



OPEN ACCESS

EDITED BY

Mubarak Mujawar,
University of Technology Brunei, Brunei

REVIEWED BY

Chinenye Adaobi Igwegbe,
Nnamdi Azikiwe University, Nigeria
Yi Wang,
Guangdong University of Technology,
China

*CORRESPONDENCE

Tongqian Zhao,
zhaotq69@163.com

SPECIALTY SECTION

This article was submitted to Water and Wastewater Management, a section of the journal Frontiers in Environmental Science

RECEIVED 12 July 2022

ACCEPTED 15 August 2022

PUBLISHED 12 September 2022

CITATION

Wu L, Fu J, Song B, Zhao T, Liu H and Li X (2022), Factors influencing the photodegradation of acid orange 8 by nitrocellulose membranes. *Front. Environ. Sci.* 10:992202. doi: 10.3389/fenvs.2022.992202

COPYRIGHT

© 2022 Wu, Fu, Song, Zhao, Liu and Li. This is an open-access article distributed under the terms of the [Creative Commons Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Factors influencing the photodegradation of acid orange 8 by nitrocellulose membranes

Li Wu¹, Jiwei Fu¹, Baihui Song¹, Tongqian Zhao^{1*}, Hong Liu² and Xiaolin Li¹

¹Institute of Resources and Environment, Henan Polytechnic University, Jiaozuo, China, ²School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan, China

Nitrocellulose membranes (NCM) have broad application prospects in the field of organic wastewater treatment. In this research, acid orange 8 was used as the target pollutant, and the effects of factors, such as concentration, light intensity, anions, and cations, on the photodegradation of acid orange 8 were investigated under simulated sunlight by NCM. The results showed that the degradation rate constant of acid orange 8 in the NCM system was $1.94 \times 10^{-3} \text{ min}^{-1}$, which was 27.3 times that in the pure water. The photodegradation rate increases with decreasing concentration in the range of 20–120 $\mu\text{mol/L}$ for acid orange 8. The photodegradation rate increased with increasing NCM area. The degradation effect of acid orange 8 increased with the increase of light intensity. Acidic conditions were favorable for the degradation of acid orange 8. The optimal conditions for photodegradation of acid orange 8 were the solution concentration of 20 $\mu\text{mol/L}$, membrane area of 17.35 cm^2 , light intensity of 481 $\mu\text{mol}/(\text{m}^2\text{s})$, and pH value of 3.0. The effect of different components in water on the photodegradation of acid orange 8 was different. Ca^{2+} , Mg^{2+} , and NO_3^- could promote the photodegradation of acid orange 8, while CO_3^{2-} could inhibit the photodegradation. The effect of degrading acid orange 8 by NCM under light conditions is obvious, which can provide a new method for the removal of acid orange 8 in wastewater.

KEYWORDS

nitrocellulose membrane, acid orange 8, photodegradation, influencing factor, advanced oxidation

Introduction

In recent years, the discharge of azo dye wastewater has gradually become a source of environmental pollution worldwide and has caused serious environmental problems (Cui M. H. et al., 2021). The discharge of azo wastewater and pollutants in the printing and dyeing industry accounted for more than 70% of the entire textile industry, and was listed as one of the ten key industries for special rectification in the “Water Pollution Prevention Action Plan”. The dye concentration in the wastewater may be between 50 and 1000 ppm, however, even a very low concentration (10–50 ppm) will produce strong colors (Koyuncu et al., 2004). The global production of azo dyes exceeded 700,000 tons, and

10–15% of the dyes were lost during the dyeing process and discharged with wastewater (Mulushewa et al., 2021). These compounds can change the pH and chemical composition of water bodies (Umar et al., 2021) and can affect the safety of the entire ecosystem via bioaccumulation (Shi et al., 2021). Even wastewater increased the chemical oxygen demand and biological oxygen demand of the water. Dye wastewater entering the aquatic environment reduces the transmittance of light and affects the light and action of aquatic organisms (Berradi et al., 2019; Bessy et al., 2022). However, the damage to light and action will have an inhibitory effect on plant growth, reduce dissolved oxygen levels (Jin et al., 2022). Dye wastewater interferes with the natural habitat of aquatic organisms (Yakar et al., 2020) and even harmful to humans. If the ingested water contains azo dyes, more serious injuries such as increased heartbeat, vomiting, diarrhea, irritation of the gastrointestinal tract, nausea, shock, and confusion will continue one after another (Ferreira et al., 2014). In addition, the CO₂ emitted by textile industry wastewater also greatly increased the greenhouse effect. NO_x, SO_x, and dust all increased air pollution (Shyamika et al., 2018). As one of the common toxic acid substances in azo dyes, acid orange 8 is widely used in textile printing and dyeing, food, papermaking and printing industries, accounting for more than 50% of the world's annual production of 1 million tons of dyes (Elizalde-González and García-Díaz, 2010). According to the Chinese standard "Ecological Textile Standard 100", acid orange 8 is a banned aromatic amine substance. Among acidic monoazo dyes, acid orange 8 does not have outstanding color development performance, but it has high color brightness and low production cost. However, monoazo dyes were still used in large quantities to produce cheap products and are abundant in wastewater (Stylidi, 2003). Therefore, textile wastewater needs to be treated before environmental discharge. On the one hand, the treatment of textile wastewater can effectively improve the water quality in the river and improve the living environment of aquatic organisms. On the other hand, it can make full use of freshwater resources in nature and strive for more recyclable water sources for humans.

The treatment of azo dye wastewater is related to its own carcinogenicity, mutagenicity, harmful effects of wastewater color, and the habitual resistance of wastewater to biodegradation (Elizalde-González and García-Díaz, 2010). According to reports, there are many types of pollutants in textile wastewater, especially printing and dyeing wastewater, which has a large pollution load. It is necessary to adopt different methods to treat textile wastewater (Yakar et al., 2020). Traditional treatment methods such as electrodialysis, ion exchange, reverse osmosis, microfiltration and ultrafiltration, oxidation and solvent extraction, etc., are relatively expensive and cannot effectively remove dyes (Mulushewa et al., 2021). The advanced oxidation method can efficiently generate active oxygen, such as hydroxyl radicals and superoxide anion

radicals, and can quickly oxidize and remove a variety of organic pollutants in water under certain conditions (Aleboye et al., 2003; Chong et al., 2010; Macías-Quiroga et al., 2020). In recent years, it has received extensive attention in the field of water treatment. The advanced oxidation technology methods for degrading acid orange 8 mainly include Fenton oxidation (Kumar et al., 2020), ozone oxidation (Muniyasamy et al., 2020), electrochemical oxidation (Li B. et al., 2019) and photocatalytic oxidation (Qin et al., 2014). Some advanced oxidation methods, such as Fenton oxidation, ozone oxidation, and electrochemical oxidation, have high processing cost, complicated operation and easy to produce secondary pollution (Sable et al., 2018). Therefore, it is necessary to develop new treatment methods to improve the degradation effect of pollutants. Photocatalytic oxidation technology is a better method for the degradation of textile dyes. The photocatalytic oxidation technology is cheap, and produces clean by-products, is environmentally friendly (Siddique et al., 2020). More importantly, this technology has strong oxidative properties and can effectively degrade organic pollutants (Venkatesh et al., 2018). Research has shown that TiO₂ and ZnO nanoparticles were used as effective photocatalysts for wastewater treatment (Bhatkhande et al., 2001), while the use of advanced oxidation technology can effectively remove antibiotics in wastewater (Mahdi et al., 2021). When the photocatalyst was synthesized by hydrothermal method, its degradation rate was as high as 95% (Sun et al., 2009). When non-metallic substances such as phosphorus were used as photodegradation catalysts, they had a certain impact on the removal of pollutants in wastewater (Yao et al., 2022). For azo dye wastewater, studies have shown that nitrocellulose membranes (NCM) with high specific surface area had a better effect on the adsorption and photodegradation of organic wastewater (Tai et al., 2018; Khalil et al., 2019). The concentration of organic wastewater can also affect the degradation effect. High concentration organic wastewater may cause saturation of the photocatalyst surface, resulting in a decrease in the photocatalytic degradation rate (Mohamed et al., 2018). The water composition in the water body can affect the degradation of organic pollutants. The addition of cations such as Ca²⁺ and Mg²⁺ increased the degradation rate of acid orange 8 (Wang et al., 2012), while anions had different effects on the degradation of organic wastewater (Chen et al., 2021; Wu et al., 2021). In the photochemical reaction system, the photodegradation rate decreased with the weaken of light intensity within a certain range (Elizalde-González and García-Díaz, 2010). The acidic environment was favorable for the degradation of acid orange 8. At the same time, pH also had an important effect on the degradation of acid orange 8 (Özcan et al., 2004), and acidic conditions were more conducive to the degradation of acid orange 8.

