INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING VOL. 12 NO. 3 (2020) 207-215

© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Gravitational Aeration Tower Filter System to Increase the Dissolved Oxygen Amount for Iron Removal in Groundwater

E. Z. Radzi[1], M. S. Wahab[1, *], M. Z. Sahdan[2], R. Hamdan[3], R. A. Zakariah[1]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[2]Faculty of Electric and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[3]Faculty of Civil Engineering and Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2020.12.03.024
Received 20 December 2019; Accepted 31 January 2020; Available online 27 February 2020

Abstract: This paper discusses the Gravitational Aeration Tower Filter System (GATS) aims to increase the amount of Dissolved Oxygen (DO) for iron removal in groundwater. The groundwater is mainly used in remote areas. The presence of a large volume of iron contained in the groundwater will subject to water contamination besides limiting the lifespan of existing water filter to filter the contaminants. Pre-treatment systems i.e., aeration techniques are often used to reduce the amount of iron contained in the groundwater. One of the aeration techniques i.e., the GATS is proposed and designed for this work. The GATS is tested to assess its effectiveness in increasing the DO and in the removal of iron in the water. The study area is located in Kampung Majid Ibrahim, Simpang Renggam. The initial value of the iron in the tubewell ranged from 1.4 mg/L to 2.3 mg/L, which exceeded the standard limit of 0.3 mg/L. Using AQUAREAD AP2000 and Hanna High Iron Checker, data collection is carried out in-situ testing. The flow rate is set at 5.5 L/min through the GATS, with varying air parameters. The results of the GATS test demonstrate the DO percentage increases up to 90.50 % and the percentage of iron removal is up to 10.24% with an airflow of 1.0 L/min.

Keywords: Groundwater, Gravitational Aeration Tower System (GATS), Iron removal, Dissolved Oxygen, Aeration

1. Introduction

The primary source of drinking water in the world is groundwater, which is easily accessible and provides a consistent water quality. Groundwater is also the preferred source of drinking water in rural areas, particularly in developing countries, because no treatment is often required and the source of the groundwater can be found close to consumers. Based on studies conducted in [1], the demand for surface and groundwater water in Malaysia are expected to increase by 63% from year from 2000 to 2050. Moreover, the groundwater in Malaysia contributes for over 90% of the country's water resources, with an estimated 5 trillion cubic meters of groundwater in aquifers, with an annual recharge rate ranging from 64 billion to 120 billion cubic meters [2]. Water extracted from the soil called "Groundwater" is located below the ground, filling the gap between grains or cracks and the opening in the rocks. Groundwater is formed from the rain and percolation down through the soil. Groundwater has some important advantages compared to surface water: higher quality water, better protection against any possible pollution, less subjected to seasonal and perennial changes, and much more uniformly spread over vast regions than surface water. Groundwater may also be accessible in areas where there is no surface water. Putting groundwater well into operation is also less costly compared to the

*Corresponding author: saidin@uthm.edu.my

requirement needed by surface water, which often requires considerable capital investments. These benefits, combined with reduced groundwater fragility due to pollution, have mainly led to widespread use of groundwater as a source of water.

1.1 Overview of Groundwater and Presence of Iron in Groundwater

Due to the high demand for groundwater, it has been identified as a new source of water for the next generation and is mainly used for drinking water supplies in many countries around the world [3]. However, before consuming groundwater, it must be tested and treatment [4] first in order to detect the impurities content to ensure all proper protocols are met and the best water quality is produced. Sulphates, nitrogen compounds such as ammonia and nitrates, petroleum products, phenols and heavy metals are the main contaminants present in groundwater. Since the industrial revolution, precipitation and accumulation of heavy metals have been one of the major concerns regarding groundwater contamination [5]. Heavy metal concentrations such as lead, manganese, chromium, iron, zinc and cadmium [6] can be present in groundwater, and iron and manganese are common and frequently found elements. This argument can be best supported by the findings of the National Hydraulic Research Institute (NAHRIM), where a thorough monitoring on Tioman Island Malaysia, Jenderam Hilir Selangor has been carried out, which identifies that the water contains a high iron content [7]. Another study found that iron and manganese concentrations are at the maximum permissible level in a tubewell in Taiping, Perak when the water samples are collected at different depths [8]. Furthermore, the Melaka groundwater quality shows the turbidity, total dissolved solids, iron, chloride and cadmium concentrations exceed the limits of drinking water quality standards [9]. Iron is abundant and naturally occurring elements in the earth's crust that are often present in natural water sources [10]. The presence of iron in the groundwater may cause the water to turn into reddish colour and therefore produce a metallic taste and smell [11].

