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Research Progress of Printing and Dyeing Wastewater Treatment

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Abstract

In the textile industry, printing and dyeing technology, as an essential technical basis, produces a lot of printing and dyeing wastewater (PDW) that jeopardizes the ecological environment and human health. PDW generally has the characteristics of large discharge, high chromaticity, strong toxicity, strong alkalinity, complex componentization, poor biodegradability, large fluctuations in water quality and quality, and high content of organic pollutants, belonging to the type of industrial wastewater that is difficult to manage. In this paper, the current research progress of PDW treatment technology from the aspects of physical technology, chemical technology, and biological technology are reviewed. In addition, measures to reduce the damage caused by printing and dyeing wastewater from three perspectives: treatment principle, processes, advantages, and disadvantages are discussed, which provides a reference point for the treatment of printing and dyeing wastewater. It is worth noting that the article reviews the ABS system, which is gaining attention as an emerging technology under biological technology. The purpose of this paper is to provide a reference basis for the selection and application of technology, and then promote the innovation and development of printing and dyeing wastewater treatment technology.

Keywords: Printing and dyeing wastewater, Treatment technology, Research progress

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1. Introduction

Currently, the textile technology industry generates a large amount of wastewater. Among these are unused complex chemical materials from different processing units, which are discharged together with the wastewater from the different textile processing units. The textile industry relies on printing and dyeing as a necessary process. Printing and dyeing are indispensable processes in the textile industry. Color and leather industry technologies are still essential for the sector. Where organic dyes used in textile dyeing and retained in wastewater from the leather industry harm the environment and ecosystems (Brio et al., 2017). For example, gentian violet (GV) can cause skin damage and even cancer in humans and other animals (Chen et al., 2021b; Li et al., 2023b; Mcdonald et al., 1984), while methyl blue (MB), when accidentally ingested, can cause poisoning and insanity and even just touching the eyes can cause blindness (Yagub et al., 2014). Aromatic and azo structures, which are present in most dyes, contain large amounts of aniline substances in their breakdown products, which can lead to abnormal biological development, such as skin tumors, myocardial edema, and decreased heart rate (Blennow, 2018; Jiang et al., 2020; S.V et al., 2020; Wu, 2021). Therefore, the pre-discharge treatment of industrial wastewater is crucial for removing organic dyes.

Since the growth in demand for textiles is directly proportional to the increase in the size of the middle class, the number of textile mills is expected to increase (Pang et al., 2013). Textile wet processing consumes significant freshwater resources. In China, freshwater resources are scarce, unevenly distributed, and underutilized (Nan et al., 2011). The textile industry's dyeing and finishing activities account for 20% of global wastewater discharges. With socio-economic development, the water demand is also increasing, and the contradiction between water resources and socio-economic development is becoming more and more obvious(Liu et al., 2022). The textile industry consumes large quantities of water, and in areas where drinking water is scarce, textile wastewater is often recycled to minimize water usage. However, this increases the risk of exposure to harmful compounds (Cervantes et al., 2011).

Overall, the growth of the textile industry will lead to a significant increase in water pollution if wastewater is not treated properly. The textile industry plays an important role in providing basic services and meeting the basic needs of the population. Therefore, the textile industry has a positive impact on the economic development of countries and the world at large (Verma et al., 2012). Dyeing wastewater can have varying compositions depending on the type of dyes and the dyeing methods used. The use of various colorants and additives during the dyeing process leads to the presence of dyes in the water system, which reduces light penetration. This, in turn, affects photosynthesis and gas solubility, ultimately disrupting the nutrient chain. Such effluents have high toxicity, high concentrations of organic matter, and dark color. Wastewater-containing dyes are difficult to treat and biodegrade. Various processes such as ion exchange, chemical oxidation, electrochemical treatment, ozonation, and adsorption are used for this purpose(Al-Hammadi et al., 2018; He et al., 2018; Rahmi et al., 2019).

In textile mills, fibers are obtained either dry or wet. The wet process consumes large amounts of potable water and generates highly polluting wastewater. These processes include sorting, deinking, screening, bleaching, marketing, dyeing, printing, and finishing (Bali et al., 2007; Rongrong et al., 2011). Textile dyeing is the most important part of textile production and takes place in the dyeing process. In this process, various chemicals are used to enhance the adsorption of dyes and fibers. However, some of these dyes and chemicals remain in the wastewater of the textile industry after the finishing process is completed (Carmen et al., 2012).

