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Textile Wastewater and Treatment Technologies: A Review

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ABSTRACT

Textile industry is one of the most common and essential sectors in the world and it is responsible for one of the major environmental pollution problems in the world because it releases undesirable dye effluents. Textile wastewater contains dyes mixed with various contaminants at a variety of ranges. The toxic and carcinogenic effect of untreated textile effluent is well understood. The decolorization and detoxification of industrial dye effluents is most important aspect and is major concern to meet environmental regulations. This paper presents a review of literature on characteristics, composition of textile wastewater and conventional treatment methodologies for textile wastewater with their advantages and disadvantages. Over the years, researchers have developed several bioremediation technologies to treat textile effluents but little effort has been made to put the entire literature review of these technologies in one refereed paper, this review paper is an attempt to compile the existing information on various treatment technologies of textile effluent.

Keywords: Decolorization, Effluent, Textile, Wastewater

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1. INTRODUCTION

Textiles being the largest industries in the world are the industries to cater to the basic needs of humans, and have been rapidly growing, more so in the developing countries **(**Yaseen and Scholz, 2018). In Ethiopia, this sector was given a special attention and numbers of foreign and local investors who are engaged on to it are increasing (Hailu *et al*., 2014). As a result, Ethiopia has more than 60 garment factories and 15 textile mills in operation, as the country tries to position itself as the next source country for the world's clothing industry (Meseretu, 2015). The annual production capacity of those factories is around 37 million kilograms of yarn, 88 million meters of woven fabric, 30 million kilograms of knitted fabric, 62 million pieces of knitted garment and 18 million pieces of woven garment (Meseret *et al*., 2019). Obviously, this figure is ever increasing as new investments continue to be attracted towards the industry.

The textile industry generates huge quantities of complex chemical substances as a part of unused materials including dyes in the form of wastewater during various stages of textile manufacturing and processing (Hua Yin *et al*., 2018). The same authors also cited that the important pollutants present in a typical textile waste effluent are color, bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), toxic heavy metals, residual chlorine, dissolved solids (DS), suspended solids (SS) and nonbiodegradable organics. Characteristically wastewater generated by different production steps of a textile mill have a high pH, temperature, detergents, oil, suspended and dissolved solids, dispersants, leveling agents, toxic and no biodegradable matter, color and alkalinity. Textile dyeing processes produce colored wastewaters that are heavily polluted with dyes, textile auxiliaries and chemicals.

All organic and inorganic pollutants released in water are much higher than allowable limits and cause series impact on the receiving environment (Abrha *et al*., 2014). These pollutants are highly toxic, persistent, mutagenic, carcinogenic, disrupt the endocrine systems and are not completely removed during treatment processes or might be degraded into other byproducts that are sometimes more toxic than the parent compounds (Ayanda, 2014). Most of the used dyes are stable to photo degradation, biodegradation and oxidizing agents and even they are highly visible even at low concentration (Tekolglu and Ozdemir, 2010). When the colored effluent discharged into water bodies, they block the sunlight passage through the water, hamper photosynthesis, increase the biological oxygen demand and affect the aquatic life (Muralimohan *et al*., 2014).

For natural recycling the contaminants are beyond its capacity due to large volume discharge and in addition to that treating this wastewater is too difficult with the use of ordinary physical, chemical and biological methods due to their intensive color, high contents of surfactants and other organic compounds has a significant toxicity and poor biological recovery (Kos *et al*., 2010). Technological advances have seen an increase in diversity and complexity of synthetic textile dyes with the objective of product improvement through enhancement of dye properties such as fading, improved deliver of dyes to fabrics and increased variety of shades. This increase in diversity and complexity of dyes is coupled with higher resistance to environmental degradation leading to pollution problems by textile effluents (Ayanda, 2014; Ramalho *et al*., 2005).All these problems increase public concern about environmental issues which has led to search for different treatment technologies for wastewater treatments (Babu *et al*., 2007). Therefore, it is very important to explore newer treatment technologies and/or combine the present available treatment processes that was ensure effluent discharge standards and total removal of organic dyes is achieved. Meanwhile, the current track record of Ethiopia indicates that most of the textile industries lack competency in environmental compliance/management and are not in line with the global demand of carbon neutrality and environmental pollution (Mekdes, 2019). There are no enough and well-established effluent treatment facilities and even those installed are not functioning properly in many plants (Meseret *et al*., 2019).

The overall aim of this review is to evaluate the scattered literature regarding textile wastewater constituents, typical characteristics and their impact on the environment. It also presents preferable treatment methodologies for domestic companies and environmentalists that need to run and manage ecofriendly textile industries in this globally competitive business.

2. CHARACTERISTICS OF TEXTILE WASTEWATER

2.1 Composition of textile wastewater

Textile industry is one of the major contributors to pollution due to its high-volume water consumption and discharging complex and high volume of wastewater (Muda *et al*., 2013; Tokoglu and Ozdemir, 2010). The characteristics of textile effluents vary and depend on the type of textile manufactured and the chemicals used (Vineta *et al*., 2014). The effluent contains high amounts of suspended and dissolved solids, biological oxygen demand (BOD), chemical oxygen demand (COD), chemicals, trace metals like Cr, As, Cu and Zn and color (Figure 1 and Table 1.) (Meseretu 2015). It consumes mainly processing water (90-94 %), and cooling water (6-10 %) and finally it is loaded with different pollutants; dyes, surfactants, acids or bases, salts, heavy metals, and suspended solids (Kamaruddin *et al*., 2013). Fiber production in textile factories includes dry and wet processes. The wet process uses a considerable quantity of potable water and releases highly contaminated wastewater (Yaseen and Scholz, 2018). This process in textile industry is categorized into five common textile processing procedures namely sizing, fabric preparation, dying, printing and finishing each process producing varying amount of effluent. The chemicals used in the process range from inorganic compounds and elements to polymers and organic products (Buthelezi *et al*., 2012).

