Study of Performance Aeration Rate Effects on Iron and Manganese Removal in Groundwater Using Gravitational Aeration Tower System (GATS)

E Z Radzi1, F N Ngimran3, R Hamdan3, M S Wahab1*, M Z Sahdan2, A Madun3

1 Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia.
2 Faculty of Electric and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia.
3 Faculty of Civil Engineering and Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia.

E-mail: saidin@uthm.edu.my

Abstract. Groundwater is one of the significant sources for water supply for various purpose. However, it is easier to get in contact with contaminants such as iron and manganese. Iron and manganese contaminant can be treated by aeration process before geto post-filtration system. The aeration process as pre-treatment has done it by using Gravitational Aeration Tower System (GATS). The aeration performance in this experiment has controlled the airflow and water flowrate to observers iron and manganese removal from groundwater than compare the water quality based on the guideline National Drinking Water Quality Standards by Ministry of Health Malaysia. The study has been carried out at the existing tube well in the Research Centre for Soft Soils (RECESS), Universiti Tun Hussein Onn Malaysia (UTHM). The system started from pumping out the groundwater from the tube well and flows it through GATS with a different flow rate of 5.0 L/min and 10.0 L/min, and an airflow rate 0.5 L/min and 1.5 L/min. The sampling of groundwater was taken at before and after the aeration process through GATS and analyze the parameter such as pH, dissolved oxygen (DO), iron and manganese. The results show that pH was in the range of 6.90 to 7.01 and the DO value before GATS maximum is 3.64 mg/L but after aerated with GATS is 6.67 mg/L. Hence, the maximum iron removal efficiency is 10.63%, and the maximum manganese removal efficiency is 14.25%. Aeration process by GATS shows that suitable for DO value increasing than can remove iron and manganese in groundwater.

Keywords: groundwater, iron, manganese, Aeration, Gravitational Aeration Tower System (GATS)

1. Introduction
Groundwater is a reliable source of clean water that is available to the point of consumption, making it an ideal source for the demand potable water in urban areas [1]. Groundwater might also be used as drinking water and is essential for human consumption where it depends on several factors such as physical activities, health issues, ages, and environmental conditions. It must be clean, free from any impurities and drinkable without any side effects. Also, the quality of drinking water must be safe for
consumption without causing any harm [2]. The contaminated groundwater cannot be a take for drinking purpose as a high concentration of heavy metals such as iron and manganese because can lead to serious public health [3]. Therefore, purification of contaminated groundwater is essential since many people use it for drinking purpose. Previous study about the quality of groundwater in the Research Centre for Soft Soils (RECESS) in Universiti Tun Hussein Onn Malaysia (UTHM) had conducted. However, the method currently used have not been able to remove unwanted heavy metals [4].

The cleaning of contaminated groundwater is not as easy as surface water due to its location, which, makes it difficult and expensive as it needs further exploration from underground. One of the methods to minimize the difficulties is to provide the pre-treatment process, which is portable aeration, and it can be conducted on-site to test the parameters presents in the groundwater. Therefore, the objectives of this paper are to study the performance of Gravitational Aeration Tower System (GATS) at different aeration rate performance for iron and manganese removal from groundwater and than compare the drinking water quality based on the Drinking Water Quality Standards by Ministry of Health Malaysia.

The contamination of groundwater in RECESS is caused by layers of sediment and fossil from tidal sea centuries ago [5]. Heavy metal induces the contaminants in groundwater resource where it relies on the concentration in the environment [6]. Excessive iron may be present in groundwater or can occur due to the corrosion of iron pipes [7]. Iron usually exist in the form of ferrous [8]. Other than that, manganese is a naturally occurring and abundant element that is essential in biological systems in the form of manganous. The contamination of manganese in the groundwater caused by leached from overlying soils and minerals in underlying rocks as well as from the minerals of the aquifer [9]. Manganese usually exists in the form of manganous bicarbonate [8]. Since most of the groundwater contamination problems come from heavy metals such as iron and manganese, several treatments can be conducted especially for the removal of iron and manganese such as aeration. The concept of aeration is bringing in water and air in close contact to remove dissolved gases such as carbon dioxide and oxidizes metals such as iron and manganese, hydrogen sulphide and volatile organic chemicals (VOCs) [10]. The equation for the oxidation reaction of ferrous bicarbonate shown in equation (1.1) and the oxidation of manganous bicarbonate shown in equation (1.2) below,

$$4\text{Fe} (\text{HCO}_3)_2 + \text{O}_2 + 2\text{H}_2\text{O} = 4\text{Fe(OH)}_2^- + 8\text{CO}_2.$$  (1.1)
$$2\text{Mn} (\text{HCO}_3)_2 + \text{O}_2 = 2\text{MnO}_2 + 4\text{CO}_2^- + 2\text{H}_2\text{O}.$$  (1.2)

