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Review Article

Treatment of Textile Industrial Wastewater using Membrane Technology: A Review

Pengolahan Limbah Cair Tekstil dengan Teknologi Membran: Review

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Abstract

Textile industry wastewater is a very complex pollutant-containing waste with high dye intensity, requiring proper and appropriate treatment. Membrane technology is one of the appropriate methods for treating textile wastewater due to several advantages such as environmentally friendly and biopolymer-based processing. Therefore, this review aimed to determine the effectiveness of membrane technology and provide information regarding the appropriate treatment of textile wastewater. The articles subjected to review were obtained from several journal sources such as ScienceDirect, Elsevier, Springer, Google Scholar, and national journals. The results showed that several membranes had been used in textile wastewater treatment, such as PTFE (Polytetrafluoroethylene), PES (Polyethersulfone), Polysulfone-Polyvinyl Pyrrolidone Blend Polymer Composite Membrane, CA (Cellulose Acetate), Cellulose Membrane of Sargassum Sp., polysulfone (PSF), Bacterial Cellulose Membrane, and cellulose acetate propionate (CAP). Furthermore, membrane technology was found to reduce dye pollutants in textile wastewater with the highest coefficient value of approximately 97%.

Keywords: membrane; membrane technology; textile industry; treatment methods; wastewater

Abstrak

Limbah cair industri tekstil merupakan limbah mengandung polutan yang sangat kompleks dengan intensitas pewarna yang tinggi. Karena itu, pengolahan limbah cair tekstil ini harus ditangani dengan baik dan tepat. Teknologi membran merupakan salah satu metode yang tepat dalam mengolah limbah cair tekstil. Pengolahan berbasis ramah lingkungan dan bersifat biopolimer merupakan keunggulan dari teknologi membran. Review ini bertujuan untuk mengetahui efektivitas teknologi membran dan memberikan informasi mengenai teknologi membran dalam mengolah limbah cair tekstil yang tepat. Metode yang digunakan dalam review ini adalah meninjau artikel dari beberapa sumber jurnal seperti sciencedirect, elsevier, springer, google scholar, dan jurnal nasional. Terdapat banyak membran yang digunakan dalam pengolahan limbah cair tekstil, seperti: PTFE (Polytetrafluoroethylene), PES (Polyethersulfone), Polysulfone-Polyvinyl Pyrrolidone Blend Polymer Composite Membrane, CA (Cellulose Acetate), Membran Selulosa Sargassum Sp., polisulfon (PSF), Bacterial Cellulose Membrane, cellulose acetate propionate. Metode teknologi membran dapat mengurangi polutan pewarna dalam limbah tekstil dengan nilai koefisien tertinggi hingga 97%.

Kata kunci: *industri tekstil; limbah cair; membran; metode pengolahan; teknologi membran*

1. Introduction

Indonesia is one of the largest countries in the sector industry, particularly fabric or textile. This shows that textile industry plays a significant role in the national economy, as indicated by many workers who live and work in the sector. However, waste is often generated as pollution from industrial activities that produce hazardous and toxic materials (B3) [1],[2],[3].

Textile industry is currently dominated by 63% synthetic fibers, most of which are derived from petrochemicals, causing CO2 emissions. This is followed by cotton, whose production can cause water scarcity and toxic pollution due to its widespread use [4]. Textile wastewater contains very complex pollutants with high dye intensity. Some dyes are toxic and have carcinogenic and mutagenic effects on aquatic life and humans [5],[6]. Remazol red ($C_{18}H_{14}N_2Na_2O_{10}S_3$), remazol black ($C_{26}H_{21}N_5Na_4O_{19}S_6$), naphtol yellow ($C_{10}H_4Na_2O_8S$) are examples of dyes commonly used in textile industry. Dyes have high synthetic color content, chemical oxygen demand (COD), and metal values [5],[6],[7],[8],[9]. In the process, 95% of dyes will be discarded and only approximately 5% is effective in binding fabric. Therefore, there is a need for appropriate and environmentally friendly processing methods. Previous analysis of textile wastewater processing is shown in Figure 1.

