

Industrial wastewater treatment using venture injector type Micro-bubble Aeration as a reduction of dissolved Iron (Fe^{2+}) levels

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ABSTRACT

Water quality problems that are often encountered, especially by-product wastewater resulting from industrial processes that do not meet the requirements for wastewater quality standards. Iron levels in wastewater can cause the water to turn brownish yellow and produce an unpleasant odor, which of course has a big impact on the environment. Therefore, it is necessary to implement a treatment process to reduce the iron level in the water, ensuring that the water is safe when discharged into the environment. The purpose of this research is to analyze the initial parameters of temperature, pH, TDS, TSS, dissolved oxygen (DO) and dissolved iron (Fe^{2+}) in industrial waste water and then wanted to know whether the venture injector type micro bubble aeration process was able to increase the value of dissolved oxygen (DO) and decrease the dissolved iron content (Fe^{2+}) in wastewater and to know the micro bubble type aeration process Venture injectors are the best to use. The research was conducted with an experimental design using a completely randomized design (RAL) with two factors: air flow (2 LPM, 4 LPM, and 6 LPM) and aeration time (0 minutes, 15 minutes, 30 minutes, 45 minutes, and 60 minutes), each with two repetitions. In the results of the initial parameter analysis, the pH value was 8.02 (alkaline), the temperature value was 28°C, the TDS value was 1548.3 mg/L, the TSS value was 291 mg/L, the DO value was 0.1 mg/L and dissolved iron (Fe^{2+}) of 7.453 mg/L. After conducting research, it was found that the venture injector type micro bubble aeration process was able to increase the value of dissolved oxygen (DO) and reduce dissolved iron (Fe^{2+}) in industrial waste water, the best increase in dissolved oxygen (DO) at 6 LPM air flow for 60 minutes was able to increase oxygen dissolved (DO) to 2.40 mg/L. The most efficient and effective reduction in the value of dissolved iron (Fe^{2+}) at 6 LPM air flow with a time of 15 minutes was able to reduce the value of dissolved iron by 84.42%.

Keywords:

industry waste; iron (Fe); air flow; micro bubble; aeration; waste water treatment.

Introduction

The rapid population growth and the acceleration of industrialization, the quality of the environment is also declining due to pollution caused by waste. Based on the source, waste can be divided into household waste and industrial waste, while polluted waste can be divided into organic and inorganic pollutants (Kurratul et al., 2012). Dense settlements, imperfect sanitation, and direct disposal of industrial wastewater into the environment are the main causes of pollution, especially in the quality of water around industrial sites. Therefore, waste from industry must be treated so that it is safe and harmless, if not treated it will pollute the surrounding environment (Raimon, 2011). Industrial waste must be considered because it contains toxic chemicals, namely iron (Fe) and cobalt (Co) (Elmanfe et al., 2022; Gautam et al., 2016; Wardiyati et al., 2010).

Industrial wastewater treatment can be done physically, chemically and in combination. Before industrial waste treatment is carried out, the parameters of temperature, pH, Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Dissolve Solid (TDS) must be analyzed first. In general, industrial wastewater treatment processes can be carried out by precipitation, extraction, solvent, reverse osmosis, and membrane separation processes. However, all of these processes require large amounts of chemicals and can produce other wastes from this processing. Therefore, wastewater contains large amounts of metals, especially iron (Fe) and has a negative impact on the environment (Kurratul et al., 2012; Xu et al., 2012). Iron in the form of Ferro (Fe^{2+}) is easily oxidized with the help of oxygen in the air to become Ferric (Fe^{3+}) (Febrina & Ayuna, 2014; Venkataramani, 2021) but iron can be suspended in water with organic matter in the form of iron cations (Fe^{2+}) and ferric (Fe^{3+}) (Yazid et al., 2021). Therefore the need for modern technology that does not require large chemicals. However, the processing technology chosen must be in accordance with the technological capabilities of the community concerned (Fiksel et al., 1999; Oztemel & Gursev, 2020; Suyasa, 2015).