Nitrocellulose (NC) is the most widely distributed and richest polysaccharide in nature and is rich in hydroxyl groups. It is also a nitrification product of cellulose. It is soluble in organic solvents such

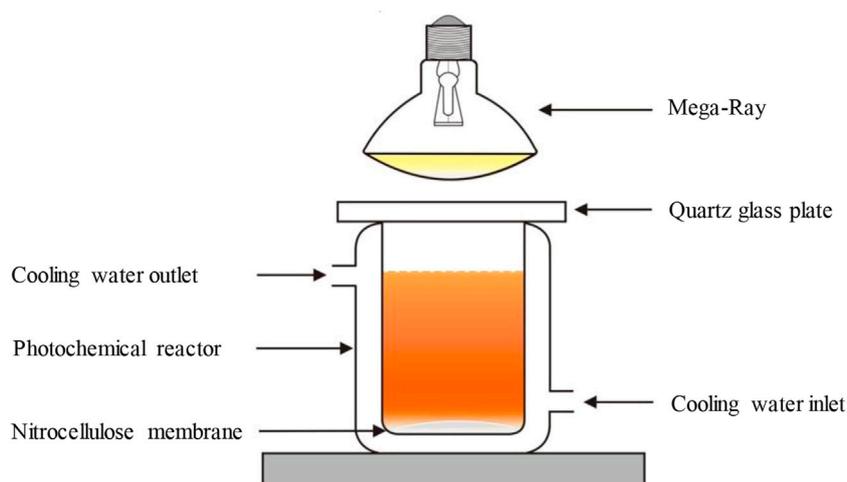


FIGURE 1
Schematic illustration of photodegradation reactor.

as ethyl acetate and acetone (Sun B. B. et al., 2020). NC is currently an effective and low-cost host material (Zhou et al., 2019). The application of NC largely depends on the nitrogen content. When the nitrogen content is between 10.7% and 20.3%, it can be used for coatings and printing inks (Wei et al., 2018a; Wei et al., 2018b). NCM has a micro-scale porous structure and high specific surface area, which is a low-cost material (Fridley et al., 2013; Sun S. et al., 2020). It has characterized by rapid reaction, mild conditions and easy control in degrading organic compounds (Wu et al., 2021). NCM has been widely used in the field of environmental science (Yang et al., 2018). For example, hydroxyl radicals can be generated on the NCM surface, thereby promoting the oxidation and degradation of organic pollutants (Fridley et al., 2013). Under simulated solar irradiation, the quantum yield of hydroxyl radicals from the NCM reached 1.72×10^{-4} (Tai et al., 2018), which is higher than that from TiO_2 (Ishibashi et al., 2000). NCM has been used to remove pollutants such as phenol and thiamphenicol in water. Adding H_2SO_4 to NCM can effectively degrade pollutants in wastewater (Purves and Falconer, 2002). Studies have also found that the static electricity between organic pollutant molecules and NCM can interact to promote the degradation of pollutants (Tai et al., 2018). The characteristics of NCM can be changed by chitosan (Tang et al., 2022). The three-dimensional microstructure of NCM also plays an important role in the degradation of organic pollutants (Sun et al., 2019). NCM is generally dissolved in an organic solvent. When the organic solvent evaporates, the NCM will precipitate. The precipitated NCM has a higher porosity. This characteristic had a certain impact on the degradation of organic compounds (Fridley et al., 2013). The use of NCM to treat organic pollutants in wastewater is still at an early stage, and its degradation mechanism may be affected by factors such as environmental conditions, water composition, and light

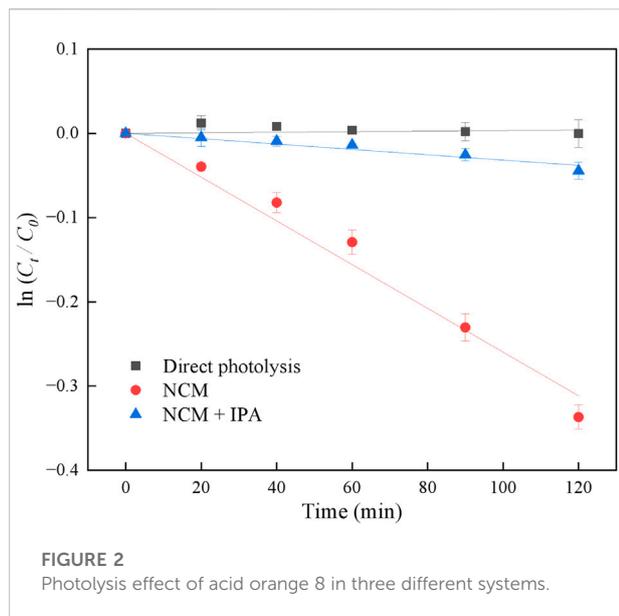
intensity (Wu et al., 2021). Therefore, in-depth research on the organic pollutant degradation by NCM is of great significance for practical applications and elucidating the degradation mechanism.

In response to the above problems, this research uses a new advanced oxidation technology to treat azo dyes, with acid orange 8 as the target pollutant, NCM as the source of active oxygen species, and a photodegradation experiment under a simulated light source. The new advanced oxidation technology analyzes the effects of light intensity, solution pH, temperature, membrane area, initial concentration and water composition on NCM photodegradation acid orange 8. Aiming to explore the best conditions for photodegradation of acid orange 8 by NCM. The experiment explores the influence of water body composition on the photodegradation of acid orange 8 of NCM, in the hope that this technology can be applied in actual production activities in the future.

Materials and methods

Chemical reagents

NCM (Whatman™, 0.45 $\mu\text{m}/47$ mm) and acid orange 8 (85%) were obtained from GE Healthcare (United Kingdom) Life Science and Sigma (United States), respectively. Sodium carbonate (99.8%) was purchased from Xilong Chemical Co., Ltd. (Shenzhen, China). Calcium perchlorate (reagent grade) was obtained from Alfa Aesar Chemical Co., Ltd. (United Kingdom) and magnesium perchlorate ($\geq 83\%$) was obtained from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Sodium dihydrogen phosphate (99%), dibasic sodium phosphate (99%), and isopropanol (IPA, 99.7%) were purchased from Kermel Chemical Reagents (Tianjin, China). All



regents except calcium perchlorate hydrate were analytical grade purity. Millipore-Q water was used in this study.

Experimental method

The photodegradation experiment of acid orange 8 was carried out in photochemical reactor (Wu et al., 2021). The schematic illustration of photodegradation reactor is shown in Figure 1. A simulated sunlight source was placed above the reactor. The reaction temperature was controlled by a high-precision constant temperature bath (Model XOGDH-1010, Nanjing Xian'ou Instruments Manufacture Co. Ltd., China). Light intensity was measured using a photosynthetically active radiometer (Model GLZ-C, Zhejiang Top Instrument Co., Ltd, China). Phosphate buffer (0.02 mol/L) was used to adjust the pH of solution. The concentration of acid orange 8 was measured by Ultraviolet-Visible spectrophotometer (UV-Vis) (Model UV-2600, Shimadzu, Japan). The scanning wavelength range was from 200 to 700 nm, and the scanning speed was 1 nm/sec. The absorbance of acid orange 8 was measured at the maximum absorption wavelength of 488 nm to determine its content. The photodegradation efficiency of acid orange 8 was measured at different reaction times. Each experiment was repeated three times and the average value was taken.