Wastewater from textile mills contains dyes, metals, and other pollutants. Among them, dyes are the most difficult pollutants to treat due to their complex chemical composition. Due to their complex chemical composition, as shown in Table 1, dyes can be categorized based on their origin, structure, and chemistry. Among dyes, a distinction can be made between natural and synthetic dyes. Synthetic dyes are widely used because they are easier to manufacture, available in a variety of colors, and more durable than natural dyes (Khehra et al., 2006). Synthetic dyes are classified into different groups according to their chemical structures (azo, anthraquinone, sulfur, phthalocyanine, triarylmethane, etc.) and application methods (e.g.reactive, direct, disperse, base, and reduction dyes)(Popli et al., 2015).

Table 1. Different ways to categorize dyes.

Basis of Delineation	**Classifications**	**Specific Division**	**Reference**
Classification according to the source of the dye	Natural dyes	Vegetable dyes, Animal dyes	Popli et al., 2015
	synthetic dyes	According to the chemical structure can be divided into azo ammonia, anthraquinone, sulfur, phthalocyanine, and triaryl methane Reactive, direct, disperse, basic, and reduction dyestuffs according to the mode of application	
Classification of dyes according to their structure and their ionic charge upon dissociation in aqueous solution	Ionic dyes	Cationic dyes (including basic dyes) Anionic dyes (including acid dyes, reactive dyes, and direct dyes)	Moradihamedani, 2022; Tan et al., 2015
	Nonionic dyes	Reducing dyes Dispersing dyes	
Classification according to whether the dye can exist in water in the form of ions or not	Soluble dyes	Reactive dyes Direct dyes	Liu et al., 2019;Zhang et al., 2020b
	Insoluble dyes	Disperse dyes	

Color, pH, cooking oil (Ncibi et al., 2007; Sekomo et al., 2012), suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD) (Yaseen et al., 2016), temperature (Santos et al., 2007; Shah et al., 2013), and salinity are all issues that we need to take into account for dye wastewater. Therefore, it is important to monitor these parameters before discharging them into the receiving water. After treating the dye wastewater, they are compared to standard concentrations. In addition, the treatment performance of other parameters such as o-phosphate-phosphorus (PO_4-P), nitrate-nitrogen (NO_3^-N), total organic carbon (TOC), and ammonia-nitrogen (NH_4-N) also need to be monitored due to the levels required for other pollutants in water pollution. According to Appendix A of the Wastewater Treatment Project technical specification for dyeing and finishing of the textile industry, we can see that different types of printing and dyeing wastewater have different water quality parameters. For example, the pH value of printing and dyeing wastewater for polyester (excluding alkali reduction) is between 8.0 and 10.0, and the chemical oxygen demand (COD) is between 250 and 350 mg/L.

Certainly, the monitoring methods for PDW quality in China usually include various means such as physical monitoring, chemical monitoring, and biological monitoring, depending on the type and concentration range of pollutants to be monitored. The most common method is to monitor the chemical oxygen demand (COD) using the potassium dichromate method (GB/T 11914-1989)(Xi et al., 2024). The degree of organic pollution in water samples is reflected by measuring the amount of oxidant consumed when reducing substances are oxidized. Biochemical oxygen demand (BOD5) is usually monitored using the dilution and inoculation method (GB7488)("Water quality—Determination of biochemical oxygen demand after 5 days (BOD_5) for dilution and seeding method," 1987). Evaluate the biodegradability of water samples by measuring their oxygen consumption under microbial action. Chromaticity is usually monitored using the dilution ratio method (GB11903)("Water quality-Determination of colority," 1989), which determines the chromaticity of a water sample by comparing the dilution ratio of the water sample with the standard color scale. The monitoring methods for other indicators such as pH value, suspended solids, ammonia nitrogen, sulfides, hexavalent chromium, copper, aniline, etc. are all based on corresponding national or industry standards.

The purpose of summarizing existing PDW treatment technologies in this article is: on the one hand, by summarizing the PDW treatment processes, the importance and urgency of PDW treatment can be clarified; On the other hand, by analyzing the advantages and disadvantages, the application scope, and performance in practical applications of this technology, reference can be provided for the selection and application of this technology, thereby promoting innovation and development of PDW treatment technology.

First, we identified the research topic “printing and dyeing wastewater”, then we searched for relevant papers in the Web of Science database and conducted bibliometric analysis and keyword co-occurrence analysis of the retrieved papers using citespace as a tool. Finally, based on the above literature and keywords, the main points of the literature were extracted and reviewed. So, there are three aspects of the PDW treatment technology and their application measures are discussed below. As shown in Figure 1, we organized this article based on each of the three technology categories.

