IWA Water and Development Congress & Exhibition
1 - 5 DECEMBER 2019 - COLOMBO, SRI LANKA

Design of Up-flow Aerated Filters for the Removal of Iron from Groundwater

T.Thinojah*, B.Ketheesan, G.B.B.Herath*****

* Demonstrator, Faculty of Engineering, University of Jaffna, Sri Lanka (thinojahthiru@gmail.com)
** Senior Lecturer, Faculty of Engineering, University of Jaffna, Sri Lanka (kethees@eng.jfn.ac.lk)
*** Professor, Faculty of Engineering, University of Peradeniya, Sri Lanka (gemunuh@gmail.com)

Abstract: Groundwater contains iron (Fe) that can be difficult to remove by singular physical-chemical methods. The aim of this presented study was to investigate the suitability of up-flow aerated filters as an upgrading step for the removal of the total Fe from groundwater. Granular activated carbon (GAC) was applied as a pollutant carrier and compared to bio-pac media (BPM) by conducting column test to treat synthetic groundwater (SGW). Initially two adsorption kinetic studies were done for GAC. The effect of influent Fe concentration, hydraulic retention time (HRT) and air supply to the system were investigated using column experiment. The sorption result follows the pseudo-second order kinetics with the adsorption amount of 1.36 mg/g. Column experiment results show that around 99% and 70% Fe removal efficiency can be achieved for the best condition of 3 mg/L influent Fe concentration with 7 hours HRT for GAC and BPM respectively. The air supply into the column did not show any improvement in Fe removal efficiency. The performance of GAC is found to be much better than BPM. All over, the new combined treatment method aeration followed by filtration demonstrated to be an effective technique for Fe removal from groundwater and also satisfied the World Health Organization (WHO) drinking water standard for Fe concentration.

Keywords: Groundwater; iron removal; granular activated carbon; bio pack media; column test

Introduction

Water is an essential element of human life, its main domestic uses being drinking, preparing food and maintaining personal hygiene. Providing enough water for all community members in safe sanitary conditions must be a permanent concern of local communities and central authorities. Domestic, agricultural and industrial activities in the Jaffna peninsula located in the Northern part of Sri Lanka highly depends on groundwater which is the only foremost natural water source with lower percentage of surface water because of its karstic nature and flat terrain (Senaratne, 2015). The quality and the supply of water in the Peninsula was affected by the groundwater contamination resulted in a serious threat to human health. There is a prospect that the groundwater sources could contain a variety of organic and inorganic chemicals that are used to supply public water systems. Inorganic contaminants are usually present at much higher concentrations than their organic counterparts. Fe is the common element in earth crest and dissolution of Fe with groundwater can occur when it percolates through soil and rock (Dvorak, 2014). Contribution of well casings, pump components, pipes and storage tanks also found to be the sources of Fe ion contamination with groundwater (El et al., 2016). Settling of iron (hydroxide) particles or post treatment flocculation of dissolved Fe could lead to the degeneration of water quality in the distribution system even when clear water meets the drinking water standards.

Higher concentration of Fe in the distribution systems possibly increases the growth of chlorine tolerant microorganisms, which can raise the cost of disinfection (Marsidi et al., 2018). According to WHO the maximum concentration level in drinking water should not exceed 0.3 mg/L for Fe. In order to avoid problems with iron particles and post-flocculation and subsequent sedimentation and re-suspension of Fe in the distribution network, a proper treatment technique should be suggested to get very low Fe concentration.

Although conventional treatment processes (precipitation, electro-coagulation, filtration and sedimentation) are widely used for the removal of Fe ions, they present a number of drawbacks in terms of treatment capacity, efficiency, stability, space requirements, and the generation of large volumes of sludge, thus increasing maintenance and operational costs(Patil et al.,2015; Xia,2004). There are two main physicochemical mechanisms of iron removal in filters, namely the oxidation–floc formation mechanism (floc filtration) and the adsorption–oxidation mechanism (adsorptive filtration/catalytic iron removal). In the floc filtration mode of iron removal, commonly applied in many groundwater treatment plants, soluble iron(II) is first oxidized to insoluble iron(III) by aeration or chemical oxidation and the flocs formed are subsequently removed in a rapid sand filter (Salvato, 1992). In several conventional plants, however, oxidation is only partially achieved before filtration and, as a consequence, besides oxidation–floc formation, adsorption–oxidation plays a role as well. In addition to rapid head loss development and short filter runs, various other practical problems associated with the conventional iron removal systems, like long ripening periods, iron passing through the filter and large volume of sludge produced, have been reported (Marsidi et al., 2018).