Calculation of photodegradation parameters

The acid orange 8 photodegradation rate was calculated as follows (Zhang et al., 2017).

$$\eta = \frac{C_0 - C_t}{C_0} \times 100\% \quad (1)$$

where, C_0 represents the starting concentration of acid orange 8, C_t represents the concentration of acid orange 8 at reaction time " t ".

A linear regression was fitted with t as the abscissa and $\ln(C_t/C_0)$ as the ordinate. The slope of the straight line was the photolysis rate constant of acid orange 8. The photolysis rate constant was calculated as follows (Aleboyeh et al., 2003).

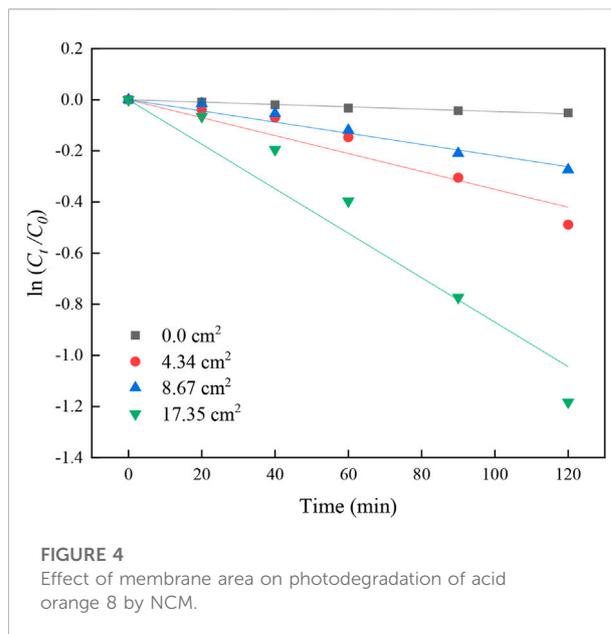
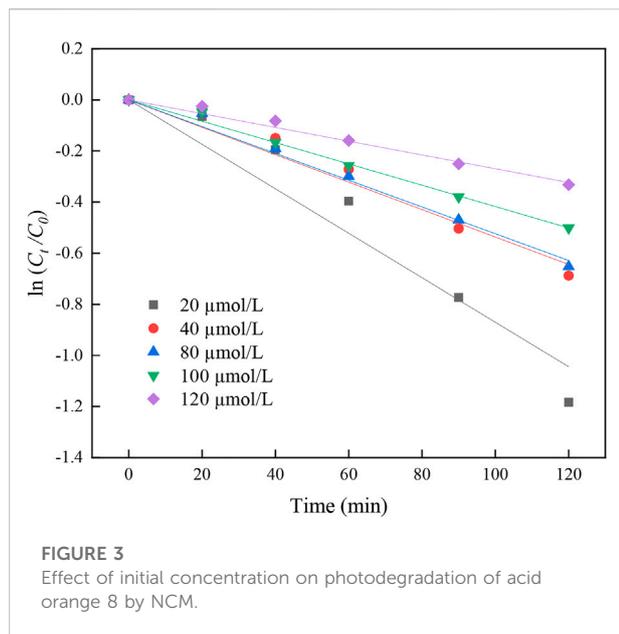
$$\ln \frac{C_t}{C_0} = -Kt \quad (2)$$

where K represents the primary reaction kinetic constant.

Results and discussion

Direct photolysis of acid orange 8

The photolysis of acid orange 8 in pure water, NCM, and NCM and IPA system was investigated (Figure 2). The photolysis rate constant of acid orange 8 in pure water is $6.83 \times 10^{-6} \text{ min}^{-1}$, and the degradation rate was less than 3%, indicating that acid orange 8 hardly underwent photolysis reaction in this system. In the NCM system, the photolysis rate constant for acid orange 8 reached $1.94 \times 10^{-3} \text{ min}^{-1}$ and the degradation rate was about 27.3 times higher than that of pure water. Hydroxyl radicals can be generated on the NCM surface, and the radicals reacted with organic compounds to promote their oxidative degradation (Tai et al., 2018). The NCM system significantly degrades acid orange 8 under illumination. The photolysis rate of acid orange 8 was significantly reduced after the addition of 10 mmol/L IPA to the NCM system. It indicates that the hydroxyl radicals generated by NCM play an important role in the degradation of acid orange 8. IPA is an effective scavenger of hydroxyl radicals, has a high reaction rate with hydroxyl radicals (Marchisio et al., 2015; Ismail et al., 2016). Usually, it reacts with hydroxyl radicals preferentially to the target contaminant. In the NCM and IPA system, the hydroxyl radicals generated by NCM was consumed by IPA, which was responsible for the decrease of the photolysis rate of acid orange 8. The more azo groups in the dye, the stronger the adsorption capacity under illumination (Ahmad et al., 2020). Light can stimulate NCM to form photoelectron-hole pairs and generate hydroxyl radicals, which can mineralize or destroy organic compounds by hydroxyl radicals (Wei et al., 2020). Azo dyes had a high reaction rate with hydroxyl radicals and can be used as scavengers for removing hydroxyl radicals (Dostanić et al., 2020; Cao et al., 2021). Therefore, the photodegradation of acid orange 8 has the best effect in the NCM system.



Effect of the change of acid orange 8 concentration on photodegradation

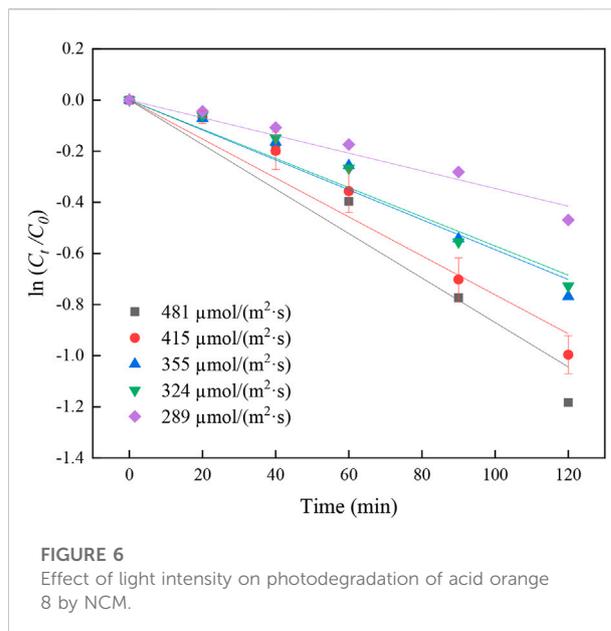
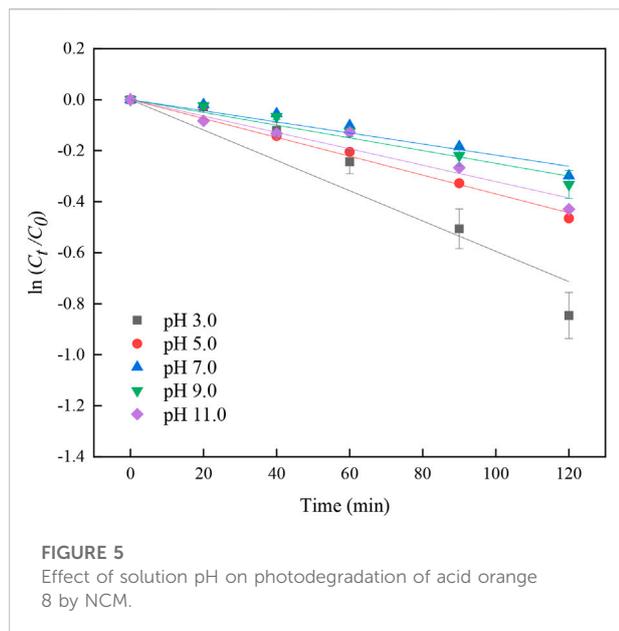
The solution concentration was one of the important factors affecting dye degradation (Ong et al., 2012). The effect of degrading acid orange 8 at different concentrations by NCM was shown in Figure 3. The photodegradation effect decreased with increasing concentration of acid orange 8. The highest photodegradation rate was observed when the concentration of methyl orange was 20 $\mu\text{mol/L}$, corresponding to a photodegradation rate constant of $12.81 \times 10^{-3} \text{ min}^{-1}$. The concentration of acid orange 8 was in the range of 20–120 $\mu\text{mol/L}$, and the photodegradation rate was negatively correlated with the concentration. The amount of UV radiation absorbed by acid orange 8 in solution increases accordingly as the concentration of acid orange 8 increases. As a result, the hydroxyl radicals produced in the reaction system were reduced, and the photolysis rate was decreased (Shu et al., 2004). In addition, an increase in concentration results in more acid orange 8 molecules adsorbed on the surface of NCM, reducing the active site for adsorption of hydroxyl radicals. The reaction between acid orange 8 and hydroxyl radicals was inhibited, causing a decreased in the photodegradation rate (Shu et al., 2004).

