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RESEARCH PAPER

Treatment of leachate from Bantargebang Landfill using oxidation process with H_2O_2

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Abstract. Leachate produced from old landfills has a low level of biodegradability making it suitable for physico-chemical treatment. A low level of biodegradability is characterized by a concentration ratio of $BOD_5/COD \leq 0.1$. The leachate at the Bantargebang Integrated Waste Management Unit (UPST) has a BOD_5/COD concentration ratio of 0.05. The current state of processing leachate at the wastewater treatment plant (IPAS) employs biological processing technology. This research uses inlet leachate from IPAS 3 UPST Bantargebang, with a batch system reactor. The reactor is a glass beaker with a capacity of 1 L, operated using a magnetic stirrer with a stirring speed of 200 rpm. The reactor is covered with aluminum foil to prevent oxidation caused by light. The dosage used is based on H_2O_2/COD concentration ratios, which are 1.0625 and 2.125. Reactions time applied are 60 minutes and 180 minutes. The initial pH levels of the leachate used are 5, 6, 7, and 8. The variations that have optimum values are at pH 6, H_2O_2/COD 2.125, and a 60-minute reaction time, resulting in average color removal, BOD_5, COD, TSS, TN, and H_2O_2 reacted by 65%.

Keywords: H_2O_2; leachate; oxidation; pH; reaction time

1. Introduction

The Bantargebang integrated waste processing unit (UPST) is located in three urban villages, namely Ciketing Udik Village, Cikuwul Village, and Sumur Batu Village, in District Bantargebang, Bekasi City. UPST Bantargebang began operation in 1989 under the supervision of the Jakarta and West Java Provincial Environmental Conservation Agency. UPST Bantargebang covers an area of 104.7 Ha consisting of 81.4 Ha designated for landfill (divided into 6 zones) and 23.3 Ha allocated for facilities and infrastructure (UPST-DLHDKI Jakarta, 2022).

Piles of waste can form leachate through rainwater infiltration and physical-chemical-biological reactions during infiltration, as well as from the water content contained in the waste itself (Said & Hartaja, 2015; Tejera et al., 2021). The organic content, heavy metals, acids, dissolved salts, and microorganisms in leachate are relatively high, which can make leachate very dangerous if it pollutes the environment. The characteristics of leachate depend on climatic conditions, landfill age, waste composition, and hydrogeology conditions (Said & Hartaja, 2015).

The age of landfills can be classified into three, young (<5 years), intermediate (5–10 years), and old (>10 years) (Yao, 2017). Each landfill age produces different leachate characteristics.

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Young landfills have leachate characteristics with a high biochemical oxygen demand concentration (BOD_5) (4,000–15,000 mg/L), a high chemical oxygen demand concentration (COD) (25,000–60,000 mg/L), a low ammonia-nitrogen concentration (<400 mg/L), high biodegradability (BOD_5/COD ≈ 0.5 – 1), and a pH lower than 6.5. Old-aged landfills have leachate characteristics with low COD concentration (<4,000 mg/L), ammonia-nitrogen concentration (400–5,000 mg/L), low biodegradability (BOD_5/COD <0,1), and a pH higher than 7.5 (Amor et al., 2015; Tejera et al., 2021). Intermediate-aged landfills have leachate characteristics that fall between the two extremes. Leachate from young-aged landfills can be processed biologically due to its high level of biodegradability, meanwhile, leachate from old landfills is treated physically and chemically, using methods such as coagulation/flocculation, chemical precipitation, membrane technologies, or advanced oxidation processes (AOPs) because of its low biodegradability (Tejera et al., 2021).

Based on laboratory test reports, the concentration values of BOD_5, COD, total suspended solids (TSS), total nitrogen (TN), and pH of UPST Bantargebang leachate, measured between July 2021 to September 2021, were in the respective ranges of 49–336 mg/L, 91–6,500 mg/L, 37–420 mg/L, 46–5,000 mg/L, and 8.3–8.6. The average values for BOD_5, COD, TSS, TN, and pH were 151.4 mg/L, 2,794.6, 216.7 mg/L, 2,278.4 mg/L, and 8.2, respectively. Based on that data, the BOD_5/COD concentration ratio equals 0.05. If the leachate's BOD/COD concentration is less than 0.1, it indicates a low level of biodegradability, necessitating physical-chemical treatment (Tejera et al., 2021; Yao, 2017).

UPST Bantargebang has three wastewater treatment plants (IPAS), namely IPAS 1 and IPAS 3. which employ the technology of equalization pool – facultative pool – rotating biological denitrification – aeration – coagulation–flocculation – pond precipitator – sand filter. Additionally, IPAS 2 utilizes equalization pool – filters – AOPs – aeration technology. The leachate treatment technology of IPAS 1 and IPAS 3 is biological, which makes it less suitable for the leachate characteristics of UPST Bantargebang. Physical-chemical processes are required for treating leachate with low biodegradability levels. The most commonly used physico-chemical processes in leachate treatment include coagulation/flocculation, reverse osmosis, activated carbon adsorption, and AOPs (Tejera et al., 2021).

