Sustinere
Journal of Environment and Sustainability
Volume 8 Number 2 (2024) 230-241

Print ISSN: 2549-1245 Online ISSN: 2549-1253
Website: https://sustinerejes.com E-mail: sustinere.jes@uinsaid.ac.id

RESEARCH PAPER

A comparative study of ferrous and persulfate catalysts for the H_2O_2/UV oxidation of batik wastewater

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Article history:
Received 7 July 2024 | Accepted 26 July 2024 | Available online 31 August 2024

Abstract. The increasing number of batik industries in Indonesia may lead to water pollution due to wastewater containing high levels of organic pollutants. This study evaluated advanced oxidation processes (AOPs) utilising H_2O_2/UV to decolourise and remove organic contaminants (measured as chemical oxygen demand, COD) from batik wastewater. The study aims to compare the effectiveness of adding ferrous and persulfate as catalysts as catalyst in the H_2O_2/UV process, specifically evaluating the H_2O_2/Fe^{2+}/UV and $H_2O_2/S_2O_8^{2-}$/UV processes. The results indicated that all treatment methodseffectively decolourised and degradedCOD in the batik wastewater. COD and colour removal achieved up to 96.51% and 78.70% for H_2O_2/UV, 97.20% and 83.53% for H_2O_2/Fe^{2+}/UV, and 97.20% and 83.53% for $H_2O_2/ S_2O_8^{2-}$/UV, processes, respectively. Additionally, the use of persulfate as a catalyst accelerated the oxidation processes, reaching completion in 45 minutes compared to 60 minutes with the other catalyst.

Keywords: Advanced oxidation processes; Batik wastewater; Fenton; Persulfate

1. Introduction

Textile industries, including the batik industry in Indonesia, have experienced rapid development in recent years. Significant growth in the batik industry is particularly evident in regions such as Java, including Jogjakarta, Pekalongan, Sidoarjo, and several other areas. Jetis Village in Sidoarjo, for example, continues to develop its batik industry (Hidayahtullah et al., 2022). However, environmental issues arise due to the wastewater generated in the industry, which contains organic pollutants, such as dyes which are difficult to degrade. This can lead to increased water pollution if untreated effectively (Kordbacheh & Heidari, 2023; Rosa et al., 2020). The batik industry can produce wastewater amounting to 80% of the water used. Batik dyes not only impact color to the fabric but also contribute significantly to the pollutants in batik wastewater. Compounds in the dyes, especially diazonium salts, significantly increase in the total dissolved solids (TDS) and total suspended solids (TSS) levels in the batik wastewater (Fauzi & Rachmanto, 2018). This wastewater is primarily generated during the batik colouring process, which is often involve the use of naphthol dye ($C_{10}H_8O$) as shown in Figure 1. Naphthol dye is a type of azo dye. In this colouring step, salt is added to the dye to enhance the colour (Kencana &

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DOI: https://doi.org/10.22515/sustinere.jes.v8i2.421

Radityaningrum, 2022; Larasati et al., 2021). As a result, salts and other contaminants may be present in batik wastewater.

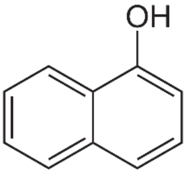

Figure 1. Naphthol Dye (So, 2023)

Advanced oxidation processes (AOPs) are treatment methods used for textile wastewater treatment. There are two main categories of AOPs: photochemical and non-photochemical methods. Photochemical methods use ultraviolet (UV) light and include techniques such as hydrogen peroxide (H_2O_2)/UV, Fenton/UV, and photocatalytic oxidation. Non-photochemical methods encompass ozonation with increased pH, ozone/H_2O_2, ozone/catalyst, and the Fenton system. Both types of AOP radical ions, such as hydroxyl radicals (OH•), superoxide radicals (O_2•), and sulphate radicals (SO_4•), which are responsible for degrading pollutants in wastewater into simpler compounds, like H_2O and CO_2.

UV light energy can be sourced from UV lamps or sunlight, and its effectiveness can be enhanced with added oxidants to increase the formation of hydroxyl radicals. The use of UV light in AOPs can degrade pollutants through direct photolysis and by generation of hydroxyl radicals via the decomposition of H_2O_2. Pollutant degradation occurs through two mechanisms: direct photolysis, where UV light breaks down pollutant molecules, and the reaction of H_2O_2 with UV light, which produces highly reactive hydroxyl radicals that degrade the pollutants (Wang et al., 2023).

