© 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

Rapid-Slow Sand Filtration for Groundwater Treatment: Effect of Filtration Velocity and Initial Head Loss

Mohammad Hakim Che Harun[1,2,3], Muhammad Irfan Ahmad[2], Ahmad Jusoh[2], Asmadi Ali[2,3], Sofiah Hamzah[2,3*]

[1]Department of Chemical and Biological Engineering,
University of Sheffield, S1 3JD, UNITED KINGDOM

[2]Environmental Sustainable Materials Research Interest Group,
Universiti Malaysia Terengganu, 21300 Kuala Nerus, Terengganu, MALAYSIA

[3]Faculty of Ocean Engineering Technology and Informatics,
Universiti Malaysia Terengganu, 21300 Kuala Nerus, Terengganu, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2022.14.01.026
Received 17 March 2021; Accepted 07 October 2021; Available online 07 March 2022

Abstract: Iron (Fe) and manganese (Mn) are two of many substances that are causing harm to human health and various environmental contamination. This study investigates the performance of rapid sand filter as an improvement to the existing commercial filter media. Rapid sand filters were tested using groundwater collected from Kg Budi Kelantan. Groundwater collected were tested using seven velocities ranging from 0.89 to 5.04 m/hr. The concentration of Mn, Fe and turbidity of the treated groundwater were compared. It is found that the highest Mn, Fe and turbidity removal were recorded by using velocity of 4.38 m/hr followed by 2.95 m/hr and 2.4 m/hr. These three velocities represent more than 95% removal of final treated groundwater, where final Fe, Mn and turbidity ranging from 0.06 mg/L to 0.09 mg/L, 0 to 0.4 mg/L and 0.9 to 3.0 NTU, respectively. A positive trend also recorded where the initial head loss of the sand filter is directly proportional to the flow velocity. This means the filter media was still under a clean condition and no accumulation of sediment deposit occurs. The significance of this study to treat groundwater by removing the iron and manganese especially in rural areas were achieved successfully.

Keywords: Sand filter, optimum velocity, groundwater, wastewater, filtration

1. Introduction

Heavy metals such as iron and manganese content in groundwater will cause a stark color condition. When exposed to air and any kind of oxidation contact, groundwater contains dissolved iron and manganese will turn to indissoluble. This will turn the clear water into brown-reddish color. Excessive heavy metal have a long term effect and problems such as indirect economic problems and health concerns such as neurotoxicity and Parkinson's [1], [2]. Therefore, it is important to treat groundwater containing high iron (Fe) and manganese (Mn for safe and clean water supply security [3]. Conventional groundwater treatment plants usually consist of aeration and rapid sand filtration. They are merely designed and optimized for iron (Fe) and manganese (Mn) removal. Aeration and rapid filtration are very economics and there are no chemicals required. This technology also may be utilized to generate a waste stream with rich iron (Fe) that can be used for many applications such as fertilizers and food additives. Aeration also important for the carbon dioxide removal, ammonia, sulfur and volatile organic chemicals such as benzene. This removal is

*Corresponding author: sofiah@umt.edu.my

crucial as excessive amounts of carbon dioxide can cause major problems to the operability of the filter due to high pH value [4].

Untreated water always associated with the risk of biological, chemical, and physical contamination. It is important to treat the groundwater up to the drinking water quality standard in term of turbidity, pH, heavy metal contents, odor, and color that may cause offense to the consumers [5]. This also means assuring that the raw water's chemical elements do not cause operational problems and maintenance cost in the treatment system. Due to that reason, environmentally friendly and low-cost water treatment technologies are crucial to eliminate heavy metals and various harmful organic contents from the water supply [6], [7]. Conventional treatment process such as precipitation, filtration, and electrocoagulation are highly reliable and considered to be very well designed for Fe and Mn removal. However, the technologies present a number of disadvantages in terms of treatment capacity, efficiency, stability, and space requirements [8], [9]. Marsidi et al. (2018) stated that conventional treatment process generates a large volume of sludge which subsequently requires high maintenance and operational cost. Another problem related to groundwater is the reddish color due to the presence of ferrous and manganese. Initially, this color is invisible, however become visible after it has been exposed to the air. Air will promote the oxidation of dissolve metals in groundwater which stimulate the precipitation of ferrous and manganese [1]. Eventually, the groundwater turns into reddish in color.

Individual toxicity resulting from heavy metals could be caused by several factors. These include heavy metals dose, chemical species, route of exposure, gender, age, and nutrition status of a person. Mineral is important for the human body, in fact Fe has been an essential element for the red-blood production. However overdose may cause severe health problems such as diarrhea, anorexia, diphasic shock, vascular congestion of the gastrointestinal tract, metabolic acidosis, neuromembranes, spleen and thymus, and death [10]. Allen et al. [11] reported that there is no health consequence if a healthy person accidentally consumes Fe contains water on the basis of lower than 0.4–1 mg Fe/kg of their body weight per day. On the other hand, Mn has been discovered to affect the central nervous system. Mn substances can also cause disturbance on human crucial organ such as lung, liver and vascular stream including a low blood pressure, and brain damage [8].

Filter media is the main character in filter design as well as filter operation and efficiency. The detail description for each layer of media in rapid sand filter is classified as shown in Table 3 shows the comparison media design and sizing for a particular layer and actual size used in this study.

