A Bench Model Design of Gravitational Aeration Tower System as Treatment System for Iron Removal in Groundwater

E Z Radzi¹, M S Wahab¹, M Z Sahdan², R Hamdan³, A Madun³, R A Zakariah¹

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

Abstract. Groundwater is an alternative source of water and is in high demand in Malaysia, particularly in rural areas where hot climate and water scarcity are still challengeable. However, groundwater sources are contaminated by high concentrations of iron in certain regions of Malaysia. In this research work, groundwater samples from tube wells in Kampung Majid Ibrahim, Simpang Renggam were collected and found iron content from 1.9 mg/L to 2.4 mg/L, which exceeds acceptable iron concentration level of 0.3 mg/L. Aeration and filtration methods are commonly employed to remove the iron from groundwater. Despite, there is low water production due to water loss through the air; the aeration process is still economic and efficient. Gravitational Aeration Tower System (GATS) was designed by using SOLIDWORK 2017 and fabricated at bench scale model to mitigate these problems. The GATS was developed with two concepts consisting of aeration from air to water and then from water to air with combination of several processes required for the treatment of water after aeration. Experimental work was conducted at the tube well location and data was collected through AQUAREAD AP2000 and Hanna Iron Checker tools using in-situ test method. The flow rate was set directly through the GATS by the flow of water at 10.0 L/min and by changing the parameters of air. Results demonstrate that dissolved oxygen (DO) levels rises by 86.5% and iron removal increases by 8.03 %. In conclusion, the GATS system is capable of increase the DO levels and decrease iron removal rates with continuous water flow.

1. Introduction

Groundwater plays a substantial role in water supply and a significant source of water for maintaining a functional ecosystem and serving as a fundamental resource for human well-being. Also, groundwater imparts essential role to maintain social well-being and ecosystem integrity in order to achieve resource sustainability on a global scale. In rural areas, groundwater is preferred as one of the major sources of drinking water due to close availability of water resources to consumers. It is mainly because of the attractive characteristics of groundwater such as higher quality compared to surface water, more secure against potential contamination, less vulnerable to seasonal and permanent fluxes, and much more
evenly spread through large regions. It is also less expensive to put groundwater well fields into operation compared to what surface water needs, which often requires significant capital investment. These advantages, together with the reduced vulnerability of groundwater to pollution, have mainly resulted in widespread use of groundwater for water supply [1].

But on the other hand, the existence of iron in groundwater is a straightforward consequence of its natural existence in underground rock materializations and precipitation water that penetrates through these materializations. As the water moves through the underground rocks, some of the iron dissolves and accumulates in aquifers and become as source of groundwater [2]. The cause of iron pollution in groundwater is either natural or anthropogenic, including industrial seeding, landfill or dumping, and acid rain drainage [3]. Iron presence in groundwater with dissolved iron tends to last and leaves the water yellowish to reddish-brown when exposed to air. The glitches caused by iron are aesthetic damage, indirect health concerns and economic issues [4]. The United States Environmental Protection Agency (USEPA) (2004) has established a secondary maximum contaminant level of 0.3 mg/L for total iron in drinking water [5]. The effects of the iron content in groundwater will have an impact on the distribution systems, leading to a reduction in the pipe diameter and eventually to the clogging of the pipe [6]. The presence of bacteria is another problem associated with iron in water. Such iron bacteria pose no threat to health, but they can cause the red-brown appearance of iron sludge in toilet tanks and clogging of water systems. The growth of iron and bacteria occur in light or dark environments when iron is present in water [7].

Generally, bypassing the problem and removing the iron by oxidation and filtration are two recognized iron removal methods. However, it should be noted that these methods are not appropriate for all local conditions and essential to evaluate each of them for their particular requirements. Considering bypassing the problem; sometimes discovering alternative source of water source may become the cost-effective result. Unfortunately, in situations where iron has polluted huge aquifers, or when alternative sources of water are excessively far away, bypassing the problem is not the proper solution. In this condition, removing iron physically from the groundwater is the only solution. Removing iron from groundwater can be through two-stages. In the first stage; the iron is oxidized and converted from soluble form to insoluble ferric form (Aeration) and consequence the suspension of small oxidised iron particles (rust) in the water. Normally, aeration oxidation is the most common method of removing iron from groundwater in public water systems [8]. In aeration process; the iron oxidation is carried out by finding the dissolved oxygen (DO). Basically atmospheric oxygen easily oxidized the iron and the dissolved atmosphere oxygen transformed the iron into an insoluble form without the use of chemicals. Moreover; this process can be used to treat water aeration systems to minimize the iron content, odour, and taste and colour [9]. In addition, the effect of aeration prevents iron from dissolving, resulting in the formation of sediment instead. In the second stage, it is essential to remove the suspended iron particles from the groundwater. Normally this process is carried through filtration, and its success is completely reliant on the quality of the filtration process. Inappropriate and inadequate filtration may risk the whole filtration process. Figure 1 illustrates the traditional water treatment processes used in the groundwater aeration process for the treatment of water [10]. Generally, there many types of aeration system for water treatment, among them; gravitational aeration is bit low cost and required less maintenance. In gravitational aeration process; water is allowed to fall due to gravity such that maximum area of stream of water is exposed to atmosphere.
The existence of iron particles in water is a challenge mostly faced by operators and when deciding on how best to remove the iron from water system. Thus in this research work, a gravitational aeration tower system (GATS) was constructed and iron removal and dissolved oxygen was evaluated in a bench-scale model through experiments. The efficiency of aeration system based on the obtained iron removal and dissolved oxygen in groundwater after entering the GATS was also calculated.

