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International Journal of Health & Life Sciences

[ISSN: 2383-4390] [eISSN: 2383-4382]

Free of Charge

DOI: http://dx.doi.org/10.22110/IJHLS.2017.80509
Classification: Environmental sciences

You can cite this article as follows:

Makhdoum P. A review on textile wastewater production, characterization, and treatment technologies. *Int J Health Life Sci.* 2017, 3 (1): 27-35.

International Journal of Health & Life Sciences
2017; 3 (1): 27-35

A review on textile wastewater production, characterization, and treatment technologies

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ARTICLE INFO

Article Type:
Review article

Article History:
Received: 2017-02-06
Accepted: 2017-04-12
ePublished: 2017-07-01

Keywords:
Textile industry
Azo dyes
Treatment
Environmental technology

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ABSTRACT

In the past, the industrial sewage was discharged into the environment without considering its consequences. Alternatively, the increase in the human population and the industrial and economic growth has created several issues regarding environmental pollution, at present and for future. The textile industry is considered as main concerns by its environmental effects and hazardous wastes. The textile industry comprises a broad spectrum of units and generates large amount of wastewater containing several hazardous and toxic matters including heavy metals, pesticides, pigments and dyes (azo dyes), acids and soda, and polycyclic aromatic hydrocarbons (PAHs). Consequently, that can be created the environmental problems and several health effects such as cancers, allergies, and irritability. However, immediate approaches must be taken to prevent these issues. Based on literatures, the characteristics of wastewater streams that arise from different industrial units have been reviewed. The main concerns related to textile wastewaters include choosing the best technology and providing an appropriate treatment method. Most common successful treatment methods include using physicochemical and biological approaches.

Introduction

Often, our environment is exposed to pollutions and municipal, agricultural, and industrial discharges. Among these, the industrial and agricultural wastes have caused more destruction. The discharge of these wastewaters containing a wide range of organic/inorganic pollutants in our environment has been recognized as an important environmental concern. Table 1 presents details of few polluting industries with their respective polluting agents that can cause threat to the environment. Textile industries are considered as one of the main industries in several countries. Fig. 1 illustrates the textile manufacturing diagram. Accordingly, it can generate a large volume of waste/wastewater during its units and processes. From Table 1, it is evident that we are dealing with a strong mixture of wastewater containing different inorganic salts, acidic and alkaline solutions, solvent, heavy metals pigments, and toxic dyes. Untreated discharges to the environment and water bodies can cause several ecotoxicological effects such as genotoxic and mutagenic effects [1,2]. Chemical agents and functional groups of chemical are the main causes of toxic environments, For example, azo groups with N=N bonds [4]. The present study aimed to investigate the characteristics of textile containing wastewater, toxicity mechanisms, treatment strategies, and controlling methods.

Health effect of textile wastewater

Toxic soluble dyes including azo group can be dangerous when they are metabolized by the liver enzymes and consequently may cause several adverse effects such as cancer and mutagen disorders. Several studies have demonstrated that azo dyes cause health risks to humans. Moreover, the toxic dyes damage the ecosystems when the untreated textile wastewater is discharged into the receiver systems [1].

Table 1. Major polluting industries [2]

Row	Industry	Pollutants
1	Thermal power plants	Fly ash, heavy metals, coal, oil, suspended solids
2	Fertilizers	Organics, ammonia, nitrate, phosphorus, fluoride, cadmium/other heavy metals, and suspended solids
3	Petroleum/ Petrochemicals	Oil, acid, soda sludge, hydrogen sulfide, lead sludge, hydrocarbons, spent filter clay, ethylene glycol
4	Mining industry	Heavy metals like copper, lead, zinc, mercury, cadmium oxide, calcium oxide, sodium oxide, barium oxide, cuprous oxide, zinc oxide, sulfates, chlorine, lithium oxide, manganese oxide, magnesium oxide, silica, gypsum, hydroxides, carbonates, cyanide, sulfur
5	Pharmaceuticals	Polycyclic aromatic hydrocarbons (PAHs), arsenic trioxide, chlorambucil, epinephrine, cyclophosphamide, nicotine, daunomycin, nitroglycerin, melphalan, physostigmine, mitomycin C, physostigmine salicylate, streptozotocin, warfarin over 0.3%, uracil mustard, halogenated/nonhalogenated solvents, organic chemicals, sludge and tars, heavy metals, test animal remains
6	Pesticides	Volatile aromatics, halomethanes, cyanides, haloethers, heavy metals, chlorinated ethane, phthalates, PAHs
7	Dye and pigment / textiles	Complex mixture of salts, acids, heavy metals, organochlorine-based pesticides, pigments, dyes, PAHs

