



Photocatalytic decomposition of textile dyeing effluents using TiO₂, ZnO, and Fe₂O₃ catalysts

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Abstract

Textile dyeing industries are facing the challenge of environmental sustainability due to the discharge of large volumes of textile dyeing effluents containing residual reactive dyes and chemicals. Hence, it is imperative to treat the discharged effluents before releasing them into the environment. The study aimed to degrade textile dyeing effluent using some selected catalysts. The study collected some effluent samples from the Bangladesh Small and Cottage Industries Corporation (BICIC) of Rajshahi and were subjected to photocatalytic decomposition using three catalysts such as TiO₂, ZnO, and Fe₂O₃. It considered several operational parameters, including irradiation time, catalyst concentration, pH, and dose of the oxidizing agent for optimizing the color removal efficiency. Besides, the kinetics and the mineralization of the photocatalytic decomposition reactions were examined. The study results showed that the maximum 81.6 % decomposition was achieved using ZnO catalyst at the optimized conditions. It also showed that total organic carbon (TOC) and chemical oxygen demand (COD) were reduced by about 97.9% and 43.53%, respectively. Kinetics study of the degradation process of the effluents showed pseudo-first-order reactions indicating the potentiality of the catalysts. The study observed that the ZnO is suitable for photocatalytic degradation in the textile dye effluents treatment.

Keywords: Degradation, effluent, photocatalyst, textile dye, treatment

Introduction

Dyes and pigments are mostly used in the textiles, plastics, leather, paper, food, and cosmetic industry to color their products. Textile industries generate 100 -170 L dye effluent per kg of cloth processed that could be characterized by a strong odor, high chemical oxygen demand (COD), and wide pH range. Every year, textile dyeing industries used more than 10,000 dyes, and 280,000 tons of effluents are discharged worldwide (Hsueh et al., 2005; Mostafa et al., 2011; Chowdhury et al., 2013). It is estimated that from 1 to 15% of the dye is lost during the dyeing section of a textile industry process and is released in wastewaters Galindo et al., 2001; Sarnaik & Kanekar, 1995; Islam & Mostafa 2020. Dyes are highly persistent in environments because they are produced with great chemical and photolytic stability. Dyes also can cause severe damage to human beings, such as disturbing or failure of the liver, kidney, and brain functions, reproductive and central nervous systems, etc. (Salleh et al., 2011; Rahim & Mostafa, 2021; Islam & Mostafa, 2021). In this manner, the improvement of the efficient and secure treatment process of textile dyeing effluents is a crying need for keeping up a pollution-free environment.

Several chemical methods, including adsorption, coagulation-flocculation, chlorination and ozonation are used to degrade these effluents (Mostafa et al., 2017; Islam & Mostafa, 2018; Chowdhury et al., 2015; Mostafa & Hoinkis, 2012; Uddin et al., 2011). However, these methods are non-destructive since they transfer the non-biodegradable materials into sludge only. This gives rise to a new type of pollution that requires further treatment (Arslan et al., 2000; Stock et al., 2000). In such cases,

advanced oxidation processes (AOPs) have been considered effective technology. AOPs are a group of processes that are based on the generation of hydroxyl radicals, which are highly reactive oxidants. The short mechanism of AOPs includes two steps: (a) the generation of hydroxyl radicals, and (b) oxidative reaction of these radicals with molecules (Azbar et al., 2004). UV, UV/O₃, UV/ H₂O₂, Fe⁺²/ H₂O₂, TiO₂/ H₂O₂, and several processes can generate highly effective hydroxyl radicals (Mandal et al., 2004). AOPs can convert the dissolved organic pollutants to CO₂ and H₂O. These can oxidize a wide range of compounds that are otherwise difficult to degrade biologically. AOPs are potential destructive technology leading to the total mineralization of most organic pollutants (Schiavello, 1988; Serpone & Pelizzetti, 1989). TiO₂ is the most widely used catalyst in the photocatalytic degradation of pollutants due to its suitable band gap energy (Tang & Chen, 1996). It is non-toxic, insoluble, reusable, and photostable. ZnO is considered to be a suitable alternative to TiO₂ since its photocatalytic degradation mechanism is very similar to TiO₂. It is an n-type semiconductor and has a wide band gap of 3.37 eV compared to TiO₂ (E_g anatase = 3.2 eV) and a large exciton binding energy of 60 meV, making it another attractive photocatalyst (Tang & Huang, 1995). It is capable of generating hydroxyl radicals in sufficient quantity. It is transparent to most of the solar spectrum. Besides, many compounds of iron like Fe(III) oxides, oxyhydroxides (FeOOH), etc., have also drawn the attention to scientists for their special photocatalytic properties to oxidize organic pollutants (Leland & Bard, 1987). The objective of the study was to photocatalytic degrade textile dyeing effluents for sustainable effluent

management. The study focused on the optimization of the process parameters for the photocatalytic decomposition of the effluent, which included the catalyst and its concentration, pH, irradiation time, and oxidizing agent dose (Kulkarni & Thakur, 2014). Besides, the kinetics of the photocatalytic decomposition reactions were also studied. The extent of mineralization of the effluent by photocatalytic treatment was studied by measuring the COD and TOC values of the effluent.

