A MINI REVIEW ON THE APPLICATION OF OZONE TECHNOLOGY TO TREAT TEXTILE DYEING WASTEWATER

Hoang Van Hung[1*], Van Huu Tap[2], Luu Thi Cuc[3], Nguyen Hoang[3], Nguyen Thi Ngoc Ha[3]
[1]Thai Nguyen University, [2]TNU - Center for Advanced Technology Development, [3]TNU - Lao Cai Campus

ARTICLE INFO

Received:	**04/4/2023**
Revised:	**27/4/2023**
Published:	**28/4/2023**

KEYWORDS

Ozone technology
Textile dyeing wastewater
Characteristics
Challenges
Wastewater treatment

ABSTRACT

The application of ozone technology in textile dyeing wastewater treatment is a new and promising direction. This article explores an overview of textile dyeing wastewater, ozone technology, and the application of ozone technology in textile dyeing wastewater treatment through analysis of studies on characteristics of textile dyeing wastewater, sources, treatment efficiency, and challenges when using ozone technology to treat textile dyeing wastewater. This underscores the importance of further studies to determine properly the advantages and disadvantages, as well as the industrial and broad applicability of ozone technology in textile dyeing wastewater treatment, in order to ensure sustainable treatment efficiency, minimize the risk of adverse impacts on human health and the environment. Methods used in this study are information analysis, synthesis, and comparison to evaluate and make valuable comments. The research results are useful for those beginning to study textile wastewater, ozone technology, and its application, helping them get an overview and orientation for their research.

TỔNG QUAN VỀ ỨNG DỤNG CÔNG NGHỆ OZONE TRONG XỬ LÝ NƯỚC THẢI DỆT NHUỘM

Hoàng Văn Hùng[1*], Văn Hữu Tập[2], Lưu Thị Cúc[3], Nguyễn Hoàng[3], Nguyễn Thị Ngọc Hà[3]
[1]Đại học Thái Nguyên, [2]Trung tâm Công nghệ mới – ĐH Thái Nguyên
[3]Phân hiệu Đại học Thái Nguyên tại tỉnh Lào Cai

THÔNG TIN BÀI BÁO

Ngày nhận bài:	**04/4/2023**
Ngày hoàn thiện:	**27/4/2023**
Ngày đăng:	**28/4/2023**

TỪ KHÓA

Công nghệ ozone
Nước thải dệt nhuộm
Tính chất
Thách thức
Xử lý nước thải

TÓM TẮT

Ứng dụng công nghệ ozone trong xử lý nước thải dệt nhuộm đang là hướng đi mới, nhiều triển vọng. Bài viết này trình bày tổng quan về nước thải dệt nhuộm, công nghệ ozone và ứng dụng công nghệ ozone trong xử lý nước thải dệt nhuộm thông qua việc phân tích các nghiên cứu về tính chất, nguồn phát sinh, hiệu quả xử lý cũng như thách thức khi sử dụng công nghệ ozone trong xử lý nước thải dệt nhuộm. Từ đó nhấn mạnh tầm quan trọng của việc cần có các nghiên cứu sâu hơn để xác định đúng những ưu điểm và nhược điểm, cũng như khả năng ứng dụng công nghiệp và mở rộng của việc sử dụng công nghệ ozone trong xử lý nước thải dệt nhuộm, nhằm đảm bảo hiệu quả xử lý bền vững, giảm thiểu các nguy cơ tác động xấu đến sức khỏe con người và môi trường. Phương pháp được sử dụng trong nghiên cứu này là: Phân tích, tổng hợp và so sánh thông tin để đánh giá và đưa ra những nhận xét có giá trị. Kết quả nghiên cứu hữu ích cho người mới nghiên cứu về nước thải dệt nhuộm, công nghệ ozone và ứng dụng của nó, giúp họ có được cái nhìn tổng quan và định hướng được cho công việc nghiên cứu của mình.

DOI: https://doi.org/10.34238/tnu-jst.7668

* Corresponding author. *Email: hoangvanhung@tnu.edu.vn*

1. Introduction

Due to the elevated amounts of chemical and organic pollutants it carries, textile dyeing wastewater is a major contributor to global water pollution [1]-[3]. Textile production is estimated to be responsible for around 20% of global clean water pollution from dyeing and finishing products [4]. The effluent from textile dyeing has a high concentration of organic molecules, colors, dyeing agents, hazardous chemicals, and inorganic compounds such as sodium hydroxide, hydrochloric acid, sodium chloride, and detergents [3]. High amounts of color, suspended particles, biological oxygen demand (BOD), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), and heavy metals are characteristics of dyeing wastewater, according to a study by M. A. Hassaan et al. [4]. Toxic, mutagenic, and carcinogenic agents, textile dyes endure as environmental pollutants and traverse entire food chains, resulting in biomagnification [5]. High organic content, colors, dyestuff, hazardous chemicals, and inorganic substances such as sodium hydroxide, hydrochloric acid, sodium chloride, and detergents are components of textile dyeing wastewater [2]. The dyeing process consists of three phases: pretreatment, dyeing, and finishing. Before dyeing, unwanted impurities are removed from fibers using an aqueous alkaline solution or detergents [3].

Several technologies, such as biological treatment procedures, chemical precipitation, adsorption, and membrane technology, can be used to treat textile wastewater [6]. In a 2001 study published in Chemosphere, C. M. Kao et al. [7] sought to assess the effectiveness of standard wastewater treatment procedures in lowering pollutant concentrations in textile dyeing effluent. Pretreatment removes undesired contaminants from fibers before dyeing, which can be accomplished with an aqueous alkaline solution or detergents [7]. High organic content, colors, dyestuff, hazardous chemicals, and inorganic substances such as sodium hydroxide, hydrochloric acid, sodium chloride, and detergents are components of textile dyeing wastewater [5]. Ozone can cure textile dyeing effluent. Printing wastewater treatment with integrated ozone treatment yielded a direct-discharge effluent at 135 mg/l [8]. Gas chromatography–mass spectrometry with 100 mg/L ozone, 15.7 min contact time, and 2.9 gas–liquid ratio removed 100% of volatile phenols, sulfides, and aniline from wastewater [10]. Ozone technology is an eco-friendly alternative to vat and sulfur dye reduction and oxidation [6].