Table 3. Smaller grain sizes will pose higher head loss while bigger grain sizes resulted in smaller head loss but end with inefficiency in filtering. In Malaysia, local surface water quality and/or portable and drinking water system is monitored by Department of Environment (DOE). Nevertheless, DOE have introduced two specific guidelines to control local water quality through River water (Surface Water) Quality Monitoring Programme by using two standards such as the Water Quality Index (WQI) as shown in Table 1 and Interim National River Water Quality Standards (INWQS). WQI takes parameters into account, such as the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH_3N), pH, Dissolved Oxygen (DO), Suspended Solids (SS) and heavy metal contents such as Fe and Mn.

Table 1 - Water Quality Index (WQI) recommended by Department of Environment (DOE) Malaysia [12], [13]

Parameter	Unit	Value
Ammoniacal Nitrogen	mg/L	<0.1
Biochemical Oxygen Demand	mg/L	<1
Chemical Oxygen Demand	mg/L	<10
Dissolved Oxygen	mg/L	>7
pH	-	>7.0
Total Suspended Solid	mg/L	<25
Water Quality Index	-	<92.7
Aluminum, Al	mg/L	<0.1
Iron, Fe	mg/L	<0.3
Manganese, Mn	mg/L	<0.1
Lead, Pb	mg/L	<0.01

2. Materials and Methods

In order to remove iron (Fe) and manganese (Mn) from groundwater, several fundamental steps were strategized to create a proper and accurate methodology of this research. The performance of sand as a potential filter media was evaluated through its head loss performance (initial head loss and maximum achievable operational head loss), effluent quality (filtrate turbidity and TSS), specific deposited sediment and filter run (total service time). Other prospect of sand such as physical properties including shape, specific gravity, size, and porosity were determined in this study. The progress of this experiment set up was clearly shown in Fig. 1.

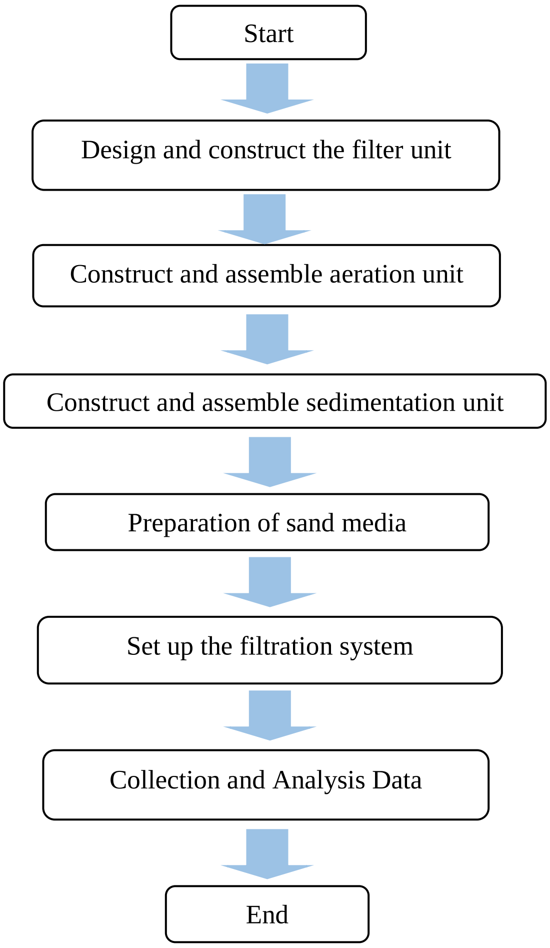

Fig. 1 - Flow Chart of a briefing methodology on filtration system progress

First steps, design of the overall system treating the groundwater which contains such a high iron and manganese as shown in Table 2. The systems consist of aeration, sedimentation, and filtration. This simple system was selected based on the effectiveness in removing iron and manganese. Both iron and manganese could be oxidized by aeration as description in Eq. (1) and Eq. (2).

Table 2 - Raw water quality of groundwater in Kg. Budi, Kelantan

Parameter	Unit	Average Value
Turbidity	NTU	59.1
pH	-	7.5
Iron, Fe	mg/L	3.40
Manganese, Mn	mg/L	0.23

$$Fe^{2+}{}_{(aq)} \rightarrow Fe^{3+}{}_{(aq)}) + e^{-} \quad (1)$$

$$MnO_4^{-}{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)} + 4H_2O \quad (2)$$

The overall system was shown in Fig. 2. The iron and manganese exist in groundwater in soluble forms as ferrous (Fe^{2+}) and manganese (Mn^{2+}). The aeration process converted the ferrous (Fe^{2+}) ions to ferric (Fe^{3+}) and the manganese (Mn^{2+}) to manganese (Mn^{4+}). Both ferric (Fe^{3+}) and manganese (Mn^{4+}) were insoluble in water. Therefore, they were precipitated in water. The most appropriate process to remove ferric and manganese was the sedimentation process. Thus, the second process after the aeration was sedimentation process.

However, the sedimentation process only could remove a partial of (Fe^{3+}) and (Mn^{4+}). Next, the filtration process was determined by preparation of filter media, determination of optimum velocity and determination of head loss pattern. In order to obtain polish or a better-quality water in future, the filtration and titration of chloride could remove small particulate matter and produced such a clear water with low turbidity and ferric as well as Mn^{4+}.