H_2O_2 is a strong oxidizing agent that plays a role in degrading compounds in wastewater. H_2O_2 was found to be effective in degrading wastewater compounds (Shokrollahzadeh et al., 2012). Leachate treated with H_2O_2 can remove COD by 20.7% from the initial COD concentration of 1,900-2,700 mg O_2/dm^3 at pH 4 (Pieczykolan et al., 2012). The organic matter in wastewater is easily oxidized due to the presence of H_2O_2, making its use very efficient for COD removal (Ksibi, 2006). The data shows that the COD concentration decreased from 322 mgO_2/L to 44 mgO_2/L. In addition, H_2O_2 as an oxidizing agent has the advantage of being relatively inexpensive, easy to obtain, easy to handle, soluble in water, and does not produce toxins or colors in by-products (Marhaini & Wibowo, 2016). Therefore, H_2O_2 can be applied in degrading leachate either directly or in combination with Fe^{2+}/ H_2O_2, O_3/ H_2O_2, and UV/ H_2O_2 (Kurniawan et al., 2006). H_2O_2 can be used alone or in combination with substances such as Fe^{2+}, UV, and ozone (Ksibi, 2006).

An oxidation method using H_2O_2 is desirable for its good performance in processing leachate. Therefore, this study will further investigate the effect of pH, H_2O_2 dose, and reaction time on H_2O_2 oxidation.

2. Materials and method

2.1. Research preparation

The preparation of tools and materials aims to support research activities to ensure the success of the research conducted. During this stage, tools and materials needed for both preliminary and main research are prepared. Tools necessary for research include a spectrophotometer, a magnetic stirrer, pH meters, various glassware, and stopwatches. Materials essential for the study comprise samples from the IPAS 3 Bantargebang UPST inlet, H_2O_2 30% (w/w) of pro analysis grade, H_2SO_4 95%–97% (w/w) of pro analysis grade, and pro analysis grade NaOH for pH adjustment, as well as distilled water.

The samples used in this study were taken from inlet IPAS 3 Bantargebang UPST inlet. A total of 20 L of samples were collected and placed in a 20 L jerry can container. These jerry cans are made of sealed plastic to prevent environmental contamination, and they are further wrapped in black plastic to block light, which could alter the sample characteristics and quality, potentially interfering with the analysis. The samples were transported from IPAS 3 Bantargebang UPST to the Water Quality Engineering Laboratory University of Indonesia, with a travel time of approximately 1.5 hours. During transportation, the samples were kept in an ice box to maintain their quality. The sealed jerry cans containing the IPAS 3 Bantargebang UPST inlet samples were subsequently stored in a refrigerator for future use. The research was conducted using a batch reactor system, with the reactor employing a 1-liter glass beaker. The reactor was operated with a magnetic stirrer at a speed of 200 rpm for a duration of 60 and 180 minutes (Pieczykolan et al., 2012). The H_2O_2 oxidation process must take place without light, as UV light could potentially affect the oxidation. To ensure this, the reactor was covered with aluminum foil.

2.2. Research implementation

The initial pH of the leachate was adjusted to pH 5, 6, and 7 using H_2SO_4 8M. The original pH of leachate was 8. High pH value (>6-8) is one of the primary factors that contributes to the decomposition of H_2O_2 (USPTechnologies, 2022b). Subsequently, the dosage of H_2O_2 was added based on the H_2O_2/COD concentration ratio, which was equal to 1.0625 and 2.125. Stirring was then carried out using a magnetic stirrer for both 60 minutes and 180 minutes. Once the specified reaction time has elapsed, a residual H_2O_2 test was immediately conducted. Experimental samples that have been tested for H_2O_2 residue, were neutralized to pH 8 using 8 M NaOH. Once the experimental sample's pH reached a value of 8, it was transferred to a 1-L HDPE bottle. These bottles containing the samples were stored in a refrigerator. The sample will be used for water parameters analysis, including BOD_5, COD, TSS, TN, color, and H_2O_2 residue. The research flowchart can be seen in Figure 1.