Table 2. Characteristics of textile wastewater

Parameters	unit	average ranges
flow rate	m3/day	10000-35000
pH	-	6-11.23
Temperature	°C	25-40
Colour	(pt-co)	600-4600
TDS	mg/L	250-2200
TSS	mg/L	35-1200
Sulfide	mg/L	0.1-2
Free chlorine	mg/L	0.01-1.1
COD	mg/L	1000-2500
BOD	mg/L	150-650
Oil and grease	mg/L	6-10
DO	mg/L	10
NO3-	mg/L	20
NH3	mg/L	0.05-2.7
PO4-3	mg/L	0.1-4.5

Table 3. Wastewater characteristics of each units of textile industry

Primary washing	↑↑ BOD	↑ TSS	↑ Oil and grease	↑ Temperature
Sizing/ desizing	↥ BOD	↑ TSS	↑ pH	↑ Temperature
Bleaching	↥ BOD	↑TSS	↑ pH	-
Dyeing and Printing	⇡BOD ↑ COD	⇡ TSS	↕ pH	-
Washing the colored chloth	⇡BOD ↑COD	⇡TSS ↑ TDS	↕ pH	-

↑↑ very high , ↑ high
↥ relative high, ⇡ moderate
↕ varied

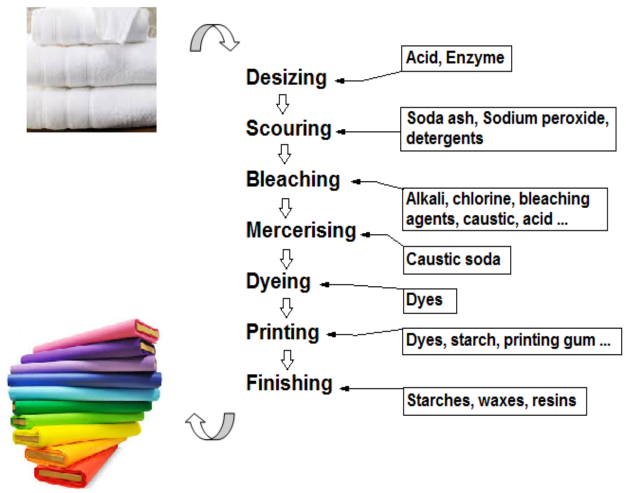


Figure 1. Textile manufacturing diagram

Table 4. Maximum allowable concentration (MAC) values

Parameters	unit	ranges
Temperature	°C	40
pH	-	6.5-8.5
COD	mg/L	500
BOD	mg/L	300
TSS	mg/L	350
Sulfides	mg/L	1
Sulfites	mg/L	2
Sulfates	mg/L	600
Free chlorine	mg/L	0.5
Phenol	mg/L	30
Nitrogen (as NH4)	mg/L	30
Oil and grease	mg/L	6-10
Biodegradable detergents	mg/L	25
CN-	mg/L	1
Total P	mg/L	5
Lead	mg/L	0.5
Cadmium		0.3
Total chromium		1.5
Hexavalent chromium		0.2
Copper		
Zinc		1
Manganese		1
		2

- According to NTPA (GD,2005)

Wastewater characteristics and units

The textile industry includes a broad spectrum of units, processes, and apparatus, which generate different wastewater in terms of content and amount. The wastewater is collected from each unit and then those join to gather. Before than mixing those, better management is handling separately [3]. Most important units comprise chemical unit, mercerization, printing, dyeing, and finishing. The characteristics of textile wastewater is varies in its contents and volume. Table 2 presents the characteristics of several textile mills[2]. Considerably, it is clear that all criteria are variable, for example, the flow rate value can fluctuate from 10,000 to 35,000 m^3/day or the pH from 6 to 11.23 [4]. The textile wastewater classifications are presented in Table 3. This table presents the core processes of textile manufacturing with their characteristics [2]. All units generate medium to high concentrations of organic, total dissolved solids, and total suspended solids.