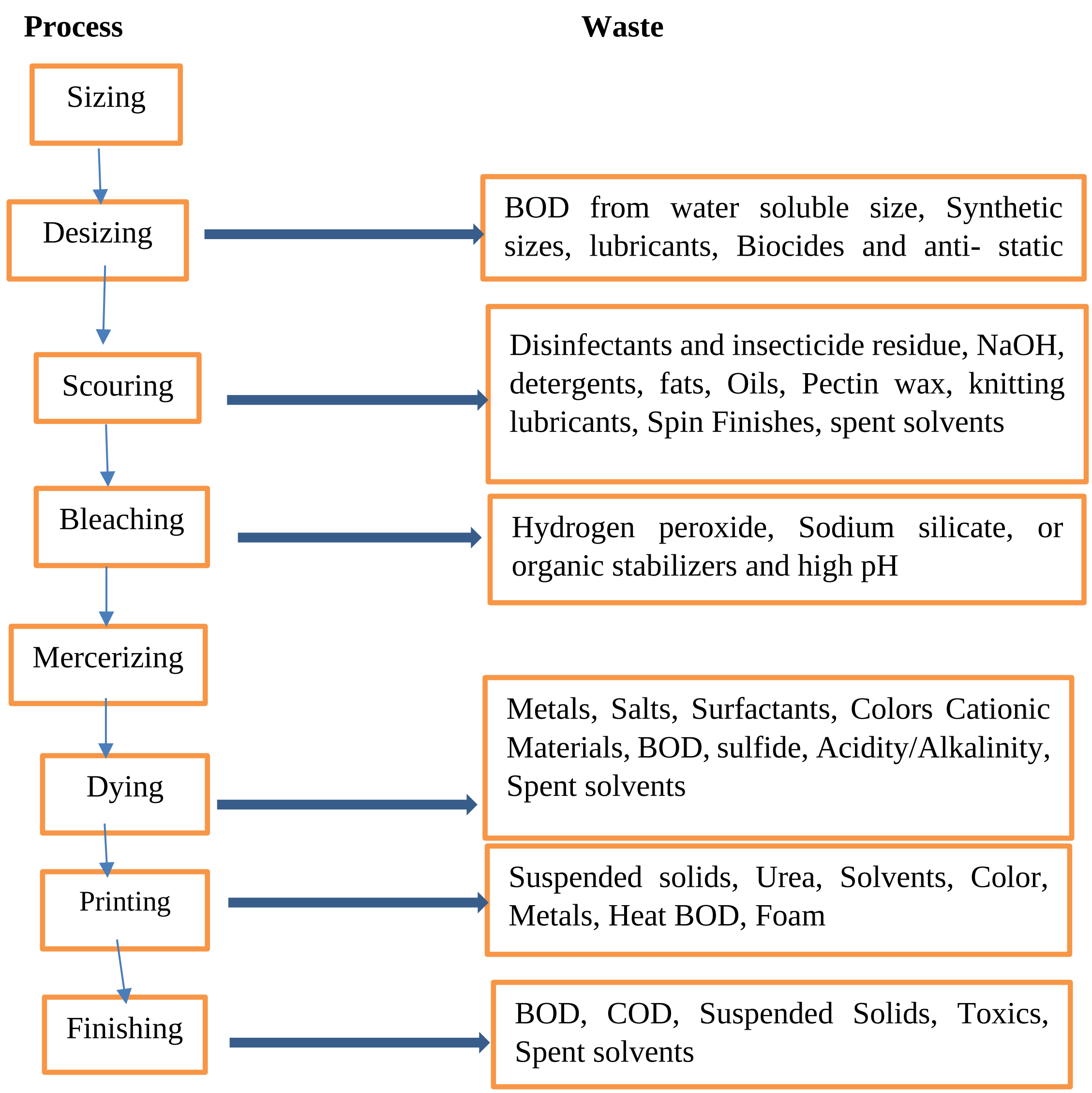

Figure 1. Characteristics of Wastewater from Different Wet Processes (*Source*: Meseretu,2015).

Table 1: Typical characteristics of textile effluents (source: Awoke 2008).

Process	COD (g/L)	BOD (g/L)	TS (g/L)	TDS (g/L)	pH	Color (ADMI)
Desizing	4.6-5.9	1.7-5.2	16.0-32.0	-	-	-
Scouring	8	0.1-2.9	7.6-17.4	-	10-13	694
Bleaching	6.7-13.5	0.1-1.7	2.3-14.4	4.8-19.5	8.5-9.6	153
Mercerizing	1.6	0.05-0.10	0.6-1.9	4.3-4.6	5.5-9.5	-
Dyeing	1.1-4.6	0.01-1.80	0.5-14.1	0.05	5-10	1450-4750

COD chemical oxygen demand, BOD 5-day biochemical oxygen demand, TS total solids, TDS total dissolved solids, pH power of hydrogen, ADMI American Dye Manufacturer's Institute

2.2. Dyes in textile effluents

Next to water textile industry consumes the largest portion of colorants; this encouraged the global market to produce more than 100,000 commercial dyes. This growing demand in return led to the production of more than 700,000 tons of dyes annually (Muda *et al*., 2013).

