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Research paper

The Effects of using Stepped Cascade Aeration and Multimedia Filter System for Iron Removal in Groundwater

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Abstract

Tahfiz school is an alternative education system for Muslims in Malaysia. Most of the traditional tahfiz school have been modernized and technologically well-equipped. However, they always have issues with water supply because most tahfiz schools are located in remote areas. Hence, an access to groundwater is provided to the school. A study was done by using groundwater samples taken from Sekolah Menengah Islam Darul Bayan, Paka, Terengganu and its recorded high amount of iron which is 13.7 mg/L. The iron value is exceeded the raw water standard of 1.0 mg/L, thus affecting its quality and it is not safe for domestic purpose. In this work, two methods of iron removal have been studied using stepped cascade aeration design and multimedia filter system. Using the stepped cascade aeration, the amount of removed iron content is 1.6 mg/L hence lowering its value to 12.1 mg/L with 11.67% removal. Meanwhile, the multimedia filter system is able to remove 12.7 mg/L, hence making its value to 1.0 mg/L with 92.7% removal. Therefore, the usage of stepped cascade aeration for groundwater with iron content less than 2.0 mg/L is sufficient. Whereas, the usage of multimedia filter system is needed for groundwater with iron content more than 2.0 mg/L.

Keywords: *Groundwater, Stepped Cascade Aeration Design, Multimedia Filter System, Water Quality Standards*

1. Introduction

Water is a global vital source of human life. There has been an increase in freshwater demand due to the country's economic growth and infrastructure development over the last three decades. Besides sourcing from surface water such as dam, lake and river, groundwater source is also used for various purposes. For example, in Malaysia, especially in East Coast states like Kelantan, Pahang and Terengganu, as well as Sabah and Sarawak particularly in the rural areas, are depending on groundwater as their main water source [1]. Based on observations, Kelantan reportedly having more than 70% of its water supply are obtained from groundwater sources [2].
Based on conducted studies, the demand for surface and groundwater in Malaysia is expected to increase by 63% from 2000 to 2050 [3]. Furthermore, groundwater contributed more than 90% of the overall country's water resources. The groundwater storage in aquifers estimated at about 5000 billion cubic meters with an annual recharge rate of 64-120 billion cubic meters [4]. Preliminary data on groundwater pollution were collected from nine Mineral and Geoscience Department (JMG) groundwater monitoring wells, Air Kelantan Sdn Bhd (AKSB) water treatment plant and National Hydraulics Research Institute of Malaysia (NAHRIM). The result shows that raw groundwater in Kelantan contains high concentration of iron and thus required an alternative treatment [5]. Iron is a natural metal found in water. It ranks fourth among the most copious elements on earth, while in earth's crust, it ranks second [6].
The main reason behind the presence of iron in groundwater is due to leaching from iron bearing rocks and minerals. The presence of iron in groundwater give water the reddish colour, metallic taste, and odour [7]. The Consuming Water Exceptional Surveillance Unit, Engineering Services Department, Ministry of Health Malaysia (KKM) prepared a hard and fast of guidelines wherein the standard raw water quality of iron is 1.0 mg/L and drinking water quality is 0.3 mg/L [8]. Therefore, the parameters of iron in the groundwater whose values exceed the standard considered contaminated and necessary for the treatment. This treatment should be carried out first so that the value of iron readings is within the specified water quality standard.
This research are divided by two groundwater remediation method of which are stepped cascade aeration conscript design and multimedia filter system. Both are designed using a pilot scale. Both of these treated samples water will be compared with raw water quality standard by KKM. The purpose of this research is to determine effectiveness and ability of removing high iron content in groundwater by means of these two abovementioned processes. Besides that, the propose is to determine the most suitable process for such level of iron in the groundwater.