The initial concentration of the substrate had a certain impact on the efficiency of the photocatalytic reaction in terms of mechanism and application (Saqib and Muneer, 2003). When the initial concentrations were 40 $\mu\text{mol/L}$ and 80 $\mu\text{mol/L}$, the photodegradation rate did not change much. High concentration of organic matters caused oxidation and decomposition of some solutes, and the by-products produced

would react with hydroxyl radicals (Saqib and Muneer, 2003; Gültekin et al., 2009), resulting in a decrease in the amount of hydroxyl radicals and a decrease in the rate of acid orange 8 degradation.

Effect of NCM area on photodegradation of acid orange 8

The effect of NCM area on the photodegradation of acid orange 8 was examined (Figure 4). The photodegradation rate of acid orange 8 decreased with the decrease of the NCM area. The photodegradation rate of acid orange 8 was almost zero without NCM in the system. The photodegradation efficiency of acid orange 8 was highest at the membrane area of 17.35 cm^2 , and its photodegradation rate constant was $0.43 \times 10^{-3} \text{ min}^{-1}$. The surface of the NCM was a uniformly distributed porous structure, increasing the membrane area of NCM increased its hydrophilicity (Niu et al., 2010; Nawaz et al., 2021), which promoted the organic wastewater by NCM. The high porosity of NCM increased the specific surface area and the absorption rate of light was enhanced (Li J. et al., 2019). In addition, the larger specific surface area increased the production of hydroxyl radicals, improved the photocatalytic activity, and promoted the effective degradation of acid orange 8 (Cui Y. et al., 2021). As the membrane area was increased, the photodegradation rate also increased rapidly (Nawaz et al., 2021). believed that the porosity of the NCM surface, its hydrophilicity, and the degradation rate of organic pollutants decreased with the decrease of the membrane area.



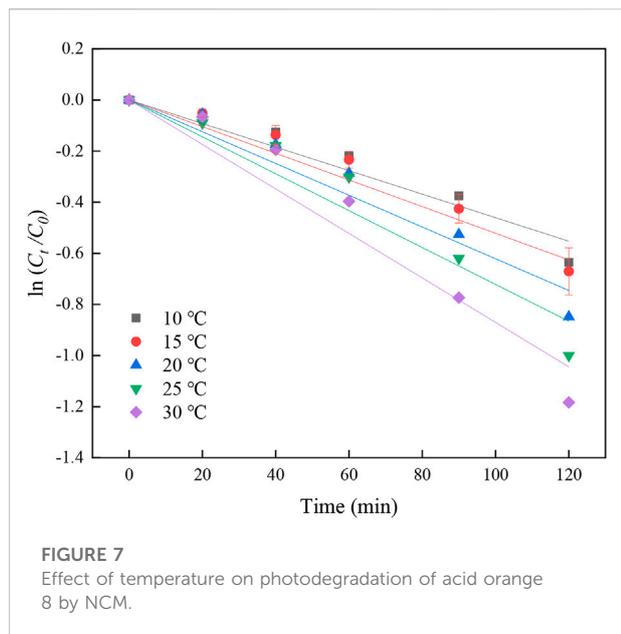
Effect of solution pH on photodegradation of acid orange 8

The solution pH is an important influencing factor in promoting the removal rate of dye (Ulson de Souza et al., 2007). The effect of pH on the photodegradation of acid orange 8 by NCM was investigated (Figure 5). The change of solution pH affected the photodegradation efficiency of acid orange 8, and acidic conditions were more favorable for photodegradation (Elizalde-González and García-Díaz, 2010). When the solution pH was 3.0, the photodegradation rate of acid orange 8 was the highest. After 2 h of reaction, the degradation rate of acid orange 8 was about 59%. Solution pH affects the ionization state and adsorption characteristics of organic matter (Saqib and Muneer, 2003). Under the acidic conditions, more protons increase the attraction of adsorption sites between positive and negative charges, increasing the amount of dye adsorbed (Meng et al., 2019). Under the alkaline conditions, the photodegradation rate of acid orange 8 increased with the increase of solution pH. However, alkaline conditions were favorable for the photodegradation of acid orange 8. The reason was that the negative charge repelled the dye, thereby reducing the degradation of the dye in an alkaline environment (Saqib and Muneer, 2003). In addition, hydrogen peroxide decomposed into water and oxygen under alkaline conditions, resulting in a decrease in the concentration of hydroxyl radicals (Narayanasamy and Murugesan, 2013; Kumar et al., 2021). Besides, the change of solution pH will disturb the structure of the water body,

which will decrease the absorbance of the solution, and cause the decrease of photodegradation rate. (Elizalde-González and García-Díaz, 2010). In addition, the change of solution pH will disturb the structure of the water body, reduce the absorbance of the solution, and reduce the photodegradation rate. The deprotonation of molecules in organic pollutants, which reduces the potential migration to the interface of cavitation bubbles, is the main reason why alkaline conditions reduce the rate of photodegradation (Meng et al., 2019).

Effect of environmental factors on photodegradation of acid orange 8

The effect of light intensity on photodegradation of acid orange 8 was shown in Figure 6. The degradation rate of acid orange 8 decreased with the decrease of light intensity in the range from 289 to 481 $\mu\text{mol}/(\text{m}^2\cdot\text{s})$. Under the light intensity of 481 $\mu\text{mol}/(\text{m}^2\cdot\text{s})$, the photodegradation rate constant of acid orange 8 was $9.86 \times 10^{-3} \text{ min}^{-1}$, and the degradation effect was the best. NCM could promote the degradation of organic matter under certain light intensity (Leiw et al., 2013). When the light intensity increased, the NCM was able to excite more hydroxyl radicals, and the acid orange 8 molecule reacted fully with hydroxyl radicals to remove the organic pollutants from the azo dye solution more effectively (Fard and Fazaeli, 2016). Therefore, lower light intensity was not conducive to the degradation of acid orange 8.