Materials and Methods

Materials

The catalysts TiO_2 , ZnO and Fe_2O_3 were used as photocatalysts in this study purchased from Merck Pvt. Ltd (Germany). The raw effluents were collected from the outlet of a silk industry located in Bangladesh Small and Cottage Industries Corporation (BICIC) area of Rajshahi, Bangladesh. The collected effluents were taken to the laboratory for analyzing the parameters using the standard methods. All chemicals including H_2O_2 used were reagent grade, and all experimental solutions were prepared with deionized water.

Photocatalytic treatment procedure

The photocatalytic activity of TiO_2 , ZnO , and Fe_2O_3 was studied for the degradation of this effluent. A photocatalytic reactor was designed to perform catalytic degradation experiments in a wooden chamber equipped with a 15w UV light (model-PHILIPS TUV 15W G15 T8 UVC) as an illumination source. The wooden chamber was 4 feet long, 2.5 feet high, and 2 feet wide. The degradation process was carried out in a 250 mL glass beaker placed on a magnetic stirrer running at constant speed inside the UV chamber. All photocatalytic experiments were performed in triplicate at room temperature, and their average values are presented here. At first 50 mL of effluent was taken in the beaker and a certain amount of catalyst and H_2O_2 were added. The beaker was then placed on a magnetic stirrer and the effluent was stirred in dark for 1/2 hour to achieve heterogeneous equilibrium. Afterward, the effluent was photo catalytically decomposed for a definite time using UV light. At the end of the experiment, the beaker was removed from the photocatalytic reactor. Some portion of the decomposed effluent was then centrifuged with a high-speed centrifuge machine for removing suspended catalyst particles. A 5 ml centrifuged effluent was carefully drawn with a syringe and the absorbance of the decomposed effluent was measured in a UV spectrophotometer. The percentage of decomposition or decolorization efficiency was calculated using the following equation:

$$\text{i.e., \% of decomposition} = \frac{C_0 - C}{C_0} \times 100$$

Where, C_0 = Concentration of Initial effluent
C = Concentration of effluent after decomposition.

Similar experiments were performed varying initial dye concentration, catalyst type, catalyst concentration, oxidizing agent, pH value, reaction time, on the

percentage of decomposition to find the optimum conditions. The results were compared among the degradation efficiencies of catalytic, photolytic, and photocatalytic processes. The decomposition of the effluents was evaluated in terms of COD and TOC before and after photocatalytic treatment. These were analysed according to the standard procedures stated in the American Public Health Association (APHA, 2017).

Results and Discussion

Photocatalytic decomposition of the effluent

The degradation efficiency of three photocatalysts namely, TiO_2 , ZnO , and Fe_2O_3 was investigated for the treatment of the collected textile effluent under UV radiation. The effects of various process parameters, like initial effluent concentration, irradiation time, catalyst type, catalyst concentration, pH, and dose of oxidizing agent on the photocatalytic degradation efficiency were considered. The concentration of the effluents was estimated using the absorbance recorded on a UV-spectrophotometer (UV mini-1240, SHIMADZU).

Effect of catalyst

The photocatalytic degradation of the effluent with different catalysts like TiO_2 , ZnO , Fe_2O_3 , and their combinations under UV light irradiation for 3 hrs was studied. The maximum 58.9% degradation of the effluent took place in the case of the ZnO photocatalyst (Fig. 1). The next better photocatalytic degradation efficiency was shown by the mixed catalyst $\text{ZnO}+\text{Fe}_2\text{O}_3$ (1:1), where 56.1% degradation of the effluent was achieved. In most cases, the degradation efficiency of single catalysts was higher than that of mixed catalysts. When TiO_2 , ZnO , and Fe_2O_3 were used for 3 hrs under the same conditions 54.4%, 58.9%, and 49.2% of degradation occurred, respectively. The photocatalytic degradation efficiency of these catalysts after 3 hrs of irradiation was of the following trends: $\text{ZnO} > (\text{ZnO}+\text{Fe}_2\text{O}_3) > \text{TiO}_2 > (\text{TiO}_2+\text{ZnO}) > (\text{TiO}_2+\text{ZnO}+\text{Fe}_2\text{O}_3) > \text{Fe}_2\text{O}_3 > (\text{TiO}_2+\text{Fe}_2\text{O}_3) > \text{No catalyst}$. A study on the photocatalytic decolorization of textile industrial wastewater by TiO_2 (rutile), TiO_2 (anatase), and zinc oxide showed efficiencies in the following order: $\text{ZnO} > \text{TiO}_2$ (anatase) $> \text{TiO}_2$ (rutile) (Hussein & Abass, 2010). Mohabansi et al. (2011) also reported that ZnO was a better alternative photocatalyst compared to TiO_2 for the degradation of MB. The mixture of Fe_2O_3 and TiO_2 was reported to be less active than the original TiO_2 itself for the degradation of MB and other dyes (Crittenden et al., 1997), which supports the present findings. The study observed that the efficiency of photocatalytic degradation of catalysts varies among different effluents, and it depends on the nature of both effluents and catalysts. The effluent is almost resistant to self-photolysis as shown in Figure 1 and the results showed that without any catalyst the photolytic degradation was only 9.6 %. It can be said that both UV light and catalyst were needed for effective degradation. It can be assessed that ZnO was a more efficient catalyst than the others for the photocatalytic degradation of this effluent (Fig. 1).