1.1 Stepped Cascade Aeration

The conventional strategies for iron removal have been further divided into different techniques such as oxidation-precipitation-filtration process, zeolite softening or ion exchange, limestone bed filtration, filter media separation, supercritical fluid extraction, Vyredox technology, solid sorption separation/adsorption, wetland treatment, electro flotation, aeration and sequestering or stabilization process. The process of oxidation-precipitation-filtration has been widely used for removing excessive iron from the estuaries. The oxidation of ferrous iron to ferric iron is a simple process, which involves the use of an oxygen and oxidant. Oxidants generally employed for remediation of iron from water consists of hypochlorite, potassium permanganate (KMnO4), hydrogen peroxide, chlorine, ozone and chlorine dioxide [9]. An aeration step may precede oxidation for oxygenation and removal of carbon dioxide (pH increase), sulfurs and other volatile substances [10]. In aeration system, common methods that are used to remove iron is biological aerated filter, chemical reaction, stepped spillway and stepped cascade aerator [11]. For high potential air-water gas exchanger, stepped cascades aeration is recognized [12]. Due to strong turbulent mixing, the large residence time, and the substantial air bubble entrainment of stepped cascade, it make very efficient for aeration process [13].

1.2 Multimedia Filter System

In this process, the media content can be modified in accordance with the condition of the water contained therein. This technique is preferable because the water quality successfully reaches the predetermined standards. This method is applied to remove suspended particles such as clay, colloidal, and precipitated natural organic substances, metal salt precipitates of coagulation, precipitates of lime softening, inorganic metal such as heavy metal and microorganisms.

Sand, crushed anthracite coal, and granular activated carbon are commonly used as filter media for iron remediation of groundwater [9].Therefore, activated carbon (AC) is widely used as a suitable adsorbent for groundwater remediation and can effectively remove unpleasant taste and smell from water [14]. Granular activated carbon (GAC) media type is a commonly used filter for water treatment nowadays and its possessed advantages such as low operation cost and chemical-free [15]. However, the media needs to undergo regular maintenance and necessary changes if the chemical properties of water are contaminated.

2. Material and methods

2.1 Study Area

The area of study is located at Sekolah Menengah Islam Darul Bayan, Paka, Terengganu, Malaysia (SMIDB). The school fully utilizes groundwater for domestic purposes due to inaccessible to municipal water supply. The area is located at The area is located at Kampung Pinang Merah, Paka. Groundwater resources are taken from shallow tube wells with a depth of 25 meters and the water flowrate is $2m^3/h$. The total number of student is 300 and they accommodated the school dormitories. The proposed study area is also located near the sea, hence allowing the tides to affect the constructed tube wells at Sungai Paka.

2.2 Measurement Technique for Quality Sampling

Table 1 shows the KKM standard quality of both raw and drinking water. There are 7 main parameters taken in this study as stated in the table below which are pH value, turbidity, iron content, manganese content, TDS, conductivity, and total coliform. The samples were taken at two conditions; (a) before the treatment process, where the samples are taken directly from the tube well discharges and (b) after the treatment process, where the discharges will pass through the stepped cascade aeration and multimedia filter system. The samples will be tested using the abovementioned methods. The test results are shown in the Table 2 below.

There are several methods to identify the iron content in the groundwater. However, for this experiment the iron content in the groundwater is measured using method 3125 B (APHA 2013) by means of Inductively Coupled Plasma Mass Spectrometry (ICP-MS) as lab instrument. As for pH values, conductivity, and TDS, the test was done in-situ.

Table 1: Water quality sampling with KKM standards quality

No	Parameters	KKM Water Quality Standard	
		Raw Water	Drinking Water
1	pH	5.5-9.0	6.5-9.0
2	Turbidity (NTU)	1000	5
3	Iron (mg/L)	1.0	0.3
4	Manganese (mg/L)	0.2	0.1
5	Total Dissolved Solid, TDS (mg/L)	1500	1000
6	Conductivity (µS/cm)	-	-
7	Total Coliform (MPN/100 mL)	5000	Absent

The lab tests results shown in Table 2 were obtained using the abovementioned methods. The quality test of pre-processed water shows high amount of iron content (13.7 mg/L) which exceeded the KKM standard.

Table 2: Raw groundwater quality sampling results

No	Parameters	Sampling Quality	Method
1	pH	5.75	*APHA 4500-H+ B, 2013*
2	Turbidity (NTU)	12.2	*APHA 2130 B, 2013*
3	Iron (mg/L)	13.7	*APHA 3125 B, 2013*
4	Manganese (mg/L)	1.51	*APHA 3125 B, 2013*
5	Total Dissolved Solid, TDS (mg/L)	219	*APHA 2540 C, 2013*
6	Conductivity (µS/cm)	443	*APHA 2510 B, 2013*
7	Total Coliform (MPN/100 mL)	19.7	*APHA 9221 C, 2013*

2.3 Method of Removal Iron

2.3.1 Stepped Cascade Aeration Design

The stepped cascade aeration had designed as shown in Figure 1 below. The dimension for the completely stepped cascade aeration is 3m (h) x 4m (l) x 1m (w). The design for the step of cascade is 0.2m (h) x 0.3m (l) x 0.3 (w). The system is able to produce different flow regime depending on inlet from the upstream. The water will then be stored in the treated groundwater tank.