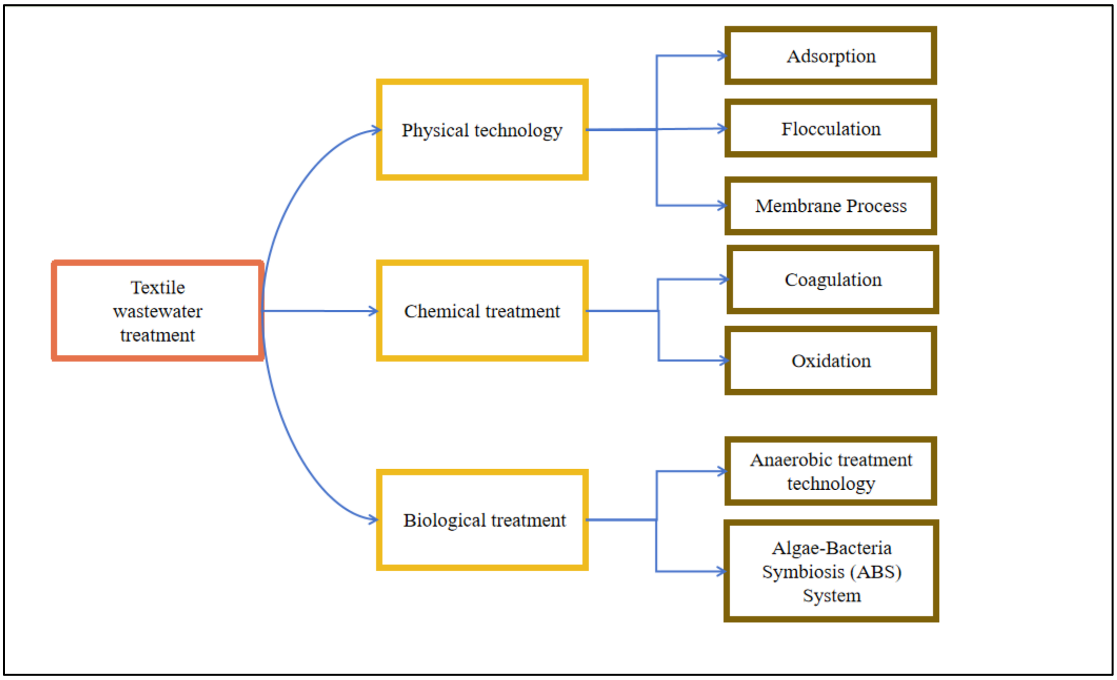

Figure 1. Overview of textile wastewater treatment techniques

2. Methods Physical Treatment Method

Physical technology includes adsorption, flocculation, and membrane technology, mainly used to remove suspended solids, colon, and part of the COD. Although wastewater from the printing and dyeing industry contains a variety of pollutants and contaminants that complicate water quality, targeting the most harmful substances will minimize the impact of wastewater on the environment. Therefore, it is practical to focus on the treatment of these substances to minimize the environmental impact of the printing and dyeing industry effectively (Guo, 2008). In treating more hazardous substances, physical techniques offer significant advantages.

2.1 Adsorption

Adsorption methods are frequently used in treating wastewater from dyeing and printing industries because of their high removal rates (Abbas et al., 2019). Its adsorption will use a variety of materials. Natural or synthetic adsorbents can be used to attract and accumulate water pollutants on their surfaces, ultimately precipitating them. Some of these adsorbents may possess specific recognition functional groups for targeted pollutants, while others have a broader range of adsorption capabilities (Muhammad et al., 2023). The principle is that molecules or atoms on the surface of a solid have residual surface energy due to uneven forces, and when certain substances collide with the surface of a solid, they are attracted by these unbalanced forces and remain on the surface. More often, materials such as resins and activated carbon are used. This is the basic principle of the adsorption method, and its development is more mature. In PDW with low concentrations, activated carbon can be used for adsorption treatment, but it cannot meet the purpose of recycling. Activated carbon, as an adsorbent material, has limited adsorption capacity and is prone to physical property changes. At this point, even if recycled, its reuse value is greatly reduced (Muhammad et al., 2023). Although a high dose of adsorbent can be used to deal with the high concentration of PDW (Zhang et al., 2024), it is still not an ideal solution because the adsorbent is expensive and difficult to regenerate. Moreover, it cannot be used to remove all types of dyes (Zhao et al., 2014). Thus, additional methods of dye mineralization treatment are necessary. It is difficult for one adsorbent to completely adsorb a variety of dyes, requiring the use of different adsorbents (Dassanayake et al., 2021). In addition, the ability of activated carbon to adsorb pollutants is dependent on its pore size. Different substances require different pore sizes to pass through, and the focus of treating substances within printing and dyeing wastewater varies, which necessitates selecting adsorbents based on their pore size. Options include micropores (pore size less than 2 nm), mesopores (pore size between 2-50 nm), and macropores (pore size greater than 50 nm) (Li et al., 2023a). Due to its limited adsorption capacity, it may not be the best option for treating wastewater in-depth (Dassanayake et al., 2021). However, it can still be useful for treating wastewater in certain scenarios where its adsorption capacity would suffice (Liu, 2017). Future development will mainly focus on the research of large pore-size activated carbon, which can effectively improve treatment efficiency and quality. Resin can also be used as a kind of adsorbent, with better recovery ability for chemical products, especially the weakly alkaline ion exchange resin has more applications (Zhang et al., 2022a).