2. Methods and Material
The methodology discusses on how the groundwater sample was collected in the chosen study area using suitable sampling technique, then undergo through the treatment which was aeration and the testing of the parameters such as pH, dissolved oxygen (DO), iron and manganese. The system used for this study is a Gravitational Aeration Tower System known as GATS for groundwater treatment which is focusing on the aeration as pre-treatment process. The figure 1 below shown that the GATS is designed using SOLIDWORK 2017 before fabricate using acrylic material for the experiment. GATS consists of one inlet from a tube well and one outlet to post-filtration for another process level.
The study area was at the existing tube well at the Research Centre for Soft Soils (RECESS) in Universiti Tun Hussein Onn (UTHM) were the source of groundwater located in the depth of 80.0 meters from the surface of tube well. Figure 2 shown the GATS is setup for operating at tube well using a bench-scale model of GATS.

2.1 Operation of the GATS system
The operational system of GATS started by allowing groundwater to enter directly from the tube well into the inlet GATS by a pump-out Electrical Submersible Pump. By adjustable voltmeter power to control the speed of water flowrate and the reading flowrate can saw using a digital flowmeter. The groundwater moves upward along the water inlet until it fills the GATS, and the process of aeration occurs by supplying the air using compressor through a tube inside the GATS. The aeration rate is controlling using the airflow cylinder controller. The aeration that occurs inside the GATS by air-to-water through oxidation. After the groundwater fills the tank until it reaches the top, it will once again undergo aeration by water-to-air through small holes on top of the GATS.

The excessive groundwater that had aerated flow out from the system through the outlet. Two outlets set on the GATS where one outlet is for collecting the sample, and another outlet is to flow out the water due this is because this system not store the water. The sampling of groundwater was taking
before and after the aeration process in GATS. According to the schedule of sampling, which includes the adjusted flowrate and airflow, as shown in table 1.

| Sampling Day | Flowrate (L/min) | Airflow (L/min) |
|--------------|------------------|-----------------|
| 1            | 10               | 1.5             |
| 2            | 10               | 1.5             |
| 3            | 10               | 0.5             |
| 4            | 10               | 0.5             |
| 5            | 5                | 1.5             |
| 6            | 5                | 1.5             |
| 7            | 5                | 0.5             |
| 8            | 5                | 0.5             |

2.2 Sampling
The sampling technique for collecting groundwater sample have decided as referred to the Standard Methods for Examination of Water and Wastewater. Firstly, for the handling of samples, the correct handling method must be assisted with safety and precaution to prevent any deterioration and prevent contaminations. By using the suitable bottle polytetrafluoroethylene has been acid-washed to keep the groundwater sample. So that it can withstand any physical or chemical changes before undergoing any analysis, figure 3 below shows the bottle that used during sampling.

![Figure 3. Sampling water quality bottle](image)

2.3 Testing of parameters
The parameters measured in this study were pH, DO, iron and manganese. That parameter water quality is tested by followed as stated in the Standard Methods for Examination of Water and Wastewater. Figure 4.1, and Figure 4.2, shown the testing equipment for In-Situ.
3. Results and Discussions

All the samples tested are repeated two times for an accurate result. From two results before and after GATS, is calculated by an average from two results to get the final result. The results are discussed and compared to the objective of this study. The performance of GATS for the removal of iron and manganese are measure through equation Eq. (2) for removal efficiency.

\[ \frac{\text{Before Aerated} - \text{After Aerated}}{\text{Before Aerated}} \times 100(\%) \]  

Eq. (2)

3.1 pH analysis

Table 2 below shows the analysis of pH conducted in RECESS, UTHM. The pH result from RECESS that shown table 2 below compares the average value of pH before aerated and the value for pH after aerated. However, it does not shows any difference changes. The range pH value from before and after aerated are in the low acidic class even though it is slightly approaching neutral. From the data, the highest pH reading from the study is 7.01 after aerated, where it is at the flow rate of 5.0 L/min with the aeration flow of 1.5 L/min.