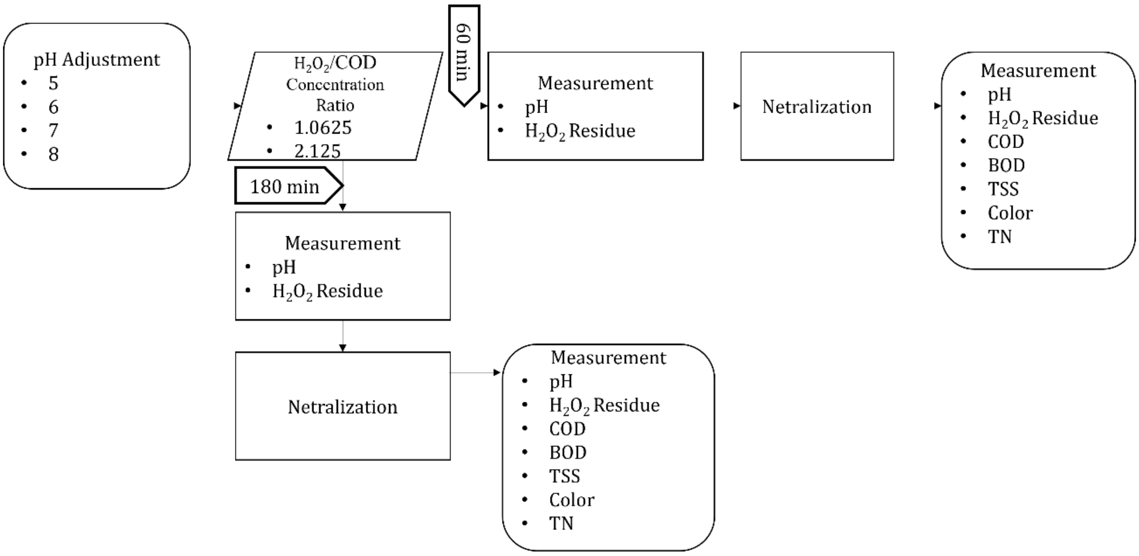

Figure 1. Research flowchart

The variations carried out in the study included changes in pH, H_2O_2 dosage, and the duration of stirring. The pH variations were applied at pH 5, pH 6, pH 7, and pH 8. These variations aim to assess the performance of H_2O_2 in leachate under different pH conditions. The variations in stirring duration were set at 60 minutes and 180 minutes. These variations were intended to evaluate the effect of mixing duration on the removal of pollutants in the leachate and the concentration of remaining H_2O_2. The stirring speed applied was 200 rpm. H_2O_2 dosage was determined based on the stoichiometric ratio to COD (equation 1, 2 and 3). This calculation assumed the complete oxidation of COD by H_2O_2 (Kim et al., 1997). The moles of H_2O_2 are twice the moles of COD. This applied H_2O_2/COD concentration ratios were 1.0625 and 2.215. This variation aimed to assess the effect of H_2O_2 dosage on pollutant removal in the leachate.

$$1\,g\ \mathrm{COD} = 1\,g\ \mathrm{O_2} = 0.03125\,mol\ \mathrm{O_2} = 0.0625\,mol\ \mathrm{H_2O_2} = 2.125\,g\ \mathrm{H_2O_2} \qquad (1)$$

$$2\mathrm{H_2O_2} \rightarrow 2\mathrm{H_2O} + \mathrm{O_2} \qquad (2)$$

$$\mathrm{H_2O_2} + X \rightarrow \mathrm{H_2O} + X\mathrm{O} \qquad (3)$$

Parameter analysis was carried out on the treated leachate using the H_2O_2 oxidation method after neutralization. The parameter analyzed includes BOD_5, COD, TSS, TN, pH, and residual H_2O_2.

3. Results and discussion

3.1. Leachate characteristics

The leachate samples from IPAS 3 Bantargebang UPST inlet were collected on May 5, 2022, at 9 P.M local time in Jakarta. Their characteristics are summarized in Table 1. Based on the measurement results, the BOD_5/COD ratio is 0.096. For comparison, the leachate characteristics of a landfill site located in Golmayo, Spain include BOD_5, COD, TN, and color values of 58±10 mg O_2/L, 4,897±650 mg O2/L, 1,734±50 mg N/L, and 18,800±1,082 Pt/L, respectively (Tejera et al., 2021), with BOD_5/COD ratio of 0.01. In another reference, the leachate characteristics of the Perungudi landfill in Chennai, India, include BOD_5, COD, TSS, and TN values of 80 mg/L, 2,240 mg/L, 900 mg/L, and 2,380, respectively (Tripathy et al., 2019), with a BOD_5/COD ratio of 0.036. A BOD_5/COD concentration value of ≤ 0.1 in leachate indicates low biodegradability, making it suitable for physical and chemical processing (Tejera et al., 2021; Yao, 2017). Such processing methods may include coagulation/flocculation, chemical precipitation, membrane technology, or advanced oxidation process (Tejera et al., 2021).

Table 1. Leachate characteristics.