The removal process is affected by the different chemical and physical characteristics of water including pH, temperature, total organic carbon (TOC) and concentration of dissolved oxygen (Filtronics, 1993). The oxidation rates are faster at high pH values and slow at low pH values. The oxidation by aeration demands a pH greater than 6.3 for iron (Filtronics, 1993).Carbonic acid lowers the pH value of water and hence slows down the oxidation rate. Increased temperature also enhances the oxidation reactions while lower temperature slows down the oxidation process. In general, the rate of reaction will double for every 10^{o}C temperature increase. In the presence of higher concentrations of total organic carbon, the oxidation of iron is reduced due to less available oxygen. In totality, the time factor also plays a crucial role. Several studies have investigated the operating mechanism of up-flow aerated filters for the pollutants removal, where aeration and precipitation can take place simultaneously inside the same filter and the longer filter runs because of the use of more coarse media (Gage et al., 2001). These treatment techniques were used to remove Fe from wastewater by early researchers, especially as biological treatment process.

This study focused on investigating the suitability of up-flow aerated filters on Fe removal from groundwater as a drinking water treatment method. Two separate columns were designed and operated with same influent conditions of SGW with different filter media GAC and BPM for the ease of comparison. The effect of initial Fe concentration, HRT and air supply to the system on Fe removal efficiency was also assessed in this study. In addition the Fe removal efficiency at different filter media heights was also explored. Kinetic experiment was done for GAC to find out the adsorption ability of GAC on Fe removal.

Material and Methods

Preparation of filter media

The filter media, GAC and BPM were selected for this study. It was decided based on the resistant to corrosion and attrition, high specific surface area, durability, should possess an appropriate specific weight, be chemically dependable, easy to manage and should not clog the reactor and purchased from Enviro-equip (Pvt) ltd in Colombo, Sri Lanka. The activated carbon particles granular in size having the sieve range of 8×20 were sieved and the mean particle size of 1.2 mm was calculated from the particle size distribution curve. The sieved particles were separately rinsed several times with constant amount of distilled water until getting a clear colour and constant pH. Then the samples were dried in the oven at 105^{o}C for 24 hours. Finally it was stored safely to avoid contamination from the environment. The BPM having the height/diameter ratio of 0.71 (height=10 mm, diameter=14 mm) having the bio surface area range of 300-850 m^2/m^3 was initially rinsed with distilled water and then dried at atmospheric temperature for further use.

Kinetic experimental studies

The SGW was simulated by adding tap water with laboratory reagent $FeSO_4.7H_2O$. The batch scale kinetic experiment was performed with SGW having 1 mg/L Fe and two types of kinetics analysed. The time range from 10 to 300 minutes was used to check the variation of adsorption amount of GAC. The best fit parameters were calculated from the adsorption curve and compared with theoretical equations. Conical flasks having 100 mL capacity were rotated with 150 rpm. The sorption kinetics was studied using pseudo-first order and pseudo-second order kinetics models and the best fit values were calculated using the linear plots.

Description of the up-flow aerated filter system

The schematic and the experimental setup are given in the Figure 1 below. The lab scale filter made from acrylic tube having the dimensions of 15 cm diameter (D) and 150 cm height (H) was designed with the effective working volume of 14L by considering the excess wall effects from filter media, channelling effects and H/D ratio to avoid short circuit. The sampling ports were placed throughout the column height with 20 cm interval for the sample collection. The air and influent synthetic groundwater were fed at 20 cm and 10 cm from the bottom respectively for mixing before entering the media. The aquarium air pump was used to supply air to the system. The top of the filter was allowed for 30 cm buffer zone to stop media being washed out in the process of backwashing. The widely used up-flow configuration was used in this study. The peristaltic pump was used to supply SGW into the column. The filter media were packed partially with 80 cm media height starting 40 cm from the bottom with the support of polypropylene mesh having the pore size less than 1 mm.

