Effect of ultraviolet and visible lights on degradation of congo red dye using Fe$^{2+}$/H$_2$O$_2$

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Abstract. Congo Red is one of the reactive dyes that often used in the textile industry. The presence of Congo red dyes in the environment can damage various living species because of high toxicity. One alternative method to degrade the Congo red is Fenton Reagent. Fenton reagent is defined as a mixture of H$_2$O$_2$ and Fe$^{2+}$. The Fenton reagent produces a hydroxyl radical (HO•), which degrades Congo red dyes under light irradiation; this reaction is called the Photo-Fenton reaction. The purpose of this research is to determine the effect of visible and ultraviolet irradiation on Congo Red degradation using the Fe$^{2+}$/H$_2$O$_2$. The results showed that the optimum condition of degradation achieved at 350 ppm, 400 ppm for H$_2$O$_2$ and FeSO$_4$.7H$_2$O concentration, respectively, and pH 3. The kinetics analysis showed that the Congo Red degradation followed the pseudo-first-order kinetics, and Congo Red degradation under UV light showed the highest rate constant.

1. Introduction

The textile industry in Indonesia will further increase people's need for clothing. The number of textile industries in Indonesia reaches 2,251 in 2011. The number of textile industries in Indonesia is not comparable to the number of proper liquid waste processing. Textile dye waste must be treated first before it discarded. Reactive dyes are dyes that widely used for color in the textile industry. Congo Red is one of the reactive dyes that is often used by the textile industry. The presence of red congo dyes in the environment can damage various living species because of the nature of red congo dyes which have a quite high toxicity. These dyes are very soluble in water and cannot be degraded biologically [1]. Synthetic dyes are one of the top pollutants because of their nature, which connects light and lead to pollution and affect environmental change[2]. Therefore, alternative methods have been developed to deal with dyes from batik wastewater.

One alternative method of processing waste pollution that is being developed to degrade various organic and industrial wastes is a photocatalytic method. The method plays an important role in reducing toxic organic wastes by utilizing UV light to oxidizing and reducing species on the surface of the catalyst[3]. Another method is advanced oxidation processes (AOPs), according to Malato et. Al.[4] AOPs have the advantage of being able to degrade hazardous compounds in the waste through an oxidative degradation process. Advanced Oxidation Processes (AOPs) are interesting techniques for process and drinking water production. These processes use hydroxyl radicals as (secondary) oxidants. These radicals are formed from a less reactive, primary oxidant (e.g., hydrogen peroxide or ozone) and have a very high standard reduction potential and able to oxidize a large number of organic compounds in water, yielding very low concentrations of these compounds[4]. One of the methods is the advanced oxidation processes (AOPs) using the Fenton reagent. Oxidation with Fenton's reagent is an oxidation method that uses hydrogen peroxide. This method has been applied for the processing of various types
of industrial wastes containing toxic organic compounds such as phenol, formaldehyde, and complex waste from pesticides, paints, and plastic additives and Congo Red [5]. AOPs involves a combination of photochemical processes with the help of light. Lights can be used in the form of visible or ultraviolet light, the energy of the light produced will further accelerate the process of Fe$^{3+}$ to Fe$^{2+}$, while producing OH radicals and acidifying the reaction media, along with their reactions [6]:

$$\text{Fe}^{3+} + \text{H}_2\text{O}_2 + \text{hv} \rightarrow \text{Fe}^{2+} + \text{H}^+ + \cdot\text{OH}$$

According to Almicar et al. [7], because of their high efficiency, the photo-Fenton reaction can be considered as one of the most convenient, environmentally friendly, and efficient methods for oxidizing AOPs. The purpose of this study is to determine which light source is better in affecting the photo-Fenton reaction. Therefore, Fenton's reagent is used with the help of ultraviolet and visible light to degrade Congo Red dyes.