| Flowrate (L/min) | Airflow (L/min) | Sampling Day | Average pH Before Aerated | Average pH After Aerated |
|------------------|-----------------|--------------|---------------------------|--------------------------|
| 10.0             | 1.5             | 1            | 6.84                      | 6.92                     |
| 10.0             | 1.5             | 2            | 6.79                      | 6.95                     |
| 10.0             | 0.5             | 3            | 6.81                      | 6.99                     |
| 10.0             | 0.5             | 4            | 6.79                      | 6.92                     |
| 5.0              | 1.5             | 5            | 6.97                      | 7.01                     |
| 5.0              | 1.5             | 6            | 6.89                      | 6.94                     |
| 5.0              | 1.5             | 7            | 6.86                      | 6.90                     |
| 5.0              | 1.5             | 8            | 6.81                      | 6.89                     |

3.2 Dissolved oxygen (DO) analysis

DO concentration results from RECESS, UTHM showed in table 3. Based on the DO result test, that there is an increment to the DO concentration towards the groundwater samples. The highest DO after aerated rising value can be seen on the sampling day seven with the flow rate of 5.0 L/min and aeration of 1.5 L/min, which is 6.67 mg/L.
Table 3: DO concentration of GATS

| Flowrate (L/min) | Airflow (L/min) | Sampling Day | Before Aerated (mg/L) | After Aerated (mg/L) |
|------------------|-----------------|--------------|-----------------------|----------------------|
| 10.0             | 1.5             | 1            | 3.44                  | 5.23                 |
| 10.0             | 1.5             | 2            | 3.29                  | 5.23                 |
| 10.0             | 0.5             | 3            | 3.21                  | 5.14                 |
| 10.0             | 0.5             | 4            | 3.23                  | 5.15                 |
| 5.0              | 1.5             | 5            | 3.43                  | 6.19                 |
| 5.0              | 1.5             | 6            | 3.42                  | 6.43                 |
| 5.0              | 1.5             | 7            | 3.64                  | 6.67                 |
| 5.0              | 1.5             | 8            | 3.48                  | 6.35                 |

Figure 5 shows the result for groundwater before and after aeration through the GATS process with the different water flowrate and airflow in this experiment. From the graph, DO value keep increasing value than before after through GATS. This is good for process precipitation to remove iron in groundwater. This higher of DO can give the good insoluble contamination iron in groundwater and help removal iron and help load process for post-filtration.

3.3 Iron (Fe) analysis

Table 4 below shows the result of iron concentration from RECESS, UTHM, where the highest value of percentage removal is 10.63 per cent with the water flowrate of 10.0 L/min with airflow of 0.5 L/min. The iron concentration of average for initial is higher than the average for after aerated through GATS process which lows than before.
Table 4: Iron concentration and removal efficiency of GATS

| Flowrate (L/min) | Airflow (L/min) | Sampling follow by Day | Before Aerated (mg/L) | After Aerated (mg/L) | Percentage Iron Removal Efficiency (%) |
|------------------|-----------------|------------------------|-----------------------|----------------------|----------------------------------------|
| 10.0             | 1.5             | 1                      | 4.41                  | 4.21                 | 4.54                                   |
| 10.0             | 1.5             | 2                      | 4.61                  | 4.32                 | 4.19                                   |
| 10.0             | 0.5             | 3                      | 4.48                  | 4.02                 | 10.27                                  |
| 10.0             | 0.5             | 4                      | 4.61                  | 4.12                 | 10.63                                  |
| 5.0              | 1.5             | 5                      | 4.98                  | 4.7                  | 5.62                                   |
| 5.0              | 1.5             | 6                      | 4.92                  | 4.56                 | 7.32                                   |
| 5.0              | 1.5             | 7                      | 4.99                  | 4.65                 | 6.81                                   |
| 5.0              | 1.5             | 8                      | 4.97                  | 4.57                 | 8.05                                   |

Figure 6 shows the result of removal of iron concentration in groundwater before and after aeration through the GATS process with the flow rate water and air in this experiment. From graph iron reading in 8 days, iron value in groundwater decreasing after going through GATS. The decreasing value not stable, but all value is decreasing after aeration through the GATS process. This shows that, GATS can reduce the value of iron content in groundwater.