Dyeing in the ancient times was practiced by using natural colorants for painting and dyeing human body parts and their surroundings. Primitive dyeing techniques included sticking plants to fabric or rubbing crushed pigments into cloth. Formerly, colorants were obtained from animal and vegetable sources (Awoke, 2008). In 1500 BC, tyrian purple which was extracted from animals (molluscs) was used by Phoenicians. The pigment itself is not in the mollusc but when the precursor is extracted, it can be converted in to dye by air or light. The well-known plant dye indigo, which was extracted from *Indigo feratinctoria* has been used since 3,000 BC. Unlike to tyrian purple, indigo is a non-plant dye still in use (Meseretu, 2015). Many compounds are colored due to their absorption of visible light. Our eyes are naturally capable of detecting many different wavelengths or energies of light, and we perceive these different wavelengths as different colors, as summarized in the Table 2 below:

Table 2: Regions of the electromagnetic spectrum and relationship between wavelengths and color (Rastogi *et al*., 1972).

Electromagnetic region	**Wavelength (nm)**	**Color perception**
Ultraviolet	< 350	Nd
Visible light	350-400	Nd
	400-435	Violet
	435-480	Blue
	480-490	Greenish –blue
	490-500	Bluish-green
	500-560	Green
	560-580	Yellowish-green
	580-595	Yellow
	595-605	Orange
	605-750	Red
	750-780	Nd
Infrared	>780	Nd

Nd = Not detected by the eye

Structurally, dyes consist of auxochromes and chromophores (Figure 1), which together are called chromogen (Rastogi *et al*., 1972). Auxochromes are electron-withdrawing or donating group, of which the most important ones are amine (─NH3), carboxyl (─COOH), sulfonate (─SO3H) and hydroxyl (─OH) (Dos Santos, 2005). On the other hand, chromophores have a delocalized electron system with conjugated double bonds having with drawing nature of electrons.

The azo (─N═N─), carbonyl (─C═O), methine (─CH═), nitro (─NO2) and quinoid groups are the most known chromophores (Vander Zee, 2002). The first classifications of dyes based on chromophores are started in 1876 (Rastogi *et al*., 1972). Based on chromophore, dyes are categorized as homocyclic (azo, nitroso, methine, anthraquione and quinoemine) and heterocyclic (indigoid, sulphur, and phthalocyanine) dyes (Meseretu, 2015). A second classification of dyes are based on their mode of application to industries. The Color Index (C.I) distinguishes about 15 different application classes such as: acid, reactive, metal complex, direct, basic, mordant, disperse, pigment, vat, azoic and ingrain, sulfur, and solvent dyes (Ramalho, 2005).

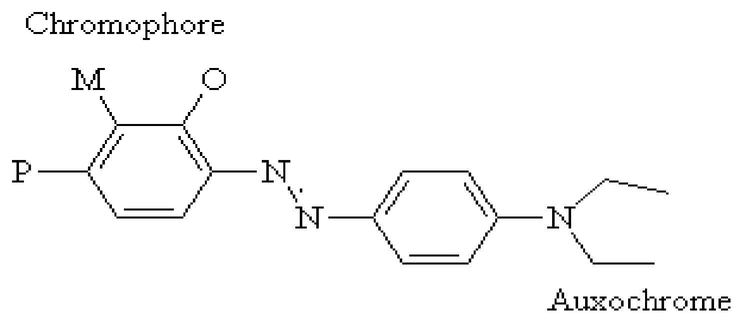

Figure 1. Examples of dye: auxochromes and chromophore for azo dye (reactive red)

Dyes used by textile industries are mostly synthetic, typically derived from coal tar and petroleum-based intermediates. They are made up of atoms responsible for the color, called chromophores, as well as an electron withdrawing or donating substituent's that cause or intensify the color of the chromophores, called auxochrome (Wang *et al*., 2011).

The most widely used synthetic dyes are Azo dyes which represent almost 70% of the textile dyestuffs produced (Awoke, 2008). Azo dyes are a compound containing azo groups (─N═N─) which mainly forms a bond to benzene or naphthalene rings. Due to their chemical structure (chromophore), azo dyes absorb light in the visible range of wavelengths from 400-750 nm (Vander Zee, 2002). Wavelengths smaller than that of violet (called Ultraviolet) and of wavelengths greater than that of red (called Infrared) is invisible (Table 2). Azo dyes are used in textile and dyeing industries in enormous amount due to their ease and cost effectiveness in synthesis, firmness and variety in color compared to that of natural dyes (Sathiya *et al.,* 2007; Seesuriyachan *et al.,* 2006).

2.1.3. Dye discharge in textile waste water

Approximately 80,000 tons of dyes used in various industries such as food processing industries, cosmetics, paper mills etc. but the textile division alone consumes about 60% of total dye production for coloring a variety of fabrics and about 10–15% of unspent dyes are let out into the clean water bodies which makes the water highly colored and polluted, typically with a concentration range 10–200 ppm (Elango *et al*., 2017).