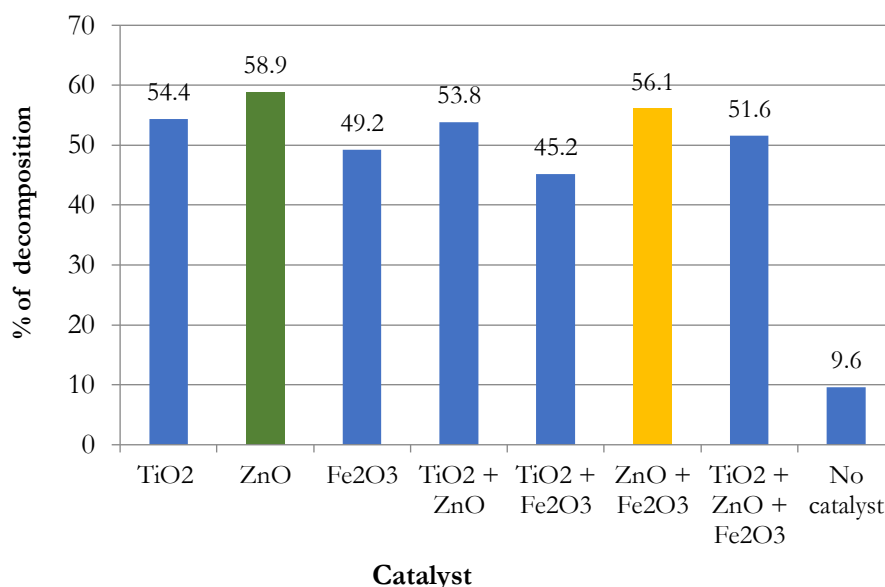


Figure 1 Effect of catalyst on % of decomposition (Catalyst conc.: 200 ppm, pH: 6.7, Reaction time: 3 hrs, H₂O₂: 300 ppm)

Effect of catalyst concentration

The effect of the photocatalyst amounts, i.e., 100, 200, 300, and 400 ppm on the decomposition of the effluent for different catalysts at 3 hrs and pH 10 was investigated. The results showed that the degradation efficiency increased to reach a maximum value of about 76.1% with a catalyst dose of 300 ppm in the case of ZnO (Fig. 2). The reason was that the number of active sites for photocatalytic reaction increased due to an

increase in catalyst concentration, which led to higher production of OH• radicals up to the catalyst dose of 300 ppm. Further increase in the concentration of ZnO to 400 ppm resulted in a decrease in degradation percentage. The photocatalyst degradation efficiency was highest at 100 ppm and decreased when the catalyst concentration was increased from 100 ppm to 400 ppm in the case of TiO₂.

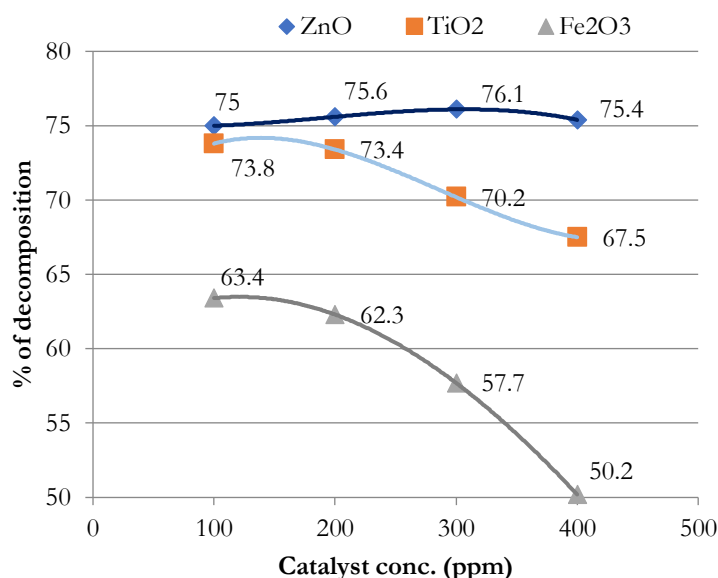


Figure 2 Effect of catalyst concentration on % of decomposition (pH: 10, Reaction time: 3 hrs, H₂O₂: 300 ppm)