Current waste industry processing technology uses many chemical and biological processes that require large operational costs and areas of land. One method of processing textile wastewater is using membrane technology. This membrane technology in the separation process has developed rapidly, particularly for processing wastewater [10].

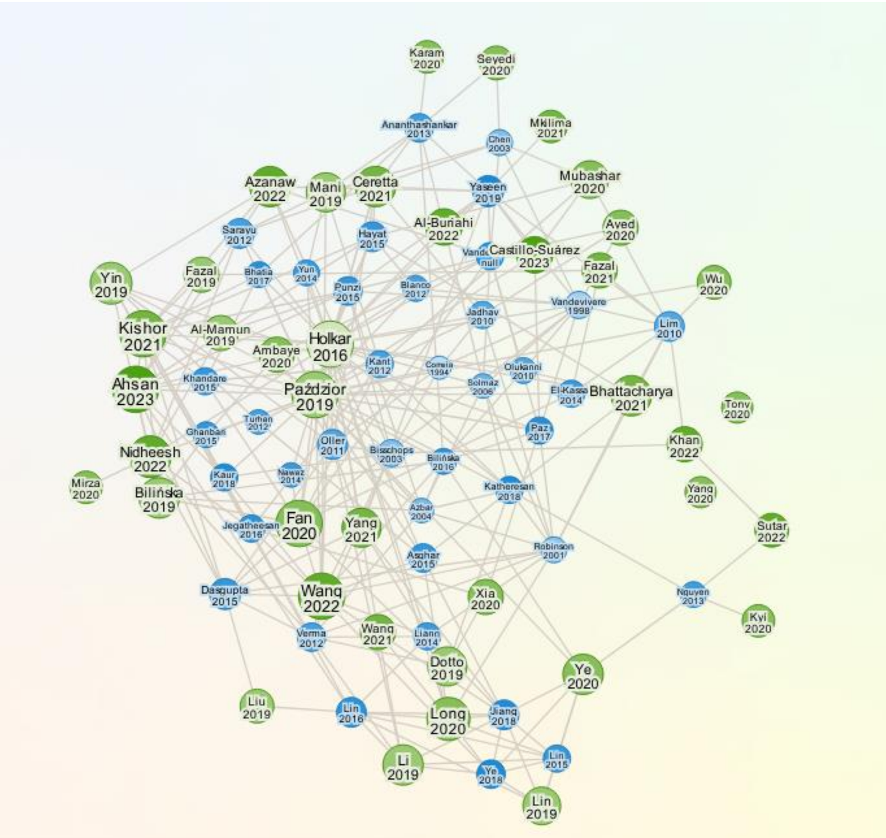

Figure 1. Study on textile wastewater treatment

Membrane technology can be used in the processing of wastewater, such as liquid tofu waste and domestic wastewater [11],[12]. It is a reliable separation method, specifically in water separation process [13],[14]. In the membrane manufacturing process, the phase inversion method is generally used[12],[15],[16],[17],[18],[19].

2. Research Method

In recent years, textile wastewater treatment has been continuously developed. There are several methods commonly used in textile wastewater treatment taken from several journal sources such as ScienceDirect, Elsevier, Springer, Google Scholar, and several national journals. Literature searches using several keywords such as textile wastewater treatment methods, textile waste, and membrane.

Based on the previous analysis, the methods commonly used in textile wastewater treatment include electrocoagulation [17],[20],[21], electrooxidation-electrocoagulation [20], phytoremediation [22], adsorption [14],[23],[24],[25]–[32],[33], filtration [23],[34],[35],[36], and membrane technology [14],[37]. Therefore, this review was conducted based on research development regarding textile wastewater treatment. The results are expected to provide information to readers regarding textile wastewater treatment and appropriate treatment methods.