Considering the aforementioned issues, it is essential to conduct research related to reducing iron (Fe) levels, particularly through the application of micro-bubble aeration. The concept of micro-bubble aeration uses a pneumatic system. Removal of Fe (iron) is carried out through aeration. Most aeration systems are based on increasing the interfacial area by injecting air into the system or spraying air into the water (van de Griend et al., 2022). This process can reduce heavy metals and other contents so that they can be disposed of into river bodies. Based on research H et al. (2009) the aeration process can reduce Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) content aerobically. Aeration methods that can be applied in waste ponds are waterfall, cascade, submerged cascade, multiple plate, spray, and bubble (Agustian et al., 2023; Ghernaout, 2019). The method that is the best and can be applied is the bubble aerator because the amount of air needed to aerate the air bubbles is not much and the air volume can easily be increased through a device. The working principle of Micro-bubble aeration is aeration using fine bubbles of variable size resulting in a bubble size of 0.49 mm with an inlet air flow of 0.98 L/minute and a bubble size of 0.12 mm when the incoming air flow is 0.24 L/min, water is added into the inlet pipe by applying pressure to the water then applying air pressure into the pipe (Fan et al., 2023; Sadatomi et al., 2005). In summary, the Venture Injector Type Micro-Bubble Aeration method can significantly improve water treatment processes by enhancing oxygen transfer efficiency. This improvement leads to faster iron removal, increased purification depth, expanded production capacity, and decreased energy consumption. This can be according to the equation of conservation of mass and energy, that the velocity of the water in the outlet pipe must be greater than the velocity of the air in the inlet pipe. A previous study conducted by Sadatomi et al. (2005) stated that micro-bubbles are small air bubbles with a diameter of less than 100 μm and are characterized by high solubility in water. Then based on the research conducted by Temesgen et al. (2017) has reported that micro-bubbles are small bubbles whose size is limited from 10-50 μm . The types of micro-bubble aeration are spiral liquid flow, spherical ball, and ejector type (Lei, 2010; Rofik, 2020; Yang, 2020). The choice of ejector type in the micro-bubble process is because it uses the venture effect to convert the motive fluid pressure energy into velocity energy with low pressure. Factors that influence the increase and decrease in dissolved oxygen levels in the ejector-type aeration process are weather, water temperature, air temperature, and sunlight (Rofik, 2020).

Based on this, it can be concluded that a continuous micro-bubble aeration system can mix and efficiently react quickly to achieve increased performance in microfluidic systems, bubble diameters range from 110 μm to 220 μm . Then the selection of an accurate and precise micro-bubble aerator is very important for micromachining. In this study, a mathematical model has been developed to predict the diameter of the micro-bubble aerator tool. It is different from other studies such as conventional aeration, namely the Spray Aerator which produces bubbles with a diameter of 15-30mm (Arakawa et al., 2008).

Methods

Materials

The tools used in this study were hoses, pumps, venture nozzles, compressors, flow meters, stopwatches, reactor tanks, reservoir tanks, Dissolved Oxygen (DO) meters, pH meters, thermometers, burettes, analytical scales, pipettes, volume pipettes, filter paper, porcelain cup, and oven. The materials used in this research are industrial wastewater containing (Fe^{2+}), aquadest, KMnO_4 , sodium oxalate, H_2SO_4 , MnSO_4 .

Procedures

The research consisted of four stages: tool preparation, tool testing, research implementation, and testing of the initial sample parameters and sample parameters after the aeration process. In the tool preparation process, the design of the tool to be used for research is carried out, the design of this tool will be carried out at the industrial chemical engineering technology laboratory. Design reactor can be seen in Figure. 1.