One of the earliest and most widely used non-photochemical AOP techniques is Fenton process, which combines H_2O_2 with iron ions to produce hydroxyl radicals. This radicals react with the contaminants in wastewater to form environmentally safe products (Buthiyappan et al., 2015; Sharma et al., 2018; Shen et al., 2022). Another AOP method involves sulphate radical-based AOPs (SR-AOPs), where sulphate radicals are generated from thermal activation of persulfate, often through photolysis or sonolysis.

Research by Hayat et al. (2015) evaluated the effectiveness of the Fenton process at pH 3 for treating textile wastewater at four concentration levels. Using H_2O_2 to Fe ratio of 1:25 and a reaction time of 30 minutes, excellent treatment results were achieved, with color reduction reaching 92%, and COD and turbidity reduced by 89% and 94%, respectively. These results indicate that an acidic pH, appropriate reaction time, and optimal reagent ratio enhance treatment efficiency. Another study applied Fe/S_2O_8 with the optimum persulfate dose of 1 g/L and a S_2O_8: Fe ratio of 1:1 at pH 3, achieving a COD removal of 70.5% for 150 min (Asha et al., 2017). Additionally, Patil and Raut (2014) determined that the optimal pH of the Fenton process was 3, with COD removal of 89% and color removal of 96% achieved by varying H_2O_2 and $FeSO_4$ concentrations.

In this study, the Fenton and persulfate processes were carried out to degrade batik industry wastewater at pH 3 and 4. Additionally, the study compared the results with and without the use of UV light. the primary objective was to assess the effectiveness of ferrous and persulfate as catalysts for generating of oxidative radical species, such as hydroxyl radicals (OH•) and sulfate radicals (SO_4•), to degrade pollutants present in batik wastewater. The performance was evaluated based on the efficiency of decolourisation and COD removal under two different pH conditions, i.e., pH 3 and 4. This evaluation also included determining the optimum reaction time for the catalyst to accelerate the H_2O_2/UV oxidation process.

2. Material and method

2.1. Characteristics of batik wastewater

Batik wastewater was collected from the Batik industry in Sidoarjo. Sampling was performed at the source point of wastewater generated after the basic colouring process, prior to wax removal. The wastewater was characterised for several parameters, including pH, organic compound (measured as COD and biochemical oxygen demand (BOD), turbidity, and colour. The initial characteristics of the batik wastewater are summarised in Table 1.

Table 1. Batik wastewater characterisation

Parameter	Result	Unit
pH	7-10	-
COD	2000-4500	mg/L
BOD	582,63	mg/L
Turbidity	454	NTU
Colour	930,75	mg/L

2.2. Chemical reagents and UV reactor

The catalysts used in this study were 1 M iron (II) sulphate heptahydrate ($FeSO_4.7H_2O$) and 1 M sodium persulfate ($Na_2S_2O_8$) as the sources of ferrous ions and persulfate, respectively. Each catalyst was combined with 30% hydrogen peroxide (H_2O_2) to perform photochemical AOPs using a 6-W UVC lamp. As shown in Figure 2**Error! Reference source not found.**, batch experiments were conducted in an AOP reactor (60×45×50 cm^3) covered with aluminium foil. The experiments using 1 L of wastewater, which was stirred with a magnetic stirrer in a beaker glass. The operating pH was adjusted by adding 2 M sulphuric acid (H_2SO_4) and/or 2 M Sodium Hydroxide (NaOH).

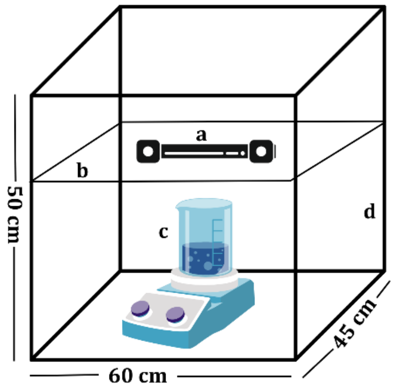

Figure 2. Batch experiment reactor equipped with a. UV lamp, b. UV lamp holder, c. beaker glass 1L with stirrer, d. reactor cover

2.3. Determination of H_2O_2

Before adding the catalysts, the optimum concentration of H_2O_2 for the experiment was determined by testing four different concentrations: 0.11 mol, 0.17 mol, 0.22 mol, and 0.28 mol of H_2O_2. Batik wastewater was placed into a 1000 mL beaker, and the H_2O_2/UV oxidation process was carried out in a batch stirring experiment at 300 rpm for 1 hour. H_2O_2 was added according to the specific concentration. After the reaction, sample were taken to analyse decolourisation and COD removal efficiency.