2. Method and Material

2.1 Drawing design of GATS using SOLIDWORKS 2017
The design of the modern GATS integrates many concepts into the conventional water filtration system including aeration, sedimentation and clarification. Aeration is based on two design aims to maximize the DO output. The first aeration is the injection of compressed air into the water and used spiral model in the GATS for mixing or combining air into the water. The second aeration design is to naturally channelize the water into the air in the form of a stream. Furthermore, the construction of the tower-shaped GATS is to provide the water passing through it facilitated with gravity pressure. The insoluble iron is deposited and falls as a result of the aeration. This concept, as a result, ensures high concentration of oxygen in the aeration. However, the built-in GATS is ideal for space-saving purpose.

2.2 Fabricated Bench-Scale GATS Model
Figure 2(a) displays the Solid Works GATS design and Figure 2(b) shows bench scale GATS model using acrylic cylinder tube. The drawing and the actual scale were kept same as 1:1 ratio. The height of GATS was 450 mm with a diameter of 300 mm. Within the GATS, the spiral rod was used to combine air and water with respect to rate of flow entered.

Figure 2. (a) Drawing of GATS (b) Fabricated bench-scale GATS.
2.3 Groundwater characteristics by in-situ testing

Before initiating the water treatment cycle through GATS, the groundwater characteristics were determined using the appropriate methods. The water quality characteristics of the wells were assessed using AQUAREAD AP2000. Using the AP2000 tool, data collection was performed by in-situ testing and the data was stored in the provided storage. In situ water quality parameters include DO, temperature, pH, conductivity and turbidity. Whereas, the iron concentration was determined by using Hanna High Iron Checker HI96721 and the obtained values are shown in Table 1.

| Parameter (s) | Method (s)          | Unit | Groundwater Quality |
|---------------|---------------------|------|---------------------|
| Temperature   | APHA 2550 B         | ºC   | 27.0-27.8           |
| pH Value      | APHA 4500-H⁻ B      | -    | 7.0-7.5             |
| Turbidity     | APHA 2130 B         | NTU  | 0-34.5              |
| Dissolve Oxygen| APHA 4500 A         | mg/L | 2.99-4.16           |
| Iron          | APHA 3500-Fe B      | mg/L | 1.4-2.3             |

2.4 Experiment setup at tube well and in-situ testing

The experimental study of GATS was conducted near Kampung Majid Ibrahim, Simpang Renggam's tube wells. The water from the tube wells was pumped up and stored in the storage tanks. Water samples were collected and checked for quality levels before introducing in the GATS. Afterwards, the water was pumped directly through the GATS and samples from the output water were taken for testing. The water flow rate was set at 10.0 L/min and the air flow parameters varied from 0 L/min, 1.0 L/min and 2.0 L/min. Changes in air parameters were observed in order to determine the aeration effectiveness of the airflow rate.

The water samples through GATS were collected and recorded by varying the parameters, however, every sample was collected for three times repeatedly. The observations were recorded with a specific time lag between before and after entering the GATS. The air parameters were varied through air supply from the air compressor. This principle is called air entering the water by GATS and considered as the first aeration method. The second aeration, meanwhile, does not use air compressor, but uses natural air in the surrounding environment, where water enters the air. Table 2 shows the time required for the GATS process water treatment, which varies with the time of the samples taken before and after the GATS, including the time taken by the AP2000 to obtain data on DO samples.

| Air flow first aeration process (L/min) | Time to complete water process through GATS (min) | Average time taken before GATS for DO in-situ testing (min) | Average time taken after GATS for DO in-situ testing (min) |
|----------------------------------------|-----------------------------------------------|------------------------------------------------------------|------------------------------------------------------------|
| 0                                      | 3.0                                           | 6-8                                                       | 3-4                                                        |
| 1.0                                    | 2.5                                           | 6-8                                                       | 2-3                                                        |
| 2.0                                    | 1.0                                           | 6-8                                                       | 1-1.5                                                      |
Figure 3 shows the actual fitting of bench scale GATS model to be filled with a stream of water from the tube well and poured into the tank. The flow rate of the water was calculated by using the valve mounted. The area used to work with GATS is limited which can be seen from the configuration.