However, more effective methods have been used for different substances that are extremely difficult to remove from PDW. For antimony (Sb), which is a heavy metal substance, it is difficult to achieve stable compliance with the Sb(V) standard of PDW by the conventional treatment process. Hu et al. (Hu et al., 2023) used magnesium-aluminum hydrotalcite modified with sodium dodecyl sulfate (DS_4^-LDH) as an adsorbent to adsorb wastewater. It was shown that antimony (Sb) could be removed efficiently. However, the adsorbent effect of sodium dodecyl sulfate-modified magnesium aluminum hydrotalcite (DS_4^-LDH) was affected by wastewater pH, dye molecules, co-existing ions, and other factors. So, its conditions should be considered in subsequent experiments. Methylene blue is a widely used substance in the dyeing process because its molecules are cost-effective and very stable, making it difficult to decompose under natural conditions. Widatallah et al. (2012) used chitosan as an adsorbent and sulfuric acid as a crosslinking agent to improve the performance of chitosan. The two combined to form a strong antiparallel structure and hydrogen-bonded chitosan chain. Compared to using chitosan as the adsorbent alone, the cross-linking of the two effectively improves the adsorption capacity, stability, and acid resistance of chitosan, while effectively reducing crystallinity. Effectively reduce the retention of methylene blue dye molecules in wastewater (Rahmi et al., 2019). The adsorbent also exhibits significant advantages in practical applications. Florinela et al. (2022) used 1 g of the adsorbent material for the treatment of wastewater containing 1 mg/L initial concentration of pollutant compounds, the efficiencies were 98% for acetaminophen, 92% for diclofenac, 88% for ketoprofen and 96% for ibuprofen.

Combining the environmentally friendly and cost-effective characteristics of living organisms, using biochar as an adsorbent also has great potential for development. Liu et al. (2022) proposed a feasible and economical technology for plant biomass carbon (PBC) to adsorb dyes. In addition, due to its integration with biological development, PBC has more adsorption value for dyes compared to commercially available activated carbon, adsorbing dye molecules that remain in the wastewater treatment process. However, the research results indicate that the adsorption effect is influenced by various factors, such as the dosage of PBC and the selection of plant biomass raw materials. So, the technology used needs to be improved in the future and can be changed in the selection of raw materials. Among them, optimization is a powerful measure to save reagents and PBC. For example, plant biomass raw materials can be used to absorb and enrich pollutants such as heavy metals, organic matter, and radioactive elements. After optimization, this function will help make the development of plant remediation possible.

2.2. Flocculation

Flocculation technology is a commonly used method for treating textile PDW in the middle and lower reaches of the enterprise. It offers significant advantages such as low material cost, small, required area, and remarkable decolorization effect. The effectiveness of flocculation technology in treating various types of printing dyestuffs varies. The treatment effect is more favorable for dispersed dyestuffs with hydrophobic properties when flocculation technology is applied (Wang et al., 2022). However, the use of flocculation technology does not deliver satisfactory results for water-soluble reactive dyes. Therefore, to achieve good wastewater treatment, staff members must use appropriate flocculants that match the specific characteristics of textile PDW (Zheng, 2020).

2.3 Membrane Process

Membrane separation technology is a popular research topic for dyeing and printing wastewater treatment, as it has the potential to remove dyes repeatedly. The treatment of dyeing wastewater is driven by membrane pressure. This technology enables the separation of dyes from the wastewater. China commonly uses ultrafiltration, reverse osmosis, microfiltration, and nanofiltration for deep treatment and recycling of PDW. Huijian et al., (2015) used microfiltration-nanofiltration technology for the deep treatment of PDW, in wastewater, with a CODCr removal rate of more than 87%, and a color removal rate of 100%; Zhang et al., (2015) used ultrafiltration-reverse osmosis for the treatment of PDW, ultrafiltration turbidity removal rate of up to 90%, while the CODCr removal rate of only about 21%, the rate of removal of salts only is 0; with the reverse osmosis treatment, the water quality to achieve the desired results, in line with the "Textile Printing and Dyeing Industry Water Pollutants Discharge Standard" (GB 4287-2012), and part of the wastewater can be recycled. Van der Bruggen et al. (2001) prepared positively charged hollow fiber nanofiltration membranes for removing cationic dyes such as Victoria blue, crystal violet, and malachite green from aqueous solutions. The experimental results show that positively charged hollow fiber NF membrane can remove 99.8% of victoria blue and bright green in water, and 99.2% of crystal violet. Due to the spatial position resistance effect and electrostatic interaction, nanofiltration membranes are very effective in removing cationic dyes. This is the main factor that determines the ionic solute separation performance of charged nanofiltration membranes. According to the previous summary among all membrane separation processes, nanofiltration membrane is considered as a technology with room for development. Under appropriate pressure, nanofiltration technology will demonstrate great superiority in removing low molecular weight organic compounds. However, there are also appropriate loopholes in nanofiltration technology, such as concentration polarization and membrane fouling during the filtration process, which reduce the flux during the NF process (Al-Amoudi et al., 2007; Van der Bruggen et al., 2005; Van der Bruggen et al., 2001). However, when a nanofiltration (NF) membrane is used to treat industrial dye effluent, concentration polarization can occur. This happens when solute molecules accumulate near the surface of the membrane, causing pore clogging and reducing the flow of water through the membrane. As a result, the high levels of contaminants in unprocessed industrial dye effluent make it unsuitable for direct treatment using NF.