The dye concentrations in textile effluent are reported over a wide range of values. Laing (1991) indicated that the dye level in the textile effluent is 10–50 mg/l whereas, (Shelley, 1994) reported that the reactive dyes in cotton factories are discharged at a concentration of 60 mg/l and similarly a concentration between 100 and 200 mg/l was indicated by (Yaseen and Scholz, 2018). The dye effluents concentration ranging between 600 and 800 mg/l was also the concentration described by Koprivanac *et al*. (1993). This concentration is extremely high, compared to other references, and may refer to effluent discharge from a specific textile industry. Abid *et al.* (2012) reported outflow dye concentrations ranging between 20 and 50 mg/l from 14 Ramadhan textile industries in Iraq. Sivakumar (2014) mentioned that the outflow concentration of the dye Acid Orange 10 from the final clarifier of a textile factory in India is 45 mg/l. However, Ghaly *et al*. (2014) mentioned that the dye concentrations discharged from dye houses ranged from 10 to 250 mg/l. Depending on the American Dye Manufactures Institute (ADMI) (Figure 2), the intensity of the dye in the colored effluents was reported to be between 1000 and 1500 ADMI units (O'Neill *et al*., 1999).

Figure 6. Black (above) and Red (low) Textile wastewater in united states of America, 1999

2.2. Environmental impact of textile wastewater

As mentioned earlier, textile industry, which is the largest water consumer, produces the wastewater comprising of various recalcitrant agents such as dyes, sizing agents, and dyeing aids. Dyes used in dyeing process are the most environmentally problematic recalcitrant agent (Ramalho *et al.*, 2005). The wastewater from the dye house is generally multi-colored. A large amount of waste discharge which is absorbed by the soil causes water pollution. The farmers use the polluted water to irrigate their fields. The vegetables and crops produced in such away are consumed by the human beings resulting into a number of health hazards (Mishra and Soni, 2016). If the effluent is discharged in to rivers and streams, it impedes light penetration, decrease dissolved oxygen, damage the receiving stream and become toxic to organism and aquatic life and disturb the integrity of the ecosystem (Awoke, 2008). Moreover, there are considerable evidences that certain anaerobic metabolites of dyes are being toxic, carcinogenic and mutagenic agents of some microorganisms, aquatic life and human being. There was description that the textile effluents have effect on fishes by that suspended solids can clog fish gills, either killing them or reducing their growth rate (Tüfekci *et al.*, 2007).

Most of the azo dyes are water soluble and readily to be absorbed through skin contact and inhalation leading to the risk of cancer and allergic reactions, an irritant for the eyes and highly toxic, if inhaled or consumed (Sudha *et al*., 2014). The highly alkaline and saline water is also causing damage to ground water and it causes aesthetic displeasing to the compounds. The presence of heavy metals in the effluent has accumulative effect (Wang *et al.*, 2011). The water pollution is considered to be the biggest environmental threat all over the world. Generally, surface water is used for dyeing, printing, sizing, bleaching and washing, and therefore, this water mixes with the water in rivers and thereby increases pollution (Tokoglu and Ozdemir, 2010).

Table 3: Sources of water pollution at various stages of textile processing (Vineta *et al*., 2014).

Process	**Possible Pollutants**	**Nature of Effluent**
Desizing	Starch, glucose, PVA, resins, fats and waxes do not exert a high BOD	Very small volume, high BOD (30-50% total volume), PVA
Kiering	Caustic soda, waxes, soda ash, sodium silicate and fragments of cloth.	Very small, strongly alkaline, dark color, high BOD values (30% of total
Bleaching	Hypochlorite, chlorine, caustic soda, hydrogen peroxide, acids.	Small volume, strongly alkaline, low BOD (5% of total)
Mercerizing	Caustic soda	Small volume, strongly alkaline, low BOD (Less than 1% of total)
Dyeing	Dye stuff, mordant and reducing agents like sulphides, acetic acids and soap	Large volume, strongly colored, fairly high BOD (6% of total)
Printing	Dye, starch, gum oil, china clay, mordants, acids and metallic salts	Very small volume, oily appearances, fairly high BOD.
Finishing	Traces of starch, tallow, salts, special finishes, etc.	Very small volume, less alkaline, low BOD

Imtiazuddin *et al.* (2012) indicated that the textile wastewater pollutes the soil. The soil is the most important medium for growing plant, bushes, crops, etc. The quality of crops depends upon the quality of the soil. So, when the quality of the soil decreases due to polluted industrial wastewater, subsequently, the amount and quality of crops also decline. It is also seen that the lower lands become more polluted than the higher lands, as the effluents are ultimately deposited in the lower lands. Mahmoud *et al*., (2007) also reported that most processes performed in the textile mills produce atmospheric emissions. Gaseous emissions have been identified as the second greatest pollution problem (after effluent quality) for the textile industry. The major air pollution problem in the textile industry occurs during the finishing stages, where various processes are employed for coating the fabrics (Meseretu, 2015). Coating materials include lubricating oils, plasticizers, paints and waterrepellent chemicals essentially, organic compounds such as oils, waxes or solvents, acid vapor, odors and boiler exhausts (Karan, 2018).