This was probably because further increases in catalyst dose increased turbidity and reduced the amount of light penetration in the effluent solution (Nomikos et al., 2014; Martínez et al., 2011). Another reason behind this phenomenon is the catalyst-powder agglomeration and the subsequent decrease in the active surface sites (Tayeb & Hussein, 2015). The results are in good agreement

with those reported in the literature (Mills et al., 1993; Chen & Mao, 2007). In all experiments, ZnO showed better degradation efficiency than TiO₂ and Fe₂O₃. Although a catalyst dose of 300 ppm shows the highest degradation (76.1%) in the case of ZnO, the dose of 100 ppm shows a degradation efficiency of 75%, which is not much lower than the highest value. Hence for

commercial purposes, 100 ppm concentration of ZnO catalyst should be the optimum choice.

Effect of pH

It is extremely difficult to interpret the effects of pH on the efficiency of the photodegradation process. This is because dye degradation can be caused by three different reaction mechanisms: hydroxyl radical attack, direct oxidation by the positive hole, and direct reduction by the electron in the conducting band. The contribution of each depends on the substrate nature and pH (Tang et al., 1997). Photocatalytic degradation experiments on the effluent by catalyst ZnO were performed at different pH values of 4 to 10. The results are shown in Figure 3. The results revealed that the photo degradation efficiency decreases with the increase in pH from 4 to 8. At low pH value (pH = 4) the photocatalytic degradation efficiency reached to 71%. When the pH value of effluent was increased from 4 to 8, the photocatalytic degradation efficiency decreased to 60.1% at pH 8. This is because the effluent might be negatively charged in an acidic medium, whereas ZnO is positively charged below pH 8, which is reported as pH of point of zero charges (pzc) for ZnO (Daneshvar et al., 2007). So, the increasing pH tends to change the charge on ZnO from positive to negative by adsorbing HO^- ions, which favours the

formation of $\text{HO}\cdot$ (Wang et al., 2007), and consequently, the photocatalytic activity decreased due to the increase in electrostatic repulsion between ZnO and anionic effluent. Besides, the electron/hole (e^-/h^+) pairs recombination rate might be increased by an increase in pH and thus, photocatalytic activity decreased (El-Bahy et al., 2009). Further, the photocatalytic degradation efficiency achieved was 75.6% at pH 10 which was the highest pH range. The reason may be a larger amount of OH^- available to react with the h^+ on the ZnO surface resulting in a larger production of $\text{HO}\cdot$ which is the main species for degradation. The pH is a vital parameter in photocatalytic degradation as it determines the surface charge properties of the catalysts and dye molecules, aggregates size, adsorption on the catalyst surface, and the concentration of hydroxyl radicals (Sakthivel et al., 2003; Aguedach et al., 2005).

So, the optimal pH value (10) for the photocatalytic degradation of the effluent was selected. Alkaykh and Ali-Shattle (2020) reported a similar observation that illustrated the photocatalytic degradation of methylene blue (MB) in an aqueous solution by MnTiO_3 nanoparticles under sunlight irradiation favoured in an alkaline medium.

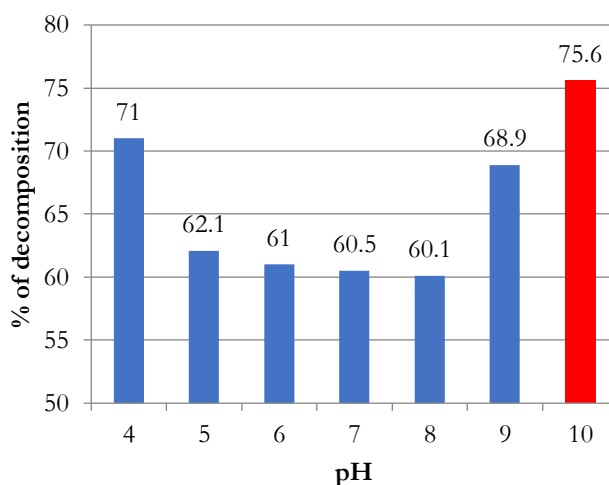


Figure 3 Effect of pH on % of decomposition (Catalyst: ZnO, Catalyst conc.: 200 ppm, Reaction time: 3 hrs, H_2O_2 : 300 ppm)

