Removing Iron and Manganese by Using Cascade Aerator and Limestone Horizontal Roughing Filters

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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 and horizontal roughing filter using limestone as the media for further removal. The oxidation process can reduce iron and manganese in water by increasing the dissolved oxygen. Meanwhile, the filtration by various size of the limestone can help to reduce the concentration of heavy metals as these limestones able to adsorp heavy metals into theirs surface. 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 22mL/s. Model B with higher in height has higher dissolved oxygen and aeration efficiency. The highest removal of iron and manganese for model B are 45.2% and 21.68% respectively. The highest removal of iron and manganese for model A are 39.95% and 12.09% respectively. Three different sizes of limestone were filled into horizontal bed filtration for further removal. The adsorption of these limestone was observed and the smallest range of the limestone has the highest removal for both iron and manganese. The optimum sizes of the limestone are 0.425mm – 2.35mm with removal of 82.75% for iron and 56.78% for manganese.

1. Introduction

Groundwater in Malaysia accounts for over 90% of the country’s water resources and is spatially distributed all over the country. Due to the huge economic and infrastructural development in the country’s growth within the last three decades, there has been an increase in freshwater demand [1]. The country’s groundwater demand has been estimated to rise by 63% from 2000 to 2050 [2], particularly as an alternative water source in the urban areas. Groundwater extracted from shallow dug wells is used for daily consumption among the rural populations. However, groundwater may or may not be suitable for direct use. Its quality has to be monitored to ensure its suitability for human consumption. Water used for cooking, drinking or other domestic uses should be potable, palatable and aesthetically appealing. Hence, the Ministry of Health (MOH), Malaysia has drawn up guidelines, namely National Drinking Water Quality Standard [3], that are applicable to water treatment plants to ensure that safe and wholesome drinking water is supplied to the consumer.
The most common type of water quality problems of groundwater sources, particularly wells, is the excessive amount of iron and manganese, which causes bad taste, undesired color, clogging of pipelines and other operational problems [4]. Iron and manganese are naturally-occurring metals that can be found in soils and rocks in the aquifer. These metals can dissolve when groundwater comes in contact with these soils or rocks. Iron and manganese can usually be found in groundwater as divalent ions; Fe$^{2+}$ and Mn$^{2+}$, and are considered as contaminants due to their organoleptic properties. The drinking water standard limits for iron and manganese set by WHO (World Health Organization) is 0.3 mg/L and 0.1 mg/L respectively [5]. These limits are similar to the limits set by the Ministry of Health, Malaysia.

In an effort to provide water suitable for use at Rumah Nur Kasih, a 15 meter-deep tube well was constructed by Universiti Sains Malaysia (USM) [6] to extract groundwater to be used as an alternative water supply to help lower the orphanage home’s operating cost. The groundwater at Rumah Nur Kasih was found to contain concentrations of iron and manganese above the drinking water standard, which render it unsuitable for domestic consumption. Iron and manganese are common groundwater contaminants that are not health threatening. However, their presence in water resulted in staining and objectionable tastes and appearances.

Removal of iron and manganese from groundwater can be accomplished in several ways but for the treatment of groundwater at Rumah Nur Kasih, the method should strive to be as simple as possible, without incurring high operational cost. Most methods, such as electrocoagulation, ion exchange, dissolved air flotation (DAF), adsorption, membrane filtration and coagulation-flocculation require high capital and operating costs. The coagulation-flocculation process generates sludge, which requires extra operational cost for sludge disposal as well as expertise in sludge management. Due to the risk of fouling and rapid clogging, ion exchange is not recommended for removing large concentrations of iron and manganese. Membrane filtration process is not recommended as well due to its complex operation, low permeate flux and membrane that is prone to fouling.

The most commonly applied method to remove iron and manganese from groundwater would be the oxidation-filtration processes. A low-cost method of oxidation used in water treatment process for groundwater would be aeration, which is a relatively simple process and does not require the use of chemicals. It is often sufficient with aeration and filtration to lower the levels of iron and manganese to acceptable levels. The quality of groundwater from the existing tube well could be further improved through the aeration process by increasing the air entrainment/mass transfer of oxygen using cascade aerator. The secondary treatment that is filtration will used limestone as the media to filter and adsorp the heavy metal inside the groundwater. Therefore, in this study, the suitable cascade and bed filtration media will be observed to remove the highest amount of iron and manganese.

