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Effects of Textile Industry Effluents on Water Quality Index

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ABSTRACT: Textile processing is one of the oldest and most technologically complex industries. This industry's fundamental strength stems from its strong production base of a diverse range of fibers/yarns ranging from natural to synthetic fibers and chemicals. Textile mills and their wastewater have grown in proportion to the increase in demand for textile products, causing a major pollution problem around the world. Many chemicals used in the textile wet-processing like dyes and auxiliary chemicals are hazardous to the environment and human health. The global environmental problems associated with the textile industry are typically those related to water pollution caused by the discharge of untreated effluent, and the use of toxic chemicals, during processing. Textile effluent is a critical environmental concern because it reduces oxygen concentrations due to the presence of hydrosulfides and blocks the passage of light through water bodies, both of which are harmful to the water ecosystem. Thus, this review focuses on textile effluent treatment techniques and the physical-chemical treatment parameters taken into consideration during primary, secondary, and tertiary treatment processes. It also discusses effluent of biological-oxygen-demand (BOD) and chemical-oxygen-demand (COD), pH, total dissolved solids (TDS), total suspended solids (TSS), and turbidity. With more severe restrictions expected in the future, control measures must be implemented to minimize effluent pollution. Textile manufacturing processes encompass pretreatments, dyeing, printing, and finishing operations. These production processes not only consume large amounts of energy and water but also produce a significant amount of waste products. To reduce the impact of textile process pollution, practices like sustainable dyeing, the use of new and less polluting technologies, effective treatment of effluent, and recycling waste processes need to be adapted.

KEYWORDS-textile, water quality index, effluents, pollution, wastewater

I. INTRODUCTION

Water quality standards imply statements and numeric values that describe water quality and fall within the following three components:

1. Designated uses of the water body as related to water supply, aquatic life, agriculture, or recreation.
2. Water quality criteria and general statements that describe good water quality and specific numerical concentrations for various parameters.
3. Anti-degradation policy designed to maintain and protect the existing water uses for each water body.

The standard used for particular water is a function of the expected use of the water. The general norm for reporting water quality parameters by comparing the different analyzed parameters with their respective permissible limits and standards set by regulating bodies at local, regional, national or international levels has been deduced to be ineffective in environmental monitoring program by both managers and the general public [12]. Carlos and Alejandra [13] argued that providing statements that summarize the water quality data in a simple expressible format that describes the general health or status of a water body is more preferable to environmental managers and the general public rather than been asked to give a rather biased interpretation to complex and technical environmental data. The Water Quality Index (WQI) was first developed by Horton [14] and presents a mathematical method of calculating a single value to represent water quality from multiple water quality parameters. The index represents the level of quality of a water body such as lake, river or stream by using some of the regularly used water parameters (BOD, temperature, turbidity, conductivity etc.) [15]. The WQI is based on the measurement of different water quality parameters thus providing a mechanism for presenting a cumulatively derived numerical expression for defining water quality [16]. The water quality index reduces water quality data to common scale and combines them into a single number in accordance with a chosen method or model of computation. WQI reflects the composite influence of different water quality parameters and is calculated from the point of view of the suitability of both surface and groundwater for intended usage.[1,2,3]

The method follows three steps namely:

1. Selection of parameters
2. Determination of quality function for each parameter and
3. Aggregation through mathematical equation.
4. Overall Water Quality Index which includes the protection of human health, aquatic ecosystems and wildlife.

Table 1. Sets of some established standards.

Parameters	WHO	CCME
pH (mg/l)	6.5–8.5	8.5
DO (mg/l)	—	5
Temperature (°C)	25	15
Turbidity (NTU)	5	5
TDS (mg/l)	500	500
Ammonia (mg/l)	0.2	1.37
Nitrate (mg/l)	50	48.2
Lead (mg/l)	0.01	0.01
Iron (mg/l)	0.3	0.3
Chromium (mg/l)	0.05	0.05