Effect of irradiation time

The effect of irradiation time on the photocatalytic decomposition efficiency of different catalysts like TiO_2 , ZnO, and Fe_2O_3 , and their combinations for the effluent were investigated for different periods up to 7 hrs. The results showed that the degradation increased from 25.2% at 1 hour to 79% at 7 hrs using ZnO as photocatalyst (Fig. 4a). It was observed that during the first few hrs of reaction, the degradation rate was high,

reaching 75.3 % for ZnO and 66.7% for TiO_2 after 5 hrs. Then, the degradation rate gradually decreased, reaching 79% for ZnO and 70.1% for TiO_2 after 7 hrs. This occurred due to the number of active sites on the catalyst surface remaining high in the beginning. As a result, a greater degradation rate was observed. The degradation rate was gradually reduced because of catalyst consumption, i.e., reducing the active sites (Salama et al., 2018).

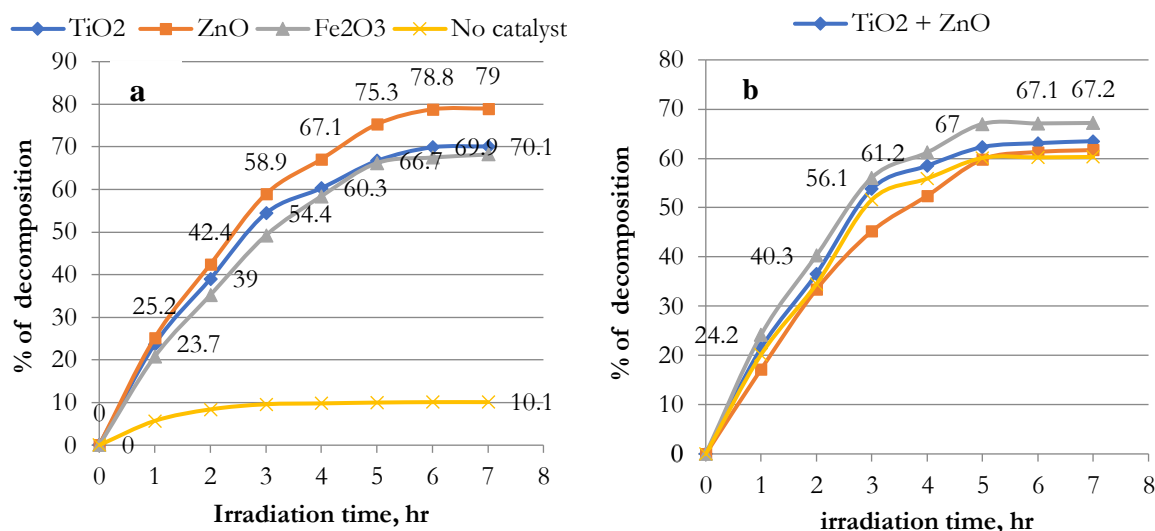


Figure 4 Effect of irradiation time on % of color decomposition by a) single catalysts and b) mixed catalyst (Catalyst conc.: 200 ppm, pH: 6.7, H₂O₂: 300 ppm)

A study on the photocatalytic decomposition of model textile wastewaters containing azo dyes by TiO₂ showed that C.I. Reactive Black 5 was degraded from 75% at 30 minutes to 93% at 120 minutes with 1 g/L of TiO₂ (Saggiaro et al., 2011). The percentage of decomposition increases rapidly in the first few hours of irradiation as the excitation of the electrons from the valence to the conduction bands. The photocatalysts generate lots of electron/hole (e⁻/h⁺) pairs that migrate to the surface and produce free radical oxidizers. Thereafter, there is a plateau that may result from the consumption of the catalyst (Alshabanat & AL-Anazy, 2018). Similar results were observed by several other researchers (Ghasemi et al., 2016; Che Ramli et al., 2014). Beyond 5 hrs, the degradation didn't increase significantly. There were no better results observed by the mixed catalyst for 7 hrs of irradiation time (Fig. 4b). It is noticeable that for a 3 hrs reaction 58.9% decomposition was achieved and further reactions up to 7 hrs gave more decomposition. But for any industrial operation time is a factor and continuing any process over a longer period is cost-effective and less desirable. Therefore, it is wise to improve degradation efficiency by changing other parameters. Hence, the next experiments were carried out for 3 hrs of irradiation.