2. Experimental

2.1. Sampling and Characteristic
Sampling and characteristic test were conducted into two ways which were in-situ (at Rumah Nur Kasih) and laboratory. Dissolve oxygen (DO), pH and temperature were measured at site using YSI Probe meter. 10L of groundwater sample was taken back to the Environmental Laboratory Universiti Sains Malaysia. Several tests were tested using the sample included, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Iron and Manganese concentration using Inductively Coupled Plasma (ICP) and Atomic Absorption Spectroscopy (AAS). All of these tests conducted to observed the groundwater characteristic at Rumah Nur Kasih and to classify the level of groundwater accord to the National Water Quality.

2.2. Aeration Study
Two types of cascade aeration were used in this study. These cascades were different in height and angle of slope but same in length. Model B has higher height which was 865 mm while model A is 727 mm. 100 L of groundwater sample was taken from Rumah Nur Kasih and taken the initial value
for both Iron and Manganese Concentration. The groundwater was filled into 100L water tank and was pumped into the cascade aerator using submerged. The flow of the water was controlled using the valve at the cascade. Four values of flows were used which were, 15 ml/s, 18 ml/s, 22 ml/s and 25 ml/s. The flowrate was validate using Ardunio Flow sensor which detect the flowrate value along the cascade aerator. The optimum value of flow was obtained by observing the highest increasing of dissolved oxygen inside the cascade aerator.

2.3. Preparation for Limestone Horizontal Roughing Filter
Limestone was choosed as the media because of its ability to adsorp heavy metals. In this study, three different ranges of sizes were observed which 0.425 mm – 2.35mm, 3.35 mm – 10.00 mm and 10.00 mm – 20.00 mm. Sieve analysis were conducted to find the average size for these limestone. Then, all of these limestone were filled into the horizontal roughing filter which was same size for all the limestone. This horizontal roughing filter was the secondary treatment after the aeration process.

2.4. Removal of Iron and Manganese
The removal of iron and manganese was measured by measuring the initial, middle and final concentration. The middle concentration was the removal by aeration of cascade aerator while the final concentration was the removal by filtration of limestone horizontal roughing filter. In this test, synthetic solution of iron and mangese was mixed with 100L of ionized water. The concentration of iron and manganese was based on the sample characteristic value. In the aeration part, constant flowrate was chooses in the cascade aerator based on the optimum flowrate result. Dissolved Oxygen (DO) was measured at the first step of cascade and set as initial value of DO while the final value of DO was measured at the fourth step of the cascade. 24 samples of DO were measured for both cascades to calculate the DO efficiency. 6 samples of synthetic solution were collected at the middle water tank to measure the concentration for the middle value using ICP. The aeration efficiency, $E_{20}$ was calculated for the entire test. For filtration part, the middle value was the initial value and the third water tank was the final concentration value. Water was pumped from the second water tank using the perilstatic pump into the horizontal roughing filter. Water flow slowly passing through the limestone media and filled into the third water tank. Removal efficiency was calculated to find the best media size for this study. The optimum condition for removal of iron and manganese was validate using the measurement by AAS.

3. Results and Discussions

3.1. Groundwater Characteristic
The groundwater characteristic was compared with the National Water Quality to evaluate the standard of the groundwater. The summary of the findings was shown in table 1.

| Characteristic                  | Average Value | Standard Class I | Standard Class IV |
|--------------------------------|---------------|------------------|-------------------|
| Iron (mg/L)                    | 6.12          | 0.3              | 1                 |
| Manganese (mg/L)               | 0.56          | 0.1              | 0.2               |
| Dissolved Oxygen (mg/L)        | 7.2           | > 7.0            | < 3.0             |
| Biochemical Oxygen Demand (mg/L)| 11.01         | < 1.0            | 6.0 – 12.0        |
| Chemical Oxygen Demand (mg/L)  | 69.0          | <10.0            | 50.0 – 100.0      |
| pH                             | 6.5           | 6.5 – 8.5        | 5 - 9             |
| Temperature (°C)               | 27.7          | -                | -                 |

Table 1. Groundwater characteristic at Rumah Nur Kasih, Taiping Perak.
From the table 1, only two characteristic are within the acceptable range for Standard pH. and I (drinking water) which are dissolved oxygen. Other characteristic are within the value for Standard IV (irrigation) which are BOD and COD. However, the concentration of Iron and Manganese exceed the maximum value for Standard IV. These values indicate that the usage of groundwater at Rumah Nur Kasih is prohibited for any usage. The treatment for the removal of these heavy metals is essential before the groundwater can be used for any purpose.

