Effect of Cascade Aerator Height and Flow Rate on Removal of Iron and Manganese from Groundwater at Rumah Nur Kasih

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Abstract. The quality of groundwater at Rumah Nur Kasih consist high concentration of iron (6.12 mg/L) and manganese (0.56 mg/L). The groundwater only used for external usage such as cleaning purposes. In order to reduce iron and manganese, it is proposed cascade aerator system for oxidation process. The oxidation process can reduce iron and manganese in water by increasing the dissolved oxygen. Cascade aerator is greatly influenced by the flow rate along the step and the dimension of the cascade aerator. In this study, two lab scale cascade aerators with different in height of cascade were used to find the highest removal of iron and manganese. It was found out that the optimum flowrate for both cascade aerator was 22 ml/s. Model B with higher in height has higher dissolved oxygen and removal efficiency. The removal of iron and manganese for model B are 45.2% and 21.68% respectively. The removal of iron and manganese for model A are 39.95% and 12.09% respectively.

1. Introduction
Groundwater comes into contact with the solid materials that dissolve it within the aquifer, releasing their constituents, including Fe and Mn, to the water. Excessive amount of these two heavy metals often cause clogging of pipelines, bad taste, odour and colour of the water [1]. The quality of groundwater at Rumah Nur Kasih consist high concentration of iron (6.12 mg/L) and manganese (0.56 mg/L). The groundwater only used for external usage such as cleaning purposes.

There are several methods that are proven to be able to remove iron and manganese effectively. However, the most important criteria in selecting the suitable treatment for Rumah Nur Kasih is the
treatment that has lowest cost and efficient in order to avoid high operating cost for the orphanage’s house.

Cascade aerator system is a well-known method that can efficiently increase the concentration of oxygen inside the water flow. This system also regarded as a low-cost system because of the simple procedure to be engineered and does not required extra maintenance [2]. The mechanisms behind cascade aerator system are the strong water turbulent occurs after a series of steps from near the crest to the toe, large residence time and the air bubble entrainment. The turbulent variations cause the entrainment of air bubbles when the kinetic energy exceeds both the forces of gravity and the surface tension. This is to ensure the turbulent velocity normal is greater than bubble rise velocity in order for the bubbles to be carried away [3].

The performance of the cascade aerator is linked with the aeration efficiency produce after each step inside the cascade aerator system. The geometry of the cascade which primarily the step height is believed to influence the performance of cascade aerator. Another string influence into the performance of cascade aerator is the flow rate. Flow rate in cascade aerator measures the amount of volumes flows along the cascade aerator. The higher flowrate indicates the greater velocity of water entering the cascade aerator system. Therefore, the suitable height of cascade aerator and optimum flow rate need to be determined in order to obtain the highest removal of iron and manganese from groundwater through aeration process.

2. Experimental

2.1 Material

Synthetic solution of iron and manganese were used in two separate experiments. Two model of cascade aerator prototype (Model A and Model B) with different dimension, flow rate sensor, measure the concentration of iron and manganese using Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OE) and YSI Multi-meter to measure the dissolved oxygen produce (DO).

2.2 Effect of Flow Rate

Four values of flow rates (15 ml/s, 18 ml/s, 22 ml/s and 25 ml/s) were used in the aeration process with the aim to find the optimum flow rate in both Model A and Model B. The optimum flow rate will be determined by measuring the highest dissolved oxygen (DO) differential produce between primary water tank and the second water tank after the aeration process and calculated based on Equation 1:

\[ \text{DO Efficiency} (\%) = \frac{C_d - C_u}{C_u} \times 100 \]  

(1)

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where \( C_d \) is the concentration DO (mg/L) at downstream and \( C_u \) is the concentration DO (mg/L) at upstream. The test was repeated four times to find the optimum flow rate.

2.3 Effect of Cascade Height

The effect of cascade height was tested using the optimum flow rate value obtained from previous experimental. In this study, two types of cascade aerators with different dimension were used. The dimension for both models is shown in table 1 based on the schematic diagram of the cascade aerator in Figure 1. The lab scale cascade aerator model used for this study is shown in Figure 2. The result for this experimental was determined by measuring the removal efficiency from both cascade aerator based on Equation 2.

\[ \text{Removal Efficiency} (\%) = \frac{c_f - c_i}{c_i} \times 100 \]  

(2)
where \( C_f \) in mg/L is the final concentration of sample and \( C_i \) in mg/L is the initial concentration of sample.