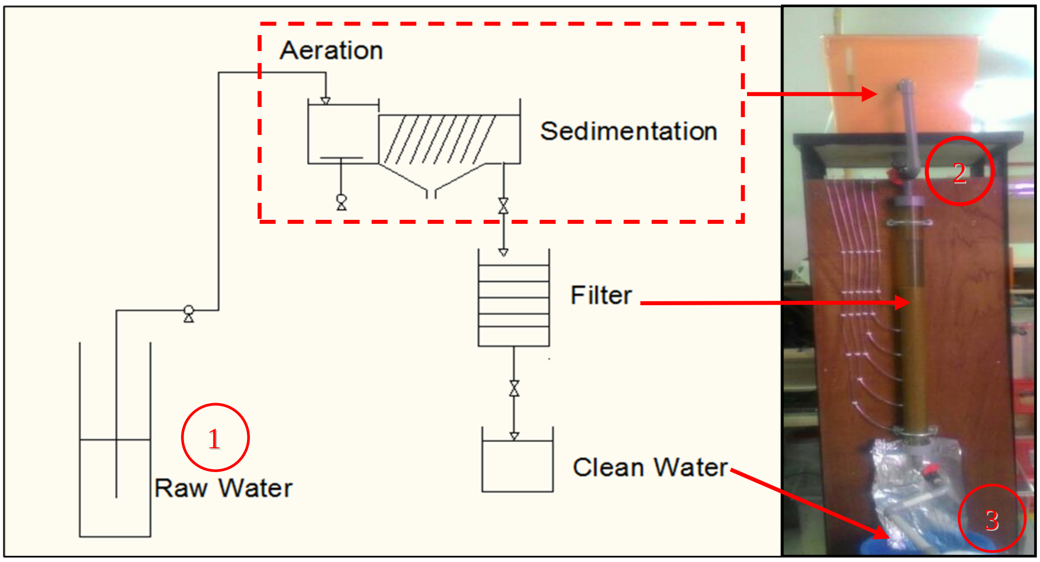

Fig. 2 - Design of the system filter. Point 1, 2 and 3 remarks the sampling point of raw water, aeration and sedimentation, and filtered water respectively

2.1 Aeration

Air scouring or aeration could avoid flat taste in water due to the dissolved metals such as Fe and Mn [14]. Aeration is one of the most conventional and cost-effective way to bring water and air in contact for the purpose of dissolved metals oxidation such as iron, manganese, and volatile chemicals (VOC's). The oxygen transferred though the thin layer of the bubbles into the water while rising to the top surface of the water body. This transport phenomenon between the two-phase fluids will promote the removal of dissolved metals from the solution through the chemical combination. C. Harun and Zimmerman [15] discussed the benefits of smaller bubble for a better mass and energy transfer in the water. They present a series of data on how the bubbles scrubbing out the biofilm layer on the surface of membrane filtration which caused by the turbulence of aeration. It is important to ensure the untreated water aerated to reduce the constituent elements that could interfere with the consequent treatment process. Once oxidized, these chemicals deposited from the solution as particles in the untreated water. This could be physically removed by filtration or flotation. Aeration, where it mainly for oxidation purpose, depends largely on the amount of surface contact between air and bubbles. The smaller the size of bubbles, the higher the surface contact area between air and bubbles [15].

2.2 Sedimentation

Sedimentation was the process of particles suspended and settle out of the water under the effect of gravity. The heavier particles become a sediment at the bottom of the water which usually known as sludge. The mechanical assisted layer formation is known as sludge. Sedimentation was applied after the aeration for the purpose of reducing the particles that are suspended. This is crucial to prevent overloading of cake formation on the subsequent filtration systems. Some would consider this solids-liquid separation of aeration and sedimentation as compulsory pretreatment prior filtration due to their cost-effective compared to other methods such as dissolved air floatation.

2.3 Filtration Media Preparation

This study used the most conventional style (gravity flow with sand media) to treat the groundwater. The sand media was washed and rinsed for at least three times by using clean water before putting into real operation. The collected sand media will be soaked for 24 hours with clean water to reduce salinity and pH stabilization. It was used to determine the filter's capacity in terms of operation time. To obtain the constant flow, the control valve at the influent and effluent pipe was opened continuously and the flow rate of effluent was checked gradually. The flow rate was evaluated in filtration operation. During filtration progress, a filter was evaluated on its influent turbidity, effluent turbidity, concentration of iron and manganese. The head loss at different heights of bed depth were recorded and analyzed at difference time intervals.

The sand used in this study was collected from the local riverbank sand while packed sand bought from the local hardware shop. Sea sand was unsuitable for this study to avoid the influence of salinity from sand. In current study, the effective size of sand is 0.45 mm with uniformity coefficient of 3.30. The sieving mechanical machine was used for sieving process. Once the effective media size was obtained, the sand was then washed and cleaned. Finally, the media was prepared and poured into the filtration unit and ready for operations.

Filtration efficiency greatly dependent on its typical physical properties. These include media porosity and ratio of the media depth to the media grain diameter. It is important to make a proper selection of filter media as a part of filter design. Filter media controls the suspended solids capacity and hydraulic loading rate on the filter bed which subsequently affects the quality of the finish water. In this study, the sand would be used as single media filters to treat raw water. Table 3 shows the comparison media design and sizing for a particular layer and actual size used in this study.

Table 3 - Typical media design values for various filters [16], [17]

Parameter	Mono-media	Actual size used
Anthracite layer		
Effective Size, mm	0.50-1.50	
Uniformity coefficient	1.2-1.7	
Depth, cm	50-150	
Sand Layer		
Effective Size, mm	0.45-1.0	0.45
Uniform coefficient	1.2-1.7	3.3
Depth, cm	50-150	10-60
Garnet Layer		
Effective Size, mm		
Uniform coefficient	-	
Depth, cm		

2.3.1 Determination of Optimum Velocity of Rapid Sand Filter

A study on the appropriate velocity passing through the filter media was necessary. For instance, a faster velocity may reduce the water quality and a slow velocity may produce a good water quality. However, a slow velocity results a low capacity of water production. Therefore, the determination of the optimum velocity is very importance. The range of velocity that would be study is between 0.5 m/h to 6.0 m/h which is quite similar to the study by Song et. al [18] and Sela [19] which is 0.15 m/h to 5 m/h.