Effect of oxidizing agent (H₂O₂) dose

The effect of oxidizing agent dose on the photocatalytic degradation of the effluent using the catalyst ZnO at pH 10 for 3 hrs was studied. Different photocatalytic degradation experiments were carried out by varying H₂O₂ doses viz., 200, 300, 400, 500, 600, and 700 ppm. The results illustrated that the percentage of photocatalytic decomposition increased with increasing concentration of H₂O₂ (Fig. 5). A higher concentration of H₂O₂ liberated more hydroxyl free radicals, which caused the dye decomposition. Oxidizing agents greatly enhance the photocatalytic degradation rates (Guettai & Amar, 2005; Madhu et al., 2007). The degradation increased from 68.4% at 200 ppm of H₂O₂ to 81.6% at

500 ppm of H₂O₂. Further increase in H₂O₂ dose (from 500 ppm to 700 ppm) had no significant effect on the degradation percentage. At a higher concentration of H₂O₂ reaction, the solution becomes acidic resulting in reduced decomposition rates. However, an increase in the H₂O₂ concentration beyond certain limits (critical concentration) does not increase the reaction rates as it tends to act as a hydroxyl radical scavenger instead of a free radical generator (Guettai & Amar, 2005; Madhu et al., 2007). Although in the H₂O₂ dose of 700 ppm, the highest degradation (82.2%) was observed, the dose of 500 ppm showed a degradation efficiency of 81.6%, which was not lower than the highest value. Hence, 500 ppm was considered as the optimum value of H₂O₂ loading for the photocatalytic degradation of this effluent.

Comparison among decomposition processes

Comparisons among various decomposition processes viz., catalytic, photolytic, and photocatalytic were observed to assess the efficiency of each degradation process. Each process was carried out with or without H₂O₂ as the oxidizing agent. The photocatalyst, UV irradiation, and oxidizing agent are the major key players in the total decomposition process of effluent.

The results presented in Figure 6 showed the degradation efficiencies of these processes after 3 hrs of irradiation, and these followed the trends: photocatalytic (with H₂O₂) > photolytic (with H₂O₂) > photocatalytic (without H₂O₂) > catalytic (with H₂O₂) > catalytic (without H₂O₂) > with only H₂O₂ > photolytic (without H₂O₂). It is noticeable that the role of the oxidizing agent is very important in these decomposition processes as all three processes without H₂O₂ showed poor performance. H₂O₂ increases the rate of hydroxyl radical formation, which is the main factor of dye decomposition (Guettai & Amar, 2005; Madhu et al., 2007). Again, the single key players, i.e., photocatalyst,

UV irradiation, and H_2O_2 achieved 10.9%, 9.61%, and 10.26% of decomposition, respectively, which proves that the contribution of each factor is almost equal in the whole degradation process. In the presence of ZnO without irradiation, slight decomposition was observed due to the adsorption of the dye on the surface of the catalyst. The study observed that these factors all

together created a synergistic effect in the degradation process and thus the photocatalytic process with an oxidizing agent (H_2O_2) created the best decomposition result of 54.36%. Besides, the photolytic process with H_2O_2 also gave the second-best decomposition result of 48.6%.

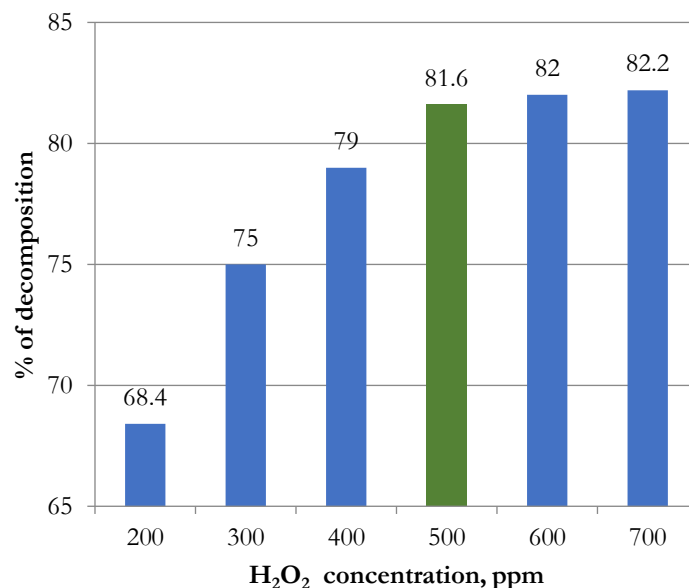


Figure 5 Effect of H_2O_2 dose on percentage (%) of decomposition (Catalyst: ZnO, Catalyst conc.: 100 ppm, pH: 10, Reaction time: 3 hrs)