The report of Rajkumar et al. [10] on dyes and pigments emphasized this issue and provided numerous remedies. One potential option is using advanced oxidation processes (AOPs) that have effectively eliminated various contaminants from wastewater. AOPs transform toxic organic pollutants into harmless byproducts using oxidizing agents such as hydrogen peroxide and ozone. The application of ozone technology to remediate textile dyeing effluent has shown promise. According to studies, ozonation can increase the biodegradability of wastewater and enhance treatment performance [11], [12]. It has been discovered that ozone is useful in cleansing textile effluent and eliminating color [13] and is used in various textile processes, including dying and finishing. Ozone technology is viable for treating high-strength textile dyeing wastewater [14].

This short review paper aims to give readers an overview of the efficacy of ozone technology in eliminating various pollutants from textile dyeing effluent. The article will also emphasize the difficulties and potential applications of ozone technology in treating wastewater from textile dyeing, as well as the benefits and drawbacks of its use and potential applications in Vietnam.

2. Materials and Methods

- Synthetic approach: The study uses this method to acquire data and information on textile wastewater, ozone technology and the application of ozone technology in textile dyeing wastewater treatment, which is collected from studies published in prestigious scientific journals around the world. These include studies from 1981 to recent studies published in 2023.

- Analytical techniques: This study analyses previously published materials on textile dyeing wastewater, ozone technology, and the application of ozone technology to treat textile dyeing wastewater. This enables us to assess the current status of research, with a focus on complicated, unresolved issues in this subject.

- Data processing methods: Using comparison technique to generate statistical tables, compare published research results related to textile dyeing wastewater, using ozone technology to treat textile dyeing wastewater that this research has collected and summarized.

3. Findings and discussion

3.1. Textile dyeing wastewater and its characteristics

3.1.1. Textile dyeing wastewater and its sources

Textile dyeing has long been recognized as the second-largest contributor to global water pollution and waste. This sector's water-intensive processes and high levels of pollution discharge have substantially influenced global water supplies, worsening water scarcity issues.

Textile dyeing wastewater refers to effluent produced during textile dyeing and finishing operations [13] – [15]. It contains dyes, surfactants, heavy metals, and salts, other contaminants [16]. These contaminants are harmful to the environment and human health, and if not managed properly, they can cause severe water contamination.

Rania Al-Tohamy et al. [1] researched the health concerns of textile dyeing wastewater. The investigation results indicate that the wastewater contains many dangerous elements, including heavy metals and organic contaminants. These contaminants can pollute drinking water, increasing cancer risk, liver and kidney damage, and reproductive disorders. In addition, releasing untreated wastewater into water bodies can result in eutrophication, ecosystem deterioration, and a reduction in aquatic biodiversity. Based on their findings, the authors stated that wastewater from textile dyeing should be cleaned before being released into the environment and that additional research is required to determine the long-term effects of this wastewater on human and environmental health.

Textile dyeing wastewater is produced from various sources, including dye bath wastewater during the dying process, textile wastewater from equalizing tanks after dying, and other byproducts such as metals, salts, and colors [13] – [15]. Sources of pollutants in wastewater include impurities separated from the fiber fabric such as grease, nitrogen-containing impurities, and dirt adhering to the fiber (accounting for 6% of the fiber weight); chemicals used such as starch paste, H_2SO_4, CH_3COOH, NaOH, NaOCl, H_2O_2, Na_2CO_3, Na_2SO_3,... all kinds of dyes, inert substances, absorbents, mordants, laundry detergents;…

Imtiazuddin et al. [17] conducted a study on the origins of wastewater from textile dyeing. Research results show that: Aquatic toxicity of textile dyeing industry wastewater significantly differs between production facilities. Possible sources of aquatic toxins include salts, surfactants, ionic metals and their metal complexes, toxic organic chemicals, biocides and toxic anions. Wastewater in the bleaching, polishing, dyeing, printing and finishing industries must be treated separately to reduce contaminant concentrations.

The composition of the wastewater depends on the characteristics of the dyeing material, the nature of the dye, the auxiliaries and other chemicals used. Dyes are particularly interesting because they often source metals, salts and colors in wastewater. Fabric sizing agents with high BOD, COD and surfactants are the main causes of aquatic toxicity of textile dyeing wastewater. Almost 10,000 dyes are used in the textile industry, and 28,000 tons are dumped into public sewers without being adequately treated, eventually poisoning adjacent waterways. 10% of these dyes are lost during the coloring process, and 2% of the total amount is discharged directly into aqueous effluent [17]. Azo dyes are very well-liked; an annual output of 7 x 105 tons accounts for 80% of the world's commercial dye production [18]. Azo dyes react with cotton, wool, silk, and nylon fibers to produce covalent bonds. Textile colors are not degraded by traditional aerobic textile effluent treatment, and in the absence of tertiary treatments, they are abundant in natural water supplies.

3.1.2. Characteristics of textile dyeing wastewater

Several studies indicate that textile dyeing wastewater has a high pH value, and a high concentration of suspended particles, chlorides, nitrates, and metals like manganese, sodium, lead, copper, and chromium [14], [19], [20]. Moreover, the effluents from the dyeing process typically have high levels of color, pH, suspended solids (SS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) [15]. Color, pH, electrical conductivity (EC), chemical oxygen demand (COD), biological oxygen demand (BOD), and hardness are further characteristics of textile wastewater [21], [17]. These contaminants significantly threaten the ecosystem and can devastate aquatic life and human health.

A wide range of values for dye concentrations in textile effluent was reported. Textile effluents often have dye concentrations of 10 to 200 mg/l, 50 to 1000 mg/l, 150 to 750 mg/l, and 10 to 500 mg/l [15]. Other reports indicated that the COD of textile dyes ranged from 250 to 1,500 mg/L in several textile industrial wastewater. Concerning the various kinds of catalysts utilized in the treatment process, the alkalinity reduction ranged from 10 to 22%. With values of 0.691, 0.688, and 0.711 compared to 0.398 in the untreated wastewater, the BOD_5/COD ratio of the treated actual wastewater was significantly greater than that of the untreated wastewater [22]. Depending on the processes employed, the concentration of dyes in wastewater can vary. For instance, the average COD (chemical oxygen demand) concentration of pre-treatment wastewater is 3000 mg/L, while the average COD concentration of dyeing/printing process wastewater is 1000 mg/L after mixing. In a typical polyester base reduction process, sodium hydroxide with a pH between 10 and 11 is used, resulting in high concentrations of up to 600,000 mg/L for batch processing. Chroma is an additional pollutant that originates from residual dyes during finishing processes, resulting in 200 to 500 times higher concentrations than before treatment due to the 90% dyeing rate attained by most textile industries today [18], [23], [24].