According to Williams et al. [16] stated that the turbidity removal efficiency decreased with higher velocity. The turbidity and pre-treatment of source of water to be treated should be considered too as these may affect the required filtration rate. To determine the optimum velocity in the filter, valve was controlled to find the optimum velocity that could remove iron and manganese. A few velocities were tested to find the lower the concentration of iron and manganese. Formula Q=VA was used to find the velocity, where Q is the volumetric flowrate, A is the cross-sectional area of the flow, and V is the mean velocity.

2.3.2 Determination of Head Loss Pattern

Head loss was monitored experimentally using manometer tubes. The occurrence of head loss is referred to the losses of energy of continuous water flow through the filter bed due to the form of filter bed and the drag friction at the surface of the sand media. Numerous experiments to obtain either empirical or semi-empirical equation have been tested to estimate the initial head loss. The determined head loss such as fractional void volume or porosity, the particle shape, roughness, media sizing and size distributions of the granular media, effective sizes, uniformity coefficient of filter media had been tested[16].

The head loss of filter run was observed through the height reduction of water from manometer tubes for certain level of bed depth which derived according to Bernoulli principle. The flow pattern of water throughout the filter bed was quite complex and this phenomenon had caused the decrement in pore volume of filter bed. According to [17] head loss is very sensitive to porosity, especially as velocity increase, at 15 m/h, the clean bed head loss increase from 0.17 to 0.27 m as porosity decrease from 53 to 48 percent. Head loss also influenced by water temperature where it increases when water temperature increase.

2.4 Water Quality Analysis

In this study, water quality analysis was determined in term of the concentration of iron and manganese by using AAS Spectrometer （Varian SpectrAA FS-220 Atomic). Water quality analysis also was determined in turbidity of water by using light scattering device （Thermo Scientific Aquafast AQ3010). There are three points in this filtration system will be analyze water quality. First point that analyzed in this filtration system was before the aeration process. Next, for the second point was after the sedimentation process and the third point analyzed the water was at the last tank of water. It was after the filter process. All of three points, the water was sampled to examine the concentration of iron and manganese to see the decreasing in concentration of iron and manganese.

3. Results

In this study, sand was used as filter media in mono-media filter under rapid-slow filtration conditions. All experimental outcomes were analyzed and compared. The performance of a particular filter is evaluated by several factors such as the effective size of filter media, filter depth, the optimum velocity, and head loss pattern. This chapter focuses on result of sieve analysis on sand filter media, effect of velocity to water quality, optimum velocity, and initial head loss of sand filter.

3.1 Effect of Filtration Velocity on Water Quality of Clean Water

Water quality is the main parameter as an indicator of filter performance. From this study, concentration of iron (Fe), manganese (Mn) and turbidity of filtered water was determined. Result obtained show a high reduction of up to 95% removal of iron, manganese and less than 5 NTU for turbidity parameter.

Velocity is significant in affecting the iron, manganese, and turbidity removal. The results show that greater reduction in iron, manganese and turbidity removal appeared in media at the different velocity. This means that the different velocity of water has the different water quality. The higher velocities of water have the higher concentration of iron, manganese, and turbidity at the effluent quality.

Turbidity is the key parameter to evaluate the water quality of a filter in this study. **Error! Reference source not found.** shows the variation of concentration based on three points which are raw water for the first point, the second point is after aeration and sedimentation, and the third point is after filtration. The initial raw water concentration based on turbidity was fluctuating in the range of 30-80 NTU. After aeration and sedimentation, turbidity was fluctuating in the range of 5-25 NTU. Mono-media sand filter system was carried out in triplicates and the average of turbidity after filtration varied in the range of 0-5 NTU.

Iron and manganese are the contaminants that need to be reduce in groundwater when filtration. The ranges of iron and manganese concentration at raw water are 2-5 mg/L and 0.15-0.25 mg/L. Next, for the second point at aeration and sedimentation, the ranges of iron and manganese concentration are 0.15-0.80 mg/L and 0-0.05 mg/L. Results obtained show a high reduction of up to 65% removal of iron and manganese at aeration and sedimentation. After filtration, the reduction of up to 90% removal of iron and manganese at the ranges of concentration 0.06-0.09 mg/L and 0-0.03 mg/L.

Thus, this shows the effluent quality was achieved the standard of drinking water quality. The standard of drinking water quality for manganese (Mn) is 0.1 mg/L, iron (Fe) is 0.3 mg/L and turbidity is below 5 NTU. From the **Error! Reference source not found.**, the concentration of iron and manganese at point 3 was achieved the drinking water quality standard and also the turbidity which is below than the drinking water quality standard. Therefore, the groundwater after filtration was safe to consume.

Table 3 – Progress of concentration of manganese, iron, and turbidity for each point.