1.2 Improvement of Techniques for Iron Removal Treatment

New strategies for the elimination of iron from water can be sorted into four-way categories of conventional strategies, biological strategy, membrane-based technology strategy and nanotechnology strategy, as shown in Fig.1 [12]. According to the other studies, there are several other methods for extracting iron from drinking water, such as ion exchange and water softening, activated carbon and other filtration materials, supercritical fluid extraction, bioremediation and limestone treatment, aeration oxidation, chlorination, ozonation followed by filtration, ash, aerated granular filter and adsorption. However, aeration oxidation and granular filtration is the most common method for removing iron from water in the domestic water supply system [13]. Aeration is a pre-treatment process that provides the DO needed to convert the soluble form into an insoluble form when oxidized. The most commonly used method is aeration cascade, because the extra energy and power required are less and depend on the design of the cascade for the aerated process. Aeration tower is a practical design for this process, as it has a high oxygen efficiency as an existing aeration tower. The aim of this research work is to develop a new Gravitational Aeration Tower System (GATS) design. It is used as a medium capacity to improve the amount of dissolved oxygen (DO) content in the groundwater and to help improve iron removal. The GATS as a pre-treatment for groundwater is fabricated and the performance of the newly developed system is analyzed in terms of the DO content and effectiveness of iron removal in the groundwater.

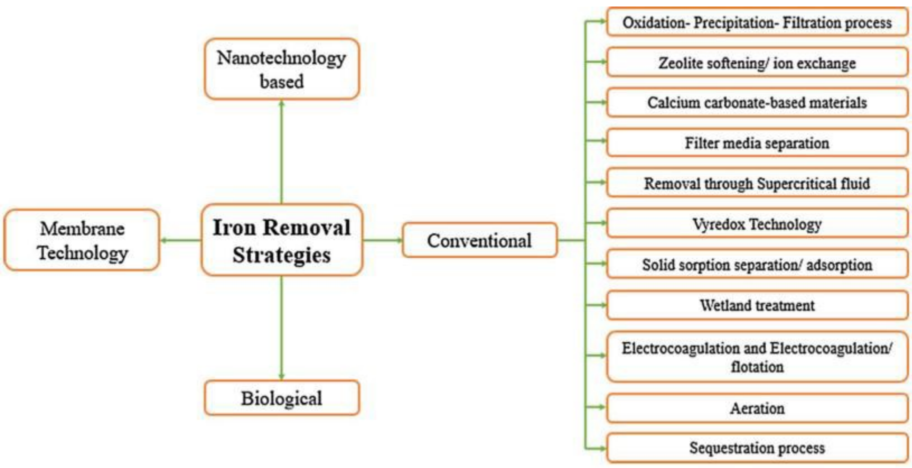


Fig. 1 - Four method classifications of iron removal strategies [12]

2. Methods and Material

This section discusses the method and material for the pre-treatment process by using aeration technique and consists of three phases i.e., phase one: characteristics analysis of groundwater at the tubewell based on the standards method of in-situ parameter, phase two: proposed design of Gravitational Aeration Tower System (GATS), and phase three: fabrication of lab-scale GATS and the experimental set up.