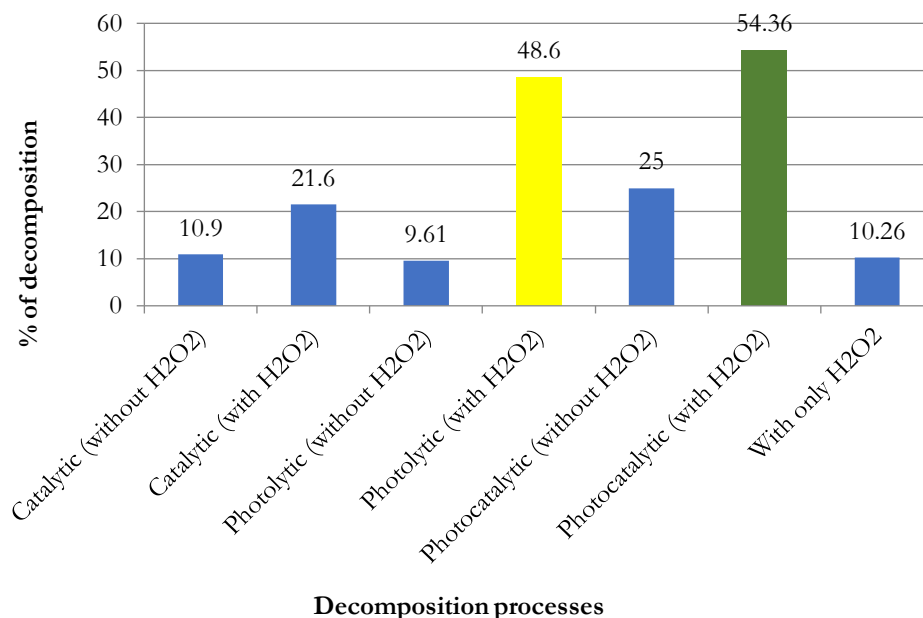


Figure 6 Comparison among various decomposition processes (Catalyst: ZnO, Catalyst conc.: 200 ppm, pH: 6.7, Reaction time: 3 hrs, H_2O_2 :300 ppm)

Mineralization of the effluent

The extent of mineralization of the effluent by photocatalytic treatment was studied by measuring the COD and TOC values before and after the treatment. The results are shown in Table 1. The results showed

that excellent mineralization of the effluent was observed as the TOC reduced was about 97.7%. It also showed that the TOC value decreased from 833 to 17 mg/L after 3 hrs. of photocatalytic treatment.

Parameters	Before treatment (mg/L)	After treatment (mg/L)	% of reduction
TOC	833	17	98
COD	2550	1440	43.53

(Catalyst = ZnO, Catalyst conc. = 100 ppm, pH= 10, Reaction time = 3 hr, H₂O₂ = 500 ppm)

The results of two individual studies showed that about 89% and 80-82% of TOC reduction were achieved by Bulc and Ojstršek (2008) and Ghaly et al. (2014), respectively. The results obtained in these photocatalytic reduction studies were lower than the present study. The results showed that the COD of the effluent decreased from 2550 to 1440 mg/L under the same conditions indicating a 43.53% COD reduction. The study observed that the COD reduction was 43.53% which was lower than the concentration reduction, which was 81.6% of the effluent under the same conditions. This indicated that the chromophore destruction was resulting in the formation of smaller uncoloured degraded products. Kulkarni and Thakur (2014) conducted a study on photocatalytic degradation of textile industrial effluent by ZnO and the results showed 37.5% COD reduction using 400 ppm catalyst for 5 hrs. The study results supported by another research result where a 29.2 %

reduction in COD was achieved using 500 ppm ZnO for 4 hrs of UV irradiation (Mondal & Bhagchandani, 2016).

Photodegradation kinetics

Chemical kinetics is concerned with understanding the rates of chemical reactions. Kinetic studies are of fundamental importance in any investigation of the reaction mechanism. The photocatalytic degradation of the textile effluent using different catalysts, i.e., TiO₂, ZnO, and Fe₂O₃ and without catalyst are shown in Figure 7. The change in concentration of the effluent (C/C₀) is plotted as a function of irradiation time (C₀: the initial concentration of the bulk solution, C: concentration at time t). The study observed that a photocatalyst and light source were necessary for an enhanced degradation reaction. About 70-80% of the effluent degraded after 7 hrs of irradiation. In contrast, a negligible amount of degradation of the effluents was observed in the absence of photocatalysts.

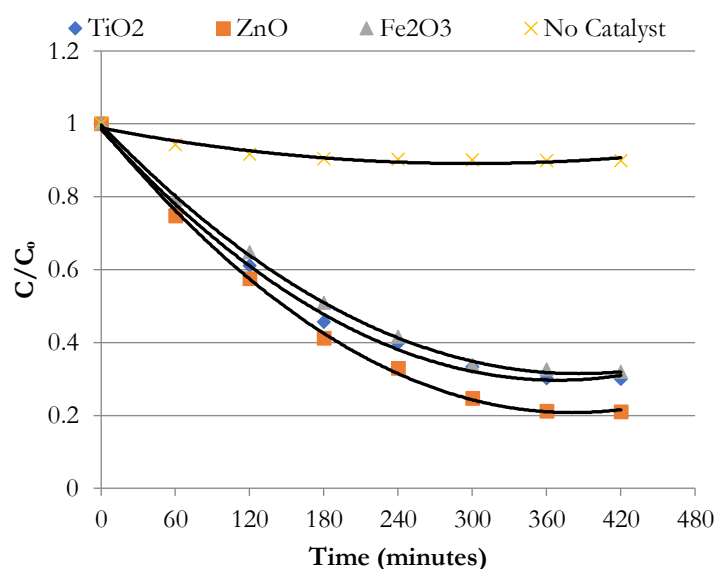


Figure 7 Photocatalytic degradation of the effluent (Catalyst conc.: 200 ppm, pH: 6.7, H₂O₂:300 ppm)