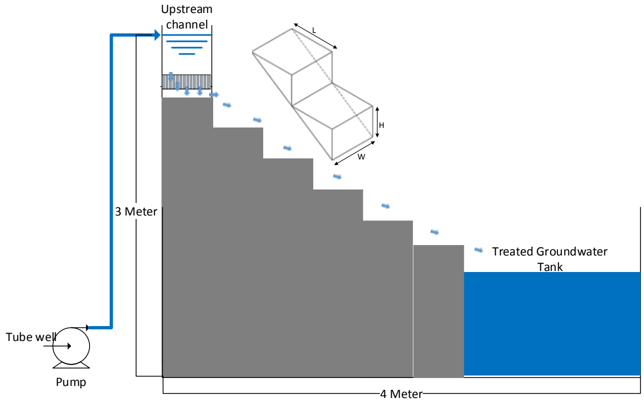

Fig. 1: Stepped cascade aeration design

The actual design made of concrete is already operating as shown in figure 2. The system designed on a pilot scale. The discharge from the tube well and going to the upstream inlet enters the system through pump with flow rate of 2 m^3/h.

Fig. 2: Concrete stepped cascade aeration

2.3.2 Multimedia Filter System

The study used multimedia filter system with 4 media installed inside the filter as shown in Figure 3. The figure also visualizes the path of inlet flow via the tube well through the multimedia filter system. The flow rate is quantify based on constant rate discharge and the recorded flow rate is within 2 m^3/h – 3 m^3/h.

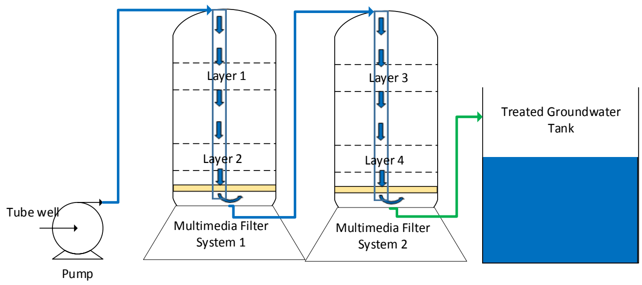

Fig. 3: Groundwater flow treatment in multimedia filter system

The filter is made from fiber reinforced plastic (FRP) vessel with dimensions of 16 inches and 65 inches for diameter and height respectively. Each one of FRP vessels consisting of 2 media layers with different particle size and bulk density. The type of media layers are listed in order as shown in Table 2 below.

Table 2: Characteristic of each media layer FRP 1

Layer	Media Type	Particle Size (mm)	Bulk Density (g/cm^3)
Layer 1	River Graded Sand 1	2.4-4.8	
Layer 2	Manganese Green Sand	0.8 – 1.5	1.26
Layer 3	River Graded Sand 2	0.3-0.8	
Layer 4	Granular activated carbon	0.6-2.0	0.3-0.5

For this study, two FRP vessels are used for the multimedia filter system. The usage span of the media is within 5 to 6 months and backwash is required once every 2 days.

Fig. 4: Fiber reinforced plastic (FRP) 1 and 2

Groundwater that has been treated of this system will be stored in a tank of polyethylene tanks water tank round series as shown in figure 5. The size of this tank top diameter dimension (H) 1850mm, bottom diameter (B) 1625mm, and diameter height with cover 910mm. Four tanks used and is capable of storing capacity of 500 gallons each tank. All tanks is connected with PVC pipe to each other at tank bottom.