Velocity (m/h)	Point	Mn (mg/L)	Fe (mg/L)	Turbidity (NTU)
5.04	1	0.1803	2.4226	35.8
	2	0	0.1723	7.94
	3	0	0.0899	1.01
4.38	1	0.2337	3.5421	65.8
	2	0.0035	0.1956	8.16
	3	0	0.0653	0.95
2.95	1	0.2267	4.1417	76.5
	2	0.0520	0.5034	14.74
	3	0.0019	0.0896	2.74
2.40	1	0.2283	3.2175	48.0
	2	0.0506	0.4767	16.93
	3	0.0067	0.0877	2.01
1.59	1	0.2589	3.3094	61.0
	2	0.0915	0.7219	22.33
	3	0.0232	0.0890	1.39

1.09	1	0.2418	3.7794	58.0
	2	0.0915	0.7302	22.46
	3	0.0366	0.0887	0.94
0.89	1	0.2384	3.3953	68.9
	2	0.0796	0.6633	21.53
	3	0.0343	0.0741	1.31

Point 1 is the raw water that was taken at Kampung Budi, Kelantan. The physical and chemical of raw water was determined in term of iron, manganese, and turbidity. The concentration of iron, manganese and turbidity from raw water was analyzed that have shown in the **Error! Reference source not found.** at point 1. Thus, the raw water needs to treat to reduce the concentration of iron and manganese to give a good water quality for safe consumed by the people at Kampung Budi, Kelantan.

Next, point 2 is the raw water was treated by aeration and sedimentation. Aeration and sedimentation are great way to treat groundwater and could removal the iron and manganese from groundwater. Aeration is one of many economical methods of introducing rich oxygen air into the water for the removal of dissolved heavy metals such as iron and manganese. Oxygen in the form of bubbles transferred into the water streams by absorption oxidized ferrous (Fe^{2+}) iron to ferric (Fe^{3+}) iron. Generally, aeration is used for eliminating iron from waters with concentrations more than 5 mg/L. The process is entirely physical and helps to reduce the cost of iron removal by avoiding the use of chemicals which may harm the environment. [21] stated that the efficiency of aeration for iron removal may be increased by introducing specific microbes into the system

A more rigorous conditions such as higher DO ranging 5-6 mg/L O_2 to precipitate Mn ions are required by the Manganese-oxidizing bacteria (MnOB). Fe ions removal however can be accomplished at lower DO of 2 mg/L with a DO and an initial pH of 7.2 [8]. The precipitation of Fe and Mn ions occurs through the oxidation process. Eq. (3) and Eq. (4) shows the oxidation of ferrous iron and manganous manganese by oxygen as follows:

$$4Fe\ (HCO_3)_2 + O2 + 2H_2O \rightarrow 4Fe\ (OH)_3 + 8CO_2 \tag{3}$$

$$2Mn\ (HCO_3)_2 + O2 + 2H_2O \rightarrow 2Mn\ (OH)_4 + 4CO_2 \tag{4}$$

Eq. (3) shows that only one mole of oxygen molecules is needed to react with four moles of Fe ions to form four moles of Fe precipitate. While Eq. (4) shows that one mole of oxygen molecules is needed to react with two moles of Mn ions to form two moles of Mn precipitate. These theoretical equations clearly confirmed that more oxygen is required for Mn ions oxidation compared with that of Fe ions [8]. Fig. 3 show the percent removal of iron, manganese and turbidity is up to 60% reduction of concentration after aeration and sedimentation. The highest removal at aeration and sedimentation is manganese that achieves 100% removal.

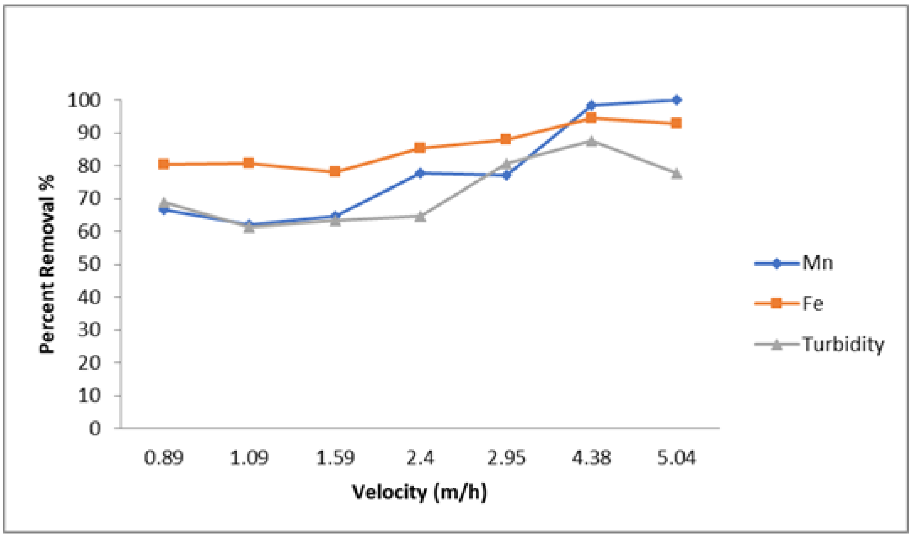

Fig. 3 - Percent removal of iron, manganese and turbidity at aeration and sedimentation

Next, point 3 is filtration which used sand as media to filter the groundwater. In this study, the sand media with effective size of 0.45mm and uniformity coefficient of 3.3, the amount of sediment deposit is always concentrated on the top centimeters of the filter media. This due to smaller effective size used (ES=0.45mm) and lower initial porosity (ε_o=0.4) of sand. Sand media has a high efficiency and filtration coefficient which lead to the ability of high suspended solids removal. Furthermore, sand media can easily capture the solid particles in raw water stream because of its low porosity, small void spaces between granules due to small effective size used and its high attachment coefficient factor. This means that the smaller size of filter media exhibits a better performance in treating raw water. It is also supported by Mesquita et al. [20] which stated that fine grained media produced better filtrate quality than the course grained media.