![Structure of Congo red](image)

**Figure 1.** Structure of Congo red.

### 2. Materials and methods

#### 2.1 Chemicals

The chemicals used in this research are Congo Red dyes, distilled water, H$_2$O$_2$, FeSO$_4$.7H$_2$O, H$_2$SO$_4$, NaOH.

#### 2.2 Materials

The materials used in this research are beaker glass 50 mL, beaker glass 500 mL, beaker glass 1000 mL, test tube, stirring rod, volumetric Pipette 1 mL, volumetric Pipette 5 mL, volumetric pipette 10 mL, volumetric flask 50 mL, volumetric flask 100 mL, volumetric flask 500 ml, filler, magnetic stirrer, UV lamp, tungsten lamp, pH indicator and UV-Visible spectrophotometer Shimadzu 1800.

#### 2.3 Methods

**2.3.1. Effect of UV and Visible Lights on initial H$_2$O$_2$ Concentration.** A total of 100 mL of Congo red dye added with various concentration of H$_2$O$_2$ which are 100, 150, 200, 250, 300, 350, and 400 ppm and added by 300 ppm of FeSO$_4$.7H$_2$O. After that, the sample is stirred for 270 minutes under UV light, visible light and dark condition. Lastly, the samples analyzed every 30 minutes to determine the Congo Red degradation and obtain optimum H$_2$O$_2$ concentration.

**2.3.2 Effect of UV and Visible Lights on Initial FeSO$_4$.7H$_2$O Concentration.** A total of 100 mL of Congo Red added with various concentration of FeSO$_4$.7H$_2$O which are 100, 200, 300, 400, 500, 600, and 700 ppm and added with H$_2$O$_2$ 100 ppm. After that, the sample stirred for 270 minutes under UV light, visible light, visible light, and dark condition. Lastly, the samples analyzed every 30 minutes to determine degradation of Congo red and obtain the optimum FeSO$_4$.7H$_2$O concentration.

**2.3.3 Effect of UV and Visible Lights Irradiation Time on H$_2$O$_2$ and FeSO$_4$.7H$_2$O Optimum Concentration.** A total of 100 mL of Congo Red dye added with the optimum concentration of H$_2$O$_2$ and FeSO$_4$.7H$_2$O. Samples are stirred for 330 minutes under UV light, visible light, and dark conditions. Lastly, the samples analyzed every 30 minutes to determine the Congo red degradation and find out the effect of optimum concentration and time irradiation.
2.3.4 **Effect of UV and visible light on pH variation in Congo Red Degradation.** A total of 500 mL of Congo Red dye added with optimum concentration of H$_2$O$_2$ and FeSO$_4$.7H$_2$O. Then, added with H$_2$SO$_4$ or NaOH to obtain pH variations of 2, 3, 4, 5 and 6. Furthermore, Samples are stirred for 330 minutes under UV light, visible light, and dark condition. Lastly, The samples analyzed every 30 minutes to determine the Congo red degradation and obtain the optimum pH.

2.3.5 **Statistical Analysis of Congo Red Degradation on Optimum Condition.** Congo Red degradation done three times under optimum concentration of H$_2$O$_2$ and FeSO$_4$ optimum pH and irradiation time 330 minutes. After that, the results tested with ANOVA statistical method to determine significance different of degradation results under UV light, Visible light and dark condition.

2.3.6 **Kinetic analysis of Congo Red Degradation on Optimum Condition.** The kinetics of Congo Red degradation under optimum condition are analyzed with graphical method to determine the rate constant and kinetics order of degradation under UV light, Visible light and dark condition.