All these points converge to indicate the need of treating textile wastes before discharge to water bodies. As dyes are designed to be chemically and photolytically stable, they are highly persistent in natural environments (Vander Zee, 2002). For instance, the half-life of hydrolyzed Reactive Blue 19 is about 46 years at pH 7 and 25 ºC (Awoke, 2008). Without any treatment discharging of textile wastewater dispose poisons in to the environment which is beyond of nature to eliminate can damages or have influence in many animal species in the environment with resultant changes in the ecological balance (Abraha *et al*., 2014).

2.3. Textile Wastewater Treatment Technologies

The release of textile wastewater causes dark coloration of surface waters that captures the attention of both the public and the authorities (Sghaier *et al*., 2019). This social concern persuade pressure on textile industry by government regulators to move toward sustainability, by reducing the environmental pollution while internal pressures to maintain or increase profit margins by reducing treatment cost as well (Beyene, 2014). As a result, for the last 50-75 years, ever-increasing efforts to somehow arrange manufacturing processes in such a way that they cause minimal damage to the environment. At the same time, these efforts are aimed at developing appropriate technologies for wastewater treatment and establish an adequate relationship between regulators and industry (Vineta *et al*., 2014).

Many techniques have been developed to find an economic and efficient way to treat the textile dyeing. The spectrum of methods for treatment of textile wastewaters is extremely broad (Wang *et al*., 2011). Even though, different treatment methods are applied the decolorization efficiency was largely influenced by the type of dye, pH, temperature, and flocculent concentration (Buthelezi *et al*., 2012). Moreover, river that is used for drinking must not be colored, as otherwise the treatment costs will be increased.

Utilizing a new approach through the use of advanced primary and secondary water treatment solutions is necessary to meet the challenges faced by both the society and the textile industry now and into the future (Awoke *et al*., 2017). Conventional wastewater treatment consists of a combination of physical, chemical and/or biological processes and operations to remove dyes and solids including colloids, organic matter, nutrients, soluble contaminants (metals, organics, etc.) from effluents (Grégorio and Eric, 2019). Studies concerning the feasibility of treating dyeing wastewater are very important (Wang *et al.,* 2011). So that, before starting wastewater treatment costs of required chemicals, operational costs (energy and material) and environmental fate and handling costs of generated waste products should be carefully considered (Awoke, 2008).

2.3.1. Physico-chemical Method

Physical treatment method: Low dye removal efficiency restricts the application of physical methods such as adsorption, filtration, precipitation (coagulation, flocculation, sedimentation), adsorption (on activated carbon, biological sludge's), filtration, or reverse osmosis membrane processes and ion exchange (Mirbolooki *et al*., 2017; Babu *et al*., 2007). Even though, all these methods can have potential for remediating wastes physical removal can lead to extra solid wastes and increased overhead (Wang *et al*., 2011).

Coagulation, flocculation, sedimentation is one of the most used methods, especially in the conventional treatments process. The inorganic coagulants such as lime, aluminum, magnesium and iron salts have been used for coagulation in the treatment of wastewater from textile industry (Wang *et al.,* 2011). These techniques are mostly applied for removing TSS, BOD_5, COD and color over many years (Adinew, 2012).

Adsorption technique is a natural process by which molecules of dissolved compound collect on and adhere to the surface of adsorbent solids. Adsorption occurs when the attractive forces at the carbon surface overcome the attractive forces of the liquid (Awaleh and Soubaneh, 2014). A combination of adsorption and nanofiltration can be adopted for the treatment of textile dye effluents (Adinew, 2012). The adsorption step precedes nanofiltration, because this sequence decreases concentration polarization during the filtration process, which increases the process output (Mirbolooki *et al.,* 2017).

Floatation produces a large number of micro-bubbles in order to form the three-phase substances of water, gas, and solid. Dissolved air pressure may be added to cause the formation of tiny bubbles which will attach to particles. Under the effect of interfacial tension, buoyancy of bubble rising, hydrostatic pressure and variety of the forces the microbes adhere to the tiny fibers. Due to its low density, the mixtures float to the surface so that the oil particles are separated from the water (Beyene, 2014).

Chemical treatment methods: This method includes Fenton's reagent, ozonation, Photochemical, Sodium hypochlorite (NaOCl) and electrolysis (Awoke,2008). This chemical method often expensive and although the dyes removed, accumulation of concentrated sludge creates a disposal problem (Tokoglu and Ozdemir, 2010).

Ozone oxidation is very effective and fast decolorizing treatment, which can easily break the double bond present in azo bonds. This method can also inhibit or destroy the foaming properties of residual surfactants and it can oxidize a significant portion of COD Ozone is a very powerful and rapid oxidizing agent that can react with most species containing multiple bond (such as C=C, C=N, N=N, etc.) and with simple oxidizable ions such as S_2 to form oxyanions such as SO_3^{-2} and SO_4^{-2} (Adinew, 2012).