3. Textile Wastewater

Wastewater treatment system in textile industry usually include primary, secondary, and tertiary treatments when the quality exceeds the applicable standard values [38]. In this review, the properties of wastewater in textile industry will be discussed. First, physical properties include density, odor, color, and temperature, the amount of dissolved oxygen (DO). Second, chemical properties include pH, DO, and COD [20]. Third, biological properties where most wastewater contains various types of microorganisms with concentrations ranging from 105 to 108 organisms/mL. In assessing water quality, bacteria also play a significant role. When waste is discharged into the environment, it will have a negative impact on the environment and become a serious problem in the industry era. The properties and composition of textile wastewater are shown in Table 1.

Textile wastewater contains large total suspended solids, bright colors, with high acidity fluctuations, temperatures, as well as concentrations of chromium and phenol. The main contaminants come from the finishing or dyeing process which includes synthetic and natural dyes to produce permanent colors and have good resistance to physicochemical treatment [16],[39].

Table 1. Properties and composition of textile wastewater parameters

Parameter	Value
pH	7,00-9,00
BOD (mg/L)	80-6.000
TTS (mg/L)	15-8.000
COD (mg/L)	150-12.000
Chloride (mg/L)	1.000-1.600
Total Kjeldahl nitrogen (mg/L)	70-80
Color (Pt-Co)	50-2.500
TDS (mg/L)	2.900-3.100

Source: [20]

4. Textile Wastewater Treatment

Several methods that have been applied in the processing of textile wastewater are shown in Table 2. Electrocoagulation can be used in waste processing by applying electrochemistry. Electrooxidation-electrocoagulation is a process to reduce organic content in textile wastewater using variations in voltage and time [20]. The phytoremediation method uses plants to reduce pollutants in waste, including water hyacinth plants as biological agents [40]. Adsorption is a method of absorbing liquids or gases where the adsorbate is bound to the adsorbent [14],[23],[25]–[29],[31]–[34]. Furthermore, the filtration method uses filtering media in separation which produces filtrate and residue. This method is included in the membrane technology method but for filtration with macro waste [23],[34],[35],[36].

Membrane technology is a water treatment method based on biopolymers and is environmentally friendly. The advantages of membrane technology include relatively low energy, maintenance of structure-separated substances, and easy operation at room temperature. Furthermore, it is clean and non-toxic due to the absence of additional chemicals. The processing of textile wastewater has a standard quality value that is a reference to avoid polluting the environment. This is regulated in Appendix II of the Regulation of the Indonesia Minister of Environment Number 5 of 2014 concerning Wastewater Quality Standards [41], as presented in Table 3.

Based on Table 2, electrocoagulation method shows COD reduction value of 112 mg/L or 50.98% of the initial COD value of the waste. However, these results do not meet the quality standards for textile wastewater. Electrooxidation-electrocoagulation method can reduce COD by 397.40 mg/L or 83% of the initial value but does not meet the quality standards. The phytoremediation method reduces biochemical oxygen demand (BOD) by 165.33 mg/L or 47.2% of the initial value of the waste. This value also does not meet the quality standards for textile wastewater. The adsorption process is only able to reduce the color concentration by 26% of the initial concentration value, which is 95% of the dye produced from liquid textile waste. The filtration method reduces the COD value by 38.81% or 211 mg/L. These results have COD value above 350 mg/L and are not included in the quality standards for textile wastewater. Furthermore, the hybrid filtration system method can reduce COD levels by 72.14% or 1066.25 mg/L from the initial total waste of 3826.6688 mg/L.

Membrane technology method reduces COD value from 1542.36 mg/L to 149.76 mg/L with a removal rate of 90.08%. These results are included in textile wastewater quality standards [13]. Additionally, the Sono-Fenton method provides results that are in environmental quality standards, namely reducing the COD value from 1532.16 mg/L to 143.36 mg/L with a removal rate of 90.64%. The sono-fenton method is effective, but it is not environmentally friendly due to the use of chemicals with a negative impact on the environment.