Parameter	Unit	Value
BOD_5	mg/L	709
COD	mg/L	7,370
TSS	mg/L	126
TN	mg/L	23,374
Color	Pt-Co	5,700
pH	-	8.1

Comparison with secondary data from the Regional Environmental Laboratory of DKI Jakarta Province that can be seen in Table 2 reveals that the primary data on leachate characteristics have higher pollutant levels. This difference can be attributed to Indonesia entering the dry season in May 2022 (Warsudi, 2022), whereas the secondary data show smaller pollutant concentration values, reflecting the transitional and rainy seasons in Indonesia during July-November 2021

(Prasetyaningtyas, 2021). However, both the primary data ($BOD_5/COD = 0.096$) and secondary data ($BOD_5/COD = 0.05$) exhibit a BOD_5/COD concentration ratio of ≤ 0.1.

Table 2. Leachate quality in July-November 2021 and average values.

Month	Parameter	Unit	Influent	Effluent
July	BOD_5	mg/L	71.73	29.12
	COD	mg/L	162.52	94.67
	TN	mg/L	4934.50	130.10
	pH	-	8.30	4.80
	TSS	mg/L	185.00	61.00
August	BOD_5	mg/L	292.54	37.76
	COD	mg/L	4036.83	80.78
	TN	mg/L	1903.00	105.60
	pH	-	8.20	6.30
	TSS	mg/L	46.00	11.00
September	BOD_5	mg/L	161.41	40.74
	COD	mg/L	5323.12	65.10
	TN	mg/L	-	-
	pH	-	8.40	8.30
	TSS	mg/L	212.00	51.00
October	BOD_5	mg/L	254.58	75.04
	COD	mg/L	3502.82	298.95
	TN	mg/L	-	-
	pH	-	-	-
	TSS	mg/L	205.00	72.00
November	BOD_5	mg/L	60.55	53.92
	COD	mg/L	2985.65	177.61
	TN	mg/L	-	-
	pH	-	-	-
	TSS	mg/L	164.00	49.00
Average	BOD_5	mg/L	168.16	47.32
	COD	mg/L	3202.19	143.42
	TN	mg/L	3418.75	117.85
	pH	-	8.30	6.47
	TSS	mg/L	162.40	48.80

The H_2O_2 dosage in this study is determined based on the H_2O_2/COD concentration ratio, with values of 1.0625 and 2.125. Based on Table 1 COD concentration is worth 7,370 mg/L, resulting in an H_2O_2 dosage of 7,671 mg/L (for the ratio of 1.0625) and 15,342 mg/L (for the ratio of 2.125).

3.2. Effect of H_2O_2 dosage and reaction time

The oxidation process using H_2O_2 is influenced by the duration of the reaction time and the dosage of H_2O_2. Figure 2 to Figure 5illustrates the relationship between reaction time and H_2O_2 dose added with water parameters.

TSS is a parameter used to measure suspended particles. Suspended solids can impact the turbidity and clarity of water (Tomperi et al., 2022). These particles consist of both biotic and abiotic components (Buana et al., 2021). Color in water can result from turbidity and precipitated solids. Therefore, the removal of TSS also affects color removal (Abdullah et al., 2014). The lowest color removal rate observed was 21%, decreasing from 5,700 Pt-Co to 4,480 Pt-Co, with a reaction time of 60 minutes, an H_2O_2/COD concentration ratio of 1.0625, and leachate pH 6. The highest color removal rate achieved was 60%, decreasing from 5,700 Pt-Co to 2,290 Pt-Co, with a reaction time of 180 minutes, an H_2O_2/COD concentration ratio of 2.125, and leachate pH 7. In a reference study of colored stock water, the addition of 30 g/L H_2O_2 resulted in 22% color removal (Thasilu & Karthikeyan, 2016). The lowest TSS removal rate observed was 38%, decreasing from 126 mg/L to 78 mg/L, with a reaction time of 60 minutes, H_2O_2/COD concentration ratio of 1.0625, and leachate pH 5. The highest TSS removal rate achieved was 73%, decreasing from 126 mg/L to 34 mg/L, with a reaction time of 180 minutes, H_2O_2/COD concentration ratio of 2.125, and leachate pH 7. In the treatment of petrochemical industry wastewater, the addition of 0.5% H_2O_2 led to a TSS concentration decrease from 48 mg/L to 10 mg/L (a reduction of 79.2%) (Adeyinka & Rim-Rukeh, 1999).