2.1 Pre-treatment Process by using Aeration Technique

Iron in groundwater can be treated in a number of ways at the early stage, known as pre-treatment process. The main purpose of the pre-treatment process is to reduce the amount of iron as much as possible until the final quantity meets the pre-determined standard value. In this work, pre-treatment process is carried out using conventional technique, known as oxidation by aeration, in order to achieve the standard. The aeration technique can be defined as the process by which a gaseous phase, usually air and water are brought into intimated contact with each other to transfer volatile substances that may contain oxygen, carbon dioxide, nitrogen, hydrogen sulfide, methane, and various unidentified organic compounds responsible for the metallic taste and unpleasant odor. This technique uses oxygen as a major source of oxidation. In addition, this work combines several other approaches to complete the entire water treatment process in order to meet the required the drinking water standard. Three phases have been a focus of learning for iron treatment and improvement of DO in the groundwater. The first phase is the analysis of the characteristics of groundwater sampled from tubewell by using some standard method guided by the American Public Health Association (APHA) and the use of some equipment. The second phase is the design and develop the tower concept system, combining the tower concept of aeration process as the pre-treatment process. The third phase is the fabrication of the design bench scale model to conduct the experiment.

2.2 Phase One: Characteristics Analysis of Groundwater based on Standards Method In-Situ Parameter

The analysis of the groundwater from the tubewell at the selected area of study is conducted by using in-situ equipment. The tubewell at Kampung Masjid Ibrahim, Simpang Renggam has been selected for the test. In addition, the procedure applies the use of multi-parameter data of AP-2000 for monitoring of in-situ water quality, including a real-time measurement, profiling, and unattended data logging. The parameters of in-situ water quality include DO, temperature, pH, conductivity, and turbidity are listed in Table 1 and analyzed using Aquaread AP2000 as shown in Fig. 2. Furthermore, using Hanna High Iron Checker, the value of iron content can be interpreted as shown in Fig. 3.

Table 1 - Standard method in-situ parameters

Parameter (s)	Methods	Unit	Values
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 2017	mg/l	1.4-2.3

Fig. 2 - AQUAREAD Probe AP-2000, Multiparameter Water Testing

Fig. 3 - HI96721 Iron High Range Portable Photometer

2.3 Second Phase: Proposed Design and Five-Step Processes Treatment of GATS

The drawing of the GATS design is assembled with respective dimensions using the SOLIDWORKS 2017 software. Fig. 4 shows the final design of the proposed GATS functions to increase the DO amount in the groundwater in order to increase the rate of iron removal. The system is designed to flow the groundwater into the system directly from the tubewell using a single pump motor. The GATS will then rely heavily on gravity energy as a process for the treatment of iron in groundwater. This system is realized with a tower that has a high-pressure force with a high gravity to provide the pressure force. During the design process, GATS height plays an essential role in achieving a high pressure. At high altitude, the high pressure will fasten the contact time for the iron and, as the result, the sedimentation process for precipitation of the solid form of iron can be accelerated. Fig. 5 shows the five processes involved in the in-situ experiment and laboratory testing. Experiments are conducted starting from Phase 1, which is the characterization of water sample. Table 2 explains the flow of processes mentioned.

Table 2 - Explanations on the process flow

No.	Descriptions
1	A process in which the water from the tubewell enters the pipe that has been pumped up to the top with absolute pressure, flow and capacity.
2	Area where oxidation occurs through the aeration process. In this area, the iron in the raw groundwater is oxidized by oxygen and will change its properties to Fe^{3+} form.
3	The process by which a combination of air and water takes place is called oxidation. In this process, the air is inserted into the water inside this area at this stage. This process helps together using the concept of the spiral. This part also is known as flocculation process.
4	At this stage, the occurrence of sedimentation processes for precipitation depends mainly on the pressure applied. High pressure on gravity accelerates the process solid form of iron to be grounded. This stage is a sedimentation tank of gravitational mats.
5	Again, the oxygen oxidation process is going to take place because the water is exposed to air. The oxidation process is carried out again in the clarification process to ensure that the level of DO and the removal of iron increases.