Table 2. Textile wastewater treatment method

Treatment Method	Waste Types	Reaction Conditions	Results	Ref.
Electrocoagulation	Wastewater from the batik industry	Reaction time: 20, 60, 100, 140 and 180 minutes Voltage: 12 volts	Decrease in COD Concentration: 50.98%, TSS: 50%, Color: 30%	[42]
Electrooxidation-Electrocoagulation	Wastewater from textile industry	Voltage: 8,12,16, and 20 volts Duration: 15 minutes and 45 minutes	TSS: - BOD: 83% COD: 75%	[20]
Phytoremediation Method	Wastewater from hand-drawn batik industry	Treatment for: 12 days Number of water hyacinths used: 7 pieces	Decrease in Concentration COD: >40% BOD: 47,2% TTS:33%	[40]
Adsorption	Wastewater from the woven fabric industry	Using a photocatalytic reactor and sunlight assistance in the process	Decrease in Color Concentration: 26%	[43]
Filtration (Macro Waste Filtration)	Wastewater from the batik industry	Using coagulant $KAl(SO_4)_2 \cdot 12H_2O$ (alum)	Decrease in Concentration COD: 38.81% BOD:40.88%	[38]
Hybrid filtration system method	Wastewater from textile industry	Raw material: Bottom Ash Duration: 4 days Temperature: 30-40℃	Decrease in Concentration: COD: 72.14% Color: 94.78 %	
Membrane Technology	Wastewater from the batik industry	The membrane is heated at temperatures: 80℃ and 90℃ Duration: 1 hour Membrane drying: 24 hours at room temperature	Decrease in Concentration of Rhodamine B Dye: B: 80.04%; Methylene Blue: 77.83%; Methyl Orange: 75.84%.	[18]
Membrane Technology	Wastewater from the eco-print textile industry	Drying membrane: 3 days	Reduce COD by 90.08%, BOD by 85.92%, and TOC by 92.34%	[13]
Sono-Fenton Method	Wastewater from textile industry	Sonication process: 10,30,60, and 90 minutes Variation of H_2O_2 and $FeSO_4$: concentration 1:1, 2:1, 4:1, 8:2	Color Concentration Reduction: 99.61%, Ph: 68.94%, COD: 90.64%, BOD: 97.48%, TSS: 91.28%.	[44]

Table 3. Textile wastewater quality standards

Parameter	Highest Level (mg/L)	Highest Pollution Load (kg/ton)
BOD	60	6
COD	150	15
TSS	50	5
Total phenol	0.5	0.05
Total chromium	1	0.1
Total ammonia	8	0.8
Sulfide	0.3	0.03
Oil and fat	3	0.3
pH	6.0-9.0	
Highest waste discharge	100 m3/ton textile products	

Source: [41]

5. Advantages and Disadvantages of Textile Wastewater Processing Methods

5.1. Electrocoagulation

The advantages of electrocoagulation method are ease of operation, absence of odor, and flocs formation like chemical coagulation. However, the method has disadvantages including the inability to treat wastewater with high electrolyte content due to short circuits between electrodes. It is also not effective in reducing heavy metal content, requires electricity consumption for processing, and small contact area of wastewater. Electrodes used for electrocoagulation should be replaced regularly because the formation of a layer on electrodes can affect the processing efficiency [17].

5.2. Electrooxidation-Electrocoagulation

Electrooxidation-electrocoagulation method is pollutant-free because electrooxidation process produces water and carbon dioxide. However, this process uses chemicals and electricity which generate new waste and consume a significant amount of energy during processing [20].

5.3. Filtration

Filtration method filters suspended solid pollutants/ types of waste with macro particles conventionally. However, the process uses chemicals and is less environmentally friendly [45].

5.4. Hybrid Method of Filtration System

Hybrid method uses bottom ash raw materials containing minerals in the form of silica (SiO_2) and alumina (Al_2O_3) which can adsorb pollutant waste. However, this method has disadvantages, namely, long contact time to obtain effective pollutant reduction and high waste concentrations can affect performance [46].