### Table 1. Dimension for prototype cascade aerator.

| Model | Height of cascade aerator (Hc) | Height of step (Hs) | Length of cascade aerator (Lc) | Length of step (Ls) | Angle of inclined (°) |
|-------|-------------------------------|---------------------|-------------------------------|---------------------|----------------------|
| A     | 727                           | 114                 | 1530                          | 300                 | 16                   |
| B     | 865                           | 160                 | 1530                          | 300                 | 22                   |

![Figure 1. Schematic Diagram for Cascade Aerator Dimension.](image1)

*Figure 1. Schematic Diagram for Cascade Aerator Dimension.*

![Figure 2. Lab Scale Cascade Aerator Model B used in this study.](image2)

*Figure 2. Lab Scale Cascade Aerator Model B used in this study.*
3. Results and Discussions

3.1 Effect of Flow Rate
The results for this experiment were illustrated in Figure 3 and Figure 4. Based on both figures the flow rate in the cascade aerator has major impact on the concentration of DO produced. The increased of flow rate means the increasing of velocity entering the cascade aerator which increases shear between gas and liquid phases thus, increases the energy dissipation rate allowing smaller bubbles to be formed. The interface area for mass transfers is therefore increasing [4]. Higher water flow rate will signify that the water in the cascade moves at higher velocity and increased speed, resulting in further bulk liquid acceleration and turbulence in each step [5, 6]. Therefore, from both models, it was observed that increasing of flow rate has increased the DO efficiency in the four groundwater samples. However, further increasing of flow rate after 22 ml/s, the DO efficiency has decreased. The explanation behind this situation would be because of phenomenon called ‘Bubble Coalescence’ where bigger bubbles which more buoyant were formed. These bubbles will move upward rapidly hence decreasing the residence time for mass transfer [6, 7]. Therefore, the optimum flow rate for both models is 22 ml/s. Further increasing of this flowrate will decrease the DO efficiency in cascade aerator.

![Figure 3. Do Efficiency Against Flow Rate in Cascade Aerator Model A.](image)

![Figure 4. Do Efficiency Against Flow Rate in Cascade Aerator Model B](image)
3.2 Effect of Cascade Aerator Height

From Figure 5, it shows the removal of iron and manganese in Model B with higher height has greater value compared to Model A. The removal efficiency of iron in Model B is 45.20% which is from 6.395 mg/L to 3.505 mg/L. For Model A, the removal efficiency of iron is 39.95% which is from 6.327 mg/L to 3.799 mg/L. Model B has higher removal efficiency as the height of the cascade aerator helps to increase the aeration efficiency which means there are higher amount of DO inside Model B compared to Model A. This available oxygen helps to oxidize iron thus reduce the concentration inside the water.

For removal of manganese, Model B manages to remove 21.68% which is from 0.610 mg/L to 0.478 mg/L. Model A manages to get removal of 12.09% which is from 0.541 mg/L to 0.475 mg/L. This proves that higher aeration efficiency produce from cascade aerator helps to increase the removal of heavy metals. By comparing the percentage removal of iron and manganese, it can be seen that the removal of manganese is lower than iron. This result proved the chemical equation of 2.1 and 2.2 which stated that manganese needs double amount of oxygen compared to iron. The rate of reaction for manganese is slower than iron.

![Figure 5](image.png)

**Figure 5.** Removal Efficiency of Iron and Manganese in Cascade Aerator Model A and B.

4. Conclusions

As a conclusion, the performance of aeration by cascade aerator is highly depending on the flow rate and dimension of the cascade aerator. In flow rate part, the rate of aeration is increasing with increasing of flow rate thus higher available oxygen is formed for oxidation of iron and manganese. However, after reaching optimum flow rate, further increasing of flow rate value will result in decreasing of dissolved oxygen. For this study, the optimum flow rate is 22 ml/s. In cascade aerator height, the higher height provides higher removal efficiency for both iron and manganese. The height of cascade aerator and the height of the step greatly affect the aeration efficiency thus contributed to the removal of iron and manganese. For this study, Model B has better aeration compared to Model A.

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