The relation between $\ln C_0/C$ and time for the photocatalytic reactions using catalysts, i.e., TiO₂, ZnO, and Fe₂O₃ is shown in Figure 8, which supports the degradation of the effluent followed by approximately pseudo-first-order kinetics. Neppolian et al. (2001) reported that the disappearance of a dye RY 17 in the solution followed approximately pseudo-first-order kinetics. Another research on the photocatalytic degradation pathway of MB in water also observed similar results (Houas et al., 2001; Mostafa et al., 2011).

The linear regression coefficients on the fitted lines were (R²) 0.9983, 0.9877, and 0.9993 for ZnO, TiO₂, and Fe₂O₃, respectively. The rate constants of the photodegradation reactions by ZnO, TiO₂, and Fe₂O₃ were calculated to be 4.74×10⁻³, 3.88×10⁻³, and 3.63×10⁻³ min⁻¹, respectively. Abo-Farha (2010) described that the photocatalytic degradation rate depends on dye structure, dye concentration, catalyst concentration, and pH of the medium. All three catalysts showed good enough capability for degrading the effluents.

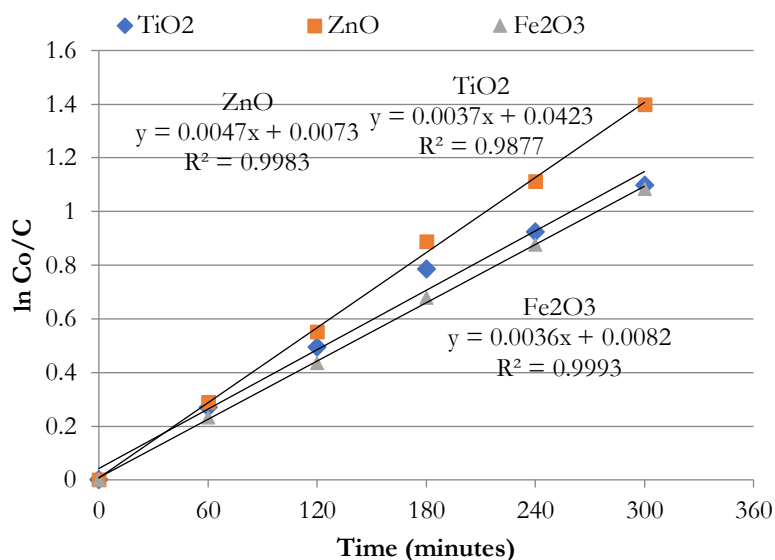


Figure 8 Kinetics of photocatalytic degradation

Conclusions

This study conducted photocatalytic decomposition of textile dyeing effluents under UV irradiation in the presence of catalysts, TiO₂, ZnO, and Fe₂O₃ with an oxidizing agent H₂O₂. The degradation efficiency was evaluated using the process parameters like catalyst concentration, dye concentration, irradiation time, oxidizing agent dose, and pH. The key factors, i.e., photocatalyst, UV irradiation, and oxidizing agent H₂O₂ degraded the textile effluents individually by about 10.9%, 9.61%, and 10.26%, respectively, indicating that the factors have almost the same contribution to the degradation processes. The study results showed that the degradation efficiency of a single catalyst was higher than that of the mixed catalysts in most cases. It also showed that the photocatalytic degradation was the maximum in an alkaline medium, and the oxidizing agents H₂O₂ enhanced the degradation significantly. The results of degradation processes illustrated that all three processes, i.e., photolytic, catalytic, and irradiation showed poor performance without H₂O₂. The study observed that the combinations of these factors created a synergistic effect in the degradation process. The maximum 81.6 % decomposition was achieved using ZnO catalyst at the optimized conditions. The TOC analysis and COD reduction of the effluent showed about 97.9% and 43.53%, respectively, following the optimizing conditions of the color removal percentage. The degradation of the effluent followed the pseudo-first-order kinetics indicating the potentiality of the catalysts. Finally, the study observed that ZnO could be a potential photocatalyst for treating textile dyeing effluent, and thus, it helps to promote sustainable industrial effluent management. Hence, further research in this area is needed for the application to an industrial scale.

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Conflicts of Interest: The authors declare no conflicts of interest.

Data Availability Statement: The data that support the finding of this study are available from the corresponding author, upon reasonable request.

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