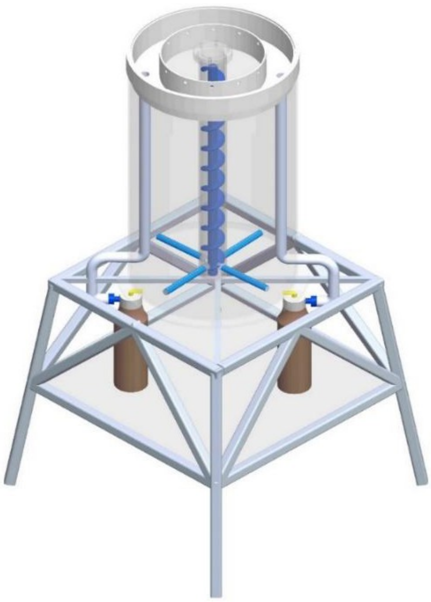


Fig. 4 - GATS drawing using the SOLIDWORKS 2017 software

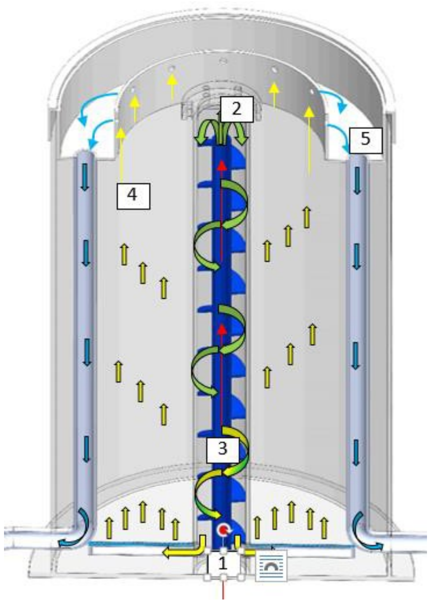


Fig. 5 - Five-step treatment of GATS

2.4 Third Phase: Fabrication of Lab-Scale GATS and Experimental Set Up

Fig. 6 shows the GATS in the form of Scala-Lab made with an acrylic cylinder tube. The purpose of using this material is to observe the processes taking place in GATS. The height of the cylinder tube is 450 mm and the diameter of 300 mm. Fig. 7 displays a setup made near the tubewell for the purpose of GATS treatment of groundwater quality. As can be seen in the figure, a complete setup that can control two parameters is needed for the system. The first requirement is the water flow rate of the tubewell, which passes through the storage tank into the GATS, which is pumped upwards. The second requirement is the air flow rate that enters the GATS from the compressor. The first GATS test is performed five times without the air flow and fully depending on the second aeration process. The second test involves the air flow rate, measured at two different air flow rates and replicated three times in a row.

Fig. 6 - Full lab-scale GATS fabricated using acrylic cylinder tube

1: GATS is fabricated by using high-quality acrylic
2: Airflow pipe inserted into the GATS
3: Flow rate meter reading
4: Control of air flow meter
5: Intake of water before entering the GATS
6: Pump motor
7: PVC valve to control the flow rate of water
8: Water storage tank
9: Water outlet after entering GATS
10: Tubewell

Fig. 7 - GATS set up to be tested at the tube well

3. Experimental Results

Experiments carried out are adjacent to the built-in tubewells, and results in a direct flow of water to GATS. The flow rate of water through the GATS is set at 5.5 L/min. The results show that there are three different air parameters of 0 L/min, 0.5 L/min and 1.0 L/min. Variable test results values are obtained by differentiating the sample reading before and after entering the GATS. The purpose of water sampling before entering GATS is that the value of the tubewell water quality is sometimes variable. Different rates of airflow are used to determine the effect of maximizing the DO value in water. The data of the sampled water shall be taken three times for each airflow rate set. The experiment is carried out with the water in the tubewell directly injected into the GATS. Each sample data is obtained by in-situ testing using the AP2000 and Hanna high iron checker.

3.1 Lab-Scale Test for GATS at Water Flowrate of 5.5 L/min

Fig. 8 shows two types of aeration process occurring in GATS with the water flow rate of 5.5 L/min through the GATS. First aeration uses the concept of inserting air into the GATS while, the second aeration, the water flows out into the air in a natural form, like the concept of a fountain. Both aeration processes are used to obtain the maximum DO level.