Wastewater classification

To treat the textile wastewater, it is essential to classify the generated wastewater in term of treatability. Thus, the wastewater can be classifeid into four categories as follows [2,3]:

1- Difficult to treat
2- Strong wastewater
3- Hazardous or toxic wastewater
4- Undesirable waste

Difficult to treat wastewater

This group includes the resistant and nonbiodegradable materials or the compounds, which may interfere in the biological treatment; this includes the nonbiodegradable inorganic/organic compounds such as metals, dyes, phenols, and surfactants and organic toxins like pesticides and phosphates. Identification and removal of these componds from the wastewater is necessary. Certain measures can be considered to reduce the concentration of these materials from the effluent:

- Chemical methods or replacement processes
- Controlling and optimization of processes
- Reuse and recycling

Hazardous or toxic wastewater

This type of wastewater contains chlorinated solvents, volatile organics (VOCs), PAHs, nonbiodegradable materials, cleaning compounds, and detergents.

Strong wastewater

Strong or hard wastewater is considered as one of the main issues of textile industries due to the high volume of generated waste and undesirable compounds. High volume of wastewater results from continuous dyeing process. Due to the variation in pH (alkali and acidic wastewater), salts, dyes, and a high ratio of COD/BOD_5 biological treatment may prove to be ineffective; however, certain approaches including recycling and reuse of wastewater, and changing or replacing the process and equipment, should be considered [5].

Undesirable waste

The following are responsible in producing the undesirable waste in this category:

- Waste released from the mercerization, dyeing, printing, and finishing processes
- Color inks from printing and printing cylinder washing
- Cotton waste (mercerization, dyeing, and washing)
- Foam from the ceil unit
- Solvents released from cleaning
- Residues obtained from the recycling of solvents
- Unused materials in the processes

Wastewater treatment concept

To solve the issues related to textile and colored wastewater, it is essential to consider the local conditions, the type of dye material, the amount and composition of wastes, drainage, area, sewer channel, and the characteristics of wastewater. In order to handle the textile and colored effluents, the most common method is to discharge the wastewater to the wastewater treatment plants; however, this must be done according to the industrial wastewater discharge standards and legal requirements. This wastewater discharge standards are represented in Table 4. Considerably, it is clear that before discharging the wastewater, the levels of considered criteria be reduced to less than the standard or maximum permissible amounts. For example, the COD and BOD must be reduced to less than 300 and 500 mg/L, or the temperature of discharges should be below 40 °C. More details regarding legal discharging are presented in Table 4. Unfortunately, due to the complexity and the nature of industrial wastewater, biological treatment is ineffective. Historically, the potential of biological processes has been investigated for colored wastewater; however, it did not operate effectively. Nevertheless, it is necessary to integrate the physiochemical processes along with the biological systems for effective treatment. Several approaches are initiated to treat the textile industry wastewater as described below:

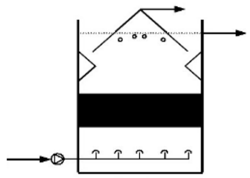
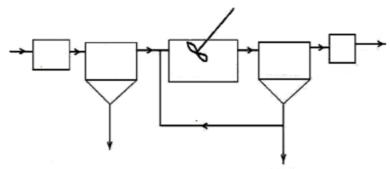
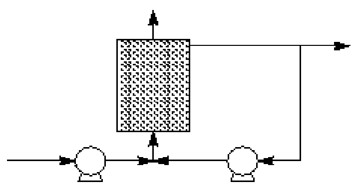
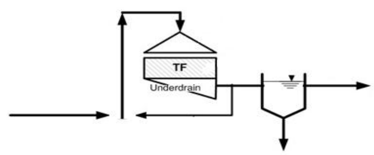
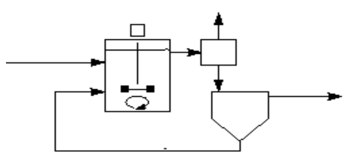
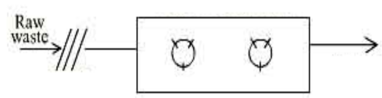
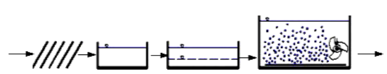
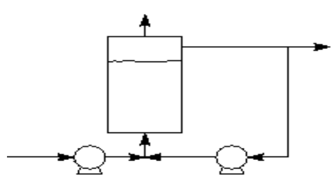
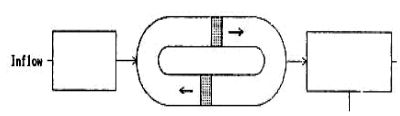
Primary treatment

Primary treatmant in operation units includes the physical removal of the particles, seeds, grease, and oil. This step is effective in reducing the organic loading of waste before its discharge for the secondary treatment. The most common units and processes are as follows [2, 3]:

- Screening:In this unit the coarse seeds and particles, that is pieces of old cloth and fibers, are removed. Fine screening can be effective in removal of fine fibers.

- Sedimentaion: Here, the suspended solid with enough retention time are separated easily.
- Equalization: To overcome the fluctuations in the hyrolytic flow and toxic shocks (controlling by dilution), the Equalizer unit is used. In certain cases, the Equalizer tank is equipped with mixing and aeration.
- Neutralization: The aim of the neutralization unit is to adjust the pH value to meet the requirements of the different processing units in the treatment facilities. Moreover, it is used to treat the acidic effluents containing metals and percipitate the metal by addition of the alkaline reagent.
- Coagulation and flocculation: The purpose of this unit is to enhance the percipation ability of the particles and colloides by addition of chemical regent like iron and aluminum salts. In general, this method is capable to remove about 80–90% of the suspended solids, 40–70% of BOD, 30–60% of COD, and 80–90% of bacteria

Table 5. the most common anaerobic/aerobic wastewater treatment processes

Anaerobic	Flow diagram	Aerobic	Flow diagram
UASB		Activated sludge	
Anaerobic Filter		Trickling filter	
Anaerobic Contact		Aeration lagoon	
		SBR	
Fluidized Bed		Oxidation ditch	

Biological treatment

To remove higher amount of the BOD, the secondary processes should be considered. In this process, the degradation of resistant compounds such as phenols, oil and grease, colloidal material, and color can be expected. Both the aerobic and anaerobic processes are carried out; however, the anaerobic digestion method is preferred essentially for strong wastewater. Moreover, the anaerobic microrganisms can generate the strong degradable enzymes and are used for higher COD containg wastewater more than 1500–2000 mg/L. Eventually, selection of appropriate methods depends on several parameters such as the organic loading rate, hydrolic flow rate, and wastewater properties. Efficient azo dye biodegradation and COD removal (about 77%) were achieved in a 1.5 h anaerobic phase via a SBR [2, 5, 6]. Furthermore, in aerobic phase complete degradation of the aromatic amine is occurred. Most common biological systems with flowdiagarms that were used to treat the industrial wastewater are discribed in Table 5.

Advanced treatment

Due to the large amounts of polymeric matters, resins, dyestuffs, pigments, and resistance to the biodegradation material in the textile industry, tertiary or advanced treatment processes are required to remove these contaminants.

Oxidation chemical

Chemical oxidation is known to be generally used for degradation of electron-rich organic compounds such as phenol and other hydrocarbons. Oxidation can be an efficient treatment option employing a variety of chemical oxidants, such as chlorine, chlorine dioxide, peracetic acid, ozone, and hydrogen peroxide. In general, the chemical oxidation is applied to remove and control: the taste and odor, the hydrogen sulfide concentration, better degradation of color, and seperation of dissolved ions like iron and manganese [7].