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Drinking Water Quality Index while the Aquatic Water Quality Index standards are used to protect aquatic life. [4,5,6]Basically, the index can be calculated for three different us The general norm for reporting water quality parameters by comparing the different analyzed parameters with their respective permissible limits and standards set by regulating bodies at local, regional, national or international levels has been deduced to be ineffective in environmental monitoring program by both managers and the general public [12]. Carlos and Alejandra [13] argued that providing statements that summarize the water quality data in a simple expressible format that describes the general health or status of a water body is more preferable to environmental managers and the general public rather than been asked to give a rather biased interpretation to complex and technical environmental data. The Water Quality Index (WQI) was first developed by Horton [14] and presents a mathematical method of calculating a single value to represent water quality from multiple water quality parameters. The index represents the level of quality of a water body such as lake, river or stream by using some of the regularly used water parameters (BOD, temperature, turbidity, conductivity etc.) [15]. The WQI is based on the measurement of different water quality parameters thus providing a mechanism for presenting a cumulatively derived numerical expression for defining water quality [16]. The water quality index reduces water quality data to common scale and combines them into a single number in accordance with a chosen method or model of computation. WQI reflects the composite influence of different water quality parameters and is calculated from the point of view of the suitability of both surface and groundwater for intended usage.

II. DISCUSSION

Textile wastewater is nowadays a major source of surface water contaminations, where different technologies have been applied for treatment of these carcinogenic effluents. Among these technologies, adsorption is one of the most promising ones. Even though activated carbon-based adsorption technology is still used for treatment of wastewater, it is not cost- and energy-efficient. Alternatively, the application of biopolymers such as chitosan is one of the emerging adsorption methods for the treatment of textile effluents containing dyes and heavy metal ions, even at low concentrations. As a result, a number of studies have recently been done for the adsorptive removal of heavy metals and dyes utilizing chitosan-based materials (Gerente et al., 2007; Wu et al., 2010; Vakili et al., 2014).[7,8,9]

Chitosan is one of the world's most abundant and low-cost biopolymers that is natural, renewable, environmentally benign, cost-efficient, nontoxic, biodegradable, and biocompatible. Acid-soluble chitosan could be synthetically produced by boiling chitin in potassium hydroxide .Chitin, the second most plentiful polysaccharide worldwide, can be also extracted from fungal species or from the exoskeleton of sea creatures such as cray fish, lobster, prawns, crab, and shrimp (Spinelli et al., 2004; Crini and Badot, 2008; Kasiri and Safapour, 2013; Ul-Islam and Mohammad, 2015).

Due to the hydrogen bonds between the molecules, chitosan is insoluble in water, alkaline solutions, and organic solvents. Meanwhile, it is soluble in acidic solutions due to the protonation of its amine groups. Based on the above properties, chitosan potentially has high affinity to adsorb pollutions such as heavy metals and dyes, due to several functional groups available on this material. But, some disadvantages such as solubility in acidic media, low mechanical stability, and low surface area limit the performance of this material in the adsorption process. That is why the modification of chitosan for dyes and heavy metal ions' removal has been investigated by many researchers (Kyoon No and Meyers, 2002; Wang and Chen, 2014; Azarova et al., 2016).

Chitosan nanoparticles/nanocomposites, as adsorbents, have considerable advantages such as attractive surface area, chemical accessibility, ease of functionalization, and absence of internal diffusion (Săg and Aktay, 2002; Qin et al., 2003; Olivera et al., 2016). These advantages are now being exploited in different research areas, including pulp and paper, textiles, medical, cosmetics, biotechnology, agriculture, food industries, chemical production, separation, and environmental applications.[10,11,12]

Chitosan has also demonstrated the potential to adsorb significant amounts of dyes and metal ions, and this has led the scientists to explore the characteristics of different processes involved in the removal of dyes and metal ions over a wide range of effluent systems and types (Geng et al., 2009; Wua et al., 2009; Wan Ngah et al., 2011; Kasiri and Safapour, 2015).

Numerous researchers are endeavoring to synthesize and characterize the various chitosan-based materials for dyes and heavy metal ions removal. It has been shown that chitosan can be used as an adsorbent to remove heavy metals and dyes due to the presence of amino and hydroxyl groups, which can act as the active sites (Vincent and Guibal, 2001; Zimmermann et al., 2010; Wang and Chen, 2014). Amino groups of chitosan-based materials could be cationized, and consequently, they have the ability to adsorb anionic dyes strongly by electrostatic attraction in the acidic media. Meanwhile, chitosan is very sensitive to pH of the media, as it can either form gel or solution depending on the pH values of the solution (Wan Ngah et al., 2011).