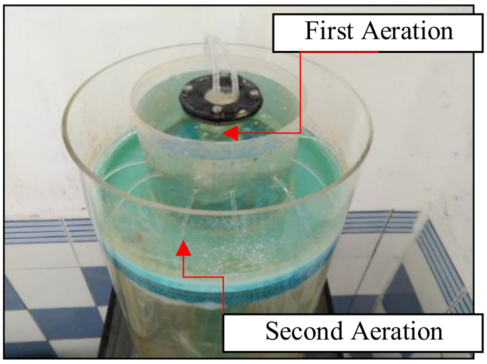
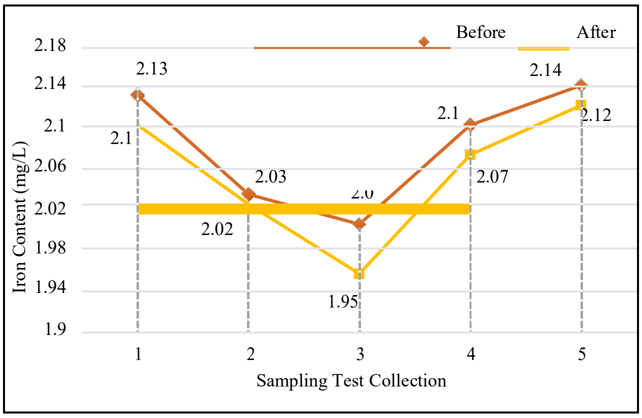


Fig. 8 - Aeration processes at the overflow of GATS

3.1.1 Water Samples without the Flow of Air

Fig. 9 and Fig. 10 display the five times reading of the water samples and the data taken before and after entering the GATS in order to observe the iron and DO contents. The flow rate of water through the GATS is set at 5.5 L/min, while the flow rate of air is zero. The time difference between the samples taken before and after entering the GATS is 4 minutes to allow the water to undergo the full process of the GATS. During the in-situ testing, the reading for each sample before entering the GATS is between 6 to 8 minutes while the reading for the data test after the GATS is between 3 to 4 minutes with the AP2000.



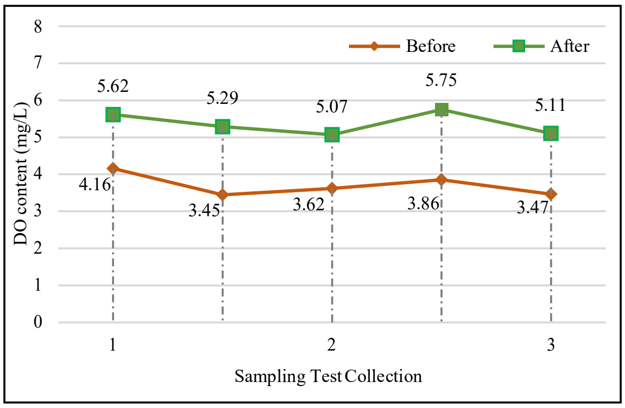


Fig. 9 - Iron content before and after entering the GATS without air flow

Fig. 10 - DO content before and after entering the GATS without air

3.2 Water Samples with the Flow of Air

Water sample with air flow rate are tested at 0.5 L/min and 1.0 L/min. The readings of three water samples for before and after flowing through the GATS are observed to analyse the iron and DO content.

3.2.1 Water Samples with Air Flow Rate of 0.5 L/min

Fig. 11 and Fig. 12 show the readings of three water samples to observe the value of iron and DO before and after entering the GATS. The airflow rate is changed to 0.5 L/min. Changes iron removal may still occur while the DO content is observed to increases significantly from the previous GATS. The sampling time taken before and after entering the GATS is 3 minutes for full water process flow through the GATS, which is much faster as a result of air support to the GATS process. The reading for each sample during the in-situ testing before entering the GATS is between 6 to 8 minutes while the reading for the data test after entering the GATS is between 2 to 3 minutes with the use of AP2000.