Fig. 5: HDPE tank for treated groundwater

3. Result and Discussion

3.1 Water Quality After Stepped Cascade Aeration

The sample is derived from the treated groundwater tank to determine the quality of water post-aeration process. Parameters such as pH value, TDS, and conductivity of the water can be determined by in–situ test, while the rest of the parameters need to undergo a lab test. Table 3 shows the data of the groundwater after the iron removal. The results found that reading of iron is 12.1 mg/L and its decrement in iron content value by 1.6 mg/L from the initial value 13.7 mg/L. The effectiveness of the system for iron removal is 11.67 %. However, this technique is unable to reduce the amount of iron content in order to meet the KKM quality standards.

Table 3: Groundwater sampling quality after stepped cascade aeration

No	Parameters	After Aeration	Method
1	pH	5.76	*APHA 4500-H+ B, 2013*
2	Turbidity (NTU)	13.8	*APHA 2130 B, 2013*
3	Iron (mg/L)	12.1	*APHA 3125 B, 2013*
4	Manganese (mg/L)	1.63	*APHA 3125 B, 2013*
5	Total Dissolved Solid, TDS (mg/L)	220	*APHA 2540 C, 2013*
6	Conductivity (µS/cm)	449	*APHA 2510 B, 2013*
7	Total Coliform (MPN/100 mL)	2.0	*APHA 9221 C, 2013*

3.2 Water Quality After Multimedia Filter System

Table 4 shows the result of using multimedia filter system for iron removal. The same test procedures are conducted to determine the following parameters. The post-processed reading of iron content value is 1.0 mg/L. The reading shows a decrement as much as 12.7 mg/L from the initial value which was 13.7 mg/L. The effectiveness of the system is 92.7 %, hence meeting the KKM quality standards.

Table 4: Groundwater sampling quality after multimedia filter system

No	Parameters	Media Filter	Method
1	pH	5.82	*APHA 4500-H+ B, 2013*
2	Turbidity (NTU)	5.61	*APHA 2130 B, 2013*
3	Iron (mg/L)	1.00	*APHA 3125 B, 2013*
4	Manganese (mg/L)	0.34	*APHA 3125 B, 2013*
5	Total Dissolved Solid, TDS (mg/L)	562	*APHA 2540 C, 2013*
6	Conductivity (µS/cm)	1135	*APHA 2510 B, 2013*
7	Total Coliform (MPN/100 mL)	18	*APHA 9221 C, 2013*

The multimedia filter system is more effective than stepped cascade aeration in removing iron content in groundwater.

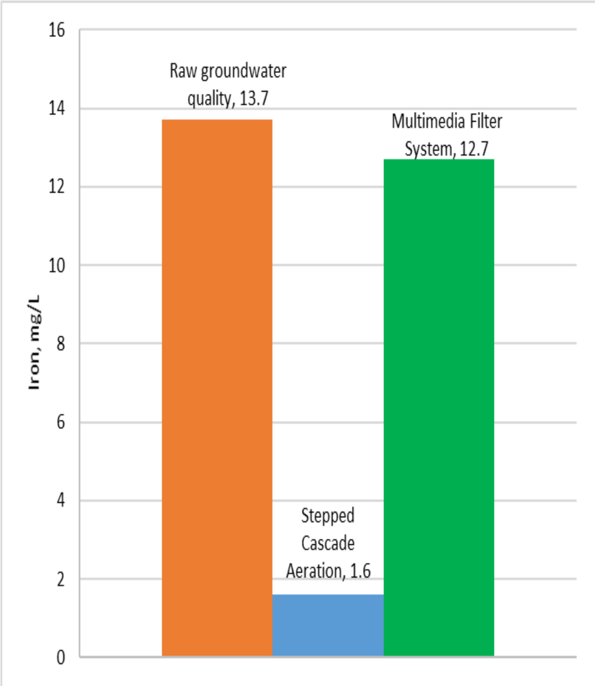

Fig. 6: Comparison removal iron between stepped cascade aeration and multimedia filter system from raw groundwater

4. Conclusion

Stepped cascade aeration system is suitable for groundwater with iron content below 2.0 mg/L to achieve the raw water standard. The study found that aeration method is unable to abundantly remove iron content and thus can be benefitted as a precedence of other treatment methods. The effectiveness of using stepped cascade aeration is lesser than that of multimedia filter system. However, stepped cascade aeration is suitable to be applied for long term usage. The stepped cascade aeration does not need any maintenance routine schedule and free of ongoing costs as it does not require any material in the process.