Operation of the up-flow aerated filter system

The porosity of filter media was measured using volumetric method. Initially the distilled water was sent up to the filter media height from the bottom. Then the system was allowed to get saturated for 20 minutes. Finally the water was drained from bottom and the drained volume was measured for both filter media separately to calculate the porosity. The procedure was continued for 3 times to take the average value of porosity to calculate relevant media flow rate. The porosity of GAC and BPM were found to be 0.28 and 0.79 respectively.

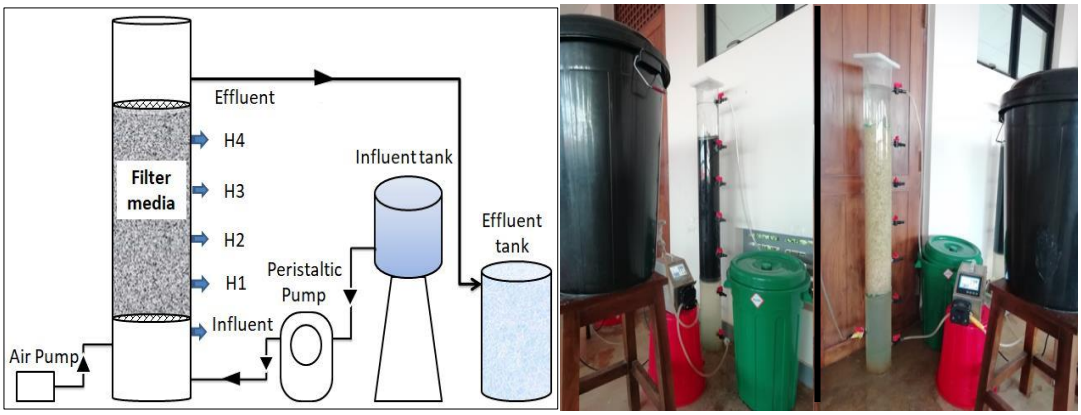

Figure 1 Schematic and laboratory scale up-flow aerated filter system, sampling ports: Influent, H1, H2, H3, H4, and Effluent

The effects of initial Fe concentration, HRT and air supply to the system were tested in 3 different phases and column was operated for 48 hours continuously in each phase. The filters were operated continuously throughout the study and backwashed after each scenario using clean water with the flow rate of 1200 mL/min for 30 minutes in the upward direction for uncomplicated operation. The samples were collected in 4 hours interval from the sampling ports including influent and effluent using 100 mL polypropylene sample bottle in each phases.

Table 1 Operating conditions of both GAC and BPM columns in each phase

	Influent Fe concentration	HRT	Aeration
Phase 1	increased from 1 mg/L to 3 mg/L	7 hours	no air supply
Phase 2	3 mg/L	reduced from 7 to 3.5 hours	no air supply
Phase 3	3 mg/L	7 hours	2.5 L/min

Analytical methods

The analysis of pH, temperature and total dissolved solids (TDS) were performed via PC 2700 multi meter. DO and total Fe were measured using Cyber scan series 600 DO meter and DR 900 HACH calorimeter respectively. At the end of column test 5g of GAC samples from top and bottom were collected and soaked in 0.5 M HCL for 1 hour then samples were filtered through 0.45 µm filter paper before measurement using atomic adsorption spectrophotometer to find out the totally removed Fe concentration on GAC media. The data was analysed using Excel spread sheet.

Results and Discussion

Kinetic study

To find out the mechanism of Fe adsorption and the potential rate controlling steps, including diffusion mass transport and chemical reaction process, it is required to characterize the adsorption mechanism. In order to understand the kinetics of Fe removal using GAC as an adsorbent, pseudo first and second order models were analysed with the experimental data. It says that the experimental data best fits to the model for Pseudo-second order kinetics and plotted in the Figure 2 below together with the adsorption curve. The Pseudo-second order kinetics model fits the experimental data with the correlation coefficient of 0.96. The parameters K_2 and Q_e were calculated as 0.01 g.min/mg and 1.36 mg/g from the linear plot results. The adsorption curve depicts the effect of contact time on the adsorption amount of Fe for GAC media. In the adsorption test, the rate of Fe removal was relatively fast at the beginning due to the greater availability of the GAC surface area. For GAC the hardness sorption shows a quickly tendency to reach equilibrium starting at 40 minutes with a maximum percent removal attained after about 240 minutes.