2.4. Fenton and Persulfate Oxidation

After performing H_2O_2/UV oxidation, the catalysts Fe^{2+} and $S_2O_8^2$ were compared using an oxidant-to-catalyst ratio (H_2O_2:Fe_{2+} and H_2O_2:$S_2O_8^{2-}$) of 1:0.06 at initial operating pH values of 3 and 4. The experiments were conducted for up to 120 minutes during the photochemical oxidation process at a stirring speed of 300 rpm. A 1000 mL sample of wastewater was placed into a beaker, followed by the addition of a specific amount of catalyst and the optimum concentration of H_2O_2 before adjusting the initial pH. Sampling was carried out every 15 minutes for each catalyst. Comparisons without UV light and with 1 UV light were carried out at the optimal pH after testing the reaction kinetics for the Fenton and persulfate processes. The UV light had an intensity of 226 $\mu W/cm^2$. The process was carried out using the same method for both the Fenton and persulfate processes using 1 L of batik wastewater.

2.5. Analytical measurement

Reaction kinetics tests were carried out on Fenton and persulfate processes using first- order and second-order reaction kinetics. The samples were then analysed for COD using the spectrophotometric method after closed reflux with a HACH test tube. The digested sample was read at 600 nm using a UV-vis spectrophotometer (721G Visible Spectrophotometer). Colour concentration was determined using standard Naphtol solution calibration and analysed by using a UV-Vis spectrophotometer at a wavelength of 600 nm. These analytical measurements were performed to determine the efficiency of COD and colour removal in batik wastewater after the treatment process. The calculation of COD and colour removal was done using Equation (1) and (2):

$$\text{Colour Removal (\%)} = \frac{C_0 - C_e}{C_0} \times 100 \qquad (1)$$

$$\text{COD Removal (\%)} = \frac{\text{COD}_0 - \text{COD}_e}{\text{COD}_0} \times 100 \qquad (2)$$

where C_0 is the initial colour (mg/L), C_e is the final colour concentration at the reaction time (mg/L), COD_0 is the initial COD (mg/L), and COD_e is the final COD at the reaction time (mg/L).

3. Result and discussion

3.1. Effect of H_2O_2 concentration

AOPs is a widely used methods that utilize a variety of oxidizing chemicals. AOPs operate at temperatures and pressures close to ambient conditions and produces strong oxidizing radical species, mainly hydroxyl radicals (OH•), for the complete decomposition of organic pollutants into non-toxic products such as CO_2, H_2O, and inorganic salts. Hydrogen peroxide (H_2O_2) is commonly used as an oxidizing agent due to its environmentally friendliness and relatively high pollutant degradation efficiency (Wang et al., 2023).

The treatment process using H_2O_2/UV was conducted by varying the concentration of H_2O_2 added: 0.11, 0.17, 0.22, and 0.28 mol. The determination of the concentration of H_2O_2 was based on stoichiometric calculations, as shown in reaction (3). If too little H_2O_2 is added, it will result in low removal efficiency. However, adding too much H_2O_2 can cause excess H_2O_2, which also affect removal efficiency. Furthermore, the presence of excess H_2O_2 can lead to the accumulation of hydroxyl radicals (OH•) in the aquatic environment (Ilhan et al., 2017).

$$\text{Organic} + H_2O_2 + Fe^{2+} \rightarrow \text{Partially oxidised species} \qquad (3)$$

$$\text{Partially oxidised species} + H_2O_2 + Fe_2+ \rightarrow CO_2 + H_2O + \text{inorganic salts} \qquad (4)$$

1 g of COD or 1 g of organic material is equivalent to 1 g O_2 (Lucas & Peres, 2009). Figure 3 shows the COD and colour removal results. The addition of H_2O_2 in combination with UV light produces hydroxyl radicals (OH•), which are important for the process. Another AOP method is sulphate radical-based AOPs (SR-AOPs). The sulphate radical often used in this method is generated from pessulus during this oxidation process s in this oxidation process (Tuncer & Sönmez, 2023). The

reaction occurring in this process is described in Equation (5). The wastewater treatment results using this process are presented in this formula:

$$H_2O_2 \xrightarrow{UV} 2OH\bullet \qquad (5)$$

$$H_2O_2 + OH\bullet \rightarrow HO_2\bullet + H_2O \qquad (6)$$

The treatment method can decompose dyes in wastewater, thereby reducing or removing them. The generated hydroxyl radicals react with the dyes in wastewater to degrade them, as shown in Equation (7).