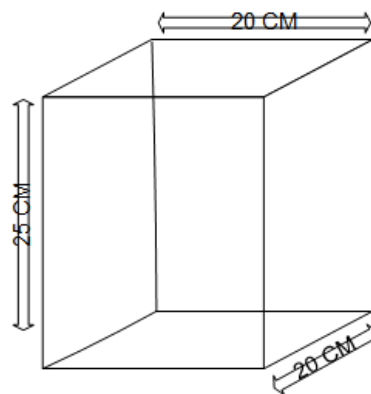


Figure 1. Design Reactor Aeration Micro-bubble

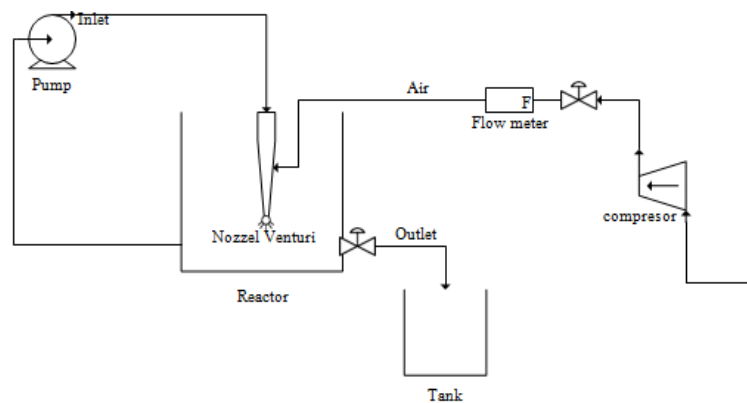


Figure 2. Flow diagram aeration micro-bubble

The reactor in Figure 1. tube which is made has a length, width, and high of 20, 20, and 25 cm, respectively, with a capacity of 10 Liters, made with acrylic material this reactor tube functions as a place for oxidation reactions to occur between wastewater and oxygen. After completing the tool design, a feasibility test is conducted to determine its readiness for research. Once the tool passes the feasibility test, an initial sample test is performed to determine the levels of DO and Fe. Subsequently, the research is conducted in three stages: the first stage involves a variation of air flow at 2 liters/minute with durations of 15, 30, 45, and 60 minutes, respectively. The second stage includes a variation of air flow at 4 liters/minute with the same time variations. Finally, the third stage consists of air flow variations at 6 liters/minute with the corresponding

time variations. After completing the research phase, samples are tested using a DO meter to determine DO content and permanganometric titration to determine Fe content in wastewater. After the research phase was completed, the samples were tested using a DO meter to determine the DO content and permanganometric titration to determine the Fe content in wastewater. Flow diagram aeration micro-bubble design can be seen in Figure 2.


In this process industrial waste water is put into the reactor tube, then the waste water will be sucked in using a pump, after that the sucked waste water is pushed towards the venture injector, this is where a fluid mechanics process occurs where the energy converts the motive fluid pressure into velocity energy which creates a low pressure zone the interesting thing is to enter the suction gas into the venture injector, but in the process this time the researcher uses the help of a compressor to be able to regulate and find out the air discharge entering the venture injector, after water and air enter the venture injector, a mixture of gas and liquid occurs in a turbulent flow creating micro-bubbles with a diameter of 40–50 μm . Wastewater that has been treated using micro-bubble aeration is then analyzed for DO, pH, temperature, and TDS.

Results and Discussions

Characteristics of Wastewater

The sample water used in this study is industrial liquid waste for which the value of the parameter content of wastewater has not been determined. To determine the value of the parameter content contained in the wastewater, an initial sample test is carried out before treatment, there are several tests of wastewater parameters including testing DO, pH, temperature, TSS, TDS, and Fe values. For the waste sample collection used in this study, the waste sample was taken from the inlet of the sewage treatment plant. The following Table 1 shows the results of the initial wastewater test.

Table 1. Analyzed initial wastewater with parameter of DO, pH, temperature, TSS, TDS, and Fe^{2+}

Parameter	Results	Waste Quality Standard	Figure
DO (mg/L)	0.100	-	
pH	8.02	6.0	
Temperature ($^{\circ}\text{C}$)	28.0	38	
TSS (mg/L)	291	200	
TDS (mg/L)	1.548,3	2.000	
Fe^{2+} (mg/L)	7,453	5	

Based on the research Table 1, there is one of the wastewater parameters that does not meet the requirements for class 1 wastewater quality standards, it can be seen in the waste sample parameter Table 1 several waste parameters meet the standards set has been established. In fact, the researcher will compare the results with the standard quality. This is similar to a previous study by Ramandani et al. (2022), which reported the comparison or contrast of product quality with standards. The pH value meets the standard parameter of 8 bases because it is not less than 6 acids. The temperature value is below the set value, namely 28°C , the set value cannot be more than 38°C , the TSS value is 291 mg/L greater than the the standard has been set at 200 mg/L, the TDS value is 1548.3 which is smaller than the standard value which has been set at 2000 mg/L, while the dissolved Fe^{2+} value has a value that exceeds the threshold which is equal to 7. 453 mg/L while the maximum group 1 threshold value is 5 mg/L. Based on several parameter values that have been obtained, the waste sample does not meet the requirements for class 1 wastewater quality standards because it has TSS and dissolved Fe^{2+} values that exceed a predetermined threshold.