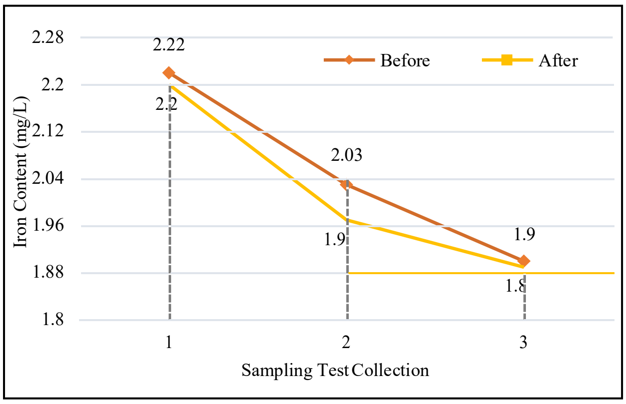


Fig. 2 - Iron content before and after entering the GATS with an airflow of 0.5 L/min

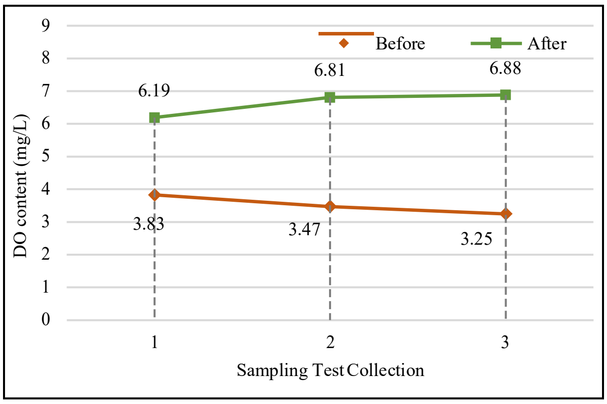


Fig. 3 - DO content before and after entering the GATS with an airflow of 0.5 L/min

3.2.2 Water Samples with Air Flow Rate of 1.0 L/min

Fig. 13 and Fig. 14 show the readings of three water samples for iron and DO observation before and after flowing through the GATS. The airflow rate is changed to 1.0 L/min. Changes in iron removal may still occur while the DO content is significantly higher from the previous GATS reading and higher than the rate of air, which is set at 0.5 L/m. The difference of sampling time taken before and after flowing through GATS is 2 minutes, which is much faster than the previous results as the air helps to push the water through the GATS. The sample reading time before entering the GATS is between 6 to 8 minutes while the sample reading time after entering the GATS is 1 to 1.5 minutes, indicating a faster result as the DO content has increases. Fig. 15 compares the percentage values of iron and DO in water that can be carried out by the GATS system with different air flow parameters. The percentage of iron removal from the GATS is not stable and not too high. The GATS is capable of removing an iron percentage up to 10.24% when the airflow is set at 1.0 L/min. It is observed that the percentage of iron removal increases when the air parameter is increased.

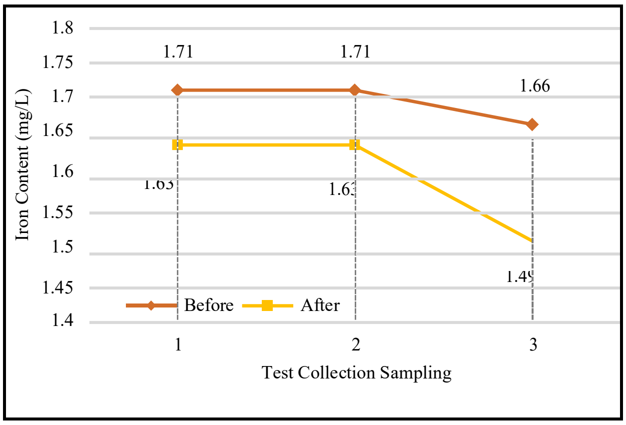


Fig. 13 - Iron content in the water before and after entering the GATS with an air flow of 1.0 L/min