$$OH\bullet + Dye \rightarrow \text{Degradation products} \qquad (7)$$

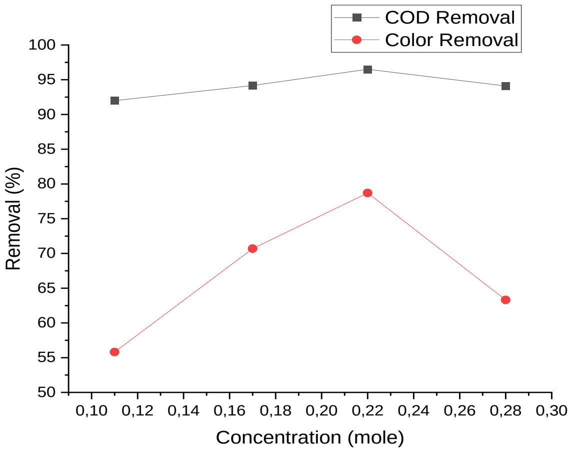

Figure 3. Effect of H_2O_2concentration on COD and colour removal in the H_2O_2/UV process

Figure 3 shows that COD and colour removal increased as the concentration of H_2O_2 added increased. The COD removal efficiency ranged from 91.99% to 96.51%, while the colour removal ranged from 55.82% to 78.7%. However, after the H_2O_2 concentration reached a level that corresponded to stoichiometry, the COD removal efficiency decreased to 94.10%, and the colour removal decreased to 63.32%. The concentration of hydrogen peroxide can affect removal efficiency, either reducing or increasing it. At higher concentrations of hydrogen peroxide, there can be a decrease in removal efficiency (Palani et al., 2016). The decrease is due to the presence of excess H_2O_2, which reacts with hydroxyl radicals to form hydroperoxyl radicals. This radical can reduce the removal efficiency of the cyclic voltammetry process because of its lower oxidising ability compared to hydroxyl radicals. The reaction that occurs, as shown in reaction (4) (Güneş et al., 2021).

3.2. COD and colour removal by H2O2/Fe2+/UV process

Catalysis is a chemical reaction method that reduces activation energy to accelerate reaction time with high efficiency. The catalyst does not undergo permanent changes during the reaction process, which reduces the transformation temperature, minimizes reagent waste, and increases reaction selectivity, thereby reducing side effects from the process (Ramadhanti, 2023; Singh & Tandon, 2014). The Fenton process uses iron ions as a catalyst to react with H_2O_2. The iron ions decompose H_2O_2 to produce hydroxyl radicals in a relatively short time (Qi et al., 2020). The Fenton method can be combined with UV radiation or light and H_2O_2. This reaction can be seen in reaction (8) to (12). The Fenton method reaction is conducted in an acidic environment.