Dissolved Oxygen (DO) Test Results

Dissolved oxygen (DO) is the amount of oxygen dissolved in water that comes from photosynthesis and absorption of the atmosphere/air. Dissolved oxygen in waters is very influential in the process of absorption of food by living things in water. To determine the quality of water in a waters, it can be done by observing several chemical parameters such as DO. DO value on wastewater after process aeration micro-bubble can see in Figure 3.

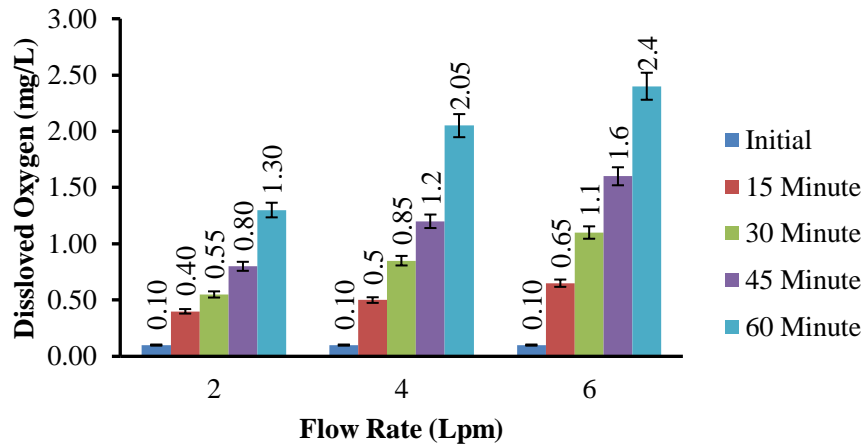


Figure 3. Analyzed dissolved oxygen (DO) in mg/L with X axis of flow rate (Lpm) and Y axis of dissolved oxygen (mg/L)

Air flow of 6 LPM with a time of 60 minutes is the best process in increasing the value of DO capable of increasing the value of DO to 2.40 mg/L, before the aeration process the value of DO is 0.10 mg/L L. In this study, the value of DO increased due to the injection of air during the aeration process. This is in accordance and modified with research conducted by (Arsawan et al., 1907).

Temperature Test Results

Temperature shows the degree of heat of an object or solution. Waste that has a high temperature will interfere with the aeration process, because it can affect the value of DO. Temperature value on wastewater after process aeration micro-bubble can see in Figure 4.

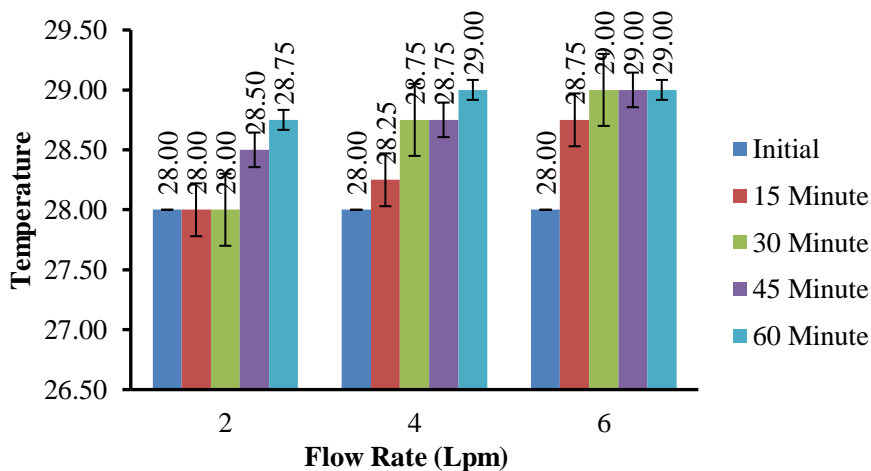


Figure 4. Analyzed temperature in Celsius with X axis of flow rate (Lpm) and Y axis of temperature.