3. **Results and discussions**

Wastewater treatment using the AOPs method is processed by oxidation of organic compounds. Oxidation of azo compounds can be done with Fenton reagent. Oxidation within the Fenton reagent is caused by the hydroxyl radical (OH) from H$_2$O$_2$ as a source of hydroxyl radicals and Fe$^{2+}$ in FeSO$_4$.7H$_2$O as a catalyst. Protons that are close to double bonds are more easily attacked by hydroxyl radicals (•OH) and break the double bonds[8]. The analysis of Congo Red degradation is using UV-Vis Spectrophotometer with maximum wavelengths at 498 nm. Degradation of the Congo Red dye is based on breaking conjugated double bonds in the Congo Red azo dye compound. The main characteristic of azo dyes is the presence of nitrogen groups that bind together with nitrogen, known as azo chains (- N = N -), in one type of dyes can consist of one or more of these chains [9]. The chain is found in the Congo Red compound linking the benzyl group with the naphthylamine sulfonate group. This conjugated double bond system will be attacked by hydroxyl radicals (•OH) breaking the azo chain causing Congo Red compounds to become simpler molecules such as H$_2$O and CO$_2$. Light radiation affects the formation of hydroxyl radicals (•OH) in H$_2$O$_2$, which used as an oxidation agent and accelerating the production of Fe$^{2+}$. Fe$^{2+}$ which is from FeSO$_4$.7H$_2$O serves as a catalyst that accelerates H$_2$O$_2$ breakdown into hydroxyl radicals (•OH). Light radiation also affects the formation of hydroxyl radicals (•OH) through the photolysis process [10]. The light source is visible light coming from tungsten lamps and UV lights with the same irradiation time. Different types of light have different wavelengths, which affect the formation of hydroxyl radicals (•OH) and lead to Congo Red degradation.

3.1 **Effect of UV and Visible Lights on initial H$_2$O$_2$ Concentration**

H$_2$O$_2$ (hydrogen peroxide) in the Fenton reagent serves as the source of hydroxyl radicals (•OH). H$_2$O$_2$ optimum concentration for Congo red dyes degradation determined by variation of initial H$_2$O$_2$ concentration start from 100 ppm, 150 ppm, 200 ppm, 250 ppm, 300 ppm, 350 ppm, and added with FeSO$_4$.7H$_2$O 400 ppm. Concentration of FeSO$_4$.7H$_2$O less than 300 ppm has minimum source of Fe$^{2+}$ to break H$_2$O$_2$ molecules and concentration more than 300 ppm can lead to an excessive amount of Fe$^{2+}$ and causing precipitation.

There is no significant increase of degradation every 30 minutes because of the hydroxyl radicals (•OH) degradation ability tend to be slow. However, the UV light has a faster rate of degradation than other conditions because UV light produces hydroxyl radicals (OH) by breaking H$_2$O$_2$ and H$_2$O. Meanwhile, visible light takes slightly longer to break down H$_2$O$_2$ and molecules into hydroxyl radicals. It happens because UV light photon energy is stronger than Visible Light.

Based on figure 2 (a), (b), and (c), degradation percentage of Congo red correspond to the change of
H₂O₂ concentrations. It is because H₂O₂ has an important role as the source of Hydroxyl radical (•OH). Hydroxyl radical (•OH) will break down Congo red dyes into an intermediate that more modest and safe for the environment. Furthermore, the intermediate will break down into CO₂ and H₂O [11].

Based on figure 2 (a) (b) and (c) optimum concentration of H₂O₂ under dark condition is 350 ppm with percentage of degradation 76.31%. Optimum concentration means H₂O₂ with the highest production of hydroxyl radical (•OH). H₂O₂ under dark condition only supported by Fe²⁺ ion, which means there is no photon energy comes from light sources that support Fe²⁺ catalyst ability in break down H₂O₂ molecules into Hydroxyl radical (•OH).

**Figure 2.** Effect of (a) dark condition (b) visible light (c) Ultraviolet on initial H₂O₂ Concentration in the degradation of Congo Red dyes. Experimental conditions : [CR dyes]= 30 ppm, [Fe²⁺] = 300 ppm.