It has been demonstrated that synthetic dyes in industrial production hurt the environment, as they are not biodegradable and can cause harm [1], [25]. To address this issue, researchers have focused on bioremediation as a possible treatment method for textile wastewater, specifically using up-flow anaerobic sludge blanket (UASB) reactors for color removal [13]. For example, Dailin et al. [26] studied the bioremediation of textile dyes in wastewater. In contrast, Ozlem Altintas Yildirim [27] investigated the negative effects of commonly used textile dyes on the aquatic environment.

Appropriate handling of textile dyeing wastewater is essential for mitigating water contamination. Textile dyeing wastewater is often alkaline due to its high concentrations of salt, COD, BOD, and color; if not adequately treated, it can have detrimental environmental effects. To efficiently treat this wastewater, its unique properties must be considered, and appropriate treatment techniques must be adopted to ensure compliance with local effluent standards and regulations. Generally, it is necessary to consider the sustainable use of water resources when managing wastewater.

3.2. Ozone technology and its applications

Ozone (O_3) technology offers several advantages over traditional disinfection techniques like chlorine, including faster disinfection times, no toxic byproducts, and the capacity to handle a variety of pollutants. As a result, it has become significantly important in water and air treatment. Ozone technology can be used in many sectors and is an efficient tool for odor control, disinfection, and purification. To avoid health hazards, it is crucial to utilize it correctly and safely, nevertheless. Ozone, a strong oxidizing agent, has been used in food processing since the early 1900s for its antibacterial qualities; according to A. J. Brodowska et al. [28], more research is needed to fully understand its benefits and drawbacks.

Ozone technology uses electricity to convert oxygen into ozone molecules [29]. This method is used in various sectors for odor control, purification, and disinfection [30]. Ozone technology has garnered considerable attention as a viable wastewater treatment method due to its potent oxidizing properties [31]. Ozone's high reactivity makes it an effective oxidizing agent capable of breaking down various organic pollutants, such as pesticides, petroleum-based, and persistent organic pollutants [32]. It can also remove color, odors, and other pollutants from wastewater. Furthermore, ozone technology can eliminate heavy metals, nitrogen-based contaminants, and other hazardous compounds from wastewater, as found in studies [33]. Notably, ozone technology doubles up as an efficient disinfectant, destroying bacteria and viruses in wastewater [34]. Ozone technology is also a cost-effective wastewater treatment method, making it an attractive option for industries and businesses. It can further minimize sludge production in the wastewater treatment process, reducing disposal costs linked to wastewater treatment. Therefore, ozone technology's broad range of applications in wastewater treatment makes it a popular choice for many industries. Ozone was discovered to be a powerful disinfectant capable of eliminating bacteria and other microbes. Moreover, ozone is remarkably effective at removing metal ions, organic pollutants, and molecules that provide water color from the environment [35].

It has been determined that ozone technology is a potent instrument for managing air pollution in both industrial and home settings. Ozone technology is a "new strategy for solving air quality challenges, with highly promising outcomes," according to L. Franken [35]. In addition to lowering the concentrations of particles, allergens, and other dangerous pollutants, it is excellent at removing smells and volatile organic compounds without using chemicals or other harmful materials, making it an affordable and secure solution for managing air quality in both industrial and home settings. Importantly, ozone can combine with sulfur and nitrogen dioxide to form less toxic compounds, improving air quality.

Recent research, such as in 2020, by Shin et al. [36] has looked at the potential dangers connected to ozone technology and its application in society. By using ozone gas to disinfect indoor air, ozone technology eliminates bacteria, odors, and other volatile organic compounds (VOCs). Ozone technology has been shown to lower air quality in specific situations, but its consequences on human health are still mostly understood. According to the World Health Organization, ozone is a harmful substance and should be handled with caution in public areas. Long-term exposure to ozone has also been linked to asthma-like symptoms and respiratory issues. Therefore, safety precautions must be taken when utilizing ozone technology. Moreover, the ozone concentration should be checked to ensure it is within permissible limits when used indoors.

3.3. Ozone technology for treating textile dyeing wastewater

3.3.1. The application of ozone technology to treat textile dyeing wastewater

Much research has been undertaken on using ozone technology to clean effluent from textile dyeing. Our investigations demonstrate that ozone can be employed for the enhanced treatment of textile effluent having a high concentration of indigestible dyes and other macromolecular organics [37]. The approach is predicated on the decolorization of the dye by ozone, and the color loss is proportional to the ozone concentration and pH value [38]. Current advancements in textile wastewater treatment include catalytic ozonation, which has shown success for color removal in a short treatment period [39]. A review article analyses the mechanics of the interaction between ozone and aqueous solutions of organic dyes [40], whilst another review covers recent developments in the use of ozone for decontamination applications in many industries, including textiles [41].

Due to its efficiency at removing pollutants, catalytic ozonation has gained popularity as a method for treating wastewater from textile companies. In their article titled "Water," authors Zhang et al. [42] examined the advantages of this technology. They discovered that catalytic ozonation increases the biodegradability of wastewater, assisting in sludge production reduction. Moreover, total organic carbon (TOC), chemical oxygen demand (COD), and total nitrogen (TN) contents in the water are all decreased by catalytic ozonation. The authors pointed out that in addition to other contaminants, colors can also be removed using this approach. They also pointed out the need for more study in this field by pointing out that the type of dye and the pH of the wastewater affect how effective catalytic ozonation is. The authors concluded that catalytic ozonation offers considerable advantages in pollutant removal and biodegradability and is a viable technology for cleaning wastewater from textile manufacturers.