Based on Figure 4, the initial temperature of the waste sample is 28°C, the temperature rises little by little, then at a flow rate of 2 LPM the temperature does not increase in the first 15-30 minutes. However, at 60 minutes it has increased to 28.75 °C. At a flow rate of 4 Lpm, the temperature increased to 28.75 °C in 15 minutes, and by 29.25 °C in 60 minutes. At a flow rate of 6 Lpm, the temperature increased in 15 minutes to 28.75°C, while in 60 minutes the temperature increased by 30°C.

pH Test Results

pH is the degree of acidity used to indicate the level of acidity or alkalinity possessed by a solution. Acidity or base in wastewater can be measured with a pH meter. Acidity or base is determined based on the high and low concentration of hydrogen ions in water (Ramandani, 2022). Wastewater samples that have a pH that is too high or low can disrupt the aeration process because it can damage the components of the tool. Because wastewater that has a low and high pH makes wastewater corrosive to those in contact with water. The pH value on wastewater after process aeration micro-bubble can seen in Figure 5

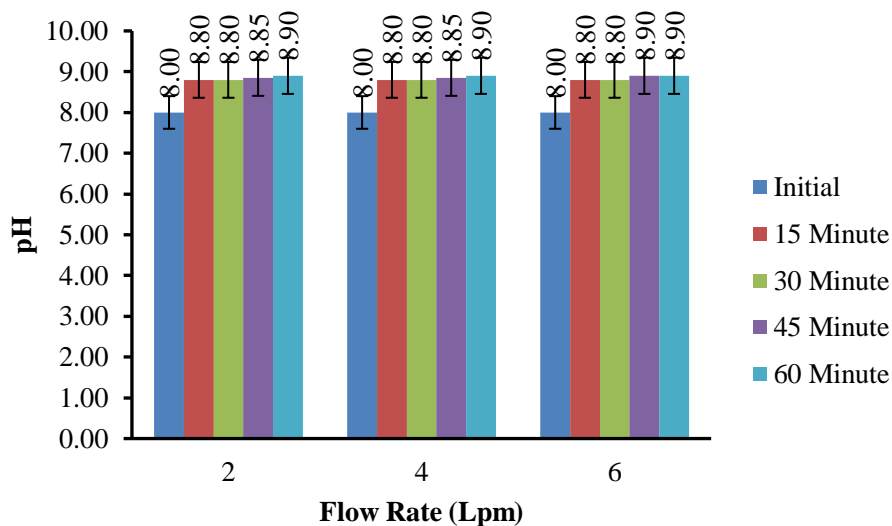


Figure 5. Analyzed pH with X axis of flow rate (Lpm) and Y axis of pH

Based on the Figure 5 at 45 minutes the pH did not increase, then at 60 minutes the pH increased to 8.90, for 60 minutes doing aeration the pH increased by 0.90. So it can be concluded that the highest increase in pH occurred at flow 2 LPM. The dissolved oxygen value correlates positively with the pH value, whereas the value of dissolved oxygen (DO) increases in the micro-bubble aeration process, the pH value also increases, of course this is very related. The pH value in water is directly related to the condition of dissolved oxygen (DO) where when dissolved oxygen is low, the pH value decreases and vice versa if the dissolved oxygen (DO) value is high, the pH value increases (Paena et al., 2015).

Total Dissolve Solid (TDS) Test Results

Total Dissolve Solid (TDS) are dissolved solids, either in the form of ions, compounds and colloids in water, the increase in TDS values can also be caused by organic matter found in waters, if the Total Dissolve Solid (TDS) increases, the hardness in the waters will increase. also increased. In this experiment, the levels of Total Dissolved Solids (TDS) were analyzed using quantitative analysis, namely the gravimetric method. As with Total Suspended Solid TSS analysis, Total Dissolve Solid (TDS) analysis is carried out in the same way. Evaporation is carried out on the solids that are not filtered or the filtered aquadest in the oven at 105°C for 1 hour. Evaporation aims to remove the water content in the filter paper and solids so that an accurate suspended

precipitate weight will be obtained. The TDS value on wastewater after process aeration micro-bubble can see in Figure 6.