Advanced oxidation

Due to the inefficiency of conventional chemical oxidation and biological methods to degrade the toxic, mutagenic, and carcinogenic pollutants from the wastewaters/waters, efficient treatment methods such as advanced oxidation processes (AOPs) should be explored [6]. In the 1980s, the AOPs were used for drinking water purification and then they was broadly cosidered for treatment of effluents. During the AOPs process, strong oxidation radicals such as OH· or SO4·− are generated and they are able to remove the refractory and resistant organic matter, trace contaminants, or certain inorganic pollutants. Moreover, these radicals efficiently increase the biodegradability rate of the wastewaters [6-8]. The following techniques are most often used in AOPs: fenton and electrofenton, photocatalysis, plasma oxidation, and ozonation oxidations [7]. The AOPs processes orginated from a combination of regents and oxidants comprising (i) H_2O_2/UV/Fe, (ii) H_2O_2/Fe, (iii), H_2O_2/UV, O_3/UV, O_3/H_2O_2/UV, O_3/TiO_2, O_3/TiO_2/UV, and O_3/ultrasonics. Based on the literatutre, most studies were related to fenton. The conventional fenton process is operated via the below mentioned systems [8].

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH\cdot + OH^-$$
$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HO^{\cdot}_2 + H^+$$
$$OH\cdot + H_2O_2 \rightarrow HO^{\cdot}_2 + H_2O$$
$$OH\cdot + Fe^{2+} \rightarrow Fe^{3+} + OH^-$$
$$Fe^{3+} + HO^{\cdot}_2 \rightarrow Fe^{2+} + O_2H^+$$
$$Fe^{2+} + HO^{\cdot}_2 + H^+ \rightarrow Fe^{3+} + H_2O_2$$
$$2HO^{\cdot}_2 \rightarrow H_2O_2 + O_2$$

Electrochemical systems

Electrochemical system (ECS) is one of the technologies, which has been considered by several researchers in the recent years [9-11]. This process has various advantages including its high efficiency, no requirement of chemicals, low sludge production, capability of process control, and easy operation and maintenance. Electrocoagulation as a branch of ECS has engrossed much attention as an environmental-friendly and effectivene process.

Alternatively, suitability potential of the electrocoagulation process for treatment of wastewater with regard to costs and environment has been demonstrated. In an electrocoagulation reactor, the electrical current passess through the electrolyte such as water or wastewater and the anode material (usually iron or aluminum). At this moment the anode scarify and the oxidizing agents and active coagulants are generated. As a result degradation and decolorization is happened. Figure 2 illustrates the schematics of ECS and a sample degraded dye [9].

$$\mathrm{Me}^{3+}(aq) + n\mathrm{H_2O} \leftrightarrow \mathrm{Me(OH)}_n^{3-n} + n\mathrm{H}^{+}(aq)$$

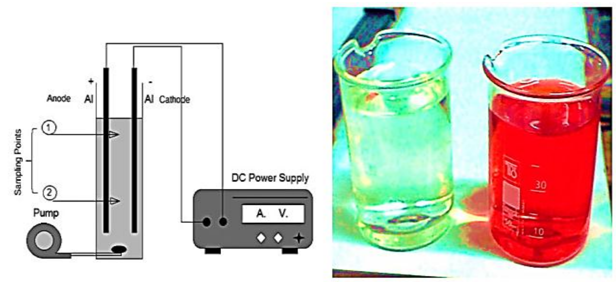


Fig 2. Schematic figure of EC reactor and photographic image of color change [9].

Application of ECS for treatment of the colored wastewater has been reported by several researches. For example, Khosravi et al. (2015) reported that the ECS process can be used as one of the best technique for degradation of dyes from wastewaters. They reported that the Reactive Red 198 is degraded about 90% under optimal operating conditions (pH: 6.45, current density: 7.2 mA/cm^2, operating time: 57.4 min, and distance: 1.9 cm[9].