3. Results

The experimental tests were conducted near the tube well. Iron content and DO in groundwater quality with in-situ tests before and after entering the GATS were recorded and presented here in this research work. Moreover, percentage of iron removal and DO before and after entering the GATS were also calculated. Figure 4 shows the results of the aeration processes in GATS which combining together and flow out as one output in GAT system. Visible bubbles appear on the surface of the GATS for the first aeration process by which air enters the GATS. Meanwhile, the second aeration air reaches the natural water is shaped like a stream and gushes through openings.

Figure 5 shows the results for iron content in groundwater quality with in-situ tests before and after entering GATS. The iron contents were recorded through High Iron Hanna Checker. The values were
ranged from 2.66 mg/l to 2.43 mg/l for iron content before entering the GATS and 2.59 mg/l to 2.47 mg/l for after GATS. It is observed that the value of the initial iron in the tube well is not stable and continuously decreasing with increasing the amount of air flow. It implies that high flow rates can increase the removal of iron from drinking water [11]. It can be clearly seen that a significant decrement obtained from 0 mg/l to 1.0 mg/l and fluctuated readings obtained from 1.0 mg/l to 2.0 mg/l. Thus, it can be concluded that the best flow rate should be maintained at 1.0 mg/l of the oxygen. However, the flow rate of 2.0 L/min through this GAT system raises the iron removal rate from 2.29 mg/L (before entering GATS) to 2.49 mg/L (after (GATS). Besides that, aeration requires careful control of the water flow through the process. If water flow is too great, not enough air is applied to oxidize the iron and manganese. If water flow is too small, the water can become saturated with dissolved oxygen and, consequently, become corrosive to the distribution system. Furthermore, it may be noted that 7.0-7.5 pH value was observed for the tested well and the pH values significantly affect the iron removal from drinking water, as [12] obtained maximum iron removal at 7.3 pH value of drinking water. Lastly, aeration is dependent on the atmosphere pressure and temperature [13]. The dissolved iron concentration increased with increases in the temperature at a set pH. They also showed that the pH has a lower effect at low temperatures [14-15]. As based on the obtained results, it is found that the iron content value decreases once the air is applied. The low iron content of this iron reading suggests that the removal of iron is high and is practical for the GATS system.

![Figure 5. Iron content in groundwater quality with in-situ tests. Symbols represent: (▲) after entering GATS and (■) before entering GATS.](image)

Figure 5 shows the results of DO obtained using AP2000 before and after the implementation of GATS. The values were ranged from 3.29 mg/l to 3.98 mg/l for DO before entering the GATS and 4.95 mg/l to 6.83 mg/l for after GATS. It has also been found that the initial DO value of the well tube is fluctuates and very low. It is mainly because of the unexposed to air. However, rapid rise can be clearly observed, once exposed to the air and considered as significant increment in DO. Basically, DO test tells how much oxygen is dissolved in the water. However, water temperature and the volume of flowing air can affect dissolved oxygen levels [14]. Oxygen dissolves easier in cooler water than warmer water [15]. Thus, higher the value of DO; the higher will be iron removal rate [16]. The results show the effects of using GATS for aeration demonstrates that the DO intensity could rapidly increase, and this change occurs immediately during the water flow into the GATS. In fact, the amount of inflow and outflow of water by GATS is the same without any depletion of water. The flow rate water of 10.0 L/min through this GAT system raises the DO amount from 3.43 mg/L (before entering GATS) to 6.83 mg/L (after (GATS).
4. Discussion
The experimental data obtained through GATS shows that increase in the air flow rate result increase in iron removal rate and DO of the drinking water. The percentage values for both iron removal rate and DO were calculated on the basis of obtained experimental data and presented as shown in Figure 7. The maximum percentage of DO achieved at 2.0 mg/L, where it increased from 43.6 % (3.43 mg/L) to 86.5 % (6.83 mg/L). Accordingly the maximum iron removal of 8.03 % occurred at maximum percentage of DO (86.5%). Generally, the efficiency of the aeration system depends on the hold-time, pH value of the testing water and atmospheric pressure and temperature of the supplied oxygen. However; the values for DO are within the WHO standards. Moreover, to increase the further efficiency of the GATS, the geometrical aspects of the system may be varied and proper control of the oxygen supplied system.