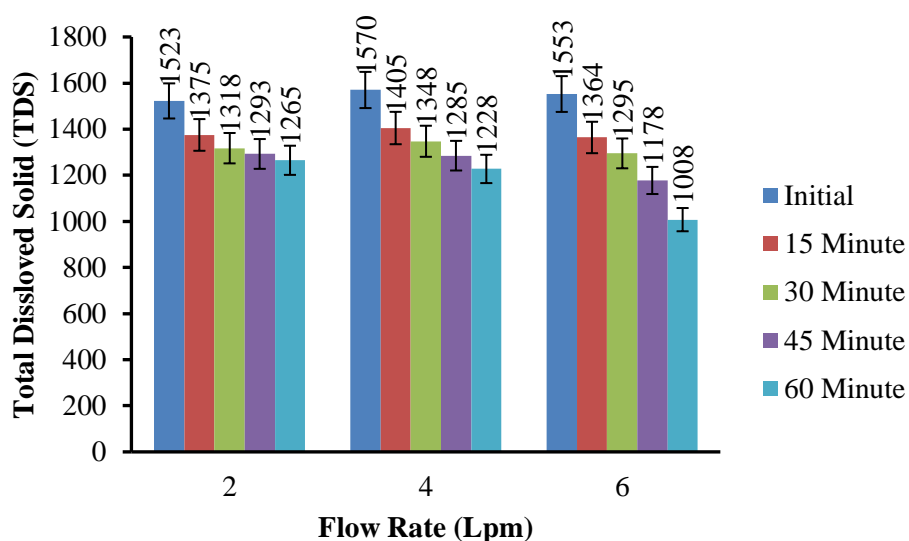


Figure 6. Analyzed TDS in mg/L with X axis of flow rate (Lpm) and Y axis of TDS

Based on Figure 6 it is known that an increase in aeration time and the amount of flow used is followed by a decrease in the value of Total Dissolve Solid (TDS) in the industrial wastewater used, where the relationship is negatively correlated. In the initial sample, with an air flow of 2 LPM, the Total Dissolved Solids (TDS) value was 1523 mg/L. After aeration for 60 minutes, the TDS decreased. At 15 minutes, it decreased to 1375 mg/L, then at the 30th minute, it further decreased to 1318 mg/L. In the 45th minute, it decreased to 1293 mg/L, and finally, in the 60th minute, the TDS decreased to 1265 mg/L. For the initial sample with an airflow of 4 LPM, the Total Dissolved Solids (TDS) value was 1570 mg/L, and after aeration for 60 minutes, the TDS value decreased. Then seen in Figure 6 the value of dissolved oxygen (DO) is negatively correlated with the value of Total Dissolve Solid (TDS), where by increasing the value of dissolved oxygen (DO) in the micro-bubble aeration process, the value of Total Dissolve Solid (TDS) decreases this is due to dissolved oxygen (DO) produced during the micro-bubble aeration process reacts with ions, one of which is dissolved iron (Fe^{2+}) to form $Fe(OH)_3$ in the form of an insoluble precipitate, so that the Total Dissolve Solid (TDS) value decreases (Nicola, 2015).

Total Suspended Solid (TSS) Test Results

Total Suspended Solid (TSS) is the amount of solids retained on the filter with a pore size not larger than $2\mu m$. Suspended solids in water in the form of organic and inorganic materials that can be filtered using filter paper, filtered solids have a negative impact on water quality because they reduce the penetration of sunlight into the water, increased turbidity can cause disruption to the growth of organisms in breaking down organic matter organic matter. Analysis of Total Suspended Solid (TSS) using the Gravimetric method. The principles of the gravimetric method are weighing, evaporation and isolation processes. The TSS value on wastewater after process aeration micro-bubble can see in Figure 7.