Fenton reaction was oxidative processes represent a widely used chemical method for the treatment of textile effluent, where decolorization is the main concern. Hydrogen peroxide is the oxidizing agent and activated to form hydroxyl radicals, which are among the strongest existing oxidizing agent and able to decolorize wide range of dyes (Adinew, 2012)

Chemical oxidation methods make the destruction and degradation of dyestuff molecules possible, but with these methods, various oxidizing agents such as O_3, H_2O_2, and MnO_4 are used. In addition to being unable to completely remove azo dyes from wastewater (because azo dyes are stable and resistant to degradation), these methods are not economical and even produce large quantities of sometimes toxic sludge (Mirbolooki *et al*., 2017). Hence, extensive research is conducted worldwide by many researchers on studying photo degradation of commercial dyes (Khan *et al*., 2016). The studies have demonstrated that heterogeneous photocatalysis is the most efficient technique in the degradation of colored (Hussein, 2011). Wastewater from the dyeing process was effectively decolorized using titanium dioxide or zinc oxide (Attia *et al*., 2008). Khan *et al*. (2016) reported that they experimental complete removal of the color; pH and reaction enhancer H2O2 played an important role in enhancing the process. They achieved complete decolorization of real textile wastewater within six hours of irradiation. Another report indicated that photodegradation of a dye, cyanosine by TiO2 is faster at pH of 8, temperature of +30°C, and in the presence of H_2O_2 (Jain and Shrivastava, 2008). Membrane bioreactor (MBR) technology has been used widely for various industrial wastewater treatments due to its distinct advantages over conventional bioreactors (Wang *et al*., 2011). Treatment of textile wastewater using MBR has been investigated as a simple, reliable and cost-effective process with a significant removal of contaminants. However, a major drawback in the operation of MBR is membrane fouling, which leads to the decline in permeate flux and therefore requires membrane cleaning. This eventually decreases the lifespan of the membrane (Vineta *et al*., 2014).

Table 4: Advantage and disadvantages of chemical methods

Methods	**Advantages**	**Disadvantage**
Fenton's reagent	Effective decolorization of both soluble and insoluble dyes	Sludge production
Ozonation	Applied in gaseous state no alteration of volume	Short half time of O_3
Photo chemical	No sludge production	Formation of bye products
NaoCl	Initiates and accelerates azo bond cleavage	Release of aromatic amines
Electrochemical destruction	Breakdown compound are non-hazardous	High cost of electricity

2.3.2. Biological methods

Biological processes are often the preferred choice for treatment of wastewater. They are considered to have low environmental impact and costs in comparison with other types of treatments, because they require only slight or no addition of chemicals and reasonable amounts of energy. Biological processes have the potential to convert or degrade the pollutant into water, carbon dioxide and various salts of inorganic nature (Awoke, 2008). Application of biological processes in the treatment of textile wastewater has been reported extensively. However, there is a practical limit to the degree of organic removal and color removal (Meseretu, 2015).

Azo dyes have a serious environmental impact because their precursors and degradation products (such as aromatic amines) are highly carcinogenic (Bhatt *et al*., 2005). Different scholars did biological treatment in different ways and by using different microbes to treat azo dyes and amines. These dyes are inevitably discharged in industrial effluents. Aerobic and anaerobic microorganisms can both be useful for treatment of textile wastewater. Enzymes with azo-reductase activity have been found in many types of aerobic and anaerobic microorganisms including bacteria, fungi and algae. The most interesting organic pollutants oxidases have been identified in microorganisms that live under aerobic conditions (Mirbolooki *et al*., 2017). These authors reported that with different processes of activated sludge, following elimination rates could be achieved about 90% BOD_5, 40-50% COD and 20-30% color from the above finding the color removal is below the required limit so that colored wastewater cannot be effectively dealt with by a single method. As a result, there has been an increasing awareness of alternative or supplementary processes.