After filtration, the groundwater has a good water quality because the iron and manganese were removed by the sand filter. In

Fig. 4, the concentration of iron is in the range 0.06 mg/L to 0.09 mg/L depends on their velocity. The best removal of iron concentration is 0.065 mg/L at velocity 4.38 m/h. For manganese, the range of concentration is 0 mg/L to 0.4 mg/L. Based on the

Fig. 4, there have two velocities that have 0 mg/l for manganese concentration; there are 4.38 m/h and 5.04 m/h.

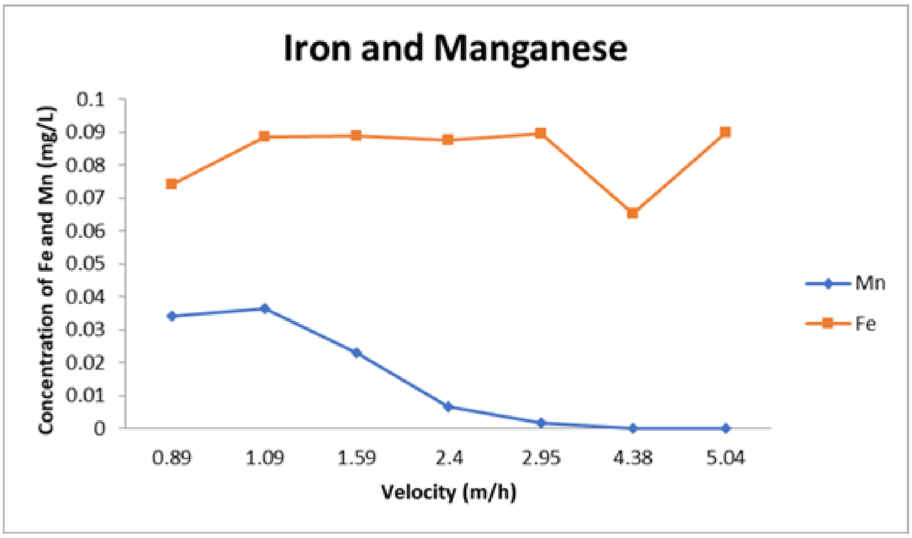

Fig. 4 - The concentration of iron (Fe) and manganese (Mn) after filtration

Next, the concentration of turbidity has shown in

Fig. 5. The range of the concentration for turbidity is between 0.9 NTU to 3.0 NTU. Though the high concentration of turbidity is at 3.0 NTU after filtration, it is still accepted by drinking water quality standard. The best turbidity is at velocities 1.09 m/h, 4.38 m/h and 5.04 m/h.

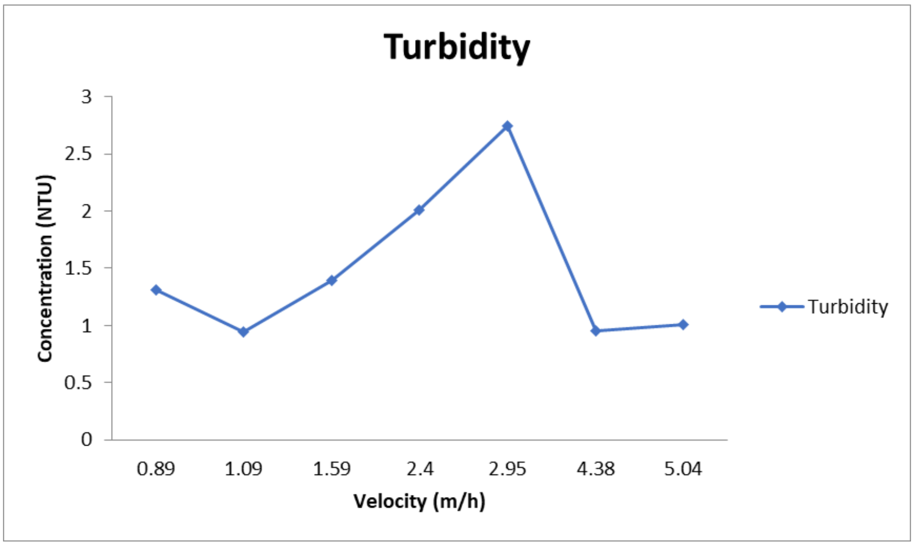

Fig. 5 - The concentration of turbidity after filtration

3.2 Optimum Velocity

The optimum velocity was determined to remove iron, manganese, and turbidity in groundwater. In this study, the range of velocity is between 0.5 m/hr to 6.0 m/hr. This range of velocity shows a high reduction of up to 85% removal of iron, manganese, and turbidity. The optimum velocity was determined by the higher percent removal of all parameters against certain velocity. As can be seen in

Fig. **6**, the velocity that has the higher percent removal of all parameters that was study is 4.38 m/hr. This is due to all suspended solid was attached to the sand and produce good water quality at this velocity. The range of the optimum velocity that we can get from the figure is from 2.4 m/hr to 4.5 m/hr. This due to all three parameter, iron, manganese, and turbidity has the highest percent removal in that range. Thus, from the optimum velocity we can get good water quality for groundwater.