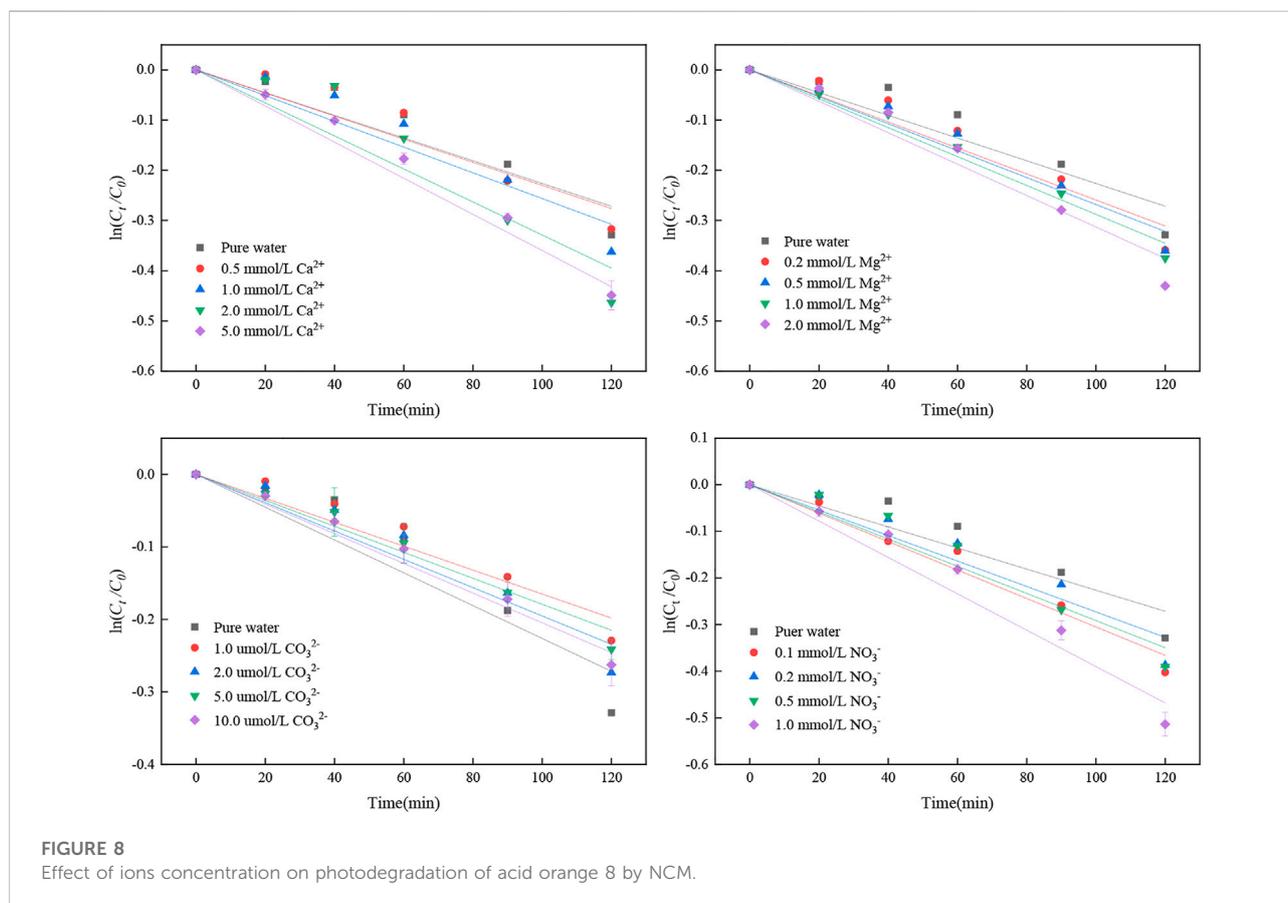


The effect of reaction temperature on photodegradation of acid orange 8 was shown in Figure 7. It could be seen that the photolysis rate of acid orange 8 decreased with the decrease of

temperature (10–30°C). Temperature affected the amount of hydroxyl radicals generated on the NCM, and the possibility of contaminant molecules binding to hydroxyl radicals increases with increasing temperature (Fridley et al., 2013; Kumar et al., 2020). Furthermore, increasing temperature promoted the movement of contaminant molecules (Wang et al., 2012; Wei et al., 2018a), and increased the activation energy of hydroxyl radicals (Silva et al., 2000), which accelerated the oxidative degradation of contaminants. In addition, when the temperature was too high, the structure of the NCM was altered, the reactive was reduced and service life was shortened, resulting in a decrease in the degradation rate of acid orange 8. To prevent mutual reactions between the substances when the temperature is too high, and to avoid the mutual conversion between by-products (Fard and Fazaeli, 2016). Based on the above factors, the optimal reaction temperature was determined to be 30°C.

Effect of ions concentration variation on photodegradation of acid orange 8

The effect of concentration changes of calcium, magnesium, carbonate, and nitrate ions in the solution



composition on the photodegradation of acid orange 8 was examined (Figure 8). The photodegradation rate of acid orange 8 increased with increasing concentration of calcium and magnesium ions, which was consistent with previous research results (Zhao et al., 2014). The photodegradation rate constant of acid orange 8 was $5.67 \times 10^{-3} \text{ min}^{-1}$ for calcium ion concentration at $5 \times 10^{-3} \text{ mol/L}$. The photodegradation rate constant of acid orange 8 was $3.57 \times 10^{-3} \text{ min}^{-1}$ for magnesium ion concentration at $2.10 \times 10^{-3} \text{ mol/L}$. In the NCM system, the addition of cations to the solution caused the azo dye to discolor, break bonds, and degrade (Zhang et al., 2010). When the concentration of Ca^{2+} was 0.5 mol/L, the photodegradation rate was the same as that of pure water system, but when the concentration of Ca^{2+} was 1.0 mol/L, the photodegradation rate increased gradually with the increase of the concentration. Appropriate increase of Mg^{2+} can improve the activity of azo dyes, make them fade, break the azo bond, and finally degrade completely (Zhao et al., 2014). The cation can directly react with the azo dye molecules, and the [H] in the reaction product has high reactivity, which can induce the cleavage of the azo bond, thereby destroying the azo dye and the conjugate system, and promoting the photodegradation of the dye wastewater (Zhang et al., 2010; Zhao et al., 2014) studied the efficient collision of dye molecules with Mg and Ca at the physical level, Mg and Ca lost electrons to become Mg^{2+} and Ca^{2+} , while the dye molecule accepted electrons, and the azo bond $-\text{N}=\text{N}-$ was decomposed into two $-\text{NH}_2$, leading to degradation.

The addition of nitrate to the solution also increased the photodegradation of acid orange 8. When the nitrate concentration was $1 \times 10^{-3} \text{ mol/L}$, the photodegradation rate constant of acid orange 8 ($4.08 \times 10^{-3} \text{ min}^{-1}$) was highest. The electrostatic reaction of nitrogen or oxygen with pollutant atoms promoted the reaction of nitrate and pollutant molecules (Tai et al., 2018). The nitrate in the reaction system could generate active oxygen species, destroy the structure of the azo dye, and promote the degradation of azo dye (Garcia et al., 2005). The solution could produce a small amount of nitrate ions in the photocatalytic process (Stylidi, 2003), which had a certain effect on photodegradation. In the photocatalytic oxidation process, the main oxidizing species such as superoxide radical anions and hydroxyl radicals could promote the oxidative degradation of dyes (Saqib and Muneer, 2003). Notably, the addition of carbonate to the solution reduced the photodegradation efficiency of acid orange 8. When the CO_3^{2-} concentration was $5 \times 10^{-3} \text{ mol/L}$, the photolysis rate constant of acid orange 8 was $2.77 \times 10^{-3} \text{ min}^{-1}$. Carbonates could react with hydroxyl radicals to bicarbonate, which were hydroxyl radical scavengers (Saqib and Muneer, 2003). Therefore, the addition of

carbonates reduced the amount of hydroxyl radicals that reacted with the pollutant for degradation. It was shown that hydroxyl radicals had a significant effect on the photodegradation of acid orange 8 in the reaction system. The hydroxyl radicals have lower redox potential and higher selectivity (Wang and Wang, 2021), CO_3^{2-} reacts with hydroxyl radicals to generate HCO_3^- (Zhao et al., 2018), which reduces the combination of pollutants and hydroxyl radicals, and the product HCO_3^- also has a slight inhibitory effect on the degradation of pollutants (Chen et al., 2019). This indicated the importance of hydroxyl radicals in the dyes degradation process and the ability of hydroxyl radicals to preferentially attack azo groups (Gültekin et al., 2009).