Based on figure 2 (b) and (c), there is a significant increase in Congo red degradation at concentrations of 100 ppm to 300 ppm. In this condition, the degradation increase proportionally to the H₂O₂ concentration addition because of more hydroxyl radical (•OH) production. H₂O₂ optimum concentration on Visible Light and Ultraviolet Light are 350 ppm. Optimum Conditions is the condition that shows the concentration of H₂O₂ with the most hydroxyl radical (•OH) production. The degradation result under visible light and UV light are 79.33% and 84.28%, respectively. However, at concentrations of 400 ppm, the degradation is decreasing because of excessive H₂O₂ addition that react with hydroxyl radicals (•OH) causing the formation of super hydroxyl radicals which have smaller potential energy than (• O𝐻) which is 1.70 V causing the degradation is less effective [12]. The reaction of hydroperoxyl radical formation is shown in this equation[12]:

\[
H₂O₂ + •OH \rightarrow HO₂• + H₂O
\]

\[
HO₂• + •OH \rightarrow H₂O + O₂
\]

The degradation at optimum conditions under UV light is better than visible light. H₂O₂ / UV systems use UV radiation that absorbed by H₂O₂ and breaks the O-O bond in hydrogen peroxide to produce hydroxyl radicals (• OH). Here is the following reaction [12]:

\[
H₂O₂ + hν \rightarrow OH• + •OH
\]
The same reaction also occurs under visible light, but the wavelength of UV light is shorter than visible light, which is from 100 nm to 380 nm, while visible light is from 380 nm to 750 nm [13]. Ultraviolet wavelengths are shorter than visible light cause Ultraviolet photon energy to be stronger than visible light.

The other difference of UV radiation is H₂O molecules can be dissolved into hydroxyl radicals (• OH) and H⁺, this reaction is called photolysis, here is the following reaction [14]:

\[ \text{H}_2\text{O} + h\nu \rightarrow \text{•OH} + \text{H}^+ + e^- \]

3.2 Effect of UV and Visible Lights on Initial FeSO₄.7H₂O Concentration

FeSO₄.7H₂O used as a source of Fe²⁺ to catalyze the photo-degradation process. Fe²⁺ optimum concentration can be determined by varying FeSO₄.7H₂O concentration start from 100 ppm to 700 ppm with the concentration H₂O₂ 100 ppm. The concentration of H₂O₂ that used not more than 100 ppm to maximize the effect of Fe²⁺ in Congo red degradation and the concentration not lower than 100 ppm is to prevent precipitation. The irradiation time of Visible and UV light is 270 minutes and analyzed every 30 minutes by UV-Vis spectrophotometer.

![Figure 3](image.png)

**Figure 3.** Effect of (a) dark condition (b) visible light (c) Ultraviolet on initial FeSO₄.7H₂O Concentration in the degradation of Congo Red dyes. Experimental conditions: [CR dyes] = 30 ppm, [Fe²⁺] = 300 ppm.

There is no significant increase of degradation every 30 minutes because of the hydroxyl radicals (•OH) ability to degrade tend to be slow. Based on figure 3(a) the percentages of degradation are increasing from 100 ppm to300 ppm. Afterward, optimum concentration of FeSO₄.7H₂O is reached at 400 ppm with degradation percentage 77.23%. However, the percentage of degradation is decreasing at concentration of 500 ppm to 700 ppm.
Based on figure 3(b) and (c), the percentages of degradation are increasing from 100 ppm to 300. Afterward, the optimum concentration is reached at 400 ppm under visible and UV light with the percentage of degradation is 81.99% and 82.72%, respectively. The highest degradation occurs in the optimum concentrations because of many Fe\(^{2+}\) produced to catalyze H\(_2\)O\(_2\) decomposition into a hydroxyl radical (•OH). Fe\(^{2+}\) will be oxidized to Fe\(^{3+}\) because it reacts with H\(_2\)O\(_2\). Fe\(^{3+}\) will be reduced to Fe\(^{2+}\) and produce hydroxyl radical with the help of photon energy, according to the following reactions [15]:

\[
\begin{align*}
Fe^{2+} + H_2O_2 & \rightarrow Fe^{3+} + OH^- + OH^- \\
Fe^{3+} + H_2O_2 + hv & \rightarrow OOH + H^+ + Fe^{2+} \\
Fe^{3+} + H_2O + hv & \rightarrow Fe^{2+} + OH^- + H^+
\end{align*}
\]