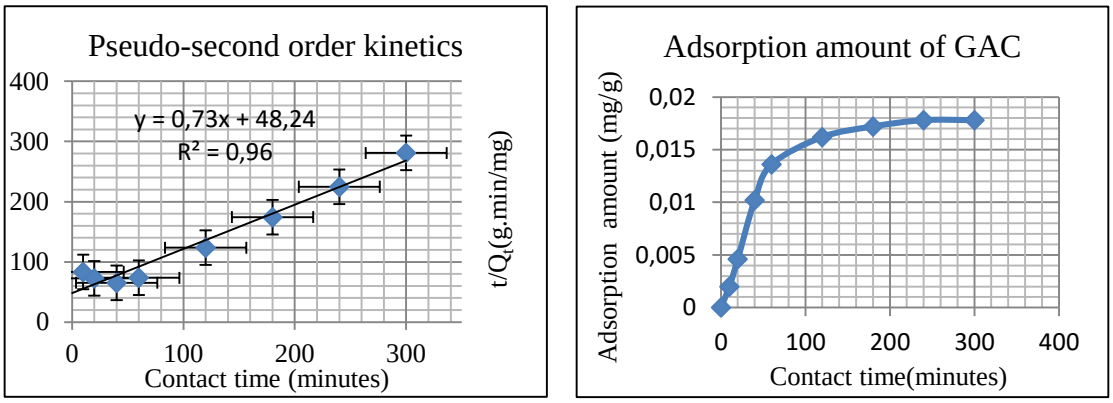

Figure 2 Pseudo second order kinetic model for GAC and the curve of adsorption amount

Performance of GAC and BPM up-flow aerated filters

Phase 1: GAC and BPM filters were operated with the flow rate of 10 mL/min and 25 mL/min for 7 hours HRT hours respectively. The rates of total Fe removal from GAC and BPM filter at different initial Fe concentration (1, 3 mg/L) are shown in Figure 3 below. It can be observed that effluent Fe removal efficiency increases approximately from 95 to 99% when increasing the influent Fe concentration from 1 to 3 mg/L for GAC filter. And also, for both initial conditions for GAC media, efficiency of Fe removal rises with the increment of media height. However considering about BPM, the Fe removal efficiency of effluent shows the oscillating variation between 20 to 80 % for both influent Fe conditions. Influence of initial pollutant Fe concentration does not show any significant improvement of Fe removal efficiency on BPM. Irregular increment in Fe removal efficiency through BPM height also proves that a filter run time of 48 hours is not enough to get steady stage on Fe removal using BPM. While GAC showing reduction in effluent Fe concentration, BPM showed the increment in effluent Fe concentration when increased the influent Fe concentration. Overall by comparing both filter media, GAC media provides better performance than BPM and increasing the initial Fe concentration improved the efficiency of GAC filter on Fe removal due to higher media packing density compared to BPM.