3.3.2. Effectiveness of ozone technology in the treatment of textile dyeing wastewater

On the same machine where it was generated and concurrently with the dyeing process tested a unique method to decolorize residual dyeing effluent [43]. In order to assess this technique's efficacy on residual dyeing effluents including Reactive Orange 7, Reactive Blue 19, and Reactive Black 5, pilot-scale investigations were carried out. The findings demonstrated that about 100% color removal and 90% COD reduction could be achieved by adjusting process variables such as pH, dye concentration, ozone production rate, and temperature. According to the study's findings, the novel technique can replace the need for a separate end-of-the-pipe wastewater treatment system with an affordable on-site option.

Table 1. *Catalytic ozonation processes condition for textile wastewater*

Catalyst material for ozonation processes	**Target Dye(s)**	**Optimum conditions**	**Efficiency (% COD removal)**	**References**
Carbon-doped magnesium oxide (C-MgO) dropped on an eggshell membrane powder	Real textile wastewater	Ozone flow rate = 0.4 L/min, Catalyst does = 0.23 g/L, Reaction time = 10 min, pH = 11	93	[44]
Poly aluminum chloride and alum	Real textile wastewater	Reaction times = 30 min, Catalyst does = 6 and 300 mg/l, pH= 7.4	89	[45]
g-C_3N_4 modified with Al_2O_3 nanoparticles	Real textile wastewater	Oxygen flow rate = 1.5 L/min, Catalyst dosage = 0.5 g/L, pH = 7.1	77	[46]
O_3/UV	Azo red-60 dye	Initial concentration dye = 100 mg/L, Reaction time = 60 min, pH = 7.5	100	[47]
Modified pulsed low frequency US cavitation processes	Real textile wastewater	Optimum O_3 flow rate = 4 g/h, Reaction time = 60 min, pH = 9.34	86	[48]
$KMnO_4$	Real textile wastewater	$KMnO_4$ dosage = 1.5 mM, O_3 dosage = 10 mg/L, The reaction time of 30 min, pH = 7	80	[49]

According to the data in Table 1, multiple catalyst materials have been employed to treat textile wastewater by ozonation. Different conditions have been tuned for each catalyst material to reach the necessary degree of COD removal efficiency. As a catalyst material, carbon-doped magnesium oxide (C-MgO) doped on eggshell membrane powder exhibited a high COD removal efficiency of 93% at pH 11 with a reaction time of 10 minutes and a catalyst dose of 0.23 g/L. Similarly, using poly aluminum chloride and alum as catalysts resulted in an 89% COD removal efficiency with a reaction time of 30 minutes and a catalyst dose of 6 and 300 mg/L, respectively, at pH 7.4. In addition, using g-C_3N_4 modified with Al_2O_3 nanoparticles as a catalyst material demonstrated a 77% COD removal efficiency at pH 7.1, with an oxygen flow rate of 1.5 L/min and a catalyst dosage of 0.5 g/L. In addition, the combination of O_3/UV treatment has produced a high dye removal efficiency of 100% for Azo red-60 dye, with an initial concentration of 100 mg/L, a reaction duration of 60 minutes, and a pH of 7.5. Also, using modified pulsed low-frequency US cavitation processes has demonstrated a COD removal effectiveness of 86% at pH 9.34, with an optimal O_3 flow rate of 4 g/h and a reaction duration of 60 minutes. Using $KMnO_4$ as a catalyst resulted in a COD removal efficiency of 80% at pH 7, with a $KMnO_4$ dosage of 1.5 mM, an O_3 dosage of 10 mg/L, and a reaction duration of 30 min. These studies indicate the potential of ozonation procedures for efficiently treating textile wastewater using various catalyst materials and under optimal circumstances. However, additional research is required to determine the viability and scalability of these methods for industrial use on a broad scale.

3.3.3. Challenges and limitations of using ozone technology for treating textile dyeing wastewater

Ozone technology has been faced some obstacles and restrictions, such as the efficacy of ozone treatment is contingent on initial dye concentration, pH, and temperature of wastewater [36]. The use of ozone gas is more appropriate for wet processing machines, which may limit its application in certain textile manufacturing processes [13]. Although ozonation has been described as having a lower environmental impact than conventional denim bleaching, it still requires careful consideration of water allocation, reuse, and recycling strategies [50].

The next drawback of Ozone technology is the high cost. According to Van Vuuren et al. [51], the high cost of ozone technology results from the energy-intensive process required to produce ozone. In addition, the system’s maintenance costs are substantial due to the need for frequent replacement of parts and consumables. The costs of ozone technology are exacerbated by the need for skilled personnel to operate the system and by the stringent safety regulations required to ensure worker safety and the environment. The high cost of ozone technology has limited its adoption in many industries and led to the development of more cost-effective alternatives. However, the potential benefits of ozone technology cannot be ignored due to the growing demand for cleaner air and water and the growing awareness of the negative effects of pollution on human health and the environment. Efforts should be made to reduce the cost of ozone technology through technological innovation and improving operational and maintenance efficiency.

Rice et al. [52] provide several potential strategies for mitigating these expenses. Initially, they advise using compressed or oxygen-enriched air as an alternative to pure oxygen. This approach can cut ozone manufacturing expenses and improve its efficiency. They propose using alternate reactor designs to enhance ozone mass transfer and lower energy usage. For instance, high-efficiency diffusers or microbubble aeration systems can increase ozone transfer rates and decrease energy requirements. Last but not least, they advocate the adoption of hybrid systems, such as ozone-biofiltration or ozone-UV procedures, which can improve the treatment system’s performance and lower its overall costs. These alternatives can assist in overcoming the high cost of ozone technology and make it a more viable option for wastewater treatment. However, additional research and development are required to maximize the effectiveness and efficiency of these methods in real applications.

The application of ozone technology requires cautious handling and safety measures to avoid exposure to dangerous ozone levels. Material and safety data sheets contain information on the handling and storage of ozone, including using ozone-resistant tubing and pipelines, repairing leaks, and evacuating places with high ozone levels [53]. Ozone generators are linked to harmful health effects, and scientific evidence indicates that acceptable amounts of ozone are unlikely to be useful at reducing indoor air pollution [54].

Moreover, ozone technology can generate harmful byproducts such as bromate and aldehydes. Ozone can also be harmful to human health, especially for those with respiratory difficulties such as asthma and chronic bronchitis. Ozone exposure can aggravate lung diseases, increase the frequency of asthma attacks, and reduce lung function. While ozone is composed of three oxygen atoms, it is an unstable and highly reactive gas that can harm health [30]. Therefore, caution should be exercised when using ozone technology, and it is important to follow safety guidelines and regulations to minimize the risks associated with its use.