Conclusion

Under simulated sunlight, the hydroxyl radicals produced by NCM promoted the photodegradation of acid orange 8 with a rate constant of $1.94 \times 10^{-3} \text{ min}^{-1}$. Within a certain range, the degradation effect decreased with the decrease of light intensity, and acidic conditions were favorable for the photolysis of acid orange 8. The optimal reaction conditions were: light intensity of $481 \mu\text{mol}/(\text{m}^2 \cdot \text{s})$, water bath temperature of 30°C , pH value is 3.0, and membrane area of 17.35 cm^2 . The photodegradation rate of acid orange 8 decreased with the concentration of cations Ca^{2+} , Mg^{2+} and anion NO_3^- , CO_3^{2-} can inhibit the photodegradation of acid orange 8, and the presence of carbonate inhibited the photolysis of acid orange 8. In addition, the process of photodegradation of acid orange 8 by NCM was a surface reaction, and the system was a heterogeneous reaction system. The degradation effect is also affected by environmental factors such as temperature and light intensity.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author. All data generated or analyzed during this study are included in this article.

Author contributions

Conceived and designed the experiments: TZ and LW performed the experiments: JW, JF, HL, and XL analysed the data: JF and BS edited the manuscript: LW, JF, TZ, and BS edited the manuscript: LW, JF, and TZ.

Funding

We would like to thank the major project for Henan Province Joint Funds of the National Natural Science Foundation of China (U1704241), the Plan for Scientific Innovation Talent of Henan Province, China (194200510010), the Key Scientific Research Project of Henan University (22A610002), and the Henan Province Science and Technology Project (222102320213), for their support.

Acknowledgments

The authors would like to thank the editors and reviewers for their insight and helpful comments.

References

- Ahmad, R., Lee, C. S., Kim, J. H., and Kim, J. (2020). Partially coated TiO₂ on Al₂O₃ membrane for high water flux and photodegradation by novel filtration strategy in photocatalytic membrane reactors. *Chem. Eng. Res. Des.* 163, 138–148. doi:10.1016/j.cherd.2020.08.027
- Aleboye, A., Aleboye, H., and Moussa, Y. (2003). Critical effect of hydrogen peroxide in photochemical oxidative decolorization of dyes: Acid Orange 8, Acid Blue 74 and Methyl Orange. *Dyes Pigment.* 57, 67–75. doi:10.1016/s0143-7208(03)00010-x
- Berradi, M., Hsissou, R., Khudhair, M., Assouag, M., Cherkaoui, O., Bachiri, A. E., et al. (2019). Textile finishing dyes and their impact on aquatic environs. *Heliyon* 5, e02711. doi:10.1016/j.heliyon.2019.e02711
- Bessy, T. C., Bindhu, M. R., Johnso, J., Chen, S. M., Chen, T. W., and Almaary, K. S. (2022). UV light assisted photocatalytic degradation of textile waste water by Mg_{0.8-x}Zn_xFe₂O₄ synthesized by combustion method and *in-vitro* antimicrobial activities. *Environ. Res.* 204, 111917. doi:10.1016/j.envres.2021.111917
- Bhatkhande, D. S., Pangarkar, V. G., and Beenackers, A. A. (2001). Photocatalytic degradation for environmental applications - a review. *J. Chem. Technol. Biotechnol.* 77, 102–116. doi:10.1002/jctb.532
- Cao, Y. H., Ren, Y., Zhang, J. T., Xie, T. F., and Lin, Y. H. (2021). Activation of H₂O₂ by photo-generated electrons for enhanced visible light driven methylene blue degradation with ZnFe₂O₄/BiVO₄ heterojunction. *Opt. Mat. (Amst)*. 121, 111637. doi:10.1016/j.optmat.2021.111637
- Chen, L., Hui, L., Andac, A., Xie, R. Z., Zhang, Y. L., and Meng, X. Y. (2019). Hydroxylamine-assisted catalytic degradation of ciprofloxacin in ferrate/persulfate system. *Chem. Eng. J.* 360, 612–620. doi:10.1016/j.cej.2018.11.218
- Chen, X. L., Li, F., Zhang, M., Liu, B., Chen, H., and Wang, H. (2021). Highly dispersed and stabilized Co₃O₄/C anchored on porous biochar for bisphenol A degradation by sulfate radical advanced oxidation process. *Sci. Total Environ.* 777, 145794. doi:10.1016/j.scitotenv.2021.145794
- Chong, M. N., Jin, B., Chow, C. W. K., and Saint, C. (2010). Recent developments in photocatalytic water treatment technology: A review. *Water Res.* 44, 2997–3027. doi:10.1016/j.watres.2010.02.039
- Cui, M. H., Liu, W. Z., Tang, Z. E., and Cui, D. (2021a). Recent advancements in azo dye decolorization in bio-electrochemical systems (BESS): Insights into decolorization mechanism and practical application. *Water Res.* 203, 117512. doi:10.1016/j.watres.2021.117512
- Cui, Y., Yang, L., Zheng, J., Wang, Z., Li, B., Yan, Y., et al. (2021b). Synergistic interaction of Z-scheme 2D/3D g-C₃N₄/BiOI heterojunction and porous PVDF membrane for greatly improving the photodegradation efficiency of tetracycline. *J. Colloid Interface Sci.* 586, 335–348. doi:10.1016/j.jcis.2020.10.097
- Dostanić, J., Huš, M., and Lončarević, D. (2020). Effect of substituents in hydroxyl radical-mediated degradation of azo pyridone dyes: Theoretical approaches on the reaction mechanism. *J. Environ. Sci.* 98, 14–21. doi:10.1016/j.jes.2020.05.022
- Elizalde-González, M. P., and García-Díaz, L. E. (2010). Application of a Taguchi L16 orthogonal array for optimizing the removal of Acid Orange 8 using carbon with a low specific surface area. *Chem. Eng. J.* 163, 55–61. doi:10.1016/j.cej.2010.07.040
- Fard, N. E., and Fazaeli, R. (2016). A novel kinetic approach for photocatalytic degradation of azo dye with CdS and Ag/CdS nanoparticles fixed on a cement bed in a continuous-flow photoreactor. *Int. J. Chem. Kinet.* 48, 691–701. doi:10.1002/kin.21025
- Ferreira, A. M., Coutinho, J. A. P., Fernandes, A. M., and Freire, M. G. (2014). Complete removal of textile dyes from aqueous media using ionic-liquid-based aqueous two-phase systems. *Sep. Purif. Technol.* 128, 58–66. doi:10.1016/j.seppur.2014.02.036
- Fridley, G. E., Holstein, C. A., Oza, S. B., and Yager, P. (2013). The evolution of nitrocellulose as a material for bioassays. *MRS Bull.* 38, 326–330. doi:10.1557/mrs.2013.60
- García, J., Gomes, H. T., Serp, P., Kalck, P., Figueiredo, J. L., and Faria, J. L. (2005). Platinum catalysts supported on MWNT for catalytic wet air oxidation of nitrogen containing compounds. *Catal. Today* 102–103, 101–109. doi:10.1016/j.cattod.2005.02.013
- Gültekin, I., Tezcanlı-Güyer, G., and Ince, N. H. (2009). Sonochemical decay of C.I. Acid Orange 8: Effects of CCl₄ and t-butyl alcohol. *Ultrason. Sonochem.* 16, 577–581. doi:10.1016/j.ultrsonch.2008.12.007
- Ishibashi, K., Fujishima, A., Watanabe, T., and Hashimoto, K. (2000). Quantum yields of active oxidative species formed on TiO₂ photocatalyst. *J. Photochem. Photobiol. A Chem.* 134, 139–142. doi:10.1016/s1010-6030(00)00264-1
- Ismail, L., Rifai, A., Ferronato, C., Fine, L., Jaber, F., and Chovelon, J. M. (2016). Towards a better understanding of the reactive species involved in the photocatalytic degradation of sulfaclozine. *Appl. Catal. B Environ.* 185, 88–99. doi:10.1016/j.apcatb.2015.12.008
- Jin, Z., Zhao, Z., Liang, L., and Zhang, Y. (2022). Effects of ferrous oxide on azo dye degradation in a sulfate-containing anaerobic reactor: From electron transfer capacity and microbial community. *Chemosphere* 286, 131779. doi:10.1016/j.chemosphere.2021.131779
- Khalil, A., Aboamra, N. M., Nasser, W. S., Mahmoud, W. H., and Mohamed, G. G. (2019). Photodegradation of organic dyes by PAN/SiO₂-TiO₂-NH₂ nanofiber membrane under visible light. *Sep. Purif. Technol.* 224, 509–514. doi:10.1016/j.seppur.2019.05.056
- Koyuncu, I., Topacik, D., and Yuksel, E. (2004). Reuse of reactive dyehouse wastewater by nanofiltration: Process water quality and economical implications. *Sep. Purif. Technol.* 36, 77–85. doi:10.1016/S1383-5866(03)00154-0
- Kumar, J. E., Mulai, T., Kharmawphlang, W., Sharan, R. N., and Sahoo, M. K. (2020). Decolourisation, mineralisation and detoxification of mixture of azo dyes using Fenton and Fenton-type advanced oxidation processes. *Chem. Pap.* 74, 3145–3159. doi:10.1007/s11696-020-01147-9
- Kumar, O. P., Ashiq, M. N., Shah, S. S. A., Akhtar, S., AlObaidi, M. A., Mujtaba, I. M., et al. (2021). Nanoscale ZrRGOCuFe layered double hydroxide composites for enhanced photocatalytic degradation of dye contaminant. *Mat. Sci. Semicond. process.* 128, 105748. doi:10.1016/j.mssp.2021.105748
- Leiw, M. Y., Guai, G. H., Wang, X., Tse, M. S., Ng, C. M., and Tan, O. K. (2013). Dark ambient degradation of Bisphenol A and Acid Orange 8 as organic pollutants