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH- + OH\bullet \qquad (8)$$

$$Fe_{3+} + H_2O_2 \rightarrow Fe^{2+} + O_2H + H^+ \qquad (9)$$

$$Fe^{2+} + OH\bullet \rightarrow Fe^{3+} + OH^{-} \qquad (10)$$

$$Fe^{2+} + O_2H \rightarrow Fe^{3+} + HO_2^{-} \qquad (11)$$

$$Fe^{3+} + O_2H \rightarrow Fe^{2+} + O_2 + H^{+} \qquad (12)$$

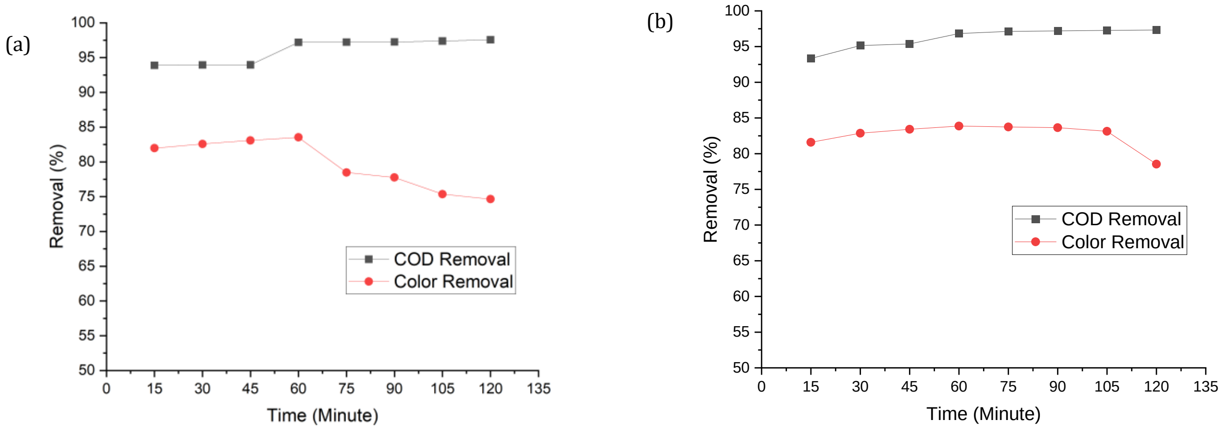

Figure 4. Removal of COD and colour during the H_2O_2/Fe^{2+}/UV process at (a) 3 and (b) 4

Figure 4 (a) shows an increase in COD and colour efficiency using the H_2O_2/Fe^{2+}/UV process at pH 3 up to 60 minutes, with efficiency ranging from 93.89% to 97.20% for COD and 81.98% to 83.53% for colour removal. After 60 minutes, the COD and colour removal efficiency decreased to 97.23% and 78.48%, respectively. Figure 4(b) shows that COD removal efficiency increased up to 45 minutes and then decreased at 60 minutes, ranging from 93.34% to 96.75% and decreasing to 96.83%. Meanwhile, colour removal increased up to 60 minutes and then decreased at 75th minutes, ranging from 81.59% to 83.87% and decreased to 83.75%. After this process, the colour of the sample turned yellow, which could be due to the addition of iron ions. Iron ions (Fe^{2+}) added during this advanced oxidation process react with some of the H_2O_2, producing hydroxyl radicals (OH•) that degrade pollutants. The remaining H_2O_2 can also oxidize these pollutants. Therefore, the addition of Fe^{2+} can increase the removal efficiency of pollutants from textile wastewater (Ilhan et al., 2017). The Fenton process exhibits high degradation efficiency and is relatively easy to operate. However, it can have some environmental impacts, such as the formation of iron sludge and operation in acidic environments (Wang et al., 2023). The advantages of the Fenton process include its ability to operate at ambient temperature and pressure, ease of application, quick reaction time between iron ions and H_2O_2, practicality and cost-effectiveness due to the cheap and easy handling, of reagents and high mineralization efficiency resulting in more environmentally friendly oxidation products (Bokare & Choi, 2014).

Acidic conditions during the Fenton process are important for effective pollutant removal because Fe(II) ions become unstable at pH 5. Proper pH adjustment is essential as it significantly impacts the efficiency of iron ion oxidation in the Fenton process. Colour removal in the Fenton process was achieved at 90 minutes with an efficiency of 95%. However, efficiency tends to decrease over time (Cetinkaya et al., 2018). The photo-Fenton process may exhibit reduce colour efficiency due to colour resurgence and residue accumulation. This reduction is attributed to the addition of iron ions, which act as catalyst to remove colour in a relatively short time. Although the reaction efficiency is initially adequate, it diminishes as the concentration of Fe(II) increases, and Fe(III) exhibits poorer properties in this regard. The decrease in efficiency in the Fenton reaction can be due to excessive amounts of H_2O_2, which can reduce treatment efficiency, as well as the interference of additives in wastewater that may complicate the treatment process (Atmaca, 2009; Eslami et al., 2013; Kang et al., 2000).

The oxidation of naphthol dyes begins hydrogen abstraction by free radicals, forming 1-naphthoxyl radicals. This radical then undergoes a chain reaction involving the formation of a carbon-oxygen double bonds, leading to the creation of 1,2-naphthoquinone and 1,4-naphthoquinone. This process disrupts the stable aromatic ring structure of naphthol. During the advanced oxidation stage, these quinone compounds are further degraded into carbon dioxide and water. The photolysis process generates hydroxyl radicals (OH•) and peroxydisulphate radicals ($SO_5^{-}\bullet$), which then react with water molecules to form hydrogen peroxide. Hydrogen peroxide acting as a strong oxidizing agent, accelerates the degradation of naphthol (So, 2023).