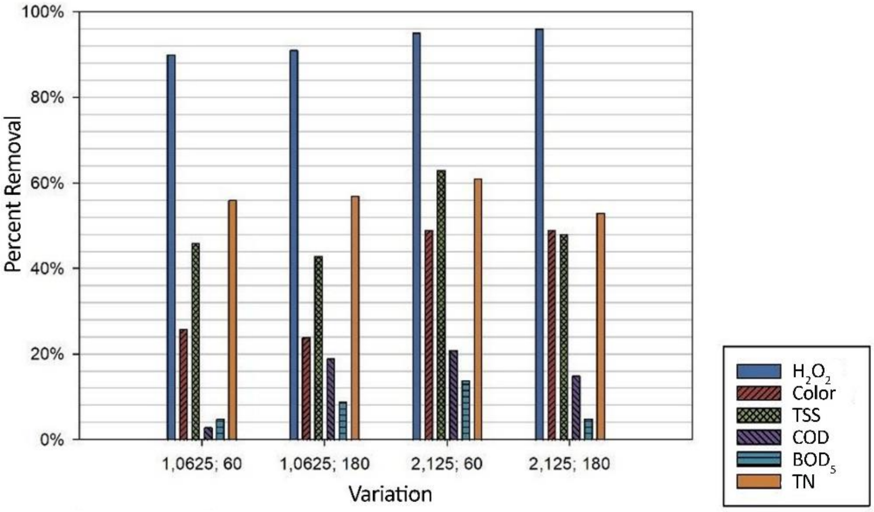

Figure 2. Effect of H_2O_2 dose and reaction time on the parameters of reacted H_2O_2, color, TSS, COD, BOD_5, and TN at initial pH 8

Based on Figure 2 to Figure 5, the removal of color and TSS showed higher removal rates due to increasing H_2O_2 dose concentration. Generally, the removal rate tends to increase with higher H_2O_2 doses, primarily due to an increased number of photons absorbed and reacted with H_2O_2 at elevated concentrations. While increasing H_2O_2 dosage may imply enhanced pollutant removal, it is crucial to determine an optimal dosage to prevent excessive chemical requirements that can lead to high chemical costs. Moreover, excessive doses may cause scavenging effects that inhibit the oxidation process, thereby reducing overall efficiency (Abdullah et al., 2014). Color removal also shows a higher removal rate with a longer reaction time, although the increase is not significant. This phenomenon can be attributed to H_2O_2 oxidizing byproducts that are more reactive than the pollutants being targeted (Zhang et al., 2006).

BOD is a characteristic that indicates the amount of dissolved oxygen required by microorganisms to reduce organic matter under aerobic conditions. On the other hand, COD represents the amount of oxygen required to break down all organic matter present in water (Atima, 2015; Sara et al., 2018). BOD does not indicate the amount of organic matter organic matter directly but rather quantifies the oxygen needed by microorganisms to decompose organic material within water bodies (Taradepa, 2021). The lowest COD removal rate observed was 3%, decreasing from 7,370 mg/L to 7,158 mg/L, with a reaction time of 60 minutes, an H_2O_2/COD concentration ratio of 1.0625, and leachate pH 8. The largest COD removal rate achieved was 82%, from 7,370 mg/L to 1,313 mg/L, with a reaction time of 60 minutes, an H_2O_2/COD concentration ratio of 2.125, and leachate pH 6. In reference, the addition of H_2O_2 to leachate resulted in a reduction in COD concentration by 10.9%, from 1900-2700 mg/L, at leachate pH 4, H_2O_2 dose of 1 g/dm^3, and reaction time of 3 hours (Pieczykolan et al., 2012). Other research about treatment of petrochemical industry wastewater, the addition of 0.5% H_2O_2 led to a COD concentration decrease from 96 mg/L to 53 mg/L (a reduction of 44.8%) (Adeyinka & Rim-Rukeh, 1999). The addition of H_2O_2 to domestic wastewater have done in research reference, reduced COD from 322 mg O_2/L to 44 mg O_2/L at pH 7.41 and a reaction time of 180 minutes (Ksibi, 2006). The oxidation method has demonstrated sufficient effectiveness in removing COD from aged landfill leachate, with a rate ranging between 50%-80% (Renou et al., 2008). In this study, COD removal rates ranged from 3%-82%. The lowest BOD_5 removal rate observed was 5%, decreasing from 709 mg/L to 676 mg/L. The highest BOD_5 removal rate achieved was 73%, decreasing from 709 mg/L to 193 mg/L, with a reaction time of 60 minutes, an H_2O_2/COD concentration ratio of 2.125, and leachate pH 6. The addition of H_2O_2 to domestic wastewater improved BOD_5 removal, even with initial oxygen levels in wastewater ranging from 0% to 10%, resulting in a reduction of BOD_5 from 47.8 mg/L to 24.1 mg/L (Jóźwiakowski et al., 2007).