Figure 7. Percentage of DO and iron removal in groundwater with different airflow
Symbols represent: (♦) percentage of iron removal (■) percentage of DO after entering GATS (▲) percentage of DO before entering GATS.
5. Conclusion
The efficiency of iron removal depends on the DO value contained in the aeration's water. The findings of the design and testing of the GATS in the wells implies that:

- The flow rates of the GATS in and out are identical and there is no leakage of water during the processes in the GATS as a result of the design.
- The results also reveal a low DO value of 3.0 to 4.0 mg/L from the inlet flow rate, but after passing the GATS with the same outflow without delay, the DO value increases from 4.97 mg/L to 5.02 mg/L without air, from 6.42 mg/L to 6.61 mg/L with 1.0 L/min air and from 6.81 mg/L to 6.83 mg/L with 2.0 L/min airflow.
- The GATS is also portable that can be placed near the tube well without having to bring back water samples which are commonly performed by other researchers.
- The output value of the GATS is the same as that specified by the set stream restriction, but the water properties still change.

Acknowledgement
This paper is partially supported by Research Innovation Commercialization and Consultancy Management (Vot. U990 and U872), Universiti Tun Hussein Onn Malaysia (UTHM). Special thanks go to the owner of the tubewell at Kampung Majid Ibrahim, Simpang Renggam, for kindly offering the location for this research work.

Compliance with Ethical Standards
This paper is partially supported by Research Innovation Commercialization and Consultancy Management (Vot. U990 and U872), Universiti Tun Hussein Onn Malaysia (UTHM). Special thanks go to the owner of the tubewell at Kampung Majid Ibrahim, Simpang Renggam, for kindly offering the location for this research work. The authors declare that they have no conflicts of interest. This research work does not contain any studies involving animals performed by any of the authors. This research work does not contain any studies involving human participants performed by any of the authors.

References
[1] Uwamariya V 2013 Adsorptive Removal of Heavy Metals from Groundwater by Iron Oxide Based Adsorbents (IHE Delft Institute for Water Education)
[2] Ityel D 2011 Ground water: Dealing with iron contamination. 16 June 2011. Cited on February 28, 2020. https://www.filtsep.com/water-and-wastewater/features/ground-water-dealing-with-iron-contamination/
[3] Nuratiqah S A 2018 A Review of Biological Aerated Filters For Iron And Manganese Ions Removal In Water Treatment J. Water Process Eng. 23 1–12
[4] Kenari S L D 2017 Integrated Fluidized Bed-Membrane Process for Advanced Iron and Manganese Control in Drinking Water Seyedeh (Université De Montréal)
[5] Ahmad M 2012 Iron and Manganese Removal from Groundwater Iron and Manganese Removal from Groundwater (University of Oslo, DUO Res. Arch.) 10852 1254
[6] Nagwa Ibrahim M I 2016 The Relations between Concentration of Iron and the pH Ground Water (Case Study Zulfi Ground Water), Int. J. Environ. Monit. Anal. 4 140
[7] Chaturvedi S and Dave P N 2012 Removal of Iron for Safe Drinking Water Desalination 303 1–11
[8] Khatri N, Tyagi T and Rawtani D 2017 Recent strategies for the removal of iron from water: A review J. Water Process Eng. 19 291–304
[9] Noubactep C and Schoner A 2010 Metallic Iron: Dawn of a New Era of Drinking Water Treatment Research Fresentius Environ. Bull. 19 1661–1668
[10] Smith C 2015 Trihalomethane Removal and Re-Formation in Spray Aeration Processes Treating Disinfected Groundwater (University of Central Florida Libraries)
[11] Tekerlekopoulou A G et al 2013 Removal of ammonium, iron and manganese from potable water in biofiltration units: a review J. Chem. Technol. Biotechnol. 88 751–773
[12] El Azher N 2008 Study of ferrous iron oxidation in Morocco drinking water in an airlift reactor Chem. Eng. Process. 47 1877–1886
[13] 1996 Iron in drinking water In: Guidelines for drinking-water quality Health criteria and other supporting information (World Health Organization vol 2) 2nd ed (Geneva)
[14] Cameselle C, Nunez M J, Lema J M and Pais J 1995 Leaching of iron from kaolins by a spent fermentation liquor: influence of temperature, pH, agitation and citric acid concentration J Ind Microbiol 14 288–292
[15] Hajihoseini J and Fakharpour M 2019 Effect of temperature on bioleaching of iron impurities from kaolin by Aspergillus niger fungal Journal of Asian Ceramic Societies 7 82-89
[16] Vasudevan S, Lakshmi J, and Sozhan G 2009 Studies on the removal of iron from drinking water by electrocoagulation—a clean process Clean 7 45–51