3.3. COD and colour removal by $H_2O_2/S_2O_8^{2-}$/UV process

In wastewater treatment, sodium and potassium persulfate are the main sources of persulfate (Nidheesh et al., 2022). The use of persulfate for oxidation of compounds requires activation to improve reaction kinetics and accelerate the process. Persulfat (PS) is commonly used as the sulphate radical in the method, and it is thermally generated via photolysis and sonolysis. Activation of persulfate can be achieved using UV light, which is one of the most effective (Kehinde & Abdul Aziz, 2015; Nidheesh et al., 2022). In this study, UV light was used to activate persulfate. The reactions in this process are shown in the reaction (13) to (16):

$$S_2O_8^{2-} + UV \rightarrow 2SO_4^{-}\bullet \qquad (13)$$

$$SO_4^{-} + H_2O_2 \rightarrow OH\bullet + HSO_5^{-} \qquad (14)$$

$$HSO_5^{-} + UV \rightarrow SO_4^{-}\bullet + OH\bullet \qquad (15)$$

$$SO_4^{-}\bullet + OH^{-} \rightarrow SO_4^{2-} + OH\bullet \qquad (16)$$

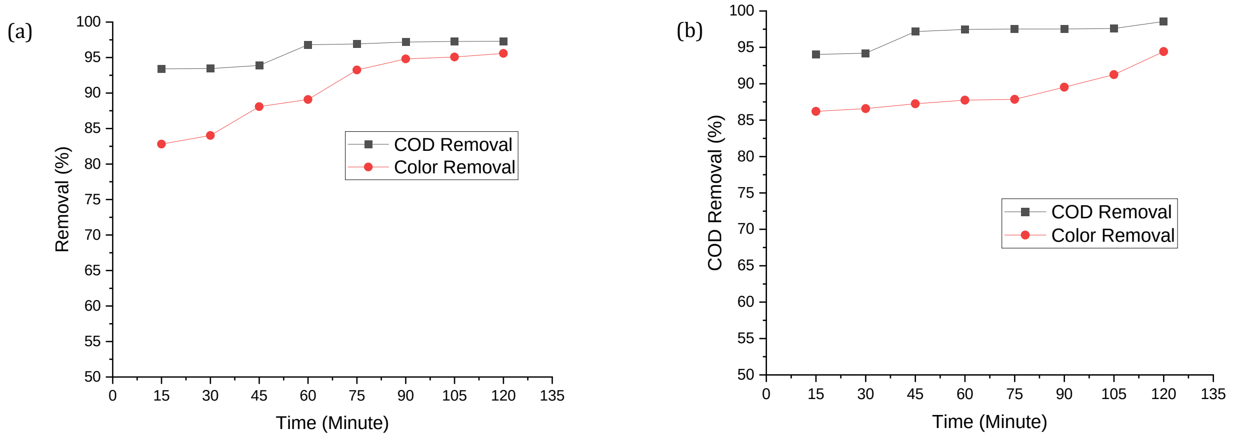

Figure 5. Removal of COD and colour during the $H_2O_2/S_2O_8^{2-}$/UV process at (a) pH 3 and (b) pH 4

In the research reported by Kehinde and Abdul Aziz (2015), textile wastewater treatment using persulfate was optimized at an acidic pH (pH = 3). Figure 5 (a) and Figure 5 (b) show that the COD and colour removal efficiencies using the $H_2O_2/S_2O_8^{2-}$/UV process increased with reaction time. The reactions occurring in the persulfate process, as shown in reaction (13) to (16), generate hydroxyl radicals that can reduce or remove organic pollutants, such as COD and colour from wastewater. The COD removal efficiency ranged from 93.41% to 97.30% for pH 3 and from 94.03% to 98.56% for pH 4. The colour removal efficiency ranged from 82.81% to 95.58% for pH

3 and from 86.20% to 94.42% for pH 4. These findings are consistent with the research conducted by Çifçi (2023), which demonstrated that UV/persulfate treatment resulted in COD and colour removal efficiency increasing with time, ranging from 50% to 90% and 40% to 85%, respectively. Another study also used the persulfate process for COD and colour removal, reporting efficiencies of 95% for COD and 72.1% for colour removal after 60 minutes (Kiani et al., 2020). As shown in Figure 6, the mechanism of naphthol degradation by hydroxyl radicals (OH•) involves the attack of hydroxyl radicals (OH•) on the naphthol molecule, followed by a hydrogen elimination reaction. The chemical reactions underlying the decolourisation process by OH- radicals are described in reaction (17) and (18) (Shiroudi et al., 2014).