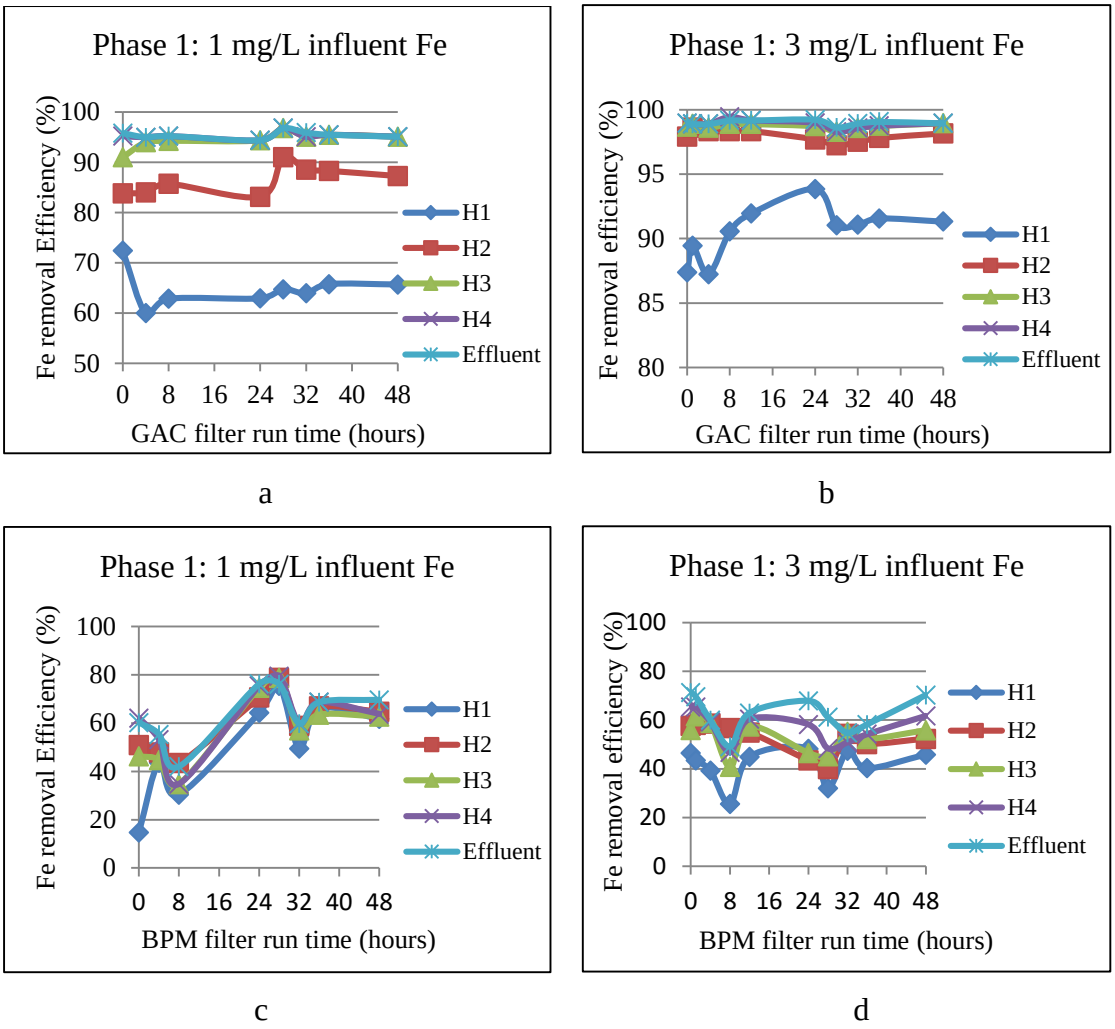

Figure 3 Removal efficiency of total Fe at Phase 1 for GAC filter with a) 1 mg/L influent Fe b) 3 mg/L influent Fe, and BPM filter with c)1 mg/L influent Fe and d) 3 mg/L influent Fe

Phase 2: At first, it selected two different HRT (HRT=3.5hrs, HRT=7hrs) to monitor the Fe concentration of the outlet water in both filters, thus the best HRT of the effluents was determined. The filters were operated at the flow rate of 10 and 24.5 mL/min namely for GAC and BPM filters at 7 hours HRT and doubled when reduced the HRT by half. In the steady operation, the treatment effect of Fe with different HRT was compared for both filters in Figure 4 below. GAC filter shows the increased Fe concentration when reducing the HRT by half for 3 mg/L influent Fe level. It can be seen that the average of 0.03 rose to 0.05 for GAC media with the reduction of HRT. The increment in flow rate leads to the reduction in contact time of pollutant with filter media which reduced the Fe removal efficiency. By considering the BPM, it also showed the increment in effluent Fe concentration with the reduction of HRT. The effluent concentration increased nearly from 1 mg/L to 1.5 mg/L with the reduction of HRT. Although BPM showed the better performance at 7 hours HRT, the effluent Fe concentration did not meet the WHO drinking water standards at any condition. Finally, it is clear that reducing the HRT has the uncooperative impact of Fe removal efficiency for both GAC and BPM filters. However, by comparing both filters GAC showed better performance than BPM.