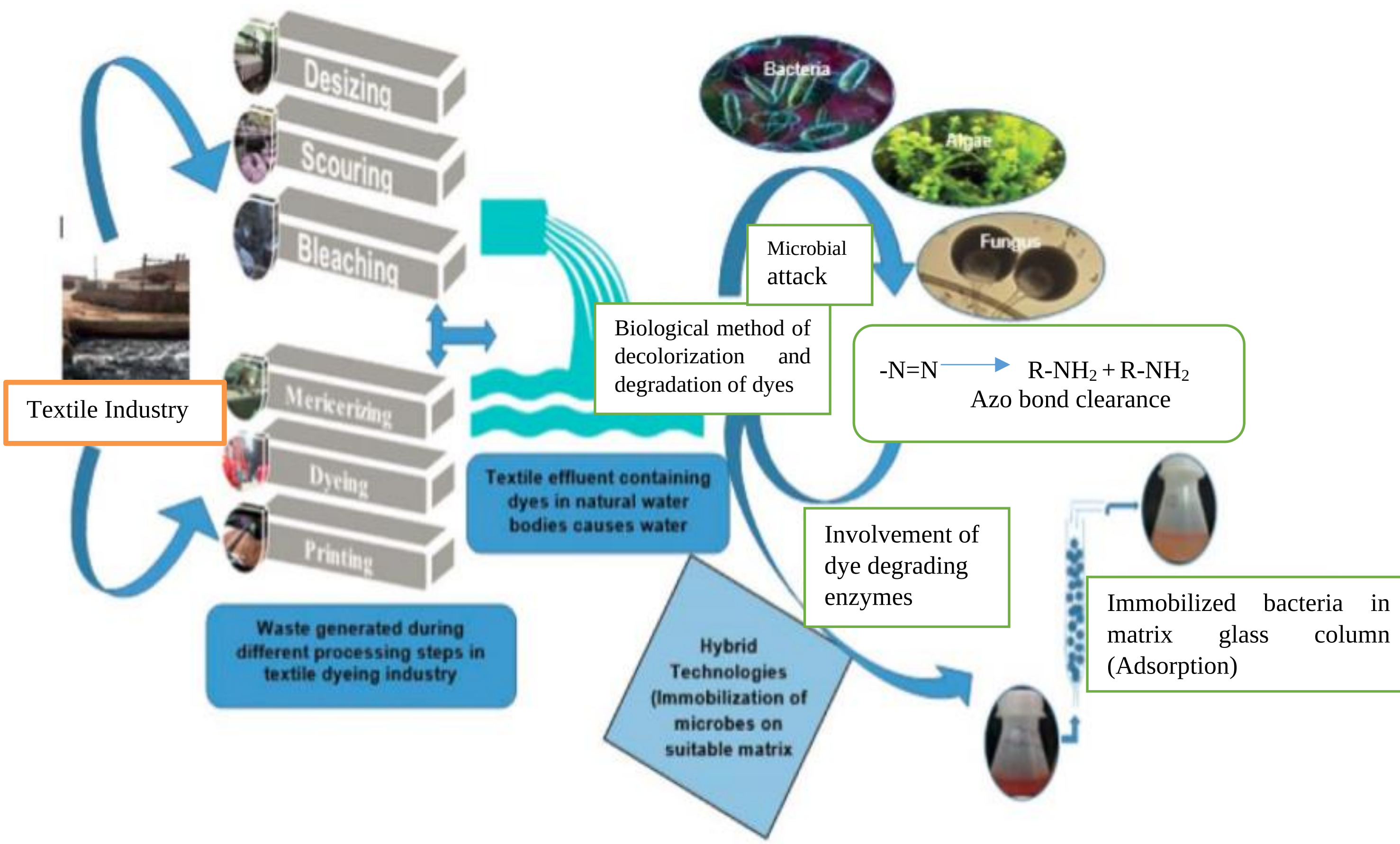

Figure 2. An overview of the waste generated by processing steps in textile industries and various biological methods for effluent treatment

2.3.2.1. Aerobic Treatment

Activated sludge treatment of wastes is often an effective and economically viable system for reducing organic pollutants in wastewater (Activated sludge is a kind of floc which is mainly comprised of many microorganisms) which has strong decomposition and adsorption of the organics (Wang *et al*., 2011). Bacteria and fungi are the type of microorganisms more commonly used for the decolorization of dyes under aerobic conditions. Bacteria are able to grow faster than fungi (Balamurugan *et al*., 2011). Aerobic bacteria capable of degrading various dyes have been used more than three decades. Numerous bacteria capable to degrade dyes have been reported. Efforts to isolate bacterial cultures capable of degrading azo dyes started in 1970's with reports of Bacillus subtilis, then Aeromonas hydrophilia, followed by Bacillus cereus (Anjaneyulu *et al*., 2005). Aerobic removal of azo compounds by Aeromonas hydrophilia was reported (Idaka *et al*., 1987). Bacterium Pseudomonas luteola was isolated from *the* sludge of an activated sludge treatment system treating dyeing wastewater, which removed the color of four reactive azo dyes (Hu, 1994; Naresh *et al*., 2013).). Some researchers have been also applied sulfate-reducing bacteria for degradation of dyes (Parshetti *et al.*, 2009). However, most treatment plants are not effective (Awoke *et al*., 2017). It is suggested that aerobic microbes cannot reduce dye linkage like azo but they can successfully stabilize dye metabolites (Tokoglu and Ozdemir. 2010).

Meseretu (2015) reported experiment that organic pollutants like BOD and nitrates removal rate is higher by aerobic microbes. Similarly, Awoke *et al*., (2017) confirmed on their experiment that decolorization rate is very low and decolorization rate is higher by anerobic bacteria. Similarly, (Wang *et al*., 2011) reported that under aerobic conditions low color removal efficiencies (10-30%) are achieved because oxygen is a more effective electron acceptor than azo dyes, but the amount of COD is reduced after aerobic treatment but it is not related with decolorization. In some studies color removal under aerobic condition can be achieved in the presence of additional energy and carbon source (Suhartini *et al*.,2019).

2.3.2.2. Anaerobic treatment

The most frequent application is aerobic way but it is inefficient in degrading azo dyes which are the main constituents of textile colorants (Wallace, 2001; Wang *et al*., 2011). However, Meseretu (2015), Awoke (2008) reported that microorganisms need oxygen for organic pollutants like BOD, COD and the degradation rate is higher in oxic reactors than anoxic reactors (Wang *et al*., 2011). So, it is necessary that anaerobic treatment requires aerobic post treatment in order to complete the mineralization of some pollutants (dyes, surfactants, residual BOD) and remove nutrients (Delee *et al*., 1998). This post-stage benefits from the anaerobic pre-treatment in several ways including the protection against BOD and toxic shock loads, the possibility of reductive decolorization and dichlorination, the mineralization of foaming and bulking problems and the sludge disposal costs. Recently different research results show that synthetic simulated wastewater can be treated efficiently in aerobic–anaerobic bio processers (Ramalho *et al*., 2005).