The function of Fe\(^{2+}\) and Fe\(^{3+}\) is also as a coagulant to form complexes that increase degradation, according to the following reaction [16]:

\[
Fe^{3+} \rightarrow Fe^{2+} + e^- \\
Fe^{3+} + R \rightarrow complex Fe^{3+}-R (R: \text{organic compound})
\]

The degradation is decreasing in the concentration of 500 ppm to 700 ppm under visible and UV light conditions. It occurs because the excessive Fe\(^{2+}\) ions will react with formed hydroxyl radicals generate ferric ions and OH\(^-\) that lead to a brownish solution. Here is the following reaction [17]:

\[
Fe^{3+} + OH\bullet \rightarrow Fe^{3+} + OH^-
\]

The percentage of degradation shows UV light irradiation has the best effect in increasing FeSO\(_4\) activity as catalyst compare to visible light and dark condition. It is because photon energy of UV light higher than visible light which lead to faster conversion of Fe\(^{3+}\) into Fe\(^{2+}\) and production of hydroxyl radical (•OH), here is the following reaction [15]:

\[
Fe^{3+} + H_2O + hv \rightarrow Fe^{2+} + H^+ + •OH
\]

### 3.3 Effect of UV and Visible Lights Irradiation Time on H\(_2\)O\(_2\) and FeSO\(_4\).7H\(_2\)O Optimum Concentration

The optimum H\(_2\)O\(_2\) and FeSO\(_4\).7H\(_2\)O concentration are 350 ppm and 400 ppm, respectively. This experiment's goal is to determine the effect of optimum H\(_2\)O\(_2\) and FeSO\(_4\).7H\(_2\)O concentration and the effect of irradiation time on degradation. UV and visible light irradiation time is 330 minutes and analyzed every 30 minutes using a UV-Vis spectrophotometer.

![Figure 4. Effect of UV and Visible Lights Irradiation Time on H\(_2\)O\(_2\) and FeSO\(_4\).7H\(_2\)O Optimum Concentrations in the degradation of Congo Red dyes. Experimental conditions: [CR dyes] = 30 ppm, [H\(_2\)O\(_2\)] = 350 ppm, [Fe\(^{2+}\)]](image)
Based on figure 4, the degradation percentages in the minute of 270 under UV light, visible light, and dark condition are 90.69%, 91.51%, and 89.50%, respectively. The degradation percentages are better than H$_2$O$_2$ and FeSO$_4$.7H$_2$O with initial concentration. It is because optimum concentration of H$_2$O$_2$ and FeSO$_4$.7H$_2$O can lead to excessive production of hydroxyl radical (•OH). Afterward, the degradation percentages in the minute of 330 under UV light, visible light and dark condition are 92.06%, 93.07%, and 89.86%, respectively. Optimum concentration of H$_2$O$_2$/FeSO$_4$.7H$_2$O can produce more hydroxyl radical (•OH) and keep the degradation of Congo red going. Longer degradation time can slowing or even stop the degradation because of hydroxyl radicals (• OH) will not only break down the Congo red compound but also the chemical species of Congo red.

There is no significant difference in degradation under UV and visible light irradiation because of optimum concentration of H$_2$O$_2$/FeSO$_4$.7H$_2$O gives a more significant impact on degradation. However, UV light irradiation gives a better degradation compare to visible light because of the photon energy in Ultraviolet light is stronger than visible light. The wavelength of UV light is shorter than visible light, which is from 100 nm to 380 nm, while visible light is from 380 nm to 750 nm. Photon energy has an important role in reducing Fe$^{3+}$ to Fe$^{2+}$ and producing hydroxyl radicals (• OH). The process of photon energy absorption causing electrons in orbitals with lower energy levels move to higher energy. The electron transfer leads to a vacancy in low energy orbitals and will be occupied with electrons that transferred from H$_2$O reducing Fe$^{3+}$ to Fe$^{2+}$ and produce hydroxyl radicals (• OH).[18] Here is the following reaction [18]:

\[
\text{Fe}^{3+} + \text{H}_2\text{O} + hv \rightarrow \text{Fe}^{2+} + \bullet \text{OH} + \text{H}^+.
\]