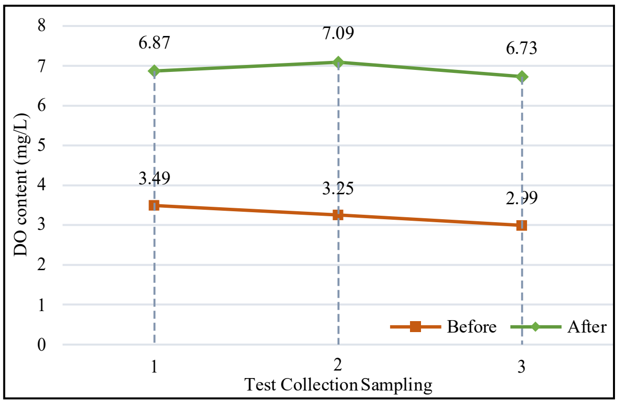


Fig. 14 - DO content before and after entering the GATS with an air flow of 1.0 L/min

From the Fig. 15, it is also found that the rate of increment of DOs from the previous reading after passing through GATS when compare before passing through GATS. Such changes have a positive effect, and the highest percentage of DO 1.0 L/min air parameters is 90.5%. The results from the data suggest that the GATS is capable of increasing the rate of DO in the groundwater to a maximum level.

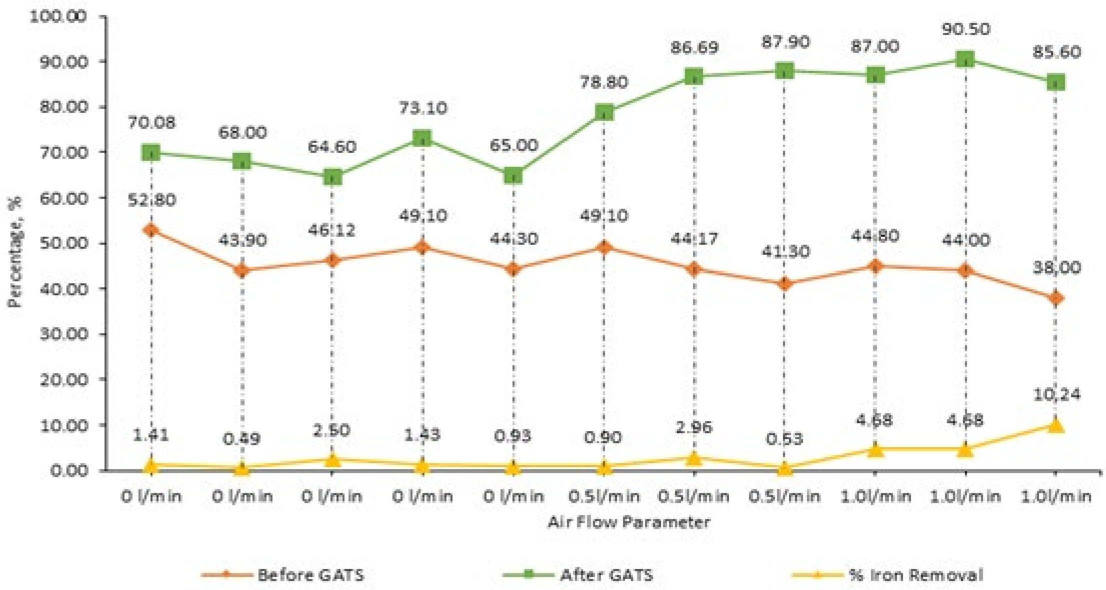


Fig. 15 - Percentage of DO and iron in the groundwater tested with varying air flow rates

4. Conclusion

This paper proposed the design of GATS to increase the amount of DO oxygen for the removal iron in groundwater. The initial sample data of the water shows that the original DO value is low which is between 2.99 and 4.16 mg/L. The primary objective of constructing the GATS is to increase the value of the DO and to assist in the removal of dissolved iron in the water. At constant water flow rate of 5.5 L/min, the GATS is capable of increasing the level of DO in the water up to 90.5%, with the airflow of 1.0 L/min, and directly increasing the DO value in the water at reduced process time. The GATS is also a space-saving system as the concept of the tower is used to conduct the aeration process. Connection of iron is not as high as expected, and the percentage of the maximum exhaust air flow is only 10.24% at 1.0 L/min. The GATS is still capable of providing sufficient time to process the conversion of soluble iron into an insoluble form. In addition, the concept of gravity to reduce sediment in groundwater is based on a precipitation process. The GATS requires some adjustment to provide sufficient retention time for the aeration as well as time for the water process to be settled so that sediment can fall. The usage of GATS as a pre-treatment is useful for increasing the DO and iron removal. However, the system still requires an additional water filtration system because the standard has not been met.