Based on Figure 7, it is known that the increase in aeration time and the amount of flow used is followed by an increase in the Total Suspended Solids (TSS) value in the wastewater sample. The relationship is positively correlated, indicating that the longer the aeration process is carried out, the Total Suspended Solids (TSS) value increases. In the graph above, it is known that the increase in Total Suspended Solid (TSS) value at 2 LPM air flow has an average increase of 44 mg/L every 15 minutes, with an initial sample of 255 mg/L experiencing an increase in the 15th minute to 308 mg/L , 30th minute to 348 mg/L, 45th minute to 378 mg/L then 60th minute

to 433 mg/L, then at flow 4 LPM has an average increase of 51 mg/L every 15 minutes, with initial sample of 260 mg/L increased in the 15th minute to 330 mg/L. It can be seen in the Figure 7 that the relationship between dissolved oxygen (DO) and Total Suspended Solid (TSS) values has a positive correlation, whereas dissolved oxygen (DO) increases, the TSS value also increases. The increase in Total Suspended Solid (TSS) value in this study was due to the injection of incoming air during the micro-bubble aeration process, so that the dissolved oxygen value increased and reacted with the ions present in the water sample, one of which was Fe^{2+} ion which reacted to form an insoluble precipitate, namely $Fe(OH)_3$, so that the Total Suspended Solid (TSS) value has increased (Nicola, 2015).

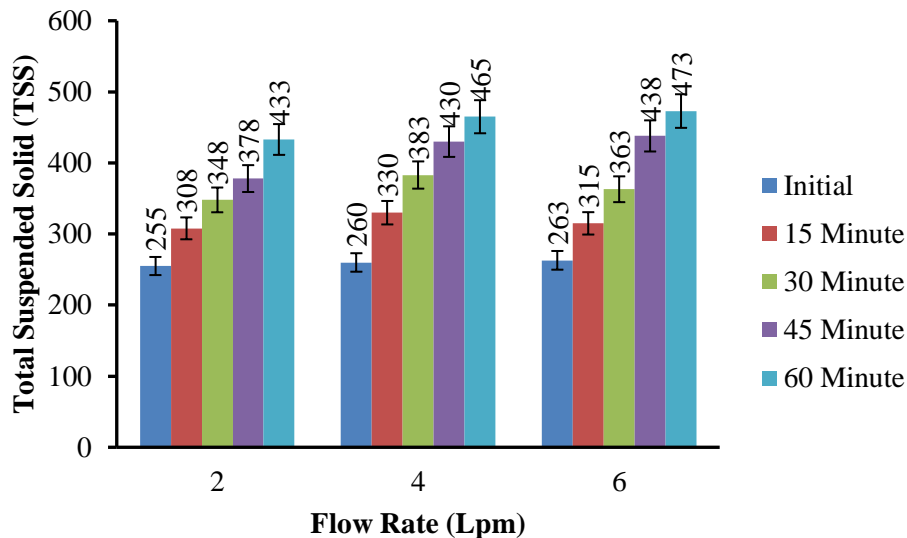


Figure 7. Analyzed TSS in mg/L with X axis of flow rate (Lpm) and Y axis of TSS

Dissolved Iron (Fe^{2+}) Test Results

Iron is a metal produced from iron ore, and is rarely found in free form, to obtain elemental iron, other mixtures must be separated through chemical decomposition. Water that is high in iron content when in contact with air becomes cloudy, smells and is unpleasant to consume. The allowable concentration of dissolved iron in clean water is up to 1.0 mg/l. If the concentration of dissolved iron in water exceeds this limit it will cause various problems (Joko, 2010). Testing for dissolved iron (Fe^{2+}) was carried out using the Permanganometric method, permanganometric is a titration method using potassium permanganate, which is a strong oxidizing agent as a titrant. This titration is based on reduction and oxidation or redox titrations. Permanganometry can also be used to determine the levels of sulfur, nitrite, phosphate, and so on. This permanganometric titration method is widely used in analyzing organic substances. Potassium permanganate has been used as an oxidizer widely for more than 100 years. These reagents are easy to obtain, inexpensive and do not require indicators unless very dilute solutions are used. The permanganometric titration was carried out with the help of heating ($\pm 70^{\circ}C$) to speed up the reaction. The Fe^{2+} value on wastewater after process aeration micro-bubble can see in Figure 8.