$$C_{10}H_8O + OH\bullet \rightarrow C_{10}H_8O_2 \quad (17)$$

$$C_{10}H_8O_2 + O_2 \rightarrow \text{Produk degradasi akhir} \quad (18)$$

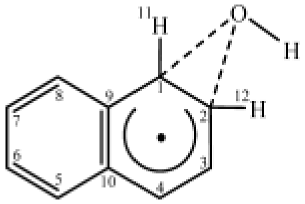

Figure 6. Naphthol Degradation by OH• (Shiroudi et al., 2014)

From the obtained data, reaction kinetics tests were also carried out for the Fenton and persulfate processes at pH 3 and 4. The tests utilized both first-order order and second-order reaction kinetics. The tests were carried out using Equations (19) and (20).

$$\text{First reaction order: } ln\frac{C_t}{C_0} = -kt \quad (19)$$

$$\text{Second reaction order: } \frac{1}{C_t} - \frac{1}{C_0} = kt \quad (20)$$

After plotting the graphs for first-order kinetics (ln C_t vs time) and second-order kinetics ($1/C_t$ vs time), the reaction rate constants and regression values were obtained, as shown in the Table 2.

Table 2. Reaction constants and regression value

Process Condition	Constants for first order (/minute)	Regression	Constants for second order (/M.minute)	Regression
pH 3, H_2O_2:Fe^{2+} = 1:0,06	0,0103	0,7879	6×10-5	0,8164
pH 4, H_2O_2:Fe^{2+} = 1:0,06	0,0086	0,8495	5×10-5	0,8854
pH 3, H_2O_2:$S_2O_8^{2-}$ = 1:0,06	0,0103	0,8308	6×10-5	0,8599
pH 4, H_2O_2:$S_2O_8^{2-}$ = 1:0,06	0,0117	0,8155	9×10-5	0,8035

From the regression values, it can be observed that the highest regression (close to 1) occurred in the second-order reaction kinetics. The finding is supported by research conducted by (El-Gawad et al., 2024), who also reported a regression value close to 1 for the second-order reaction. In the Fenton process, the highest reaction constant value was observed at pH 3 with an

H_2O_2:Fe^{2+} ratio of 1:0.06. Conversley, in the persulfate process, the highest reaction constant value was observed at pH 4 with and H_2O_2:$S_2O_8^{2-}$ ratio of 1:0.06.

The pH of the solution decreased after the reaction process in both the Fenton and persulfate processes. In the Fenton process, the initial pH of 3 decreased to 2.88. In the persulfate process, the initial pH of 4 decreased to 3.88. The decrease in pH can be attributed to the formation of H^+ ions, as shown in reactions (8) and (9). The formation of H^+ ions is due to the addition of Fe^{2+} ions, which can lower the pH of the solution (Micheletto et al., 2020). In the persulfate process, the formation of SO_4^{2-} during the reaction also affect the pH of the solution. The decrease in pH in the persulfate process tends to occur more gradually (Yang et al., 2013).

3.4. Effect of UV light

The use of UV light in the advanced oxidation processes can significantly impact the results of COD and colour degradation efficiency. The results for COD and colour removal in the Fenton process under the conditions of pH 3 and an H_2O_2:Fe^{2+} ratio of 1:0.06 are shown in the Figure 7.