Table 2. Classifications of membrane separation technology (MST).

Membrane Separation Technology (MST)	Pore size range	Principle	Applications
Microfiltration（MF）	0.1–10 µm	The application of MF in dye removal is limited to the elimination of suspended particles from dyes and the removal of colloidal dyes from dye baths. Other organic contaminants and chemicals dissolved in the dye will pass through the MF membrane as permeates.(Juang et al., 2013)	Shi et al. (2018a) evaluated the performance of polyethersulfone (PES) hollow membranes coated with polyethylene glycol (PEG) and tannic acid (TA) for the removal of rhodamine B from wastewater.
Ultrafiltration（UF）	0.01–0.1 µm	Effective removal of particles and macromolecules from solution. The molecular weight of dyes is below the UF membrane molecular weight cutoff (MWCO).(Ouni et al., 2010) Therefore, the application of UF for the removal of dyes from wastewater is limited. In some industries requiring a high degree of water purification, UF is used as a pretreatment method before NF and RO. (Barredo-Damas et al., 2010; Chakraborty, 2010)	Petrov et al. (2003) utilized polyacrylonitrile (PAN) membranes for ultrafiltration of wastewater containing yellow 3RS. Ahmad et al. (2017a) tested the performance of an ultrafiltration membrane system for the retention of Direct Blue-15 dye in textile wastewater.
Nanofiltration（NF）	0.001–0.01 µm	Nanofiltration can effectually eliminate organic compounds with low molecular weight (200–1000 g/mol)	Aouni et al. (2009) used electrocoagulation as a pretreatment followed by NF to purify industrial dye wastewater. Kebria et al. (Kebria et al., 2015)prepared a thin film composite PEI NF membrane modified with SiO2 nanoparticles.
Reverse Osmosis（RO）	< 0.001 µm	Reverse osmosis (RO) technology is an efficient method for the elimination of ions and macromolecules from wastewater effluent. The obtained permeate water from RO usually lacks color and has low salinity. The implementation of RO membranes is commonly preferred when NF permeate water quality is not satisfying to be reclaimed in the system	Nataraj et al. (2009) operated the pilot plants' spiral wound NF and RO membrane modules for the removal of methyl orange dye from wastewater. The removal of soluble indigo dyes made by commercial RO membranes was evaluated by Uzal et al. (2010).

Wastewater treatment commonly utilizes physical separation techniques such as extraction, magnetic and gravity separation, air flotation, and centrifugal methods, which demonstrate superior results (Olkiewicz et al., 2014).

3. Chemical Treatment Method

The chemical method involves adding reactants to wastewater to remove and separate pollutants through chemical reactions, including coagulation, oxidation, electrochemical treatment, and photocatalytic oxidation.

3.1 Coagulation

When flocculants are added to wastewater, they destabilize fine particles and colloids that are difficult to remove by precipitation. This helps to speed up the process of coagulation and sedimentation. The coagulation process is aided by the double electric layer and chemical bridging. Coagulation is suitable for treating suspended, colloidal, and low-solubility dyestuffs, such as dispersive and reducing dyestuffs (Yin et al., 2021).

3.2 Oxidation

Oxidizing pollutants is an effective way to convert them into harmless end products or intermediate products that can be more easily biodegraded. Some common oxidants used for this purpose include air, ozone, chlorine, and hypochlorite. Ozone is particularly useful for deodorization, decolorization, sterilization, and removal of various pollutants such as phenol, cyanide, iron, and manganese. This process can also significantly reduce the negative effects of COD and BOD. An ozone catalyst is employed in the process of using 30% hydrogen peroxide. To prepare the feed water for ozone treatment, air flotation pretreatment is carried out using polymerized ferric sulfate (PSF) as well as polyacrylamide (PAM) as a post-physical pretreatment coagulant agent. This helps in treating the organic suspended solids in the water and reducing the COD value, which in turn improves the efficiency of subsequent ozone utilization and COD degradation (Chen et al., 2021a). The principle of photocatalytic oxidation is based on the redox ability of photocatalysts light, enabling the purification of pollutants and the synthesis and transformation of materials. PDW is usually alkaline. To bring the pH level close to neutrality, excess acid and alkali in the water are eliminated through an acid-base neutralization reaction. This is the basis of the neutralization method.

