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Effectiveness of the Photofenton Process in Treating Wastewater from the IPLT Oxidation Ditch Outlet

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A B S T R A C T

Wastewater from the Sludge Treatment Plant (IPLT) often contains hazardous contaminants that can pollute water bodies if discharged without prior treatment. Wastewater treatment from the IPLT, especially the Oxidation Ditch outlet, can be carried out using one of the Advanced Oxidation Processes (AOPs), namely Fenton. This study aims to analyze the effectiveness of the Fotofenton method in the Oxidation Ditch outlet unit of the Keputih IPLT, Surabaya, on total coliform, COD, and TSS parameters. The total coliform removal percentage was 98%, the COD parameters were 82%, and the TSS parameters were 60% at a dose of FeSO4: H2O2 molar ratio of 1:15, UV lamp power of 20 watts, and sampling time of 60 minutes. This study demonstrates that the Fotofenton method can be an environmentally friendly solution for wastewater treatment from IPLT and can be applied as an advanced treatment stage to meet applicable quality standards.

Contribution to Sustainable Development Goals (SDGs):
SDG 6: Clean Water and Sanitation
SDG 3: Good Health and Well-Being
SDG 12: Responsible Consumption and Production
SDG 14: Life Below Water

1. INTRODUCTION

A Sewage Sludge Treatment Plant (IPLT) is a facility built to treat sewage sludge that has undergone preliminary treatment in a septic tank. Sewage sludge often contains parameters such as Total Coliform, COD, and TSS, which are harmful to health and can pollute the environment [1]. At the IPLT Keputih in Surabaya, an oxidation ditch unit manages sewage sludge, but it still shows high levels of certain parameters and does not meet the quality standards set by the Minister of Environment and Forestry Regulation No. 68 of 2016. Therefore, further treatment is needed to improve the quality of the water produced and ensure that it does not harm the environment.

Sewage sludge treatment can be carried out using various methods, including advanced oxidation processes (AOPs). These advanced oxidation processes provide an effective solution for managing sewage sludge and can reduce organic substances and bacteria by utilizing environmentally friendly technology. In general, advanced oxidation processes (AOPs) are a series of chemical reactions designed to remove hazardous contaminants from wastewater through oxidation reactions that form hydroxyl radicals (OH•) [2]. Hydroxyl radicals are highly reactive and non-selective oxidants that can break down various types of organic pollutants into simpler compounds. This process ideally produces water (H_2O) and carbon dioxide (CO_2). The advanced oxidation process has several advantages, including the ability to break down various types of organic compounds and the need for a smaller land area. In addition, this method can convert toxic waste into harmless waste and break down dyes without producing sludge that needs to be reprocessed, unlike coagulation and sedimentation technology [3].

Photofenton is an advanced oxidation process (AOP) that can degrade hazardous substances in sewage sludge. The process in this system involves adding Fe2+ to hydrogen peroxide (H2O2) to produce Fe3+ ions and hydroxyl radicals. Subsequently, the Fe3+ ions formed react with UV light to produce Fe2+ ions and hydroxyl radicals again [4]. The advantage of using the Photofenton method is its ability to break down various types of pollutants, including those that naturally degrade into relatively harmless products. In addition, the Fenton reagent used in the Photofenton method is environmentally friendly and does not entail significant costs [5].

1.1. Objective

The Photofenton method can degrade parameters such as Total Coliform, COD, and TSS, starting with the addition of Fe^{2+} ions that disrupt bacterial defenses, where H_2O_2 and UV light play a role in producing hydroxyl radicals that damage bacterial DNA [6]. To remove COD, this compound is converted into simpler oxidized products. Meanwhile, the oxidation of organic molecules to reduce TSS occurs when hydroxyl radicals produced from the reaction of H_2O_2 and Fe^{2+}, accelerated by UV light, form $Fe(OH)_3$ ions that bind suspended solids and produce flocs that can settle [7]. Therefore, this study aims to test the Photofenton process in reducing total coliform, COD, and TSS parameters in the outlet wastewater of the Keputih IPLT oxidation ditch.