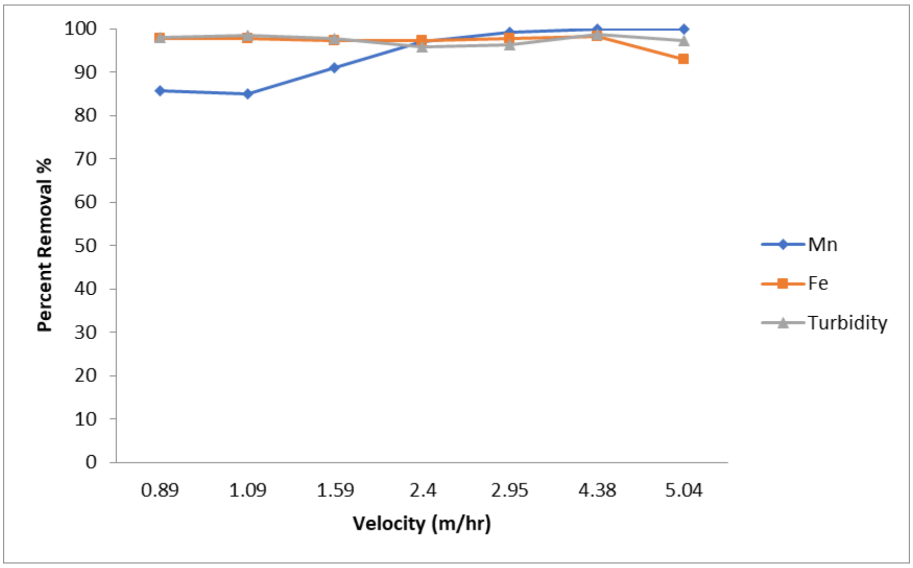

Fig. 6 - Percent removal of iron, manganese and turbidity against velocity after filtration

3.3 Initial Head Loss of Sand Filter

Initial head loss was determined when the filter media is still under a clean condition and no accumulation of sediment deposit occurs. This clean bed head loss is one of the various filter hydraulic characteristics of flow through granular media. According to Crittenden et al. [17] the water flow in granular media is governed by four flow regimes which are defined by Reynolds number. The flow in granular filter bed does not encounter a rapid transition from laminar to turbulent. However, the kind of flow in the filter bed of this study is assumed to have a Reynolds number of 0.5 to 5.0 for typical rapid filter. This Reynolds numbers fall in the regime zone at which the flow is experiencing transition between the Darcy and Forcheimer flow. The rate of head loss development in granular filter bed is mainly dependent on the particulates sizes in suspension and granular media size while at the same time a constant mass of solids is removed. From this study, it was found that initial head loss is directly proportional to the velocity.

Based on

Fig. **7**, all 6 points show the level of depth for sand filter by using manometer tube. At point 6, the depth of sand filter is 0.6m while at point 1; the depth of sand filter is 0.1m by using manometer tube. The figure shows when the velocity is higher, the head loss is higher too. Thus, this sand filter media is still under a clean condition and no accumulation of sediment deposit occurs. The sand media filter is able to use for treating the groundwater in good condition. Various strategies this study have been adapted for removing the high iron and manganese content from water. Conventionally, aeration-sedimentation-filtration process and separation through filter media showed high iron removal efficiency above 90%.

The performance of filter can be influenced by several factors such as effective sizes, types of media used, bed height and velocity. This study used sand as filter media in mono-media filtration. To achieve the objective, the physical and chemical properties of groundwater were determined. This experiment was carried out using a few velocities to remove iron, manganese, and turbidity. The percentage of iron, manganese and turbidity removal were found up to 90% against the optimum velocity. Furthermore, this study was monitored the initial head loss of sand filter to see their pattern and to show the filter is clean to be used for treating groundwater in good condition.

Finally, this study has proven that this mono-media sand filter can be an effective and economical solution to remove of iron and manganese from groundwater and achieve the standard of raw water quality which is safe and clean water for community.

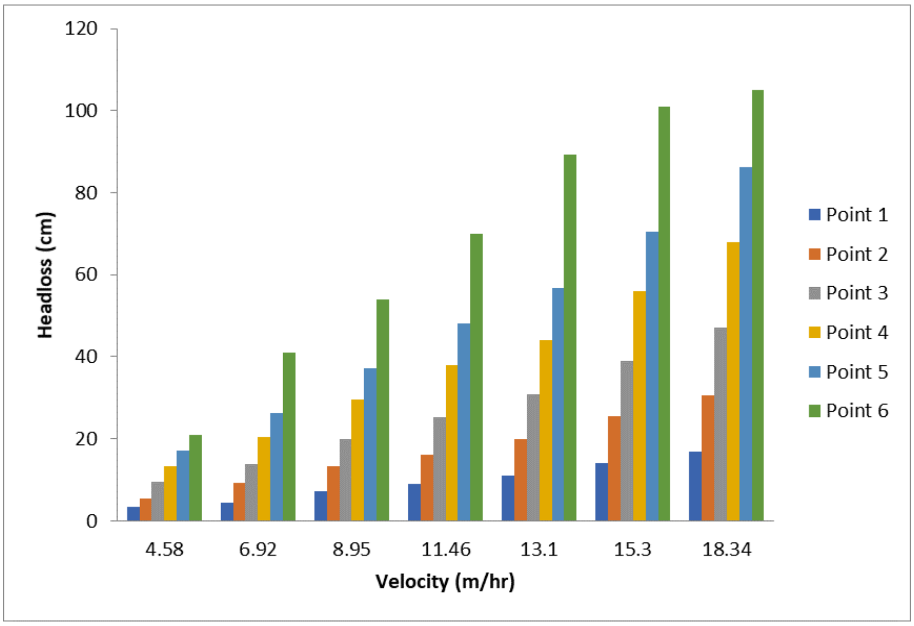

Fig. 7 - The relationship between initial head loss and velocity

4. Conclusion

Even safe, most Malaysian do not drink the water from their tap. By using optimum velocity, it is proven that Iron and Manganese removal capabilities are improved by at least 60%. Economically, Malaysian community especially in rural area would afford to improve their existing groundwater quality by adopting optimum velocity of their rapid sand filter. In the future, this research can be improved by varying the effective sizes of sand, filtration flow rate, and operational head loss need to be determined. The filtration process also needs to be complete with backwash process to evaluate the behaviour of filter media during backwash.