The presence of organic matter and other contaminants in wastewater might limit the efficacy of ozone as a disinfectant, hence affecting the efficiency of ozone technology [55]. According to Wang et al. [56], organic matter in water can devour ozone, diminishing ozone's ability to remove contaminants. Since organic matter combines with ozone through a chain reaction, hydroxyl radicals compete with ozone for reaction sites. Thus, the overall effectiveness of ozone technology is diminished, resulting in insufficient removal of pollutants. However, the magnitude of this effect depends on the type and concentration of organic materials in the water. Wang et al. [56] discovered that the presence of humic acid, a common organic molecule in wastewater, affected the effectiveness of ozone technology by up to 40%. This emphasizes the significance of comprehending organic matter's influence on ozone technology's effectiveness and devising measures to limit its effects.

According to Silva and Jardim, one way to ensure efficient pollutant removal is to optimize the ozone dosage based on the concentration and type of organic matter in the water [57]. Consider the concentration of contaminants in the wastewater, the flow rate, and the contact duration to establish the best dosage. Combining ozone technology with advanced oxidation processes (AOPs) is another method. AOPs can improve the efficacy of ozone technology by producing hydroxyl radicals, which are extremely reactive species capable of oxidizing a wide variety of contaminants. The design of the ozone reactor can also affect its effectiveness. A reactor with a high surface-to-volume ratio can facilitate a more efficient mass transfer between ozone and contaminants, increasing its overall efficiency. In conclusion, following these measures can considerably enhance the efficacy of ozone technology in wastewater treatment plants, resulting in improved water quality and a cleaner environment.

3.4. Potential application of ozone technology in textile dyeing wastewater treatment in Vietnam

Applying ozone technology in textile dyeing wastewater treatment is initially being noticed in Vietnam. Vu Thi Bich Ngoc et al. have shown that among the oxidizing agents, O_3 is highly effective in breaking straight and unsaturated bonds in drug molecules dyeing, causing rapid discoloration of textile dyeing wastewater [62]. Ozone strongly absorbs UV light (especially at 254 nm wavelength) producing H_2O_2, and immediately H_2O_2 decomposes to form *OH radical [58]:

$$O_3 + hv \rightarrow O_2 + O$$
$$O + H_2O \rightarrow H_2O_2 \rightarrow 2^{*}OH$$

In acidic environments, ozone directly oxidizes organic compounds using ozone molecules dissolved in water. Meanwhile, in high pH conditions or in conditions with favorable conditions for the generation of *OH radicals such as H_2O_2, UV, catalysts, etc., the indirect oxidation pathway through hydroxyl radicals will be essential and the oxidation efficiency is enhanced. As a result, researchers have looked for agents that can be combined with ozone or catalysts to trigger *OH radicals to improve the oxidizing efficiency of ozone when it is necessary to deal with stable, non-biodegradable compounds in water and wastewater [58].

Van Huu Tap et al. studied using metal slag from metallurgy as a catalyst for the ozone reaction to treat Reactive Red 24 in textile dyeing wastewater. The research results show that, in the composition of the waste iron slag containing FeO, ZnO and SiO_2 oxides, it has a good effect for the catalytic ozone process of dye treatment (Reactive Red 24) with high efficiency, almost 100% color loss and decompose 85% of organic matter in textile dyeing wastewater at the condition O_3 = 3,038 g/h, H_2O_2: 100 mg/L, iron slag content: 1000 mg/L and dye concentration: 300 mg/L [59].

Nguyen Trong Anh et al. evaluated the efficiency of textile dyeing wastewater treatment by ozone technology combined with UV. The results show that the high-order oxidation using H_2O_2/O_3/UV gives the highest efficiency in color and COD treatment compared to using other single agents. At the pH value of 8.0, the reaction time is 40 minutes, the H_2O_2/O_3/O3 content ratio is 0.5 and the UV light has wavelength λ = 254 nm, the color and COD treatment efficiency is 75 % respectively (185 Pt-Co) and 83.4% (166 mg/L). Combining higher oxidation with UV agent increases treatment efficiency due to higher production of free *OH radicals. Therefore, it is possible to combine ozone technology with UV to treat textile dyeing wastewater for higher efficiency [60].

Nguyen Thi Hien et al. also evaluated the effect of 5 types of metal waste slag, including iron slag, zinc slag, copper slag, lead slag and cadmium slag as catalysts for the ozone process to degrade dyes Direct Black 22. Through COD analysis, the ability to treat dyes is from 66% to 76% with the condition that the dye concentration reaches 100 mg COD/L; concentration of O_3: 3,038 g/h, H_2O_2: 100 mg/L and the dose of catalyst is 250 mg/L [61].

The research results demonstrate that catalytic ozonation is an effective way to purify wastewater from textile and dyeing factories in Vietnam due to pollutant removal and biodegradability. However, the studies also point to the need for further research by showing that the type of dye and the pH of the wastewater affect the efficiency of the catalytic ozonation process used in the treatment of textile dyeing wastewater under conditions in Vietnam.

4. Conclusion

Textile dyeing wastewater contributes significantly to water waste and pollution, posing grave environmental and human health threats. Due to its disinfection, purification, and odor control properties, ozone technology is viable for textile dyeing wastewater treatment. Research on using ozone technology in textile dyeing wastewater treatment is initially attracting attention in Vietnam with many studies being conducted. The results proved that ozone technology is a feasible technology to clean wastewater from textile dyeing manufacturers in terms of conditions in Vietnam. Although ozone technology effectively treats high concentrations of indigestible dyes and other pollutants, its efficacy depends on several variables, including initial dye concentration, pH, and temperature. Additional research is required to comprehend its advantages and disadvantages completely, and caution should be exercised to avoid potential health risks. Investing in sustainable and efficient water treatment systems is vital for limiting the risks posed by textile dyeing wastewater and enhancing water quality for human and environmental health.

Acknowledgment

This work was financially supported by the Vietnam Ministry of Education and Training under project number B2022-TNA-45.