2. MATERIALS AND METHODS

2.1. Research location

This research was conducted at the Research Laboratory, Environmental Engineering, "Veteran" National Development University, East Java, Surabaya.

2.2. Tools and materials

The equipment used in this study included a 40L tank, an acrylic box measuring 15x15x18 cm; 10x10x35 cm, a 1000 mL glass beaker, 10-watt and 20-watt UV-C lamps, aluminum foil, a 210 rpm stirrer, a pH meter, ½ inch diameter pipes, ½ inch water taps, support chairs, and analytical scales. The following is the reactor design used for this study:

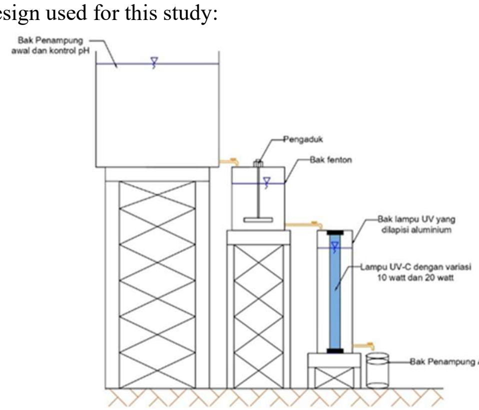

Figure 1. Research Reactor Design
Source: Research Data, 2025

In addition, the materials used for this study included wastewater from the IPLT oxidation ditch outlet unit, 30% hydrogen peroxide (H_2O_2) solution, ferrous sulfate reagent, sulfuric acid, distilled water, and NaOH.

2.3. Research Procedure

The Photofenton process begins with the preparation of tools, materials, and reactors according to the design that has been made. Once the reactor is complete, place the waste sample into the initial storage tank. Check the initial pH using a pH meter, then adjust the pH to 5 using a sulfuric acid solution. Next, the sample is poured into a 3-liter Fenton tank and activated by turning on the agitator, then mix the Fenton reagent into the sample water with varying doses (1:1; 1:5; 1:10; 1:15). Stir at a speed of 210 rpm for 5 minutes. After the stirring process is complete, the sample water will be flowed into a UV irradiation tank for varying lengths of time (30 minutes, 45 minutes, and 60 minutes). After the Photofenton process is complete, the water will be flowed into a final storage tank, where NaOH will be added to restore the initial pH and accelerate precipitation. The samples obtained from the Photofenton process will be analyzed for Total Coliform, COD, and TSS parameters.

This study began by determining the amount of $FeSO_4 : H_2O_2$ at predetermined molar ratios. The amount of H_2O_2 was calculated after obtaining the initial COD value. In accordance with the study conducted by Rais & Setiawan (2024) [8], 2.12 mg/L H_2O_2 is required to oxidize 1 mg/L COD. The formula used to calculate the requirements for $FeSO_4$ and H_2O_2 is as follows:

H_2O_2 concentration : COD concentration x 2.12
H_2O_2 molarity : H_2O_2 concentration/ H_2O_2molecular weight

Table 1. Requirements for $FeSO_4$ and H_2O_2

Variations in the Molar Ratio of $FeSO_4 : H_2O_2$	$FeSO_4$ Requirements (grams)	H_2O_2 Requirements (ml)
1:1	5.9 grams	3.44 ml
1: 5		17.2 ml
1 : 10		34.41 ml
1 : 15		51.6 ml

3. RESULT AND DISCUSSION

3.1. Initial Characteristics of Outlet Wastewater from IPLT Oxidation Ditch

The parameters contained in the IPLT Oxidation Ditch outlet wastewater are still high and do not meet the quality standards of Minister of Environment and Forestry Regulation No. 68 of 2016. The following are the results of the initial characteristic test of the IPLT Oxidation Ditch outlet wastewater:

Table 2. Preliminary Test Results of IPLT Oxidation Ditch Outlet Wastewater

No.	Parameter	Analysis Results	Quality Standard	Unit
1.	Total Coliform	6000	3000	number/100mL
2.	COD	627	100	mg/L
3.	TSS	344	20	mg/L
4.	pH	7,61	6-9	-

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3.2. The Effect of $FeSO_4$: H_2O_2 Molar Ratio on the Reduction of Total Coliform, COD, and TSS Parameters

The molar ratio of $FeSO_4$:H_2O_2 in the Photofenton process greatly affects the effectiveness of hydroxyl radical (•OH) formation, which is the main oxidizing agent in the reaction. The correct molar ratio will ensure that $FeSO_4$ is sufficient to activate H_2O_2 and produce hydroxyl radicals optimally to oxidize hazardous substances in wastewater. If the $FeSO_4$ dose is too high, $Fe(OH)_3$ iron precipitate may form, reducing the efficiency of the process. Meanwhile, if the H_2O_2 dose is excessive, it may decompose into water and oxygen, reducing the availability of H_2O_2 for the Fenton reaction. Therefore, determining the molar ratio of $FeSO_4$:H_2O_2 greatly affects the effectiveness of the Photofenton process [9]. The following are the percentages of total coliform, COD, and TSS removal that have undergone the Photofenton process based on the influence of the $FeSO_4$:H_2O_2 molar ratio, which can be shown in Figure 2.

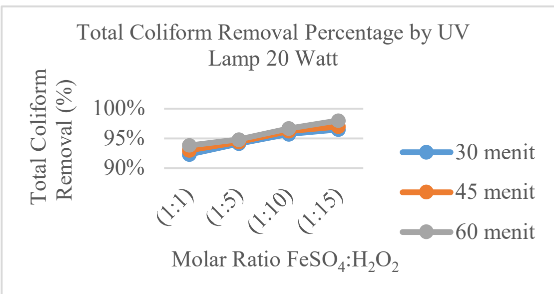

Figure 2. Relationship between the molar ratio of $FeSO_4$:H_2O_2 and the percentage of total coliform reduction under a 20-watt UV lamp.

Based on the graph above, it shows that the higher the molar ratio, the greater the total coliform removal and the better the water quality after the Photofenton process. The molar ratio in the Photofenton process can play a role in bacterial inactivation. If the molar ratio increases with the right dose, it will produce more hydroxyl radicals that can damage bacterial DNA, such as total coliform. If the molar ratio is too low, bacterial inactivation cannot work optimally due to the lack of hydroxyl radicals formed[10]. Therefore, the total coliform concentration can decrease significantly at a molar ratio of 1:15 with a removal percentage of 98% compared to a molar ratio of 1:1, which is only 92%.

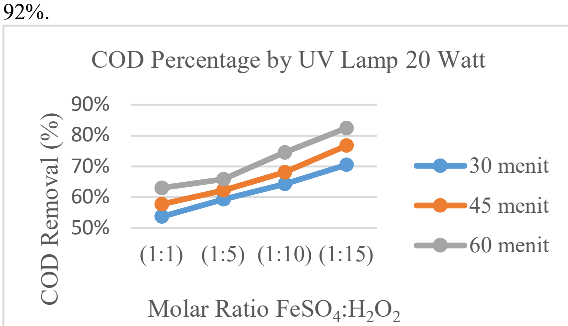

Figure 3. Graph showing the relationship between the molar ratio of $FeSO_4$:H_2O_2 and the percentage of COD removal under a 20-watt UV lamp

Based on the graph above, it shows that an increase in the molar ratio can reduce the COD concentration. This occurs because as the molar ratio increases, the amount of H2O2 added also increases, while the amount of FeSO4 remains constant. The addition of H2O2 produces more hydroxyl radicals, thereby increasing the effectiveness of oxidizing organic matter into simpler elements[11]. Thus, the COD concentration can be significantly reduced at a molar ratio of 1:15 with a removal rate of 82% compared to a molar ratio of 1:1, which only has a removal rate of 50%.