5.5. Adsorption

Adsorption uses TiO_2-volcanic ash photocatalyst absorbent but is not effective in removing pollutant parameters in complex wastewater conditions. After use, the adsorbent needs to be regenerated or washed. This method requires quite expensive costs. The adsorbed pollutants are still accumulated in the adsorbent which can cause a new problem [47].

5.6. Sono-fenton

Sono-Fenton is an effective method to remove many pollutants in textile wastewater. However, this method uses chemicals, reagent consumption costs, high process costs, and elevated amounts of iron sludge produced at the neutralization stage of the treated solution before being discharged [48].

5.7. Membrane Technology

Membrane technology is a method of processing textile wastewater that is a biopolymer. Some of the advantages include absence of large equipment, low energy, simple membrane module design, and ease of operation. This method does not require additional chemicals such as coagulants or flocculants compared to conventional water treatment processes. Membrane technology does not use high temperatures and is a non-destructive, sterile process, making it environmentally friendly. The membrane materials vary, which allows easy adaptation according to needs, hybrid processing, and simple scale-up [49],[50]. In the processing of textile wastewater, membrane technology causes a reduction in COD, BOD, and color levels at environmental quality standards [13]. The disadvantage of this method is that the flux and selectivity are inversely proportional [51].

6. Membrane

Membrane is a biopolymer derived from membrane technology processes. It is thin and semi-permeable in the form of a thin layer that can separate two phases by holding certain components and transporting others through the pores. Additionally, membrane can be widely used in various separation processes, such as in leather, pulp and paper, food (one of which is the dairy industry), seawater desalination, and drinking water, particularly in textile industry.

6.1. Types of Membrane

In the manufacture of membrane, several processes with filtration principles are widely developed. The processes in membrane technology can be classified based on the pressure difference, namely:

1. Microfiltration (MF) is filtration process that uses a porous membrane to separate airborne particles with a diameter between 0.1 and 10 μm [52, 53]
2. Ultrafiltration (UF) is a variation of membrane filtration where the fluid is forced through a semipermeable membrane by hydrostatic pressure [13, 54].
3. Nanofiltration (NF) is a relatively new membrane filtration process commonly used in waters with low total dissolved solids. This type of membrane can be used for surface and groundwater processes, as well as to soften and remove natural and synthetic organics. [65].

The application of membrane in the processing of wastewater in textile industry will continue to develop. Based on the material, membrane are divided into organic or natural such as cellulose, synthetic, and inorganic [55]. Table 4 shows the raw materials and type of membrane produced with membrane technology.

Table 4. Raw materials for membrane production and type of membrane produced

Raw material	Type of membrane produced	Ref
Polytetrafluoroethylene	PTFE (polytetrafluoroethylene) Membrane	[56]
Polyethersulfone	PES (polyethersulfone) Membrane	[57]
Polyvinylidene Fluoride	PVDF (polyvinylidene fluoride) Membrane	[13]
PVDF (polyvinylidene fluoride)-Zeolite Composite	PVDF (polyvinylidene fluoride) Membrane	[4]
Oil palm empty fruit bunches	Cellulose Acetate Membrane	[58]
Pineapple crown fiber	Cellulose Acetate Membrane	[59]
Polysulfone	PSF (polysulfone) Membrane	[60]
Fermentation of Acetobacter xylinum bacteria	Bacterial cellulose membrane	[18]
Synthesis of bacterial cellulose from coconut and sugar using Acetobacter xylinum bacteria with ZnO nanoparticles	Bacterial cellulose membrane	[61]
Cellulose triacetate	Cellulose triacetate membrane	[15]
Cellulose acetate propionate	Cellulose acetate propionate membrane	[62]

The application of membrane technology is continuously increasing, such as the production of high-quality water and the removal or recovery of toxic/useful substances from various industrial wastes, particularly in the processing of textile wastewater [63]. This has also led to the development and application of membrane in the processing of textile wastewater, such as PTFE, PVDF (polyvinylidene fluoride), CA (cellulose acetate), PES, CAP (cellulose acetate propionate).