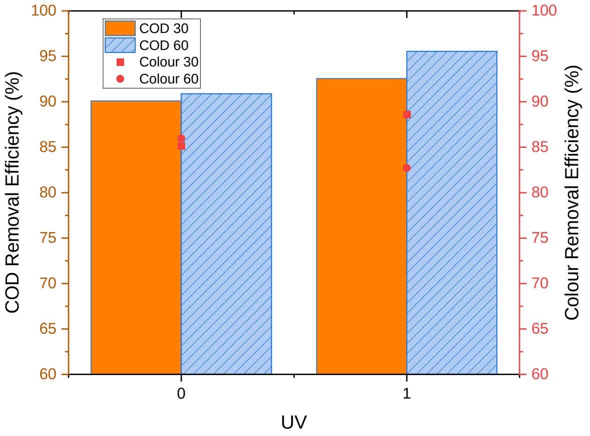

Figure 7. Effect of UV light in Fenton process

In the Fenton process, the removal efficiency of COD and colour increased both without UV light and with the use of UV light. With 1 UV light, the COD and colour removal efficiencies were 92.56% and 88.59%, respectively. The formation of hydroxyl radicals in the Fenton process increases with the intensity of UV light, resulting in improved COD and colour removal efficiencies in the wastewater. These radicals can convert Fe^{2+} ions to Fe^{3+} ions (Benassi, 2021). This finding is supported by research conducted by Kaya and Aşçı (2019) which demonstrated that increasing the UV power (6, 12, and 18 W) enhances COD and colour removal efficiency. In this study, the highest removal efficiency was observed at UV power of 18 W.

Similarly, in persulfate process, UV light activation affect the COD and colour removal efficiencies of wastewater. The results for COD and colour removal under reaction conditions of pH 4, H_2O_2:$S_2O_8^{2-}$ ratio of 1:0.06 are shown in the Figure 8.

In the persulfate process, the use of UV light significantly enhances COD and colour removal efficiency compared to conditions without UV, light. In this study, the COD and colour removal efficiencies with 1 UV light were 91.45% and 90.65%, respectively. UV light in the persulfate process reacts with $H_2O_2$and $S_2O_8^{2-}$ to produce hydroxyl and sulfate radicals. These radicals increase the COD and colour removal efficiency of the process. Persulfate accelerates dye reduction in wastewater, leading to improve removal efficiency (Ding et al., 2020; Kaya & Aşçı, 2019; Zawadzki & Deska, 2021). The results of this study are consistent with research by Al-Musawi et al. (2022), which demonstrated that using UV power levels of 8, 15, 24, and 36 W achieved the highest pollutant removal efficiency with 36 W UV power.

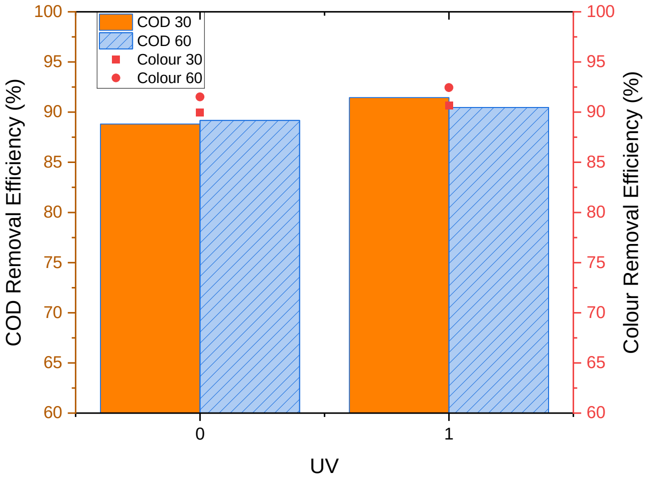

Figure 8. Effect of UV light in persulfate process

4. Conclusion

This study concluded that the use of H_2O_2/UV, $H_2O_2/Fe^{2+}/UV$, and $H_2O_2/S_2O_8^{2-}/UV$ processes effectively reduces the concentration of organic pollutants in wastewater by eliminating the colour-containing organic pollutants. The highest removal rates of COD and colour during the H_2O_2/UV process were 96.51% and 78.70%, respectively, with an H_2O_2 concentration of 0.22 mol. Higher concentration of H_2O_2 than 0.22 mol resulted in a decrease removal efficiency. Both catalysts showed a slight increase in decolourisation with similar COD removal efficiencies at higher reaction rates. The $H_2O_2/Fe^{2+}/UV$ process exhibited the highest COD and colour removal efficiencies of 97.20% and 83.53%, respectively, at pH 3 after 60 minutes. Prolonged $H_2O_2/Fe^{2+}/UV$ oxidation time tended to reduce the decolourisation, with only a slight increase in COD removal. On the other hand, the $H_2O_2/S_2O_8^{2-}/UV$ process achieved optimal COD and colour removal efficiencies of 97.17% and 87.25%, respectively, at pH 4 after 45 minutes. The use of UV light improves the COD and colour removal efficiencies for both the Fenton and persulfate processes, with optimal times of 60 and 45 minutes, respectively. Further extending $H_2O_2/S_2O_8^{2-}/UV$ oxidation time is likely to increase the decolourisation efficiency, although it consumes more UV energy.

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