3.2. Aeration by Cascade Aerator

Four values of flowrate were tested for both model of cascade aerator to find the optimum flowrate that can used as constant value for aeration part. The flowrate with highest increasing in dissolved oxygen indicated as optimum flowrate. The result for Model A is shown in figure 1. From the figure, the increase in water flow rate increases velocity in the cascade aerator, which increases the shear between both gas and liquid phases. This increases the energy dissipation rate that causes the generation of smaller bubbles/droplets. Hence, the interfacial area for mass transfer increases.

Higher water flow rates would indicate that the water entering the cascade aerator has a higher velocity and greater momentum, causing more bulk liquid movement and turbulence in the receiving tank. Hence, it was observed that, as the flow increases from 15 ml/s to 22 ml/s, the dissolved oxygen efficiency increases rapidly.

![Figure 1. Optimum flowrate for Model A cascade aerator.](image)

However, dissolved oxygen efficiency decreased with increasing flow rate after a maximum was reached. This observation was a result of an increase in water velocity that presumably, caused gas bubbles to coalesce. Bubble coalescence leads to increase in buoyant force and hence bubbles move upward rapidly, decreasing its residence time for mass transfer. Therefore, 22 ml/s is the optimum flowrate for the cascade aerator.

3.3. Sieve Analysis

Sieve analysis involved with three different range sizes of limestone with the aim to find the average size ($d_{10}$). The average size was obtained based on the graph plotted of percentage passing against the
limestone size. Example of the graph for limestone range 0.425 mm – 2.35mm is shown in the figure 2.

![Figure 2. Sieve analysis result for limestone Type A (0.425 mm – 2.35mm).](image)

Based on the figure 2, the average size for limestone Type A (0.425 mm – 2.35mm) is 0.78 mm. Others sieve analysis show that the average size of limestone Type B (3.35 mm – 10.00 mm) and Type C (10.00 mm – 20.00 mm) are 4 mm and 11.20 mm respectively.

### 3.3.1. Aeration and Removal Efficiency

The aeration efficiency, $E_{20}$ was calculated for the cascade aerator process which from initial to middle tank. Model B which has higher in height of cascade step has higher aeration efficiency for both iron ($0.35 – 0.40$) and manganese ($0.058 – 0.096$) compared to model A.

The higher height increase the potential force, decrease the pressure of the water thus increase the velocity and the formation of bubbles. Furthermore, the increasing of the cascade height has increased the rate of energy dissipation. As the rate of energy dissipation and the aeration efficiency has the linear relationship, Model B has produced greater volume of dissolved oxygen.

From the result also shows that the aeration efficiency for iron is greater than manganese. This is due to the chemical reaction and the rate of reaction for iron is faster than manganese. The ratio for oxygen to iron is 1:1 while oxygen to manganese is 2:1. Thus, the aeration efficiency for iron is greater than manganese.

As the aeration and removal efficiency has a linear relationship, the results shows that the removal of iron and manganese is greater in Model B compared to Model A. The greater number of bubbles has helped to remove higher number of iron and manganese along the jump at each of the steps in the cascade aerator. The highest removal of iron in Model B is 45.20% while Model A is 39.95%. Meanwhile for manganese, the removal in Model B is 21.68% while for Model A is 12.09%.

The removal efficiency for the filtration part was calculated based on the concentration of iron and manganese at middle tank against the end tank which after passing through the horizontal roughing filter. Limestone type A that is the smallest average size record the highest removal for both iron and manganese which 82.75% and 56.78% respectively. The removal of iron and manganese for limestone type B is 75.895 and 35.70% respectively. Total removal of iron using cascade aerator model B and limestone type A is 89.69% which from concentration of 6.278 mg/L to 0.647 mg/L. For manganese, the highest total removal is 66.15% which from 0.610 mg/L to 0.206 mg/L. Based on these value, the objective to remove iron and manganese is achieved but the lowest concentration for both iron and manganese still do not meet the Standard I which for water supply (drinking). The treatment water can be used for other purpose such as for bathing or laundry as most of the iron and manganese had been removed.
4. Conclusions
From this research, there are several conclusions can be concluded which are;

i. Only DO and pH of the groundwater meet the requirement for drinking water quality. Manganese and Iron are considered high which can give negative effect for the user. Therefore, the groundwater need to undergo treatment before can be supply to the user at Rumah Nur Kasih.

ii. The optimum flowrate for cascade aerator is 22 ml/s. Besides, the optimum design for cascade aerator is model B which has higher height of step and height of cascade aerator (165 mm, 865 mm).

iii. Optimum size of limestone which has highest removal of iron and manganese is Rock Type A (0.425 mm – 2.35 mm).

iv. Lowest concentration of iron after treatment is 0.647 mg/L while manganese is 0.206 mg/L. Both values still do not meet the requirement for Standard I.

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