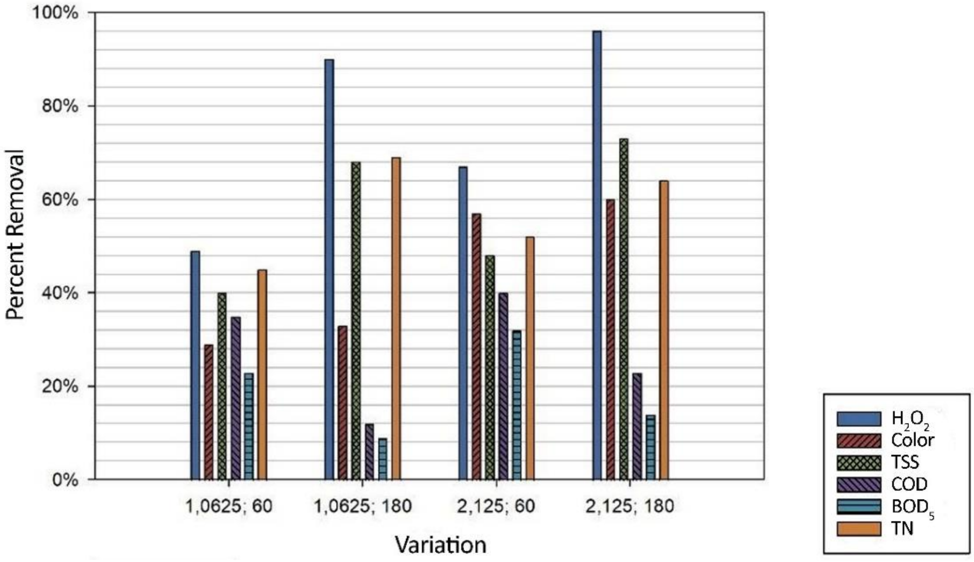

Figure 3. Effect of H_2O_2 dose and reaction time on the parameters of reacted H_2O_2, color, TSS, COD, BOD_5, and TN at initial pH 7

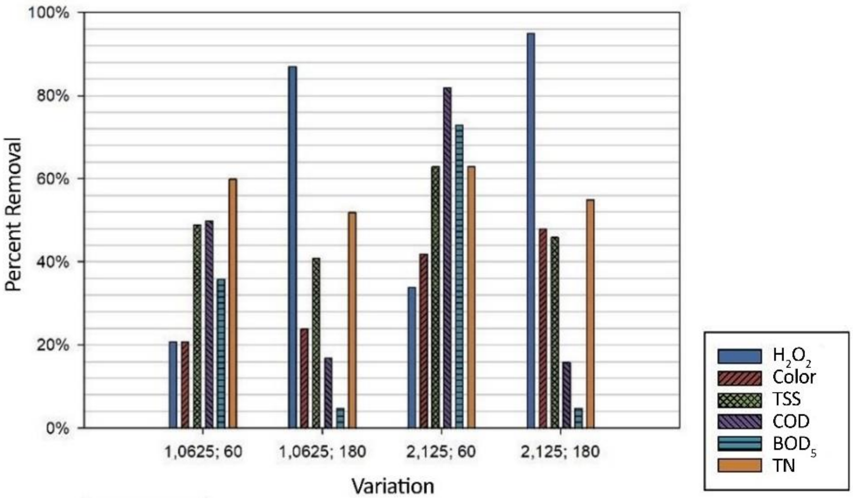

Figure 4. Effect of H_2O_2 dose and reaction time on the parameters of reacted H_2O_2, color, TSS, COD, BOD_5, and TN at initial pH 6

Based on Figure 2 to Figure 5, the removal rates of BOD$_5$ and COD exhibit lower removal efficiency as the reaction time increases to 180 minutes, causing a decrease in the removal efficiency of BOD$_5$ and COD. Conversely, a higher level of BOD$_5$ and COD removal is observed with an increase in the H_2O_2 dosage concentration at a reaction time of 60 minutes. However, the increase in H_2O_2 concentration does not lead to a proportional increase in COD removal at a reaction time of 180 minutes, regardless of leachate pH values (8, 6, and 5). This may be because H_2O_2 has not fully completed the conversion of organic carbon into inorganic carbon. This conversion process, known as partial oxidation, forms intermediate compounds that can increase COD and BOD$_5$ concentrations (Abdullah et al., 2014; Pieczykolan et al., 2012; Zhang et al., 2006). Lower COD removal can be attributed to higher ammonia concentrations. Ammonia is an inorganic compound that is difficult to oxidize (Vogel et al., 2000). In addition, the composition of the treated sample can affect chemical oxidation due to the complex matrix present. COD in leachate is affected by inorganic compounds such as Fe(II), Mn(II), sulfide, ethanol, acetic acid, ammonia, and chloride. In particular, inorganic compounds Fe(II) and sulfide can contribute to the decrease in COD (Kylefors et al., 2003).