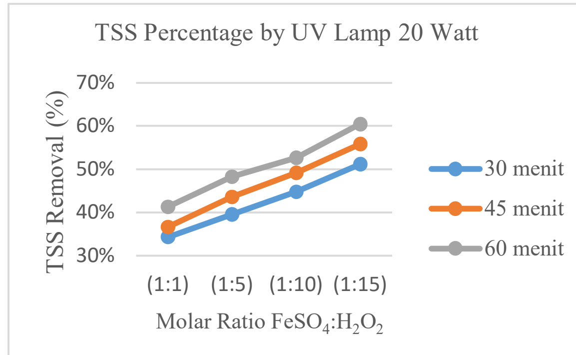

Figure 4. Graph showing the relationship between the molar ratio of $FeSO_4$:H_2O_2 and the percentage of TSS removal under a 20-watt UV lamp

The higher molar ratio, as shown in the graph above, proves that it can reduce TSS concentration because more hydroxyl radicals are produced. In reducing TSS concentration, Fe^{2+} ions from $FeSO_4$ act as coagulants that can agglomerate suspended particles, turning them into small particles that are easily precipitated [9]. Therefore, TSS concentration can decrease significantly at a molar ratio of 1:15 with a removal percentage of 60% compared to a molar ratio of 1:1, which only has a value of 31%.

3.3. The Effect of UV Lamp Irradiation Power and Sampling Time on the Reduction of Total Coliform, COD, and TSS Parameters

The Photofenton process in this study used 10-watt and 20-watt UV lamps, where the appropriate UV lamp irradiation level greatly affects the breakdown of H_2O_2 to produce hydroxyl radicals. Higher irradiation power can accelerate the formation of hydroxyl radicals and break down more organic compounds and bacteria. However, if the irradiation power is too high, it can produce harmful by-products and reduce the effectiveness of the Photofenton process [12]. In addition, the right sampling time can also increase the effectiveness of total coliform, COD, and TSS removal, and hydroxyl radical formation has enough time without producing by-products.

Based on the graph above, it shows that the highest total coliform parameter reduction occurred in the 20-watt UV lamp variation with a sampling time of 60 minutes, which was 98%. Meanwhile, the lowest total coliform parameter reduction occurred with the 10-watt UV lamp and a sampling time of 30 minutes, at 92%. With these results, the irradiation power of the UV lamp plays an important role in the formation of hydroxyl radicals that can inactivate bacteria by damaging their cell structure. The higher the irradiation power used, the more energy can react with water to inactivate bacteria. In addition, the sampling time of the Photofenton process also greatly affects the removal of total coliforms. The longer the UV light is emitted, the greater the percentage of total coliform removal. This occurs because the hydroxyl radicals formed can persist longer and more effectively inactivate or damage bacteria's cell walls [13].

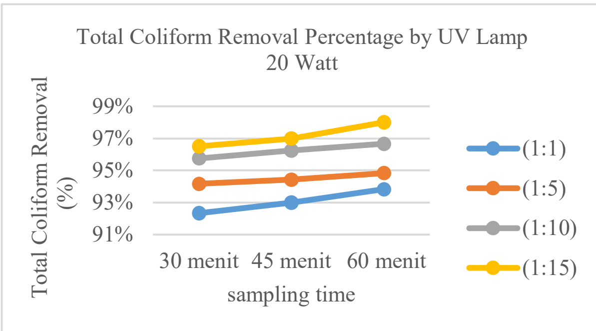

Figure 5. Connection between sampling time and total coliform reduction percentage in a 20-watt UV lamp