Zhang et al. (2022b) synthesized Mn/Mg/Ce ternary catalysts for catalytic ozone oxidation of textile dyeing wastewater. They first investigated the properties of molecular sieves (MS), silica gel (SG), bulk clay, and alumina nanoparticles using dynamic tests. The study investigated the effect of three aspects, namely, reaction time, pH, and catalyst dosage, on the decomposition of methyl orange. The results showed that under ideal conditions, the decomposition of methyl orange was 96% and the removal of chemical oxygen demand (COD) from textile wastewater was 48.7%. The study showed that the addition of catalysts significantly improved the effectiveness of catalytic oxidative ozonation for the treatment of textile printing plant wastewater. This study provides a new option for the future treatment of textile printing wastewater using ozone catalyst decomposition.

4. Biological Treatment Method

Biotechnology in textile wastewater treatment is a technology with great development potential, characterized by its low cost, absence of cross-contamination, and other advantages (Lu et al., 2009). Biological methods use microorganisms to break down organic pollutants present in wastewater and transform them into harmless substances. These methods include aerobic treatment, anaerobic treatment, and combined biological methods such as activated sludge, biofilm, and membrane-activated sludge. However, textile wastewater is difficult to decompose and often contains organic pollutants. What's more, organic pollutants consume the oxygen dissolved in water, threatening the living environment of aquatic organisms and leading to the death of a large number of aquatic organisms. In the face of this aspect, the physical and chemical treatment of PDW makes it difficult to achieve satisfactory results (Kawasaki et al., 2013; Li et al., 2020; Lun et al., 2021). Here, the great

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potential of bioprocess technology is revealed.

4.1 Anaerobic Treatment Technology

Technologies such as physicochemical processes, biological processes, and combinations of these have been used to treat textile dyeing wastewater. The greatest advantage of anaerobic technology is its low cost. Anaerobic technology improves the biodegradability of wastewater by breaking down high molecular organic pollutants, such as azo dyes, into smaller molecules (Cui et al., 2020). Anaerobic reactors include the following types Extended granular sludge bed reactors (EGSB) (Che et al., 2022), upflow and downflow anaerobic sludge bed reactors (UASB) (Romero-Soto et al., 2021), anaerobic membrane bioreactors (AnMBR) (Berkessa et al., 2020), recirculating fixed-bed bioreactors (RFBB) (Chaturvedi et al., 2021), centralized circulation anaerobic reactors (SCA) (Yang et al., 2018), baffled anaerobic reactors (ABR) (Xu et al., 2018), and others. These reactors have been studied in depth.

To ensure effective and efficient wastewater treatment, plants must collect and analyze data to determine the relationship between the treatment performance of the anaerobic system and the influencing factors (Enitan et al., 2017). In the age of data, artificial neural network techniques are often used for wastewater treatment modeling. However, this technique has been proven to have poor predictive stability because it is highly dependent on the sample size and tends to fall into local optimal solutions during the learning process (Cherkassky, 1997; Jiang et al., 2022; Shi & Xu, 2018b). Support Vector Regression (SVR) is based on the Support Vector Machine (SVM) algorithm, which has been more and more widely used in the field of wastewater treatment in recent years. SVM is a statistical learning method proposed by Vapnik (Cherkassky, 1997) and follows the principle of structural risk minimization. It can provide the most valuable solution when dealing with small sample data. However, the ability of SVR to handle complex industrial wastewater needs to be further evaluated.

Clagnan et al. (2021) proposed a partial nitrification-anaerobic ammonium oxidation (PN/A) process for wastewater treatment. This is an efficient process. In addition, the fully autotrophic nitrogen removal (ANR) process has emerged as an efficient and cost-effective alternative to conventional nitrogen removal processes for ammonia-rich wastewater. Compared to ANR, the PN/A pilot-scale sequential batch reactor treats wastewater with much higher nitrogen (N) removal and efficiency. However, anaerobic ammonium oxidation activity was inhibited, and denitrification occurred, but PN/A has a low cost and a broad development prospect, which has received the attention of most scientists.