Acknowledgement

Authors would like to thank Universiti Malaysia Terengganu and communities of Kg Budi in Kelantan for laboratories access and cooperation during this study. All authors contribute evenly in data collection, manuscript writing and experimental supervision from the beginning to the end of this study.

References

[1] Jusoh. A., Cheng. W. H., Low. W. M., Ali. N., & Megat Mohd Noor. M. J. (2005). Study on the removal of iron and manganese in groundwater by granular activated carbon. Desalination, 182(1–3), 347–353. https://doi.org/10.1016/j.desal.2005.03.022

[2] Tekerlekopoulou. A. G., & Vayenas. D. V. (2007). Ammonia, iron and manganese removal from potable water using trickling filters. Desalination, 210(1–3), 225–235. https://doi.org/10.1016/j.desal.2006.05.047

[3] Qin. S., Ma. F., Huang. P., & Yang. J. (2009). Fe (II) and Mn (II) removal from drilled well water: A case study from a biological treatment unit in Harbin. Desalination, 245(1–3), 183–193. https://doi.org/10.1016/j.desal.2008.04.048

[4] Smeets. P. W. M. H., Medema. G. J., & van Dijk. J. C. (2009). The Dutch secret: how to provide safe drinking water without chlorine in the Netherlands. Drinking Water Engineering and Science, 2(1), 1–14. https://doi.org/10.5194/dwes-2-1-2009

[5] World Health Organization (2014). Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum. Geneva.

[6] Voulvoulis. N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. Current Opinion in Environmental Science & Health, 232–45. https://doi.org/10.1016/j.coesh.2018.01.005

[7] Bolisetty. S., Peydayesh. M., & Mezzenga. R. (2019). Sustainable technologies for water purification from heavy

metals: review and analysis. Chemical Society Reviews, 48(2), 463–487. https://doi.org/10.1039/C8CS00493E
[8] Marsidi. N., Abu Hasan. H., & Sheikh Abdullah. S. R. (2018). A review of biological aerated filters for iron and manganese ions removal in water treatment. Journal of Water Process Engineering, 231–12. https://doi.org/10.1016/j.jwpe.2018.01.010
[9] Moussa. D. T., El-Naas. M. H., Nasser. M., & Al-Marri. M. J. (2017). A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. Journal of Environmental Management, 18624–41. https://doi.org/10.1016/j.jenvman.2016.10.032
[10] Abbaspour. N., Hurrell. R., & Kelishadi. R. (2014). Review on iron and its importance for human health. Journal of research in medical sciences ,19(2), 164–74
[11] Allen. L., Benoist. de B., Dary. O., & Hurrell. R. (2006). Guidelines on food fortification with micronutrients, World Health Organization. Food and Agricultural Organization of the United Nations, Geneva.
[12] National Water Quality Standards for Malaysia (2006). Interim National Water Quality Standards for Malaysia, Water Environment Partnership in Asia.
[13] Harun. H. C., Mustapha. R., Fisol. F., Azmi. A. A., Ali. A., Hamzah. S., Azaman. F., Mohamed. N. A., Zakirah. I., & Mustofa. A. F. (2021). Integration of Iron Coagulant, Copperas and Calcium Hydroxide for Low-Cost Groundwater Treatment in Kelantan, Malaysia. Letters in Applied NanoBioScience, 10(4), 2869–2876. https://doi.org/10.33263/LIANBS104.28692876
[14] Dietrich. A. M., & Burlingame. G. A. (2020). A review: The challenge, consensus, and confusion of describing odors and tastes in drinking water. Science of The Total Environment, 713, 135061. https://doi.org/10.1016/j.scitotenv.2019.135061
[15] Harun. M. H. C., & Zimmerman. W. B. (2019). Membrane defouling using microbubbles generated by fluidic oscillation. Water Supply, 19(1), 97–106. https://doi.org/10.2166/ws.2018.056
[16] Qasim. S. R., Motley. E. M., & Guang. Z. (2000). Water works engineering: Planning, design, and operation, 1st ed. New Delhi.
[17] Crittenden. J. C., Trussell. R. R., Hand. D. W., Howe. K. J., & Tchobanoglous. G. (2012). MWH's Water Treatment: Principles and Design: Third Edition. https://doi.org/10.1002/9781118131473
[18] Song. S., Rong. L., Dong. K., Liu. X., Le Clech. P., & Shen. Y. (2020). Particle-scale modelling of fluid velocity distribution near the particles surface in sand filtration. Water Research, 177, 115758. https://doi.org/10.1016/j.watres.2020.115758
[19] Guy. S. (2020). Rapid sand filtration | Cropaia. https://cropaia.com/blog/rapid-sand-filtration/
[20] Williams. G. J., Sheikh. B., Holden. R. B., Kouretas. T. J., & Nelson. K. L. (2007). The impact of increased loading rate on granular media, rapid depth filtration of wastewater. Water Research, 41(19), 4535–4545. https://doi.org/10.1016/j.watres.2007.06.018
[21] Khatri. N., Tyagi. S., & Rawtani. D. (2017). Recent strategies for the removal of iron from water: A review. Journal of Water Process Engineering, 19291–304. https://doi.org/10.1016/j.jwpe.2017.08.015
[22] Mesquita. M., Testezlaf. R., & Ramirez. J. C. S. (2012). The effect of media bed characteristics and internal auxiliary elements on sand filter head loss. Agricultural Water Management, 115178–185. https://doi.org/10.1016/j.agwat.2012.09.003