Whereas, under anaerobic conditions azo dyes are readily cleaved via four electron reductions at azo linkage generating aromatic mines (Miao, 2007). Awoke *et al*. (2017) stated that in an anoxic batch reactor they isolate the most efficient decolorizer (92–100%) bacteria within the first day of incubation. The presence of organic substrate like glucose, hydrolyze starch, yeast extract, acetate, butyrate and propionate are used electron donor for azo reduction instead of oxygen in the absence of oxygen (Akhtar *et al.*, 2005).

Generally, anaerobic system could reduce the color intensity more satisfactory than aerobic process. (Awoke *et al*., 2017). However, further degradation of the intermediate which are recalcitrant under anaerobic conditions is ready achieved under aerobic conditions. Another problem of anaerobic color removal is the reverse colorization of anaerobic degradation of products up on exposure to oxygen because of characteristics of biodegradation products aromatic amines which deteriorate to give color (Tokoglu and Ozdemir. 2010). This necessitates the combination of two systems to achieve not only decolorization but also mineralization of dyes (Wang *et al.*, 2011).

2.3.2.3. Anaerobic-Aerobic Treatment

This treatment process is a mature and widely used process in wastewater treatment in recent years (Meseretu, 2015). The purpose is aiming at degrading both organic pollutants and poorly biodegradable dyes and insoluble material in textile dyeing wastewater to small molecules and soluble substances by hydrolysis and acidification. Moreover, aerobic test demonstrated high BOD removal values of 80-85%. (Suhartini *et al*., 2019)

Aerobic treatment is potentially to have a superior performance on organic pollutant degradation than anaerobic treatment because all sludge generated in the aerobic biological treatment return into the anaerobic biological stage through the sedimentation tank. Because of the sludge in the anaerobic biochemical stage has sufficient hydraulic retention time to carry out anaerobic digest thoroughly (Wang *et al*., 2011). According to Meseretu (2015), high decolorization with little TOC, BOD or COD removal in anaerobic phase is observed but in aerobic- anaerobic treatment 88% color reduction in and only 29% color reduction in anaerobic treatment observed. Additionally, 74% and 38% color removal efficiency in anaerobic-aerobic reactors were reported by Awoke *et al*. (2017).

Many anaerobic studies and found that organic carbon is needed as the energy source for catabolizing dyes into decolorized water under anaerobic environment (Awoke *et al*., 2017; Wang *et al*., 2011. This shows that if the sequential reactor starts with aerobic reactor, all carbon sources may decompose by aerobic microorganisms and the next anaerobic reactor lacks carbon sources for dyes catabolizing (Akhtar *et al.*, 2005; Ramalho *et al*., 2005)

A wide range of microorganisms are capable of degrading a variety of azo dyes including bacteria, actinomycetes, fungi and yeast (Sudha *et al*., 2014). They have developed enzyme systems for the decolorization and mineralization of azo dyes under certain environmental condition.

The bacterial reduction of the azo dye is usually nonspecific and bacterial decolorization is normally faster. A wide range of aerobic and anaerobic bacteria such as Bacillus subtilis, Pseudomonas sp, Escherichia coli, Rhabdobacter sp, Enterococcus sp, Staphylococcus sp, Xenophilus sp, Corynebacterium sp, Clostridium sp., Micrococcus dermacoccus sp, Acinetobacter sp, Geobacillus, Lactobacillus, Rhizobium, Proteus sp, Morganella sp, Aeromonas sp, Alcaligenes sp and Klebsiellla sp have been extensively reported as degraders of azo dyes (Awoke *et al*.,2017; Sudha *et al*., 2014; Lin and Leu, 2008; Vijaykumar *et al*., 2007). Some strains of aerobic use azo dyes as sole source of carbon and nitrogen (Coughlin *et al*., 2002) others only reduce the azo group by special oxygen-tolerant azo reductases (Awoke *et al*., 2017).

The most widely explored fungi in regard to dye degradation are the ligninolytic fungi (Bumpus, 2004). Apart from this, Phanerochaete chrysosporium, Coriolus versicolar, Trametes versicolar, Fungalia trogii, Penicillium geastrivous, Rhizopus oryzar, Pleurotus ostreatus, Rigidoporus lignosus, Pycnoporus sanguineus, Aspergillus flavus, and Aspergillus niger have been reported which are capable of degrading azo dyes (Fu and Viraraghavan,2001; Wesenberg *et al*.,2003).

3. CONCLUSIONS

The textile industry is one of the largest consumers of potable water and consequently, produces a huge amount of wastewater. Although the typical characteristics of textile factory wastewaters have been previously documented, the real effluents from different textile mills presented in studies vary widely and some of the characteristic parameter values are not within typical ranges. Textile effluents are undesirable, and their treatment is extensively required for environmental protection. Physical, chemical and biological methods have been examined and used for the treatment of textile industry effluents. Physical and chemical treatment methods such as precipitation, coagulation, adsorption, flocculation, flotation, and electrolytic destruction have some disadvantages such as cost, time, and release of residues. All these techniques minimize the toxicity level but they do not to neutralize the toxicity. To alternate these techniques, microorganisms can be used to completely degrade the azo dyes because microorganisms reduce the azo dyes by secreting enzymes such as laccase, azo reductase, peroxidase, and hydrogenase. Based on the available literature, the microbial decolorization of azo dyes is more effective under combined aerobic and anaerobic conditions.

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