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

- by perovskite SrFeO_{3-δ} metal oxide. *J. Hazard. Mat.* 260, 1–8. doi:10.1016/j.jhazmat.2013.04.031
- Li, B., Meng, M., Cui, Y., Wu, Y., Zhang, Y., Dong, H., et al. (2019a). Changing conventional blending photocatalytic membranes (BPMs): Focus on improving photocatalytic performance of Fe₃O₄/g-C₃N₄/PVDF membranes through magnetically induced freezing casting method. *Chem. Eng. J.* 365, 405–414. doi:10.1016/j.cej.2019.02.042
- Li, J., Guan, Q., Hong, J., and Chang, C. T. (2019b). Electrochemical oxidation of azo dye wastewater using graphene-based electrode materials. *J. Nanosci. Nanotechnol.* 19, 7308–7314. doi:10.1166/jnn.2019.16656
- Macías-Quiroga, I. F., Henao-Aguirre, P. A., Marín-Flórez, A., Arredondo-López, S. M., and Sanabria-González, N. R. (2020). Bibliometric analysis of advanced oxidation processes (AOPs) in wastewater treatment: Global and ibero-American research trends. *Environ. Sci. Pollut. Res.* 28, 23791–23811. doi:10.1007/s11356-020-11333-7
- Mahdi, M. H., Mohammed, T. J., and Al-Najar, J. A. (2021). Advanced oxidation processes (AOPs) for treatment of antibiotics in wastewater: A review. *IOP Conf. Ser. Earth Environ. Sci.* 779, 012109. doi:10.1088/1755-1315/779/1/012109
- Marchisio, A., Minella, M., Maurino, V., Minero, C., and Vione, D. (2015). Photogeneration of reactive transient species upon irradiation of natural water samples: Formation quantum yields in different spectral intervals, and implications for the photochemistry of surface waters. *Water Res.* 73, 145–156. doi:10.1016/j.watres.2015.01.016
- Meng, L., Gan, L., Gong, H., Su, J., Wang, P., Li, W., et al. (2019). Efficient degradation of Ibuprofen A using High-Frequency Ultrasound: Analysis of influencing factors and mechanistic investigation. *J. Clean. Prod.* 232, 1195–1203. doi:10.1016/j.jclepro.2019.06.055
- Mohamed, A., Salama, A., Nasser, W. S., and Uheida, A. (2018). Photodegradation of Ibuprofen, Cetirizine, and Naproxen by PAN-MWCNT/TiO₂-NH₂ nanofiber membrane under UV light irradiation. *Environ. Sci. Eur.* 30, 47–49. doi:10.1186/s12302-018-0177-6
- Mulushewa, Z., Dinbore, W. T., and Ayele, Y. (2021). Removal of methylene blue from textile waste water using kaolin and zeolite-x synthesized from Ethiopian kaolin. *Environ. Anal. Health Toxicol.* 36, e2021007. doi:10.5620/eaht.2021007
- Muniyasamy, A., Sivaporul, G., Gopinath, A., Lakshmanan, R., Altaee, A., Achary, A., et al. (2020). Process development for the degradation of textile azo dyes (mono-di-poly-) by advanced oxidation process - ozonation: Experimental & partial derivative modelling approach. *J. Environ. Manage.* 265, 110397. doi:10.1016/j.jenvman.2020.110397
- Narayanasamy, L., and Murugesan, T. (2013). Degradation of Alizarin Yellow R using UV/H₂O₂ advanced oxidation process. *Environ. Prog. Sustain. Energy* 33, 482–489. doi:10.1002/ep.11816
- Nawaz, H., Umar, M., Nawaz, I., Zia, Q., Tabassum, M., Razzaq, H., et al. (2021). Photodegradation of textile pollutants by nanocomposite membranes of polyvinylidene fluoride integrated with polyaniline–titanium dioxide nanotubes. *Chem. Eng. J.* 419, 129542. doi:10.1016/j.cej.2021.129542
- Niu, F., Zhang, L. S., Chen, C. Q., Li, W., Li, L., Song, W. G., et al. (2010). Hydrophilic TiO₂ porous spheres anchored on hydrophobic polypropylene membrane for wettability induced high photodegrading activities. *Nanoscale* 2, 1480. doi:10.1039/c0nr00182a
- Ong, S. A., Min, O. M., Ho, L. N., and Wong, Y. S. (2012). Comparative study on photocatalytic degradation of mono azo dye acid orange 7 and methyl orange under solar light irradiation. *Water Air Soil Pollut.* 223, 5483–5493. doi:10.1007/s11270-012-1295-1
- Özcan, A. S., Erdem, B., and Özcan, A. (2004). Adsorption of Acid Blue 193 from aqueous solutions onto Na-bentonite and DTMA-bentonite. *J. Colloid Interface Sci.* 280, 44–54. doi:10.1016/j.jcis.2004.07.035
- Purves, C. B., and Falconer, E. L. (2002). Assignment of structure to cellulose 3, 6-dinitrate¹. *J. Am. Chem. Soc.* 124, 5308–5310. doi:10.1021/ja01576a061
- Qin, L., Zhang, G., Fan, Z., Wu, Y., Guo, X., and Liu, M. (2014). Templated fabrication of hierarchically porous Fe–Ti bimetallic solid superacid for efficient photochemical oxidation of azo dyes under visible light. *Chem. Eng. J.* 244, 296–306. doi:10.1016/j.cej.2014.01.082
- Sable, S. S., Shah, K. J., Chiang, P. C., and Lo, S. L. (2018). Catalytic oxidative degradation of phenol using iron oxide promoted sulfonated-ZrO₂ by Advanced Oxidation Processes (AOPs). *J. Taiwan Inst. Chem. Eng.* 91, 434–440. doi:10.1016/j.jtice.2018.06.030
- Saquib, M., and Muneer, M. (2003). Titanium dioxide mediated photocatalyzed degradation of a textile dye derivative, acid orange 8, in aqueous suspensions. *Desalination* 155, 255–263. doi:10.1016/S0011-9164(03)00303-5
- Shi, Y. Q., Yang, Z. L., Xing, L., Zhang, X. Z., Li, X. G., and Zhang, D. H. (2021). Recent advances in the biodegradation of azo dyes. *World J. Microbiol. Biotechnol.* 37, 137. doi:10.1007/S11274-021-03110-6
- Shu, H. Y., Chang, M. C., and Fan, H. J. (2004). Decolorization of azo dye acid black 1 by the UV/H₂O₂ process and optimization of operating parameters. *J. Hazard. Mat.* 113, 201–208. doi:10.1016/j.jhazmat.2004.06.007
- Shyamika, S., Erandathie, L., and Sena, P. (2018). Evaluation of the environmental and economic performances of three selected textile factories in Biyagama export processing zone. *Environ. Dev.* 27, 70–82. doi:10.1016/j.envdev.2018.07.006
- Siddique, M., Fayaz, N., and Saeed, M. (2020). Synthesis, characterization, photocatalytic activity and gas sensing properties of zinc doped manganese oxide nanoparticles. *Phys. B Condens. Matter* 602, 412504. doi:10.1016/j.physb.2020.412504
- Silva, G. G., De Souza, D. A., Machado, J. C., and Hourston, D. J. (2000). Mechanical and thermal characterization of native brazilian coir fiber. *J. Appl. Polym. Sci.* 76, 1197–1206. doi:10.1002/(SICI)1097-4628(20000516)76:7<1197::AID-APP23>3.0.CO;2-G
- Styliidi, M. (2003). Pathways of solar light-induced photocatalytic degradation of azo dyes in aqueous TiO₂ suspensions. *Appl. Catal. B Environ.* 40, 271–286. doi:10.1016/S0926-3373(02)00163-7
- Sun, B. B., Yao, B. H., He, Y. Q., and Yang, B. (2020a). Preparation and photochromic performance of homogeneous phase nitrocellulose membrane grafting spirooxazine moieties. *Coatings* 10, 569. doi:10.3390/coatings10060569
- Sun, J. H., Dong, S. Y., Wang, Y. K., and Sun, S. P. (2009). Preparation and photocatalytic property of a novel dumbbell-shaped ZnO microcrystal photocatalyst. *J. Hazard. Mat.* 172, 1520–1526. doi:10.1016/j.jhazmat.2009.08.022
- Sun, S., Feng, S., Ji, C., Shi, M., He, X., Xu, F., et al. (2020b). Microstructural effects on permeability of Nitrocellulose membranes for biomedical applications. *J. Memb. Sci.* 595, 117502. doi:10.1016/j.memsci.2019.117502
- Sun, S. Y. M., Feng, S. S., Ji, C. C., Shi, M., He, X. C., Xu, F., et al. (2019). Microstructural effects on permeability of Nitrocellulose membranes for biomedical applications. *J. Memb. Sci.* 595, 117502. doi:10.1016/j.memsci.2019.117502
- Tai, C., Zhang, S., Yin, Y., Dai, Z., Li, Y., Jiang, G., et al. (2018). Facile photoinduced generation of hydroxyl radical on a nitrocellulose membrane surface and its application in the degradation of organic pollutants. *ChemSusChem* 11, 843–847. doi:10.1002/cssc.201800047
- Tang, R., Xie, M., Li, M., Cao, L., Feng, S., Li, Z., et al. (2022). Nitrocellulose membrane for Paper-based biosensor. *Appl. Mater. Today* 26, 101305. doi:10.1016/j.apmt.2021.101305
- Ulson de Souza, S. M. A. G., Forgjarini, E., and Ulson de Souza, A. A. (2007). Toxicity of textile dyes and their degradation by the enzyme horseradish peroxidase (HRP). *J. Hazard. Mat.* 147, 1073–1078. doi:10.1016/j.jhazmat.2007.06.003
- Umar, A., Khan, M., Alam, S., Zekker, I., Burlakovs, J., dC Rubin, S., et al. (2021). Synthesis and characterization of Pd-Ni bimetallic nanoparticles as efficient adsorbent for the removal of acid orange 8 present in wastewater. *Water* 13, 1095. doi:10.3390/w13081095
- Venkatesh, T., Siddeswara, D. M. K., Mylarappa, M., Vishnu Mahesh, K. R., Nagaswarupa, H. P., and Raghavendra, N. (2018). Photo decomposition of acid orange 8 from aqueous solution by using rGO/CNT/AgO nano composite. *Mater. Today Proc.* 5, 22663–22668. doi:10.1016/j.matpr.2018.06.642
- Wang, J., and Wang, S. (2021). Effect of inorganic anions on the performance of advanced oxidation processes for degradation of organic contaminants. *Chem. Eng. J.* 411, 128392. doi:10.1016/j.cej.2020.128392
- Wang, J. Q., Liu, Y. H., Chen, M. W., Louzguine-Luzgin, D. V., Inoue, A., and Perepezko, J. H. (2012). Excellent capability in degrading azo dyes by MgZn-based metallic glass powders. *Sci. Rep.* 2, 418. doi:10.1038/srep00418
- Wei, R., Huang, S., Wang, Z., Wang, X., Ding, C., Yuen, R., et al. (2018a). Thermal behavior of nitrocellulose with different aging periods. *J. Therm. Anal. Calorim.* 136, 651–660. doi:10.1007/s10973-018-7653-5
- Wei, R., Huang, S., Wang, Z., Yuen, R., and Wang, J. (2018b). Evaluation of the critical safety temperature of nitrocellulose in different forms. *J. Loss Prev. Process Ind.* 56, 289–299. doi:10.1016/j.jlp.2018.09.004
- Wei, Z., Liu, J., and Shangguan, W. (2020). A review on photocatalysis in antibiotic wastewater: Pollutant degradation and hydrogen production. *Chin. J. Catal.* 41, 1440–1450. doi:10.1016/S1872-2067(19)63448-0