There are some review papers or book chapters about the application of chitosan for removal of dyes or metals ions from textile wastewater, but this review paper will highlight the application of chitosan derivatives, classified in distinguished groups including: chitosan and chitosan mixtures, chitosan derivatives, chitosan nanofibers and nanofilms, and chitosan nanoparticles, for removal of either dyes or metal ions from textile wastewater. The characteristics of chitosan composites, the removal target(s), the experimental conditions, and the adsorption capacity have been compiled in tables. Moreover, the effects of influential parameters such as the chitosan and chitosan-based materials characteristics, the process variables, and kinetics and thermodynamics are presented and discussed. This survey has been divided into two main parts: (i) removal of dye and other organic pollutants, and (ii) removal of heavy metals. Each part has also been further divided into shorter subdivisions to discuss and compare the results obtained at each field of research in details [13,14,15]

III. RESULTS

Various scientific fields have made immense progress in the 21st century. Extensive research has been carried out on diverse topics in the fields of Environmental Science and Engineering research in the last 20 years. Large amounts of wastewater are generated daily from the textile, cosmetics, paper, rubber, leather, and printing industries (Younis et al. 2016). It is difficult to treat the toxic and complex textile wastewater produced by industries. Currently, water contamination caused by the wastewater released from the textile industry poses a threat to economic growth. As highly water-soluble and toxic substances (microbial pathogens and organic dyes) are present in the discharged water, the wastewater directly contaminates the natural ecosystem and reduces the availability of clean and fresh water that can be utilized for drinking. The complex and stable structure of the dyes makes the degradation of dyes (present in waste water and other complex substrates) difficult. The mineralization of dyes, presence of organic compounds, and toxicity of the wastewater released from textile and dye manufacturing industries negatively affect the environment. Therefore, it is important to gain practical knowledge and develop methods to effectively treat textile wastewater to save the environment (Holkar et al. 2016).[16,17]

In recent years, extensive research has been carried out in the field of treating dyeing and weaving wastewater . To date, considerable efforts have been made to remove organic dyes/pollutants from wastewater using various methods (chemical, physical, and biological). It has been reported that it is difficult to remove color following traditional treatment methods (e.g., ozonation-, bleaching-, hydrogen peroxide/ultraviolet (UV)-, and electrochemistry-based) as most textile dyes have complex aromatic molecular structures that make their degradation difficult (Akbari et al. 2002). These dyes are stable in the presence of light and oxidants. They can also withstand conditions of aerobic digestion. Therefore, it is important to develop a green and sustainable method to effectively treat textile wastewater. Environmental scientists and engineers have focused on developing economically viable treatment methods.

It is important to characterize textile wastewater to develop effective treatment methods and process flow. Various raw materials, such as cotton, synthetic fibers, and wool, are used in the textile industry. Wastewater is primarily produced during the execution of four steps: pretreatment, dyeing, printing, and functional finishing (Figure 2 presents the possible contaminants and the nature of effluent discharged at each step of the industrial process). The percentage of a definite parameter for characterization of textile wastewater included chemical oxygen demand (COD), pH, color, suspended solids, biochemical oxygen demand (BOD_5), N-NH_x, total phosphate (TP), total Kjeldahl nitrogen (TKN), conductivity, metals, total oxygen demand (TOC), Cl^-, total dissolved solid (TDS), grease, alkalinity, surfactants, hardness, volatile suspended solid (VSS), sulfide, N-NO_x, total solids, turbidity, dissolved organic carbon (DOC), absorbable organic halogen (AOX), total carbon (TC), Org. N (Bisschops & Spanjers 2003). Composite textile wastewater is primarily characterized by analyzing BOD, COD, suspended solids (SS), and dissolved solids (DS) (Al-Kdasi et al. 2004).