4.2 Algae-Bacteria Symbiosis (ABS) System

To treat the material more naturally, Lin et al. (2019) used an algal-bacterial symbiosis system (ABS). This system is effective in making water naturally self-purifying (Boelee et al., 2014; Ji et al., 2018). Under optimal conditions, it utilizes its degradation potential and produces oxygen through photosynthesis to effectively remove pollutants such as organic matter (COD), $NH4^{+}$-N, total nitrogen (TN), and total phosphorus (TP) (Ahmad et al., 2017b; Wang et al., 2014). They are effective in producing substances useful to humans. In addition, the bacteria in the activated sludge are also effective in degrading pollutants (De-Bashan et al., 2002). The ABS process has shown great superiority in reducing aeration and removing pollutants (Muñoz et al., 2006; Zambrano et al., 2016). The system can degrade itself under light conditions, making it economically viable in areas with high solar radiation (Su et al., 2011). Lin et al. (2019) investigated the symbiotic structural relationship between mixed algae and activated sludge in the treatment of heavily polluted dyeing plant wastewater under natural light. Compared with the traditional activated sludge method, this method has great superiority. Decreasing dissolved oxygen (DO) promotes the growth of algae, while the addition of algae increases the DO in the ABS. This cycle ensures that the growth of algae is controlled in an equilibrium state, and the size distribution of sludge particles in the ABS is stabilized to ensure the purification effect (Zhen et al., 2023). However, ABS systems are also affected by a number of factors. Zhen et al. (2023) investigated the effects of extreme precipitation and flooding on the decomposition efficiency of COD in an open algal-bacterial-symbiotic (ABS) system. The results showed that the COD decomposition rate decreased from 12.64% (without the effect of precipitation) to 2.94%, 2.38%, and 1.90% when the precipitation amount was 50, 100, and 200 mm, respectively. Therefore, the ABS system is sensitive to extreme weather conditions. Zhang et al. (2020a) concluded that carbon dioxide stripping during aeration is the primary cause of ABS failure and provided guidance on the application of ABS. ABS systems also have a wide range of applications for the large volumes of anaerobically digested wastewater (ADE) generated by intensive livestock farming activities (Huang et al., 2022; Li et al., 2022b). A structural diagram of the ABS is conjectured, as shown in Figure 2.

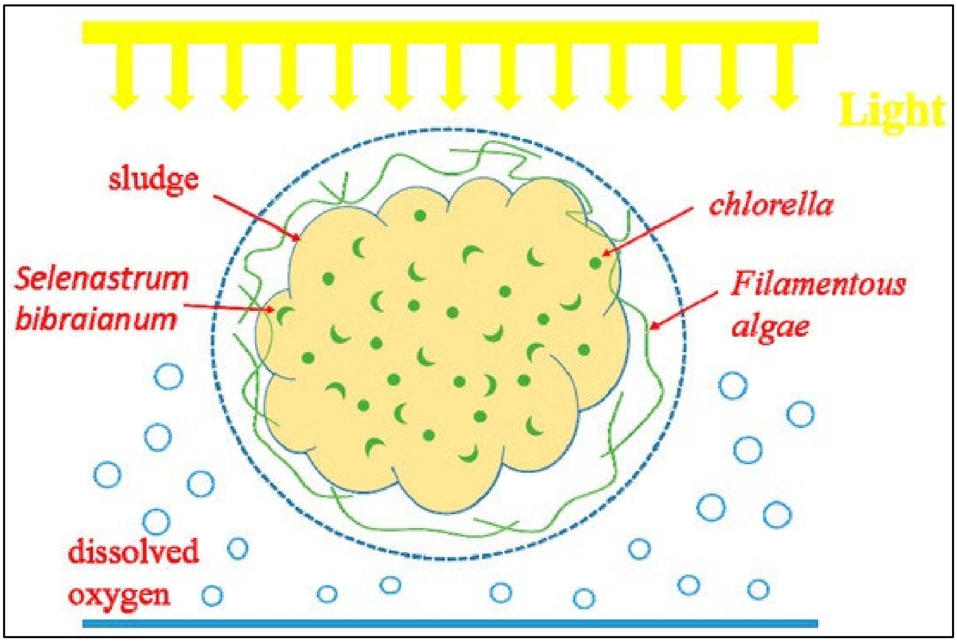

Figure 2. ABS activity index. (Reproduced from Lin, et al.(2019) with permission from MDPI).

Printing and dyeing industrial wastewater have a complex structure and is difficult to biodegrade. Therefore, Qi et al. (2022) demonstrated that a folded-flow anaerobic pilot reactor (ABR) can effectively decompose complex organic pollutants dissolved in wastewater through hydrolysis and oxidation by anaerobic microorganisms. This solution creates favorable conditions for subsequent aerobic treatment.