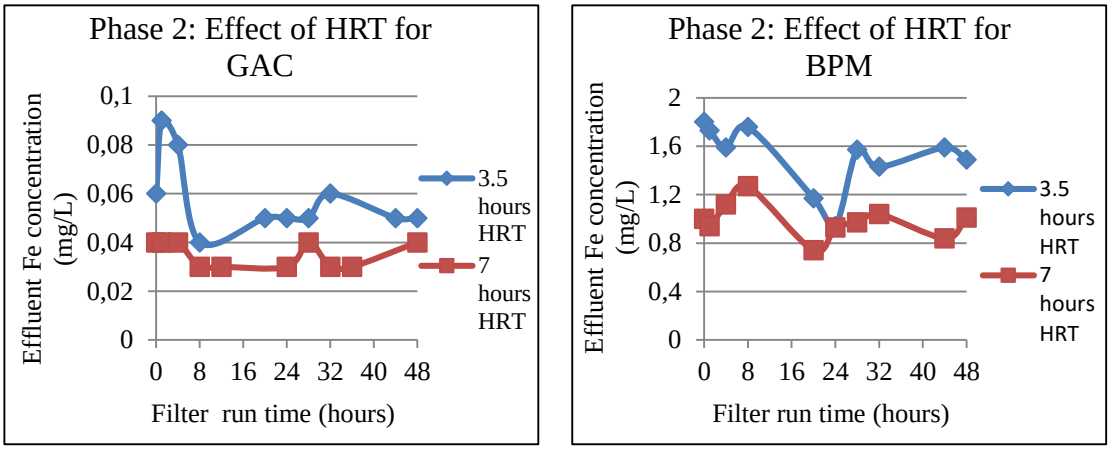

Figure 4 Effluent Fe concentration in Phase 2 for GAC and BPM filters

Phase 3: Figure 5 compares the effect of air supply to the filtration system which was tested for 3 mg/L Fe contaminated SGW with 7 hours HRT. The SGW entered in the air-water mixing area from the bottom of upflow filter to be mixed with the air using air pump with 2.5 L/min flow rate. Aeration to GAC filter showed the sudden increment of Fe concentration about 0.08 mg/L at the beginning and then dropped to 0.05 mg/L after 8 hours of continuous run of GAC filter. Then the value was varying between 0.05 to 0.08 mg/L, which is comparatively higher than the system without any air supply. Air binding was also observed during the GAC column run. BPM filter illustrated the reduction in the effluent Fe from approximately 1.5 to 1 mg/L with the effect of air and then showed the raise in effluent Fe concentration throughout the column run with the effect of air. The air bubbles stored at the bottom of the BPM were observed in the operation of the filter. The steady stage was not observed for both filters during the 48 hours of filter run. Oxygen transfer efficiency is the main factor determining the effective performance of the filter which depends on air/water ratio. Previous studies done by researchers say that 2 to 10:1 of air/water ratio gives the better removal of pollutant for aerated filters, and also increasing the air/water ratio can push down the air/water interface, where the uneven distribution of air is also possible (Kamarden et al.,2014). In this study the air/water ratio reached to 100:1 which is found to be not suitable for this study.

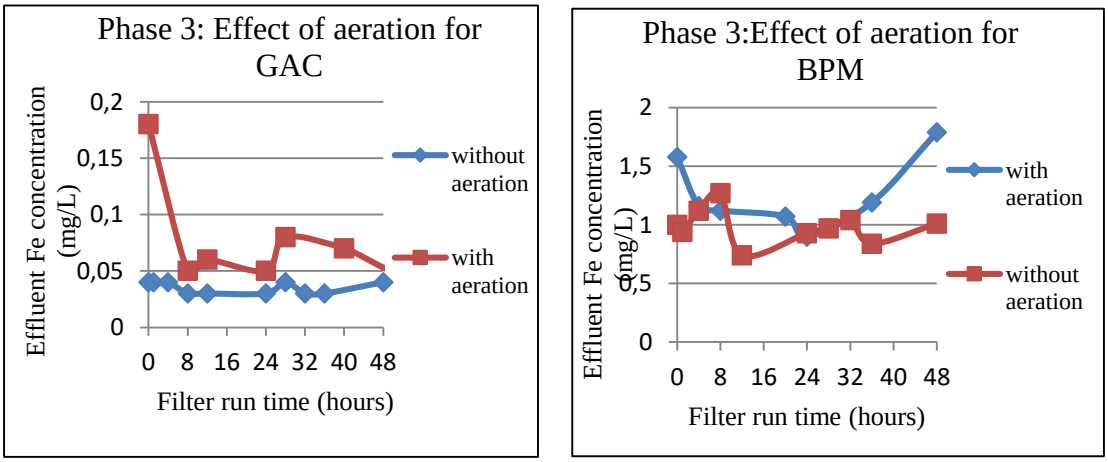

Figure 5 Effluent Fe variation in GAC and BPM filters with the effect of 2.5 L/min air supply