Acknowledgement

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

References

[1] M. A. Manap, W. Nor, and A. Sulaiman, "A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia," pp. 1621–1637, 2013, doi: 10.1007/s12517-011-0469-2.

[2] N. A. Akbar, H. A. Aziz, and M. N. Adlan, "Potential use of ozonation with limestone adsorption in ground treatment: A case study at kelantan water treatment plant," *J. Teknol.*, vol. 74, no. 11, pp. 43–50, 2015, doi: 10.11113/jt.v74.4858.

[3] M. F. M. Akhir, "Desalination of Groundwater Using Marble Filter," *Int. J. Integr. Eng.*, vol. 11, no. 1 SE-Articles, May 2019.

[4] A. A. Athirah, N. A. Saad, M. F. M. Akhir, and N. A. Zakaria, "Manganese removal in groundwater treatment using marble," *Int. J. Integr. Eng.*, vol. 11, no. 2, pp. 053–060, 2019, doi: 10.30880/ijie.2019.11.01.006.

[5] M. Ahmad, "Iron and Manganese removal from groundwater Iron and manganese removal from groundwater," *DUO Res. Arch.*, vol. 10852/1254, no. University of Oslo, 2012.

[6] K. L. Xin, N. A. Saad, M. F. M. Akhir, and N. A. Zakaria, "Removal of iron in groundwater using marble column

filter," *Int. J. Integr. Eng.*, vol. 11, no. 2, pp. 112–118, 2019, doi: 10.30880/ijie.2019.11.01.012.
[7] N. A. Akbar, H. A. Aziz, and M. N. Adlan, "A hybrid treatment of ozonation with limestone adsorption processes for the removal of Fe2+in groundwater: Fixed bed column study," *AIP Conf. Proc.*, vol. 1892, pp. 2–8, 2017, doi: 10.1063/1.5005685.
[8] K. Samuding, M. T. A. Rahman, I. Abustan, and M. H. Isa, "Heavy metals profiles in a groundwater system at a solid waste disposal site, Taiping, Perak," *Bull. Geol. Soc. Malaysia*, vol. 58, no. 58, pp. 9–14, 2012.
[9] S. M. and Shirazi, M. I. and Adham, N. H. and Zardari, Z. adn Ismail, H. M. D. and Imran, and M. A. Mangrio, "Groundwater quality and hydrogeological characteristics of Malacca state in Malaysia," *J. Water L. Dev.*, vol. 24, no. 1–3, pp. 11–19, 2015, doi: 10.1515/jwld-2015-0002.
[10] S. L. D. Kenari, "Integrated Fluidized Bed-Membrane Process for Advanced Iron and Manganese Control in Drinking Water Seyedeh," Université De Montréal, 2017.
[11] D. Vries *et al.*, "Iron and manganese removal: Recent advances in modelling treatment efficiency by rapid sand filtration," *Water Res.*, vol. 109, pp. 35–45, 2017, doi: 10.1016/j.watres.2016.11.032.
[12] N. Khatri, S. Tyagi, and D. M.E Phd, "Recent strategies for the removal of iron from water: A review," *J. Water Process Eng.*, vol. 19, pp. 291–304, Oct. 2017, doi: 10.1016/j.jwpe.2017.08.015.
[13] S. Chaturvedi and P. N. Dave, "Removal of iron for safe drinking water," *Desalination*, vol. 303, pp. 1–11, 2012, doi: 10.1016/j.desal.2012.07.003.