Total Nitrogen (TN) in water bodies significantly impacts water quality. TN consists of Ammonium (NH_3), Nitrate (NO_3) and Nitrite (NO_2), resulting from the nitrogen cycle that occurs naturally. The nitrogen cycle consumes the most dissolved oxygen when compared to other biochemical reactions in water (Aswadi, 2006). The lowest TN removal rate observed was 45%, from 23,374 mg/L to 12,895 mg/L and 12,785 mg/L, respectively, with reaction times of 60 minutes and 180 minutes, an H_2O_2/COD concentration ratio of 1.0625, and leachate pH 7 and pH 5. The highest TN removal rate achieved was 69%, decreasing from 23,374 mg/L to 7,177 mg/L, with a reaction time of 180 minutes, an H_2O_2/COD concentration ratio of 1.0625 and leachate pH 7. In the treatment of domestic wastewater, the addition of H_2O_2 increased TN removal even with oxygen levels in wastewater ranging from 30 to 40%, resulting in a reduction of TN from 134 mg/L to 117 mg/L (13%) (Jóźwiakowski et al., 2007).

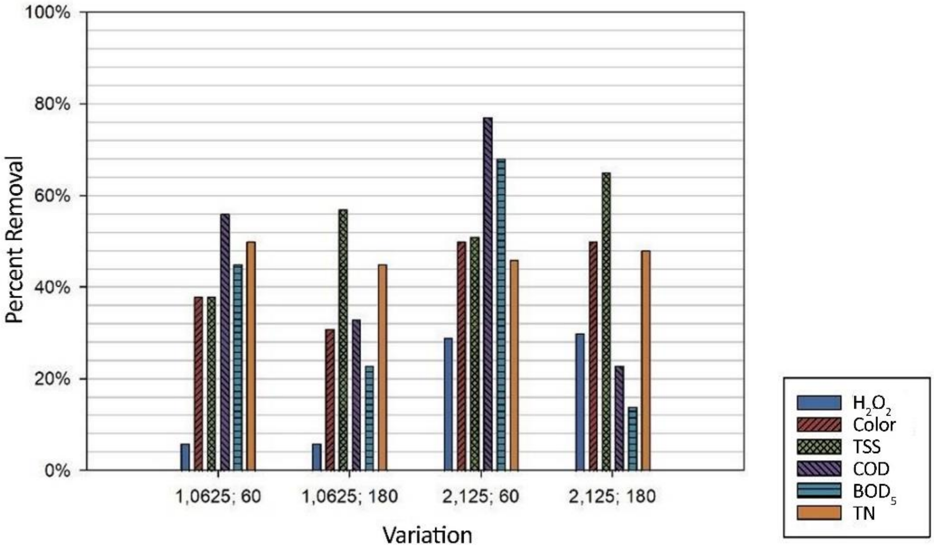

Figure 5. Effect of H_2O_2 dose and reaction time on the parameters of reacted H_2O_2, color, TSS, COD, BOD$_5$, and TN at initial pH 5

There are two mechanisms of H_2O_2 oxidation for reducing pollutants, namely direct oxidation and the provision of oxygen sources (USPTechnologies, 2022a). H_2O_2 can effectively reduce recalcitrant pollutants and alleviate the load, protecting the biological treatment process when employed in conjunction with biological treatment. Furthermore, H_2O_2 concentration can stimulate the activity of aerobic bacteria, leading to a reduction in TN, concentration, especially ammonia nitrogen. This can serve as an alternative oxygen source. TN removal, especially ammonia nitrogen, can be achieved through the nitrification process. The effectiveness of nitrification depends on various factors, including temperature, pH, organic and toxic pollutant load, and nitrogen concentration in the wastewater. However, the most critical factor is the dissolved oxygen concentration (Jóźwiakowski et al., 2007).

The presence of residual H_2O_2 in leachate can lead to an increase in the concentration of BOD_5 and COD. The increase in COD values is due to the ability of H_2O_2 to reduce $K_2Cr_2O_7$ (potassium dichromate), which can interfere with the COD analysis. $K_2Cr_2O_7$ itself is used as an oxidizing agent in COD measurement employing the dichromate reflux method (Kang et al., 1999). Furthermore, a high concentration of residual H_2O_2 in the treated leachate may indicate ineffective oxidation of pollutants by H_2O_2. The highest level of residual H_2O_2 observed was 6%, decreasing from 7,671 mg/L H_2O_2 to 7,231 mg/L H_2O_2 and 7,204 mg/L H_2O_2, with respective reaction times of 60 minutes and 180 minutes, an H_2O_2/COD concentration ratio of 1.0625, and leachate pH 5. The lowest level of residual H_2O_2 observed was 96%, decreasing from 15,342 mg/L H_2O_2 to 630 mg/L H_2O_2 and 614 mg/L H_2O_2, with respective reaction times of 180 minutes, an H_2O_2/COD concentration ratio of 2.125, and leachate pH values of 8 and 7.

$$K_2Cr_7O_7 + 3H_2O_2 + 4H_2SO_4 \rightarrow K_2SO_4 + Cr_2(SO_4)_3 + 7H_2O + 3O_4 \qquad (4)$$

Factors that affect the decomposition of H_2O_2 include temperature, pH, contaminants/catalysts, and UV light (USPTechnologies, 2022b). In addition, the initial concentration of H_2O_2 can impact its decomposition. The decrease in H_2O_2 concentration at an initial concentration of 800 mg/L is greater than the initial H_2O_2 concentration of 131 mg/L (Yazıcı & Deveci, 2011). However, the reduction observed in this study was not significant.