Conclusions

In this research a combined use of oxidation and floc-filtration experiment was done by developing GAC and BPM columns and then compared for the total Fe removal from SGW while examining at 3 varieties of phases. Positive result of increased Fe removal efficiency was found for GAC filter media when increasing the initial Fe concentration at phase 1. Highest water recovery was achieved by increasing the HRT from 3.5 to 7 hours for both filter media. Optimum condition of 3 mg/L influent Fe with 7 hours HRT leading to minimum impurity contamination in the effluent were determined. Introducing air supply to the system did not show any improvement in both filter performances due to the effect of air scouring and improper air/water mixing ratio. Overall, the GAC filter media illustrated better performance compared to BPM. This is due to the behaviour of BPM which is loosely packed inside the column and having the highest porosity compared to GAC. Hence, up-flow system with co-current air and SGW flow for GAC filter media demonstrated to be the most cost effective treatment method for Fe removal from groundwater.

References

Dvorak, B. I., Environmental, E. and Specialist, E. (2014) 'Drinking Water : Iron and Manganese', 1714.

El, A., Moghny, T., Mohamed, A., Saleem, S. and Fathym, M. (2016) 'Abu Zenima synthetic zeolite for removing iron and manganese from Assiut Abu Zenima synthetic zeolite for removing iron and manganese from Assiut governorate groundwater , Egypt', *Applied Water Science*. Springer Berlin Heidelberg, (July). doi: 10.1007/s13201-016-0435-y.

Filtronics (2012) 'Iron and Manganese Filtration Systems - A Technical Discussion', (714).

Gage, B., O'Dowd, D. and Williams, P. (2001) 'Biological Iron and Manganese Removal, Pilot and Full Scale Applications', *Ontario Water Works Association Conference*.

Labhasetwar, G. K. K. P. M. P. P. K. (2015) 'Removal of iron and manganese from drinking water supply', *Sustainable Water Resources Management*. Springer International Publishing, 1(2), pp. 157–165. doi: 10.1007/s40899-015-0017-4.

Marsidi, N., Abu Hasan, H. and 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*. Elsevier, 23(October 2017), pp. 1–12. doi: 10.1016/j.jwpe.2018.01.010.

Patil, D. S., Chavan, S. M. and Oubagaranadin, J. U. K. (2015) 'A review of technologies for manganese removal', *Elsevier B.V.* Elsevier B.V. doi: 10.1016/j.jece.2015.11.028.

Raju, N. J. (2015) 'Iron contamination in groundwater : A case from Tirumala-Tirupati environs , Iron Contamination in Groundwater : A case from Tirumala-Tirupati environs , India', (January 2006).

Salvato, J. A. (1992) Environmental Engineering and Sanitation. Fourth Edition, John Wiley and Sons, Inc. New York.

Senaratne, A. (2015) 'Palaeogeographic reconstruction of Jaffna Peninsula, Sri Lanka Palaeo-geographical reconstruction of Jaffna Penninsula', (June).

Teunissen, K. *et al.* (2008) 'Removal of both dissolved and particulate iron from groundwater', pp. 87–115.

Xia, S., Nan, J. and Liu, R. (2004) 'Study of drinking water treatment by ultrafiltration of surface water and its application to China', 170, pp. 41–47. doi: 10.1016/j.desal.2004.03.014.

Kamarden, H., Hassan, M., Noor, Z., Ibrahim, R. (2014) 'Effect of Temperature and Air flow rate on Xylene Removal from Wastewater Jurnal Teknologi Full paper Effect of Temperature and Air flow rate on Xylene Removal from Wastewater using Packed Column Air Stripper', (November 2015). doi: 10.11113/jt.v67.2795.