of a novel biosorbent as CNTs immobilized fungal biomass (CNTIB) to treat low concentration of dyes in the textile industry.

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