REFERENCES

[1] R. Al-Tohamy, S. S. Ali, F. Li, K. M. Okasha, Y. A. -G. Mahmoud, T. Elsamahy, H. Jiao, Y. Fu, and J. Sun, "A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety," *Ecotoxicol. Environ. Saf.*, vol. 231, 2021, Art. no. 113160, doi: 10.1016/j.ecoenv.2021.113160.

[2] A. Azanaw, B. Birlie, B. Teshome, and M. Jemberie, "Textile effluent treatment methods and eco-friendly resolution of textile wastewater," *Case Stud. Chem. Environ. Eng.*, vol. 6, 2022a, Art. no. 100230, doi: 10.1016/j.cscee.2022.100230.

[3] T. A. Khattab, M. S. Abdelrahman, and M. Rehan, "Textile dyeing industry: environmental impacts and remediation," *Environ. Sci. Pollut. Res. Int.*, vol. 27, pp. 3803–3818, 2020, doi: 10.1007/s11356-019-07137-z.

[4] M. Hassaan, A. E. Nemr, and M. A. Hassaan, "Health and Environmental Impacts of Dyes: Mini Review," *Am. J. Environ. Sci. Eng*., vol. 1, pp. 64–67, 2017, doi: 10.11648/j.ajese.20170103.11.
[5] B. Lellis, C. Z. Fávaro-Polonio, J. A. Pamphile, and J. C. Polonio, "Effects of textile dyes on health and the environment and bioremediation potential of living organisms," *Biotechnol. Res. Innov.*, vol. 3, pp. 275–290, 2019, doi: 10.1016/j.biori.2019.09.001.
[6] S. Judd, "The textile industry," in *Membranes for Industrial Wastewater Recovery and Re-Use*, 2003, pp. 75–101, doi: 10.1016/B978-1-85617-389-6.50002-3.
[7] C. M. Kao, M. S. Chou, W. L. Fang, B. W. Liu, and B. R. Huang, "Regulating colored textile wastewater by 3/31 wavelength admi methods in Taiwan," *Chemosphere.*, vol. 44, pp. 1055–1063, 2002, doi: 10.1016/S0045-6535(00)00502-6.
[8] A. M. Lotito, U. Fratino, G. Bergna, and C. D. Iaconi, "Integrated biological and ozone treatment of printing textile wastewater," *Chem. Eng. J.*, vol. 3, pp. 195–196, 2012, doi: 10.1016/j.cej.2012.05.006.
[9] D. Deng, M. Lamssali, N. Aryal, A. Ofori-Boadu, M. K. Jha, and R. E. Samuel, "Textiles wastewater treatment technology: A review," *Water Environ. Res.*, vol. 92, pp. 1805–1810, 2020, doi: 10.1002/wer.1437.
[10] D. Rajkumar, B. J. Song, and J. G. Kim, "Electrochemical degradation of Reactive Blue 19 in chloride medium for the treatment of textile dyeing wastewater with identification of intermediate compounds," *Dye. Pigment*., vol. 72, pp. 1–7, 2007, doi: 10.1016/j.dyepig.2005.07.015.
[11] X.-B. Gong, "Advanced treatment of textile dyeing wastewater through the combination of moving bed biofilm reactors and ozonation," *Sep. Sci. Technol.*, vol. 51, pp. 1589–1597, 2016, doi: 10.1080/01496395.2016.1165703.
[12] H. A. Eren, İ. Yiğit, S. Eren, and O. Avinc, "Ozone: An Alternative Oxidant for Textile Applications," in *Sustainability in the Textile and Apparel Industries: Production Process Sustainability*, S. S. Muthu and M. A. Gardetti, Eds., Springer, Cham, 2020, pp. 81–98, doi: 10.1007/978-3-030-38545-3_3.
[13] N. Jahan, M. Tahmid, A. Z. Shoronika, A. Fariha, H. Roy, M. N. Pervez, Y. Cai, V. Naddeo, and M. S. Islam, "A Comprehensive Review on the Sustainable Treatment of Textile Wastewater: Zero Liquid Discharge and Resource Recovery Perspectives," *Sustain.*, vol. 14, pp. 1–38, 2022, doi: 10.3390/ su142215398.
[14] X. Lu, L. Liu, R. Liu, and J. Chen, "Textile wastewater reuse as an alternative water source for dyeing and finishing processes: A case study," *Desalination*., vol. 258, pp. 229–232, 2010, doi: 10.1016/j.desal.2010.04.002.
[15] D. A. Yaseen and M. Scholz, "Textile dye wastewater characteristics and constituents of synthetic effluents: a critical review," *International Journal of Environmental Science and Technology*, vol. 16, pp.1193–1226, 2019, doi: 10.1007/s13762-018-2130-z.
[16] H. Halepoto, T. Gong, and H. Memon, "Current status and research trends of textile wastewater treatments — A bibliometric-based study," *Front. Environ. Sci*., vol. 10, pp. 1–18, 2022, doi: 10.3389/fenvs.2022.1042256.
[17] S. M. Imtiazuddin, M. Mumtaz, and K. A. Mallick, "Pollutants of wastewater characteristics in textile industries," *J. Basic Appl. Sci*., vol. 8, no. 2, pp. 554-556, 2012.
[18] M. R. Sarker, M. Chowdhury, and A. Deb, "Reduction of Color Intensity from Textile Dye Wastewater Using Microorganisms: A Review," *Int. J. Curr. Microbiol. Appl. Sci*., vol. 8, pp. 3407–3415, 2019, doi: 10.20546/ijcmas.2019.802.397.
[19] I. Petrinić, N. Bajraktari, and C. Hélix-Nielsen, "Membrane technologies for water treatment and reuse in the textile industry," in *Advances in Membrane Technologies for Water Treatment: Materials, Processes and Applications,* A. Basile, A. Cassano, and N.K.B.T.-A. Rastogi, Eds., Woodhead Publishing Series in Energy, Oxford, 2015, pp. 537–550, doi:10.1016/B978-1-78242-121-4.00017-4.
[20] P. S. Kumar and A. Saravanan, "Sustainable wastewater treatments in textile sector," in *Sustainable Fibres and Textiles*, S.S. Muthu, Ed., Woodhead Publishing, 2017, pp. 323–346, doi: 10.1016/B978-0-08-102041-8.00011-1.
[21] H. Patel and R. T. Vashi, "Characterization of Textile Wastewater," in *Characterization and Treatment of Textile Wastewater*, Elsevier, Boston, 2015, pp. 21–71, doi: 10.1016/B978-0-12-802326-6.00002-2.
[22] F. H. Hussein, "Chemical properties of treated textile dyeing wastewater," *Asian J. Chem*., vol. 25, pp. 9393–9400, 2013, doi: 10.14233/ajchem.2013.15909A.
[23] Z. Wang, M. Xue, K. Huang, and Z. Liu, "Textile Dyeing Wastewater Treatment," in *Advances in*