Notably, the major contaminants present in textile wastewater are produced during the processes of dyeing and finishing. Currently, aromatic hydrocarbons and heterocyclic dyes are commonly used in the textile industry (Holkar et al. 2016). A dye molecule consists of two parts: the dye group and the dye auxiliary pigment (Liang et al. 2014). When the dye molecules are exposed to light, the structure containing double bonds (C = C) oscillates to absorb light and produce visible colors (Akbari et al. 2002). Dye at low concentrations can also exhibit highly intense color (Nigam et al. 2000; Liang et al. 2014). The complex and stable structures exist not only in textile wastewater but also in any kind of complex substances. Dyes can be classified into various categories based on their characteristics. They are primarily classified as ionic and non-ionic dyes (Robinson et al. 2001). Ionic dyes are direct, reactive, and acidic dyes. Non-ionic dyes remain dispersed as they do not ionize in a water-borne medium (Deive et al. 2010). Methyl orange, acid red-B, rhodamine-B, Prussian red, alizarin red, Congo red, orange green, rose Bengal, and basic yellow 28 are examples of ionic dyes (Islam et al. 2018). Textile dyes are classified as acidic, alkaline, direct, disperse, active, sulfur, or reducing dyes (Table 2) (Akbari et al. 2002). Acidic dyes are negatively charged, and alkaline dyes are positively charged. The dyes are active if anionic dyes are used in the textile industry, medium if metal ions are present, reduced if they are derived from natural indigo, and disperse if non-ionic (Brillas & Martínez-Huitle 2015). Direct dyes are the most popular class of dyes, as they are easy to use, exhibit a wide range of colors, and are economically friendly. The structures of most direct dyes contain di-azo and tri-azo moieties. The maximum range of colors can be observed for the azo dye (percentage of dyes belonging to this class: 60–70%) (Deive et al. 2010).[18,19]

Table 2

Dye classification and methods of application (Akbari et al. 2002, Verma et al. 2012, Pang & Abdullah 2013)

Dye class	Characteristics	Metals in dyes
Acid	Anionic, water-soluble	Copper, lead, zinc, chromium, cobalt
Basic	Cationic, water-soluble	Copper, zinc, lead, chromium
Direct	Anionic, water-soluble	Copper, lead, zinc, chromium
Disperse	Colloidal dispersion, very low water solubility	None
Sulfur	Colloidal, insoluble	–
Reactive	Anionic, water-soluble	Copper, chromium, lead
Vat	As sulfur dye	None

In addition to harmful dyes, wastewater produced by the textile industry also contains various pigments, heavy metals, sulfates, oils, surfactants, and chlorides (Wei et al. 2017) .These contaminants can adversely affect aquatic life and water quality. Heavy metals have often been used during the process of dye fixation and also in dyes. It has been reported that the metal units present in dyes help impart color so that the dues can be used as textile colorants. Textile wastewater contains trace amounts of metals such as Cu, Cr, As, and Zn, which harm the environment.

It has been established that wastewater significantly pollutes the environment (Abdel-Karim et al. 2016). Wastewater can pollute the surface water, groundwater, soil, and air. Numerous textile and dyeing factories are found in developing countries, where wastewater is often poorly treated (Khan & Malik 2014). Textile wastewater is hazardous to the environment as it contains carcinogenic, toxic, mutagenic, and difficult-to-degrade compounds (Hubadillah et al. 2017). It has been reported that approximately 2,000 different types of chemicals (dye, transfer agents, etc.) find their use in the textile industry (Khan & Malik 2014). Dyes are one of the main contaminants present in wastewater released by the textile industry (Nor et al. 2016). Since the discovery of the first synthetic dye in 1,856, more than 10,000 different types of textile dyes (estimated annual output: 8×10^5 metric tons) have been commercialized worldwide. Approximately half of these dyes fall under the category of are azo dyes (Deive et al. 2010). A large number of these toxic dyes eventually enter the waterways, causing serious environmental problems (Nabil et al. 2014). It has been reported that the textile industry utilizes large amounts of water during the process of textile processing. The percentage of toxic and hazardous dyes present in the wastewater system ranges from 5 to 10% (Prasad & Aikat 2014). An estimated 280,000 tons of textile dyes are discharged (annually) worldwide through industrial wastewater (Zainith et al. 2016). Approximately 10–15% of the dyes are discharged into the environment during various substrates staining. The substrates include synthetic fibers, natural textile fibers, plastics, leather, paper, mineral oils, waxes, specific types of food items, and cosmetics (Bae & Freeman 2007). It is extremely difficult to handle textile wastewater as it is characterized by high content variability and color strength. The color of these dyes can potentially change the extent of turbidity causes, COD value, pH value, and temperature of the water body (Verma et al. 2012). It is estimated that approximately 2% of the dyes are directly released into the aqueous effluent and 10% of the dyes are therefore lost during the process of coloring (Mani et al. 2018).