3.3. The influence of pH

During the treatment process, the pH of the leachate was allowed to vary with the reaction time. The pH changes resulting from the H_2O_2 oxidation reaction are documented in Table 3. Prior to the measurement of water parameters, the leachate's pH was adjusted to pH 8.

H_2O_2 exhibits stable properties in acidic conditions but becomes unstable in an alkaline environment. Alkaline conditions trigger the decomposition reaction of H_2O_2 (USPTechnologies, 2022a). As depicted in Figure 2 to Figure 5, it is evident that at a leachate pH of 8, the amount of reacted H_2O_2 is significantly higher at each reaction time, as well as in terms of the H_2O_2/COD concentration ratio. For leachate pH levels of 7 and 6, at a reaction time of 180 minutes, the amount of reacted H_2O_2 surpasses that observed at a reaction time of 60 minutes. However, leachate pH 5, the H_2O_2 reacted for 180 minutes exceeds that at 60 minutes. However, leachate with an initial pH of 5 exhibits the smallest amount of reacted H_2O_2 compared to other leachate pH levels. This is attributed to the lower initial pH of the leachate.

When observed in Table 3, it is evident that there is an increase in pH following the process. This phenomenon demonstrates that H_2O_2 functions as an oxidizer. The increase in pH occurs due to the consumption of H^+ ions by H_2O_2. Under these conditions, H_2O_2 oxidizes both organic and inorganic compounds (Bagastyo et al., 2018). When leachate, treated with H_2O_2, has an initial pH of 6 or 7 and a reaction time of 180 minutes, its pH elevates to 8, becoming alkaline. At this point, H_2O_2 undergoes a decomposition reaction, causing the concentration of H_2O_2 in the leachate to decrease rapidly, as H_2O_2 is unstable at alkaline pH. Conversely, when H_2O_2 is added to leachate with an initial pH of 5, the pH increases to 6, which remains acidic. Consequently, H_2O_2 does not decompose, as it remains stable at acidic pH. Furthermore, a higher H_2O_2/COD concentration ratio (2.125) in the leachate corresponds to a greater level of reacted H_2O_2 compared to a lower H_2O_2/COD concentration ratio (1.0625) (Evonik, 2022).

Table 3. Initial pH of leachate before and after process treatment.

pH	Reaction time	H_2O_2/COD concentration ratio	pH	
			Before process	After process
8	60	1.0625	7.90	8.01
		2.1250	7.90	7.97
	180	1.0650	7.90	8.04
		2.1250	7.90	7.97
7	60	1.0625	6.99	7.58
		2.1250	6.99	7.77
	180	1.0650	6.99	7.70
		2.1250	6.99	7.86
6	60	1.0625	6.13	6.71
		2.1250	6.13	6.76
	180	1.0650	6.13	7.60
		2.1250	6.13	7.86
5	60	1.0625	5.05	5.33
		2.1250	5.05	5.33
	180	1.0650	5.05	5.72
		2.1250	5.05	5.80

Based on Figure 2 to Figure 5, the removal rate of color, BOD_5, COD, and TSS are at a lower pH level. This is because, at lower pH levels, H_2O_2 takes a longer time to oxidize pollutants in the leachate before the pH starts to rise towards alkaline conditions. Under alkaline conditions, H_2O_2 undergoes a decomposition reaction. Furthermore, at lower pH levels, the carboxylate and phenol functional groups of humic compounds become protonated, reducing the charge of humic compounds. Therefore, organic matter removal is optimized at lower pH levels. Some organic pollutants in leachate are directly oxidized to final products (CO_2 and H_2O_2) in the process, while others are initially converted to intermediate products (such as acetic acid) before further oxidation to final products. It's worth noting that humic compounds contribute to the color of water (Abdullah et al., 2014).

4. Conclusion/summary

In this study, the optimum removal variation was determined by calculating the average removal rates for all parameters in each variation. The variation with the highest average removal rate was selected as the optimum removal variation. The variation with pH 6, H_2O_2/COD 2.125, and reaction time of 60 minutes yielded the highest average removal rate among all parameters (including color, BOD_5, COD, TSS, TN, and H_2O_2 residue), reaching 65%.

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