Based on the Figure 8 it is known that the dissolved iron value decreases with the addition of air flow and the length of time used, where the relationship between time and flow is negatively correlated, the longer the time and the additional amount of air flow used, the dissolved iron (Fe^{2+}) value decreases. It can be seen in the graph that 2 LPM air flow can reduce dissolved iron (Fe^{2+}) levels by 5.90 mg/L or 79.43% for 60 minutes, in the initial sample it has a dissolved iron (Fe^{2+}) value of 7.431 mg/L in minutes the 15th minute decreased to 3.112 mg/L then in the 30th minute it decreased to 2.091 mg/L, in the 45th minute it decreased to 1.811 mg/L then in the 60th minute it decreased to 1.529 mg/L in the 15th minute the decrease in dissolved iron levels

(Fe²⁺) was very drastic at 4.31 mg/L, 609 mg/L the most significant decrease was in the 15th minute of 6.36 mg/L, after looking at the graph above it can be said that the most efficient reduction in dissolved iron (Fe²⁺) occurred in the first 15 minutes in each flow used. This is because at the beginning of aeration the value of dissolved iron (Fe²⁺) has a high concentration so that it has denser particles which results in collisions between molecules of greater intensity occurring and the reaction will run faster. Among the air flows used, 6 LPM air flow was the most effective for reducing dissolved iron (Fe²⁺) levels.

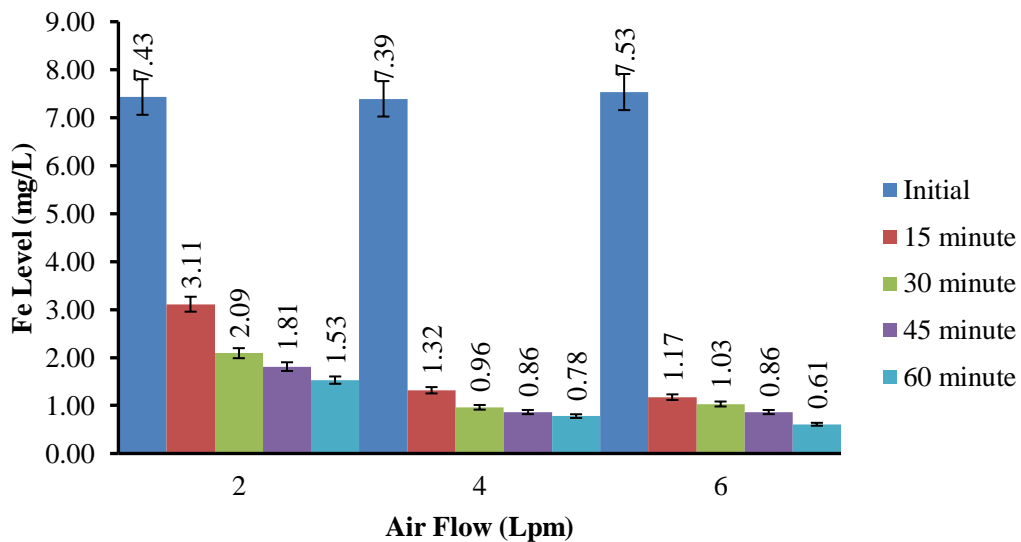


Figure 8. Analyzed Fe²⁺ in mg/L with X axis of flow rate (Lpm) and Y axis of Fe²⁺ level

Conclusion

From the previous discussion, the effect of venture injector type micro-bubble aeration on decreasing levels of dissolved iron (Fe²⁺) can be concluded from the results of the initial parameter analysis that has been carried out with a pH value of 8.02 (alkaline), a temperature value of 28°C, a TDS value of 1548,3 mg/L, TSS value of 291 mg/L, DO value of 0.1 mg/L and dissolved iron (Fe²⁺) of 7.453 mg/L. The venture injector type micro-bubble aeration process is able to increase the value of dissolved oxygen (DO) and decrease dissolved iron (Fe²⁺) in industrial wastewater. The most significant increase in dissolved oxygen (DO) occurred at 6 LPM airflow for 60 minutes, raising the dissolved oxygen (DO) level from 0.1 mg/L to 2.40 mg/L.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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