Multimedia filter system is the most suitable method for removing iron content in groundwater that exceeds 2.0 mg/L to fulfill the raw water standard by KKM. Multimedia filter system required frequent maintenance such as backwash. The backwash is needed on a daily basis so that the water is in compliance with the standard. Furthermore, multimedia filter system needs an ongoing cost to replace the filtering media.

The combination of both multimedia filter and stepped cascade aeration systems can be proposed as shown in Figure 6. It is expected that the media layers in multimedia filter system will be more durable due to the pre-treatment of groundwater by the aeration method. Hence, the pre-treatments will reduce the cost of maintenance. In addition, this approach is also free from any use of chemicals during iron oxidation process for sediment to take place. This is because the oxidation process of iron is aided by oxygen itself.

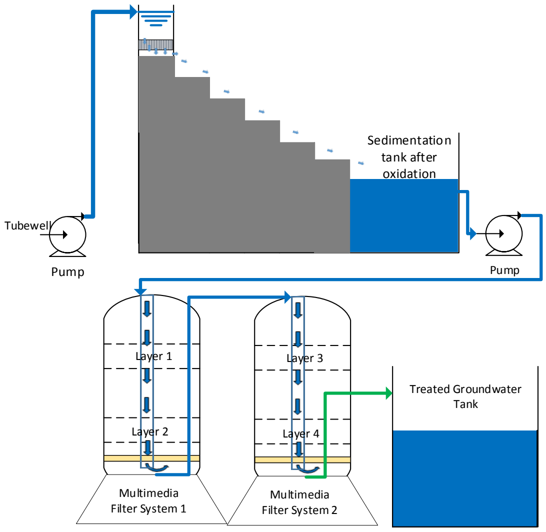

Fig. 7: Integrated between stepped cascade aeration and multimedia filter system

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References

[1] M. Nampak, Haleh and Pradhan, Biswajeet, and Abd Manap, "Application of GIS based data driven evidential belief function model to predict groundwater potential zonation," *J. Hydrol.*, vol. 513, pp. 283–300, 2014.
[2] M. A. Manap and H. Nampak, "Application of probabilistic-based frequency ratio model in groundwater potential mapping using remote sensing data and GIS," pp. 711–724, 2014.
[3] 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.
[4] C. L. Heng, "Groundwater Utilisation and Management in Malaysia by," no. November, 2004.
[5] 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.
[6] J. Silver, *Inorganic chemistry of iron*, First edit. Springer Science, 1993.
[7] 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.
[8] Ministry of Health Malaysia, "National Guidelines for Drinking Water Quality (NGDWQ)," 2010.
[9] N. Khatri, S. Tyagi, and D. Rawtani, "Recent strategies for the removal of iron from water: A review," *J. Water Process Eng.*, vol. 19, no. 13, pp. 291–304, 2017.
[10] D. Ellis, C. Bouchard, and G. Lantagne, "Removal of iron and manganese from groundwater by oxidation and microfiltration," *Desalination*, vol. 130, no. 3, pp. 255–264, 2000.
[11] M. R. Rozainy, "Jurnal Teknologi," *a Rev. Remov. Iron Manganese By Using Cascade Aeration Syst.*, vol. 1, pp. 1–6, 2015.
[12] H. Khdhiri, O. Potier, and J. P. Leclerc, "Aeration efficiency over stepped cascades: Better predictions from flow regimes," *Water Res.*, vol. 55, pp. 194–202, 2014.
[13] D. Hanbay, A. Baylar, and M. Batan, "Prediction of aeration efficiency on stepped cascades by using least square support vector machines," *Expert Syst. Appl.*, vol. 36, no. 3 PART 1, pp. 4248–4252, 2009.
[14] N. Esfandiar, B. Nasernejad, and T. Ebadi, "Journal of Industrial and Engineering Chemistry Removal of Mn (II) from groundwater by sugarcane bagasse and activated carbon (a comparative study): Application of response surface methodology (RSM)," *J. Ind. Eng. Chem.*, vol. 20, no. 5, pp. 3726–3736, 2014.
[15] V. Meshko, L. Markovska, M. Mincheva, and a E. Rodrigues, "Adsorption of basic dyes on granular activated carbon and natural zeolite.," *Water Res.*, vol. 35, no. 14, pp. 3357–3366, 2001.