It shows that stronger photon energy ease Fe$^{3+}$ reduction to Fe$^{2+}$. Photon energy in UV light can also cause photolysis in water molecules of the Congo red solution and produce more hydroxyl radicals (• OH). Here is the following reaction of the photo-Fenton system in Congo red degradation:

\[
\begin{align*}
\text{Fe}^{3+} + \text{H}_2\text{O}_2 & \rightarrow \text{Fe}^{3+} + \bullet \text{OH} + \text{H}^+ \\
\text{Fe}^{3+} + \text{H}_2\text{O}_2 + hv & \rightarrow \text{OOH} + \text{H}^+ + \text{Fe}^{2+} \\
\text{Fe}^{3+} + \text{H}_2\text{O} + hv & \rightarrow \text{Fe}^{2+} + \bullet \text{OH} + \text{H}^+ \\
\bullet \text{OH} + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{O} + \text{OOH} \\
\text{Fe}^{2+} + \bullet \text{OH} & \rightarrow \text{Fe}^{3+} + \text{OH}^-. \\
\text{Fe}^{3+} + \text{OOH} & \rightarrow \text{O}_2 + \text{Fe}^{2+} + \text{H}^+.
\end{align*}
\]

Consumption of •OH hydroxyl radicals (• OH) by dyes [19]

\[
\begin{align*}
\text{H}_2\text{O}_2 + \bullet \text{OH} & \rightarrow \text{OOH} + \text{H}_2\text{O} \\
\bullet \text{OH} + \bullet \text{OH} & \rightarrow \text{H}_2\text{O} \\
\bullet \text{OH} + \text{Dye} & \rightarrow \text{X} + \text{Oxidized Product (CO}_2 + \text{H}_2\text{O)}
\end{align*}
\]

Meanwhile, under dark conditions, production of hydroxyl radicals (• OH) is lesser and slower compare to UV and visible light. It is because without photon energy is harder to reduce Fe$^{3+}$ into Fe$^{2+}$, which lead to lesser hydroxyl radicals (• OH) production. here is the reaction [20]:

\[
\text{Fe}^{3+} + \text{H}_2\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}^{2+} + \text{H}_3\text{O}^+ + \text{HO}_2^-;
\]

Even though Fe$^{3+}$ reduction into Fe$^{2+}$ still can happen, the reaction process is slower compared to Fe$^{2+}$ conversion to Fe$^{3+}$. Meanwhile, ion Fe$^{2+}$ is important to degrade organic pollutants. It shows that the Fenton reaction is less effective.

3.4 Effect of UV and visible light on pH variation in Congo Red Degradation

This experiment aim is to determine the best pH condition under UV and visible light irradiation. The pH variation starts from pH 2 to 6 with the addition of H$_2$O$_2$ and FeSO$_4$.7H$_2$O optimum concentrations and irradiation time 330 minutes. The degradation of organic compounds is affected by the pH of the solution because hydrogen ion plays an essential role in hydroxyl radical production.
Figure 5. Effect of pH variation under the effect of UV and Visible light in the degradation of Congo Red dyes. Experimental conditions: [CR dyes] = 30 ppm, [H$_2$O$_2$] = 350 ppm, [Fe$^{2+}$] = 400 ppm.