5. Conclusions and Perspectives

The wastewater produced in factories when dyeing materials such as wool and silk is called printing and dyeing wastewater. Many researchers and academics have discussed various research techniques for treating wastewater from printing and dyeing processes. The subject of this article is the treatment of wastewater from printing and dyeing processes using different technologies. We have divided the treatment technologies for printing and dyeing processes into three categories: physical treatment technologies, chemical treatment technologies, and biological treatment technologies. With economic development, people are looking for better-quality printing and dyeing materials. The number of printing and dyeing materials (e.g. synthetic fibers) is gradually increasing. The treatment of wastewater from printing and dyeing operations is being approached in more diverse ways. More attention needs to be paid to wastewater treatment.

Adsorption technology is an example of physical treatment technology. Not only can adsorption technology effectively remove dyes, but it is also relatively simple, widely applicable, economical, and has a removal efficiency of 80%. However, it is best suited to low-concentration wastewater. The contact time with the pollutants is long. Its application in high-concentration wastewater can be improved through future research. Efforts should be made to shorten the contact time with pollutants. As for activated carbon, more attention will be paid to large pore activated carbon in the future. Improve the absorption capacity of nano-clays. In the future, we plan to investigate the potential use of calcination or surface modifiers to improve the absorption capacity of colorants by utilizing the properties of nanoclay. Of course, physical processing technology has a wide range of practical applications, and there are still many problems worth solving in the future. For example, how to address the emerging hot synthetic fibers; In the context of adsorption technology that cannot completely remove oil through hydrothermal and modification, further improvement is needed to improve the adsorption capacity of adsorbents in oil.

Membrane technology is an example of chemical treatment that has high operating costs and membrane fouling as its drawbacks. PDW pollutants can be degraded using Fenton, photochemistry, photocatalysis, electrochemistry, and ultrasonic AOPs. Green, sustainable, and easy to use and operate are the characteristics of these processes. However, changes in molecular properties or the generation of free radicals in the system may have adverse consequences. Future research can be directed towards finding ways to reduce operating costs and combine them with other substances to reduce membrane fouling. Reducing changes in molecular properties or the production of free radicals in the system through modification and other methods.
In biological treatment technology, microorganisms such as algae, fungi, enzymes, and bacteria are used to degrade organic pollutants in wastewater and convert them into harmless substances. However, it is unable to remove residual pollutants present in the dyeing wastewater. In addition, sludge treatment suffers from the dilemma of a slow degradation rate and low tolerance to toxic loads, which prevents it from being widely used. It is worth mentioning that the ABS system achieves a symbiotic state of bacteria and microalgae to degrade inorganic salts (nitrogen and phosphorus), organic matter, nutrients, and other toxic and hazardous substances in wastewater. The system can simultaneously achieve low-cost degradation of organic wastes and biomass energy recovery, realizing the sustainable use of wastewater. ABS system is gaining attention as an emerging technology under biological technology.

On the other hand, the textile dyeing and finishing industry is facing the challenge of reducing the impact of wastewater discharge on the water environment. For this reason, discharge standards for the industry are being progressively tightened. However, the tightening of standards comes at a cost in terms of increased operating costs and difficulties in treating wastewater. In practical application, we should prioritize the use of energy-saving and emission-reduction production methods to minimize water, wastewater, and pollutant emissions in the production process. It is necessary to strengthen the comprehensive analysis of PDW, combine the advantages of a variety of treatment technologies, and implement a combination of simple and easy-to-operate methods. Looking to the future must be based on the existing PDW treatment technology to innovate, and constantly optimize the overall process of wastewater treatment is the key to treating PDW.

Currently, waste management requires vast areas and large investments, making the disposal process quite expensive. However, by utilizing home design and manufacturing, waste can be converted into valuable materials, solving environmental problems and adding value. Therefore, it is crucial to conduct further research to explore the innovative applications of PDW (Akbarzadeh et al., 2020; Guangtao et al., 2017; Ksepko et al., 2019; Shamaei et al., 2020). In recent years, faced with the serious environmental pollution caused by dye-containing wastewater discharged from the textile industry, scholars have proposed various methods to eliminate the washing step after dyeing to overcome this problem. To investigate the possibility of printing with dispersed dyes without washing, Li et al. (2022a) selected several water-based polymers and added them to the ink to study their efficiency. Optimization of the dye formulation resulted in fabrics with high durability and color strength. Optimization of the dye formulation resulted in fabrics with high durability and color strength. On this basis, Jeong et al. (2023) designed and synthesized new reactive disperse dyestuffs as transfer printing inks for digital textile printing, which showed excellent performance in fastness parameters such as washing resistance, rubbing resistance, and light fastness. This technology eliminates the use of traditional printing and dyeing techniques and reduces the harm to the ecosystem. However, it is still weaker than printing and dyeing technology in some consumer needs, so this new technology has yet to be developed. In the future, we need to pay more attention to how to minimize the defects of various processing techniques to maximize the benefits. It is important to conduct future research on new reactive dispersed dyes and apply them to various dyeing applications.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

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