Treating Textile Effluent, P. J. Hauser, IntechOpen, 2011, doi: 10.5772/22670.
[24] R. Kant, "Textile dyeing industry an environmental hazard," *Nat. Sci.*, vol. 4, pp. 22–26, 2012.
[25] B. Sarkodie, J. Amesimeku, C. Frimpong, E. K. Howard, Q. Feng, and Z. Xu, "Photocatalytic degradation of dyes by novel electrospun nanofibers: A review," *Chemosphere.*, vol. 313, 2023, Art. no. 137654, doi: 10.1016/j.chemosphere.2022.137654.
[26] D. J. Dailin, N. Z. Nordin, L.T. Tan, S. Ramli, L. F. Chuah, N. Sapawe, Y. M. M. Jusoh, D.N.A. Zaidel, D. Sukmawati, and H. El-Enshasy, "State of the art Bioremediation of textile dye in wastewater: A Review," *Biosci. Res*, vol. 19, pp. 914–924, 2022.
[27] O. A. Yildirim, M. Bahadir, and E. Pehlivan, "Detrimental effects of commonly used textile dyes on the aquatic environment and human health – a review," *Feb-Fresenius Environ. Bull.*, no. 9329, pp.33-41, 2022.
[28] A. J. Brodowska, A. Nowak, and K. Śmigielski, "Ozone in the food industry: Principles of ozone treatment, mechanisms of action, and applications: An overview," *Crit. Rev. Food Sci. Nutr.*, vol. 58, pp. 2176–2201, 2017, doi: 10.1080/10408398.2017.1308313.
[29] M. F. R. Boner and P. J. Lau, *Wastewater Technology Fact Sheet Ozone Disinfection,* United States Environ. Prot. Agnecy, 2019, pp. 1–7.
[30] B. Wang, W. Shi, H. Zhang, H. Ren, and M. Xiong, "Promoting the ozone-liquid mass transfer through external physical fields and their applications in wastewater treatment: A review," *J. Environ. Chem. Eng.*, vol. 9, 2021, Art. no. 106115, doi: 10.1016/j.jece.2021.106115.
[31] S. Bai, S. Du, H. Liu, S. Lin, X. Zhao, Z. Wang, and Z. Wang, "The causal and independent effect of ozone exposure during pregnancy on the risk of preterm birth: Evidence from northern China," *Environ. Res*, vol. 214, 2022, Art. no. 113879, doi: 10.1016/j.envres.2022.113879.
[32] W. Shi, Q. Sun, P. Du, S. Tang, C. Chen, Z. Sun, J. Wang, T. Li, and X. Shi, "Modification Effects of Temperature on the Ozone–Mortality Relationship: A Nationwide Multicounty Study in China," *Environ. Sci. Technol.*, vol. 54, pp. 2859–2868, 2020, doi: 10.1021/acs.est.9b05978.
[33] G. Zhang, Q. Hu, R. Cao, R. Fu, H. Risalat, X. Pan, Y. Hu, B. Shang, and R. Wu, "Yield loss in rice by acute ozone pollution could be recovered," *Agric. Environ. Lett.*, vol. 7, pp. 1–5, 2022, doi: 10.1002/ael2.20093.
[34] F. Geering, "Ozone applications: The state-of-the-art in Switzerland," *Ozone Sci. Eng.*, vol. 21, pp. 187–200, 1999, doi: 10.1080/01919519908547252.
[35] L. Franken, *The application of ozone technology for public health and industry*, Food Saf. Secur. Kansas State Univ., 2005, p. 1-16.
[36] H. Shin and J. Kang, "Reducing perceived health risk to attract hotel customers in the COVID-19 pandemic era: Focused on technology innovation for social distancing and cleanliness," *Int. J. Hosp. Manag*, vol. 91, 2020, Art. no. 102664, doi: 10.1016/j.ijhm.2020.102664.
[37] J. Wang, H. Chen, R. Yuan, F. Wang, F. Ma, and B. Zhou, "Intensified degradation of textile wastewater using a novel treatment of hydrodynamic cavitation with the combination of ozone," *J. Environ. Chem. Eng.*, vol. 8, 2020, Art. no. 103959, doi: 10.1016/j.jece.2020.103959.
[38] A. Körlü, "Use of Ozone in the Textile Industry," in *Textile Industry and Environment*, IntechOpen, Rijeka, 2018, doi: 10.5772/intechopen.81774.
[39] L. Bilińska, K. Blus, M. Bilińska, and M. Gmurek, "Industrial textile wastewater ozone treatment: Catalyst selection," *Catalysts,* vol. 10, pp. 1–16, 2020, doi: 10.3390/catal10060611.
[40] B. Shriram, "Ozonation of Textile Dyeing Wastewater - A Review," *J. Inst. Public Heal. Eng,* vol. 15, pp. 46–47, 2014.
[41] E. I. Epelle, A. Macfarlane, M. Cusack, A. Burns, J. A. Okolie, W. Mackay, M. Rateb, and M. Yaseen, "Ozone application in different industries: A review of recent developments," *Chem. Eng. J*., vol. 454, 2020, Art. no. 140188.
[42] Y. Zhang, K. Shaad, D. Vollmer, and C. Ma, "Treatment of textile wastewater by advanced oxidation processes – A review," *Glob. Nest J.*, vol. 13, pp. 1–22, 2021.
[43] I. A. Shaikh, F. Ahmed, A. R. Sahito, and A.A. Pathan, "In-situ Decolorization of Residual Dye Effluent in Textile Jet Dyeing Machine by Ozone," *Pakistan Journal of Analytical & Environmental Chemistry,* vol. 15, no. 2, pp. 71–76, 2014.
[44] G. Asgari, J. Faradmal, H. Z. Nasab, and H. Ehsani, "Catalytic ozonation of industrial textile wastewater using modified C-doped MgO eggshell membrane powder," *Adv. Powder Technol.*, vol. 30, pp.1297–1311, 2019, doi: 10.1016/j.apt.2019.04.003

[45] O. S. Rizvi, A. Ikhlaq, U.U. Ashar, U.Y. Qazi, A. Akram, I. Kalim, A. Alazmi, S.M. I. Shamsah, K. A. A. Al-Sodani, R. Javaid, and F. Qi, "Application of poly aluminum chloride and alum as catalyst in catalytic ozonation process after coagulation for the treatment of textile wastewater," *J. Environ. Manage*., vol. 323, 2022, Art. no. 115977, doi: 10.1016/j.jenvman.2022.115977.