Based on figure 5 the optimum pH under the effect of visible light, UV light, and dark condition obtained at pH 3 with the percentage of degradation are 93.62%, 95.36%, and 90.78%, respectively. The results show that the highest percentage at pH 3 is under the effect of UV light. It is due to the dominant Fe(III) species found in the aqueous solution at pH 3 is Fe(H$_2$O)$_5$(OH)$_2^+$ [or only Fe(OH)$_2^+$] which can absorb most of the ultraviolet spectra region\(^{(21)}\). Fe(OH)$_2^+$ generate efficient photoreaction to produce hydroxyl radicals, here is the following reaction \(^{(22)}\):

$$
\text{Fe(OH)}_{2^+} + \text{hv} \rightarrow \text{Fe}^{2+} + \text{HO} \cdot
$$

Meanwhile, on the effect of visible light, the Fe(H$_2$O)$_5$(OH)$_2^+$ species absorbs less photon energy and lead to lesser production of hydroxyl radicals. The absence of photon energy from light (dark condition) causing the Fe(H$_2$O)$_5$(OH)$_2^+$ species to be less effective in producing hydroxyl radicals. In general, pH 3 has a better effect on the Fenton reagent compared to other acidity levels because at pH 3 the production of H$^+$ is in optimum condition causing OH$^-$ bind to H$^+$ and lead to more production of hydroxyl radical (OH$^-$). At pH 4 to 5, the Fenton reaction becomes less efficient due to the dissolved fraction of the Fe$^{2+}$ ion precipitate into Fe(OH)$_3$ and reducing activity of Fe$^{2+}$ catalyst. At pH 6 more iron hydroxides are formed and cause hydrogen peroxide to lose ability as oxidation agent due to decomposition into water (H$_2$O) and oxygen (O$_2$) and also a tendency to form ferric oxyhydroxide sediment (Fe(OH)$_3$) \(^{(23)}\), here is the following reaction that happen in pH above 3 \(^{(25)}\):

$$
\text{Fe}^{2+} + \text{OH} \rightarrow \text{Fe}^{3+} + \text{OH}^- \rightarrow \text{Fe(OH)}_3
$$

However, the effect of UV light is still better under these conditions due to higher photon energy. Although the activity of the Fe$^{2+}$ catalyst decreasing, the breakdown of H$_2$O$_2$ molecules and water can still occur to produce hydroxyl radicals (•OH).

Meanwhile, at pH 2, the degradation is least than other pH conditions due to the formation of complex species [Fe(H$_2$O)$_6$]$^{2+}$ which react more slowly with H$_2$O$_2$ than other species and less able to absorb light with wavelengths above 300 nm. Therefore UV light with wavelengths above 300nm has no effect and can’t absorb visible light because the smallest wavelength of the visible light is 380 nm \(^{(21)}\). Moreover, increasing amounts of H$^+$ can react with H$_2$O$_2$ to form oxonium ions (H$_3$O$_2^+$) and these ions make hydrogen peroxide more electrophilic which is more stable. It is also make hydrogen peroxide less reactive with Fe$^{2+}$ ions \(^{(24)}\), here is the following reaction \(^{(24)}\):

$$
\text{H}_2\text{O}_2 + \text{H}^+ \rightarrow \text{H}_3\text{O}_2^+.
$$

Based on the results it can be concluded that changes in pH makes Fe ions to form different species which lead to different interaction with type of light that absorbed.
3.5 Statistic Analysis of Congo Red Degradation on Optimum Condition

Congo Red degradation results on the optimum condition show there is no significant difference. Because of that another two experiments done under optimum conditions to make sure is there any significant effect of UV light or Visible light on Congo Red degradation. Here is the result:

| Table 1. Congo Red Degradation on Optimum Condition. |
|------------------------------------------------------|
| Experimental conditions : [CR dyes] = 30 ppm, [H$_2$O$_2$] = 350 ppm, [Fe$^{2+}$] = 400 ppm, pH = 3 and Time = 330 minute. |

| Light Sources | Ultraviolet | Visible | Dark |
|---------------|-------------|---------|------|
| 95.36%        | 93.62%      | 90.78%  |
| 94.81%        | 92.79%      | 90.87%  |
| 94.44%        | 92.34%      | 91.05%  |