The maximum amount of harm to the environment is caused when sunlight is absorbed and reflected by the water system containing dyes. The absorption of light changes the algal photosynthetic activity, altering the food chain (Mani et al. 2018). The discharge of these harmful substances into the soil environment and aquatic system results in low light transmittance and low oxygen consumption. This can negatively influence the process of photosynthesis and aquatic life (Holkar et al. 2016). Apart from exerting negative aesthetic effects, these dyes can harm organisms as they exert carcinogenic and mutagenic effects (Das & Mishra 2017). It was estimated that out of 3,200 azo dyes used, 130 dyes could be used to produce carcinogenic aromatic amines following the processes of reduction and degradation (Bae & Freeman 2007). Contact with azo dyes can result in skin, lung, and gastrointestinal problems. These dyes can enter the body through the digestive system and destroy the roots of hemoglobin and DNA substances. The substances can induce cancer in humans and animals (Islam et al. 2018). The contact to leukemia with multiple colors affecting the circulatory, respiratory disease, allergic reactions, neurobehavioral, and immune suppression disorders. Carcinoma of the kidneys, liver, and urinary bladder has been reported in textile workers (Islam et al. 2018). Results from experimental studies conducted on animal models by Raj et al. (2012) indicate that the main category of textile dyes, i.e., azo dyes, is directly associated with human bladder cancer, splenetic sarcomas, and hepatocarcinoma (the major cause of chromosome aberration in mammalian cells).

Mathur et al. (2006) assessed the mutation-causing ability of textile dyes from Pali (Rajasthan) by conducting an Ames bioassay. In their study, a total of seven dyes were conducted for their mutagenicity by Ames assay, using strain TA 100 of Salmonella typhimurium (Mathur et al. 2006). The results indicated that only one dye, Violet, exhibited no mutational activity. The use of the remaining six dyes resulted in mutation (Mathur et al. 2006). It has also been reported that bioassays are sensitive and reliable methods that can be conducted to determine the toxicity of industrial wastewater. Hence, they can be used to assess the efficiency of emerging tools (Rosa et al. 2001). The relative sensitivity of biological assays toward textile wastewater is arranged in descending order: plant enzymes > bacteria > algae ≈ daphnids ≈ plant biomass ≈ germination rate > fish. Significant effects on genetic toxicity were not observed (Rosa et al. 2001). The aquatic toxicity of a series of unique direct dyes containing benzidine congeners, 2,2′-dimethyl-5,5′-dipropoxybenzidine, and 5,5′-dipropoxybenzidine, and the toxicity of a commercial dye (C.I. Direct Blue 218) were assessed by conducting acute toxicity studies in the presence of Daphnia magna (Bae & Freeman 2007). The results revealed that C.I. Direct Blue 218 was highly toxic toward daphnids. It was more toxic than the unmetallized direct dyes. In addition, the results also revealed that the assay conducted with D. magna could be effectively used to assess the aquatic toxicity of dyes (Bae & Freeman 2007). Villegas-Navarro et al. (1999) used the crustacean Daphnia magna as a sensor organism and 50% lethal concentrations (LC_{50}) as the standard for measuring the toxicity of textile effluents (treated and non-treated). The results indicated that all the five textile industries could produce toxic non-treated water (ATU: 2.1–25.4). The treated water was also toxic (ATU: 1.5–7.2). This suggested that the treatment plants and methods used by the five textile industries to remove toxic water were not highly efficient (Villegas-Navarro et al. 1999). Sharma et al. (2007) used Swiss Albino rats to assess the toxicity of the wastewater generated from the textile industry.

IV. CONCLUSION

The major contaminants present in textile wastewater are high suspended substances, COD, acidity, heat, color, and other soluble substances (Al-Kdasi et al. 2004). In general, textile wastewater exhibits intense color and is characterized by high BOD/COD values and high saline loading (Holkar et al. 2016). The BOD/COD ratio for composite textile wastewater is approximately 0.25. This indicates that wastewater contains a large amount of non-biodegradable organic substances. (Al-Kdasi et al. 2004). As reported by Paździor et al. (2018), industrial textile wastewater treatment methods are studied using various effluents generated during the execution of different processes within the dye-house. These effluents are collected under conditions of equilibrium or in neutralization pools. The pollutions at a lower concentration may be present in the effluents.[20,21]

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