Membrane technology

Mechanical separation of solids, ions, and gases from the liquid streams using high porous membrane is known as membrane technology. Membranes, commonly are used efficiently to separate the dissolved solids, ions, color, hardness, bacteria, and viruses in water works and treatment technologies. According to the driving force of the operation in membrane technology, it is classified into four types; microfiltration (>0.1 μm), ultrafiltration (2–100 nm), nanofiltration (1–2 nm), and reverse osmosis (<1 nm). Ciardelli et al. (2000) have been reported a technical and economical analysis of membrane separation technique at a pilot scale for wastewater treatment of textile industy. They revealed that the membrane processes can be used as promising methods for treatment of textile wastewaters [2, 12-14]. In another study carried out by Marcucci et al. (2002), different membrane technologies including microflitration, nanofiltration, and ulterafiltration were investigated for textile wastewater [13]. They demonstrated that the quality of ultrafiltration permeate is appropriate to reuse in the production processes. The results of Ong et al. (2014) also, is indicate that the NF membrane has satisfactory rejections rate about >90% against various dyes [15].

Other treatment methods

Among the wastewater treatment methods, absorption process is commonly considered due to its cost-effectiveness and easy investment [16]. Based on the literature, the adsorption can be considered as an excellent way to treat industrial waste effluents, considering its significant advantages such as efficiency, easy operation, availability, and profitability [17]. The main mechanisms of the adsorption comprise the chemisorption, complexation, ion exchange, microprecipitation, condensation onto the surface, and surface adsorption .Merkadeh et al. (2015) have reported that the remazol brilliant blue (RBB) was successfully removed from aqoueous solutions using multiwalled carbon nanotube (MWCNT) as an adsorbant[18]. In this study, the results indicated that the maximum values for the RBB removal and uptake were 69.06% and 1.1 × 10^{-2} mM/g, respectively. Mirzaei et al. (2017) succeed in removing the Direct blue 71 (DB 71) by application of Iranian zeolite as a low-cost adsorbent [19]. Application of natural chitosan /bone char composite was investigated by Hossini et al. (2017) to adsorb the textile dye (Direct Brown 166 dye (DB-166)) from aqueous solution. They reported that the chitosan/bone char composite is able to remove the DB-166 with maximum adsorption efficiency and capacity of about 99.8% and 21.18 mg/g, respectively [16].

Reducing the adverse effect of textile wastes

Industrial effluents are known as the most important polluting sources in the environments. Due to the characteristics of industrial wastewater and relative pollutants, they cause environmental concerns. Accordingly, wastes released from these sources must be treated before they are discharged to the ecosystems [2, 5]. Considerably, several approaches to purify the effluents such as physicochemical and biological techniques have been considered; however, that need to energy and cost. Hence, to minimize the adverse effects, save energy, and to reduce the costs, following strategies are recommended:

I. Material management and improving the operating procedures
  - Record and tracing of all raw materials
  - Fewer purchase (toxic and nontoxic materials)
  - Education, training, and awareness
  - Improve the procedures for receiving, storing, and processing

II. Amendments equipment
  - Installation the warning sign for waste or waste less
  - Equipment modification to improve recycling or reuse options
  - Redesign the devices and apparatus
  - Use of new technology for reduction of waste or not waste
  - Improve the operating efficiency of devices and equipment
  - Developing and implementing a preventive maintenance program

III. Change in the production process
  - Replace the toxic materials with nontoxic material
  - Separation of waste by the type of recycling purposes
  - Remove or repair the leaks
  - Separation of hazardous and nonhazardous materials
  - Redesign or change in formulation of the final products to reduce the risk
  - Optimization of reactions and optimization of the consumption of raw materials

IV. The recycling and reuse
  - On site recycling for reuse
  - Offsite recycling
  - Waste exchange

Acknowledgement

The authors gratefully acknowledge the Research Council of Kermanshah University of Medical Sciences for the financial support (grant no. 95492).

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