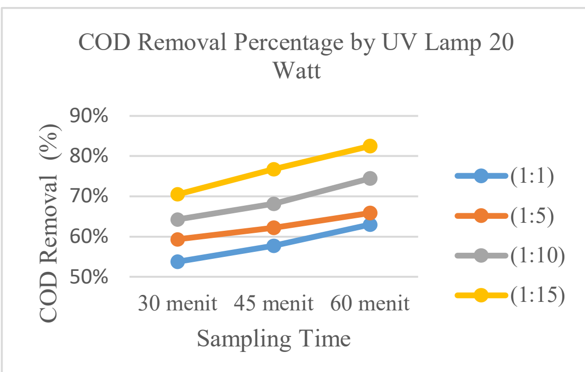

Figure 6. Connection between sampling time and COD reduction percentage in a 20-watt UV lamp

Based on the graph above, it shows that the highest COD para meter reduction occurred in the 20-watt UV lamp variation with a sampling time of 60 minutes, which was 82%. Meanwhile, the lowest COD parameter reduction occurred in the 10-watt UV lamp variation with a sampling time of 30 minutes, which was 50%. With these results, higher UV lamp irradiation power and longer sampling times can form more hydroxyl radicals and accelerate the reaction process so that COD decomposition occurs more quickly. The energy produced by UV light for 60 minutes is more effective than the previous time, because organic materials take longer to decompose into simpler substances [14]. Even though it uses 20 watts of irradiation power for 60 minutes, the Photofenton process does not produce harmful by-products and is more effective at reducing COD concentrations than 10 watts of power.

Based on the graph above, it shows that the highest TSS parameter reduction occurred in the 20-watt UV lamp variation with a sampling time of 60 minutes, which was 60%. Meanwhile, the lowest TSS parameter reduction occurred in the 10-watt UV lamp variation with a sampling time of 30 minutes, which was 31%. These results indicate that the use of a 20-watt UV lamp and a sampling time of 60 minutes can increase the effectiveness of reducing TSS concentration. Higher irradiation power with a longer sampling time can produce more hydroxyl radicals that are useful for breaking down suspended solid particles into smaller particles that are easier to settle, thereby reducing TSS levels [15].

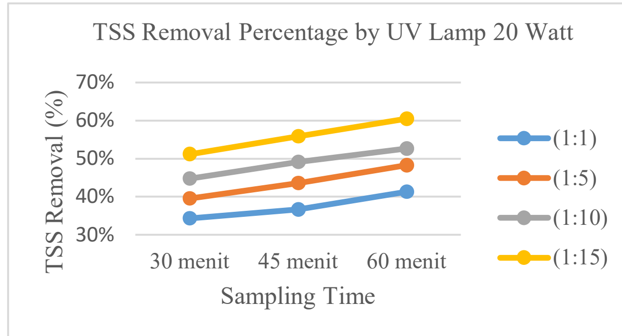

Figure 7. The connection between sampling time and TSS reduction percentage in a 20-watt UV lamp

4. CONCLUSION

Based on the results of the study, it can be concluded that the Photofenton method can degrade hazardous substances such as total coliform, COD, and TSS present in the outlet wastewater of the Keputih IPLT oxidation ditch and improve its quality. This Photofenton process can remove total coliform by up to 98% with an initial concentration of 6000 Count/100mL and reduced to 120 Count/100mL for the highest variation. For the COD parameter, it can be degraded by up to 82% with an initial concentration of 627 mg/L and reduced to 110 mg/L. In addition, the TSS removal percentage was 60% with an initial concentration of 344 mg/L and reduced to 136 mg/L. Although the Photofenton process is effective in improving the quality of the outlet wastewater from the Keputih IPLT oxidation ditch, the results still do not meet the quality standards of the Minister of Environment and Forestry Regulation No. 68 of 2016, particularly for the COD and TSS parameters. Therefore, further treatment is needed to meet the quality standards.

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