[46] M. Faghihinezhad, M. Baghdadi, M. S. Shahin, and A. Torabian, "Catalytic ozonation of real textile wastewater by magnetic oxidized g-C_3N_4 modified with Al_2O_3 nanoparticles as a novel catalyst," *Sep. Purif. Technol*., vol. 283, 2022, Art. no. 120208, doi: 10.1016/j.seppur.2021.120208.

[47] Y. D. Shahamat, M. Masihpour, P. Borghei, and S. H. Rahmati, "Removal of azo red-60 dye by advanced oxidation process O3/UV from textile wastewaters using Box-Behnken design," *Inorg. Chem. Commun.*, vol. 143, 2022, Art. no. 109785, doi: 10.1016/j.inoche.2022.109785.

[48] J. Shajeelammal, S. Mohammed, K.P. Prathish, A. Jeeva, A. Asok, and S. Shukla, "Treatment of real time textile effluent containing azo reactive dyes via ozonation, modified pulsed low frequency ultrasound cavitation, and integrated reactor," *J. Hazard. Mater. Adv*., vol. 7, 2022, Art. no. 100098, doi: 10.1016/j.hazadv.2022.100098.

[49] J. Liang, X.-A. Ning, J. Sun, J. Song, Y. Hong, and H. Cai, "An integrated permanganate and ozone process for the treatment of textile dyeing wastewater: Efficiency and mechanism," *J. Clean. Prod*., vol. 204, pp. 12–19, 2018, doi: 10.1016/j.jclepro.2018.08.112.

[50] U. Ewuzie, O. D. Saliu, K. Dulta, S. Ogunniyi, A. O. Bajeh, K. O. Iwuozor, and J.O. Ighalo, "A review on treatment technologies for printing and dyeing wastewater (PDW)," *J. Water Process Eng*., vol. 50, 2022, Art. no. 103273, doi: 10.1016/j.jwpe.2022.103273.

[51] D. P. V. Vuuren, E. Stehfest, M. G. J. D. Elzen, T. Kram, J. V. Vliet, S. Deetman, M. Isaac, K. K. Goldewijk, A. Hof, A. M. Beltran, R. Oostenrijk, and B. V. Ruijven, "RCP2.6: exploring the possibility to keep global mean temperature increase below 2°C," *Clim. Change*, vol. 109, no. 95, 2011, doi: 10.1007/s10584-011-0152-3.

[52] R.G. Rice, C.M. Robson, G.W. Miller, and A.G. Hill, "Uses of ozone in drinking water treatment," *J. AWWA.*, vol. 73, pp. 44–57, 1981.

[53] M. N. Morshed, S. A. Azad, M. A. M. Alam, H. Deb, and A. K. Guha, "An Instigation to Green Manufacturing: Characterization and Analytical Analysis of Textile Wastewater for Physico-Chemical and Organic Pollution Indicators," *Am. J. Environ. Sci. Technol*., vol. 1, pp. 11–21, 2016.

[54] E. Grignani, A. Mansi, R. Cabella, P. Castellano, A. Tirabasso, R. Sisto, M. Spagnoli, G. Fabrizi, F. Frigerio, and G. Tranfo, "Safe and Effective Use of Ozone as Air and Surface Disinfectant in the Conjuncture of Covid-19," *Gases*, vol. 01, pp. 19-32, 2021, Art. no. 103390, doi: 10.3390/gases1010002.

[55] L. G. Sorokhaibam and M. Ahmaruzzaman, "Phenolic Wastewater Treatment," in *Development and Applications of New Adsorbent Materials*, Butterworth-Heinemann, Oxford, 2014, pp. 323–368, doi: 10.1016/B978-0-08-099968-5.00008-8.

[56] X. Wang, X. Wang, J. Mi, Q. Du, Y. Wang, W. Chen, D. Sun, W. Song, M. Shao, and R. Jia, "UV/H_2O_2/O_3 removal efficiency and characterization of algae-derived organic matter and odorous substances," *J. Environ. Chem. Eng.*, vol. 11, 2022, Art. no. 109128, doi: 10.1016/j.jece.2022.109128.

[57] L. M. da Silva and W.F. Jardim, "Trends and strategies of ozone application in environmental problems," *Quim. Nov*., vol. 29, pp. 310–317, 2006.

[58] T. B. N. Vu, T. H. H. Hoang, and L. H. Trinh, "Actual color treatment of textile dyeing wastewater by advanced oxidation method," *Natural Sciences and Technology - VNU Journal of Science*, vol. 32, no. 4, pp. 97-103, 2016.

[59] H. T. Van, L. H. Nguyen, T. K. Hoang, T. P. Tran, A. T. Vo, T. T. Pham, and X. C. Nguyen, "Using FeO-constituted Iron Slag wastes as heterogeneous catalyst for Fenton and Ozonation processes to degrade Reactive Red 24 from aqueous solution," *Separation and Purification Technology*, vol. 224, pp. 431-442, 2019.

[60] T. A. Nguyen, K. H. Pham, and T. T. Nguyen, "Treating textile wastewater by combination of advanced oxidation process and UV light," *Journal of Science of Lac Hong University,* vol. 9, pp. 047-052, 2020.

[61] T. H. Nguyen, L. H. Nguyen, H. T. Van, T. D. Nguyen, T. H. V. Nguyen, T. H. H. Chu, T. V. Nguyen, X. H. Vu, and K. H. H. Aziz, "Heterogeneous catalyst ozonation of Direct Black 22 from aqueous solution in the presence of metal slags originating from industrial solid wastes," *Sep. Purif. Technol.*, vol. 233, 2020, Art. no. 115961.