Wu, L., Jin, X., Zhao, T., Wang, H., and Dai, Z. (2021). Impact factors of the degradation of bisphenol A by nitrocellulose membrane under illumination. *J. Environ. Sci.* 100, 193–202. doi:10.1016/j.jes.2020.05.012

Yakar, A., Ünlü, A., Yeşilçayır, T., and Bıyık, İ. (2020). Kinetics and thermodynamics of textile dye removal by adsorption onto iron oxide nanoparticles. *Nanotechnol. Environ. Eng.* 5, 6–436. doi:10.1007/s41204-020-0068-0

Yang, Y., Raza, A., Banat, F., and Wang, K. (2018). The separation of oil in water (O/W) emulsions using polyether sulfone & nitrocellulose microfiltration membranes. *J. Water Process Eng.* 25, 113–117. doi:10.1016/j.jwpe.2018.07.007

Yao, L., Chen, X., Yu, C., Chen, J., Lai, Y., and Li, N. (2022). Metal-free photocatalyst of few-layer phosphorene with excellent activity under different light conditions. *Mat. Lett.* 306, 130884. doi:10.1016/j.matlet.2021.130884

Zhang, C., Zhang, H., Lv, M., and Hu, Z. (2010). Decolorization of azo dye solution by Fe–Mo–Si–B amorphous alloy. *J. Non. Cryst. Solids* 356, 1703–1706. doi:10.1016/j.jnoncrysol.2010.06.019

Zhang, Y., Huang, G., An, C., Xin, X., Liu, X., Raman, M., et al. (2017). Transport of anionic azo dyes from aqueous solution to gemini surfactant-modified wheat bran: Synchrotron infrared, molecular interaction and adsorption studies. *Sci. Total Environ.* 595, 723–732. doi:10.1016/j.scitotenv.2017.04.031

Zhao, T., Li, P., Tai, C., She, J., Yin, Y., Qi, Y., et al. (2018). Efficient decolorization of typical azo dyes using low-frequency ultrasound in presence of carbonate and hydrogen peroxide. *J. Hazard. Mat.* 346, 42–51. doi:10.1016/j.jhazmat.2017.12.009

Zhao, Y. F., Si, J. J., Song, J. G., Yang, Q., and Hui, X. D. (2014). Synthesis of Mg–Zn–Ca metallic glasses by gas-atomization and their excellent capability in degrading azo dyes. *Mater. Sci. Eng. B* 181, 46–55. doi:10.1016/j.mseb.2013.11.019

Zhou, S., Stromme, M., and Xu, C. (2019). Highly transparent, flexible and mechanically strong nanopapers of cellulose nanofibers @ metal-organic frameworks. *Chem. Eur. J.* 25, 3515–3520. doi:10.1002/chem.201806417