6.2. Analysis of Membrane

In testing or analyzing membrane, there are several examples of tests or analyses that are commonly carried out, namely:

1. Morphological and functional group tests are carried out on the membrane including SEM and FTIR analysis [14],[64],[65].
2. Membrane performance tests include pure water flux, rejection, and porosity [51].
3. Mechanical test is in the form of membrane tensile strength test [66],[67].

7. Textile Wastewater Treatment Using Membrane Technology

The processing method using membrane technology applies a biopolymer-based membrane. This technology is considered efficient for wastewater treatment, particularly in textile industry [17]. Wastewater that enters through the membrane with contaminants larger than the membrane pore size will be retained, hence, the water that passes through is cleaner. Common terms used in this process include feed, permeate, and retained water [12].

The process of textile wastewater treatment using membrane technology depends on the physical properties of membrane. These include hydraulic permeability and thickness, pressure through the membrane, filtration time, as well as feed concentration, along with the various polymer materials. Table 5 shows the types of membrane and their effectiveness in textile dye wastewater treatment.

Based on Table 5, PTFE membrane can reduce dye pollutants by more than 97% in textile wastewater. PES is capable of removing dye pollutants in textile wastewater by 82%. Polysulfone-Polyvinyl Pyrrolidone Blend Polymer Composite Membrane can reduce 85.73% of dye pollutants in textile industry washing wastewater. CA membrane reduces dye pollutant levels by 81.77% in remazol red textile wastewater. Cellulose Membrane of *Sargassum Sp.* shows the potential to remove dyes with rhodamine B, methylene blue, and methylene orange types by 80.04%, 77.83%, and 75.84%, respectively. PSF membrane can reduce color pollutants in textile wastewater by 85.7%. Bacterial cellulose membrane can reduce the pollutant dye type black remazol in textile wastewater by 32.10%. Furthermore, CAP membrane reduces the pollutant dye type blue remazol in textile wastewater by 43%.

8. Conclusion

In conclusion, this review showed that membrane technology reduced pollutants by approximately 97% in textile wastewater. Compared to other methods, membrane technology offered numerous advantages such as being biopolymer, requiring less equipment, low energy, and easy to operate. Furthermore, it did not require chemicals during processing and could be operated at temperature, serving as non-destructive, sterile technology. Several types of membrane that were identified included PTFE, PES, Polysulfone-Polyvinyl Pyrrolidone Blend Polymer Composite Membrane, CA, Cellulose Membrane of *Sargassum Sp.*, PSF, Bacterial Cellulose Membrane, and CAP.

Table 5. Types of membrane and their effectiveness in treating textile dye wastewater

Membrane Type	Types of Dye Waste	Color reduction results	Ref
PTFE (Polytetrafluoroethylene)	Textile Wastewater	Color loss >97%	[56]
PES (Polyethersulfone)	Textile Wastewater	Color loss 82%	[57]
Polysulfone-Polyvinyl Pyrrolidone Blend Polymer Composite Membrane	Textile Industry Washing Waste	Color loss 85.73%	[60]
CA (Cellulose Acetate)	Textile Wastewater (Remazol Red)	Color loss 81.77%	[58]
Cellulose Membrane of *Sargassum Sp.*	Textile Wastewater (Rhodamine B)	Color loss 80.04%	[18]
	Textile Wastewater (Methylene Blue)	Color loss 77.83%	[18]
	Textile Wastewater (Methylene Orange)	Color loss 75.84%.	[18]
Polysulfone (PSF)	Textile Wastewater	Color loss 85.7%	[60]
Bacterial Cellulose Membrane	Textile Wastewater (Black Remazol)	Color loss 32.10%.	[61]
Cellulose Acetate Propionate	Textile Wastewater (Blue Remazol)	Color loss 43%	[14]

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