![Figure 6. Graph result Iron reading testing](image)

3.4 Manganese (Mn) analysis
The results of the manganese concentration found in groundwater are shown in Table 5 below. Through GATS, the value of percentage removal has proved in resulted and mostly give the percentage of the manganese removal. Based on the table below, the higher percentage of removal is 14.25% on day eight, which water flow rate is 5.0 L/min and airflow is 1.5 L/min. The different of before aerated through GATS is 0.421 mg/L, but after GATS, it turns 0.361 mg/L. However, it does not achieve the water quality standard mean that need the post-filtration process for better quality.
| Flowrate (L/min) | Airflow (L/min) | Sampling Day | Before Aerated (mg/L) | After Aerated (mg/L) | Mn Removal Efficiency (%) |
|-----------------|-----------------|--------------|-----------------------|----------------------|--------------------------|
| 10.0            | 1.5             | 1            | 0.415                 | 0.413                | 0.48                     |
| 10.0            | 1.5             | 2            | 0.388                 | 0.384                | 1.03                     |
| 10.0            | 0.5             | 3            | 0.411                 | 0.391                | 4.87                     |
| 10.0            | 0.5             | 4            | 0.389                 | 0.365                | 6.17                     |
| 5.0             | 1.5             | 5            | 0.395                 | 0.372                | 5.82                     |
| 5.0             | 1.5             | 6            | 0.399                 | 0.367                | 8.02                     |
| 5.0             | 1.5             | 7            | 0.411                 | 0.368                | 10.46                    |
| 5.0             | 1.5             | 8            | 0.421                 | 0.361                | 14.25                    |

Figure 7 shown that graph result of manganese removal after aerated through GATS. Based on the graph pattern, show that manganese value is decreasing because it’s remove by GATS. At sampling day eight show the higher value of decreasing.

![Graph result Manganese reading testing](image)

**Figure 7**: Graph result Manganese reading testing

### 3.5 Physical groundwater observation analysis

According to the Guidelines for Drinking Water Quality by WHO (2017), when the groundwater is directly pumped out from a tube well, it does not display any discolouration or turbidity. However, when it exposes to the atmosphere, the ferrous iron reacted with the air through oxidation and turns to ferric iron as a stain and produce reddish-brown colour to the water which is not dissolved in water [11]. Prove that, by observation of this experiment, this phenomenon happens when the GATS change colour in one day after the process. Figure 8.1 shows the GATS in day one which is more transparent because the groundwater just entered, Figure 8.2 shows the GATS condition in sampling day second where reddish-brown stain covering the internal wall of the GATS was found, while Figure 8.3 shows the close-up view of the GATS.
The deposits were taken and put on a piece of paper for a more unobstructed view, as shown in figure 9. Maruf et al., (2006) [12] stated that it appears to be an iron bacteria which naturally occur in groundwater as an outcome from the combination of iron and oxygen to form deposits of rust and a slimy material that sticks the bacteria to the wall.

The previous study on the presence of iron bacteria in groundwater, especially in a tube, well had been discovered by Ghosh (1962) [13] as shown in figure 10 where the difference between the colour of ferrous [Fe(II)] and ferric [Fe(III)] in the form of solution from studies conducted with the ferrous appear to be darker while ferric was found to be more reddish-brown.

The occurrence of the iron bacteria may due to the influence of DO. The lower concentration of dissolved oxygen shows that there is microbial contamination for the water resources. DO in groundwater is usually low, and it depends on the temperature where the higher the temperature, the lower the dissolved oxygen concentration. The DO higher than 0.20 mg/L may allow bacteria growth in groundwater [14]. Since all the DO results in this study appear to be more than 0.20 mg/L, so it is possible that the iron bacteria would occur. The presence of ferric iron might be due to the reaction of ferrous and air through oxidation in the equation stated by Labhasetwar (2015) [8] as shown in equation (3) below:

\[
4\text{Fe(HCO}_3\text{)}_2 + \text{O}_2 + 2\text{H}_2\text{O} = 4\text{Fe(OH)}_3 + 8\text{CO}_2. \quad \text{Eq. (3)}
\]
4. Conclusions
Based on the study, it was found that the objective which is to study the performance of GATS at different aeration for iron and manganese removal from groundwater was happened and fulfilled where it mainly due to the increasing and founded of ferric iron stains or iron bacteria in the wall of GATS which sampled along after aeration process tested immediately without any filter provided. For the comparison of groundwater to the drinking water quality based on the National Drinking Water Quality Standards, it is also not followed because as a pre-treatment process without any filtering or post-filtration. Thus, some recommendations need to be considered to seek for a better performance of the GATS in the future. The groundwater must run through aeration process of GATS earlier in a start-up period called acclimation process to allow the changes on the behaviour of the groundwater characteristics which reduce the iron and manganese and increasing the value of DO. Hence, the aeration process faster than usual to change soluble to insoluble contamination of iron and manganese. GATS can be used as an aeration process in pre-treatment due to excellent performance result and experiment.

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Compliance with Ethical Standards
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