First, the experimental result data tested with the Shapiro-Wilk test with a significance level ($\alpha$) 0.05 to check the data is normally distributed or not. The result of the Shapiro-Wilk test showed a P-value of 0.570539, which is higher than the significance level ($\alpha$) 0.05. Since p-value > $\alpha$, we accept the H$_0$. It is assumed that the data is normally distributed. After that, the experimental result data tested with Levene Test with ($\alpha$) 0.05 to check the homogeneity of the data. The Levene test result showed the significance value is 0.206, which higher than ($\alpha$) 0.05. The result shows that the experimental result data of Congo red degradation under optimum condition is Homogenous. Next, we analyze the data with ANOVA (analysis of variance): single factor. The result from ANOVA showing the F>F$_{crit}$, which means the null hypothesis rejected indicates experimental results between UV, visible light, and dark conditions are significantly different. Lastly, the Duncan and Tukey HSD (honestly significant difference) to check is there significant differences between the mean of the experimental result under UV, visible light, and dark condition. The result showed a significant difference existed between Ultraviolet, Visible light, and dark condition. It can be concluded from statistical analysis on three experimental results of Congo red degradation under the optimum condition there is a significant effect between UV light, visible light and dark condition.

3.6 Kinetic analysis of Congo Red Degradation on Optimum Condition

The kinetic analysis aims to determine the kinetic order of Congo red degradation under optimum condition and the rate constant. The kinetics order and rate constant of Congo red degradation on optimum condition is analyzed with a graphical method. Here is the result:

| Table 2. Linear regression and reaction rate constant of Congo Red degradation under UV, visible light and dark condition |
|---------------------------------------------------------------|
| Order (n) | Linear Regression ($R^2$) | Reaction Rate Constant |
| Light Sources | VIS | UV | Dark | VIS | UV | Dark |
|---------------|-----|-----|------|-----|-----|------|
| 0             | 0,954 | 0,981 | 0,959 | 1,18x10$^{-2}$ | 1,22x10$^{-2}$ | 8,72x10$^{-3}$ |
| 1             | 0,979 | 0,989 | 0,989 | 3,56x10$^{-3}$ | 4,20x10$^{-3}$ | 2,21x10$^{-3}$ |
| 2             | 0,976 | 0,928 | 0,982 | 1,14x10$^{-3}$ | 1,58x10$^{-5}$ | 5,77x10$^{-4}$ |

Based on table 2, the kinetics order of ultraviolet, visible light, and dark condition is 1. It is because linear regression on order 1 is the highest in ultraviolet, visible light, and dark condition. The highest rate constant is 4,20x10$^{-3}$ which is under ultraviolet light irradiation. Higher reaction rate constant showing a better process of degradation. It shows Ultraviolet is giving the best effect on the Congo Red degradation process. Here is the result of kinetics reaction:
Based on figure 6(a), the kinetics analysis starts from the minute of 30, and figure 6(b) showed that the degradation followed the pseudo-first-order kinetics. The following equation can determine the kinetics:

\[
\text{rate} = -\frac{d[A]}{dt} = k[A] \quad (1)
\]

If the following equation is integrated, a new equation will be obtained

\[
\int_{[A]_0}^{[A]_t} d[A] = \int_0^t k \, dt
\]

\[
\ln \frac{[A]_t}{[A]_0} = -kt \quad (3)
\]

Lastly, the equation change into \([A]_t \quad [25]:\)

\[
\ln[A] = -kt + \ln[A]_0 \quad (4)
\]
The equation above is the final form of the first-order equation of the integrated rate reaction law. \([A]_t\) represents the concentration that is owned at time \(t\), and \([A]_0\) indicates the initial concentration.

4. Conclusion
The ultraviolet and visible light affects the degradation of Congo Red. The statistical analysis showed that the ultraviolet and visible light has a significant effect on Congo Red degradation. The rate constant of ultraviolet light is higher compared to visible light, indicating that the ultraviolet light gives a better effect on Congo red degradation.

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