Journal of Environmental Science and Technology

ISSN 1994-7887

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Environmental Science and Technology 5 (6): 430-440, 2012
ISSN 1994-7887 / DOI: 10.3923/jest.2012.430.440

The Decrease of Organic Substance Concentration ($KMnO_4$) and Turbidity in Well (Ground) Water Using Biosand Filter Reactor

[1]Rubiyatno, [1]Tony Hadibarata, [2]Nova Yanti and [3]Bunrith Seng
[1]Institute of Environmental and Water Resources Management, Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, Johor, Malaysia
[2]Faculty of Environmental Science and Management, University Putra Malaysia, UPM Serdang, Malaysia
[3]Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Kofu, Japan

Corresponding Author: Tony Hadibarata, Faculty of Civil Engineering, Institute of Environmental and Water Resources Management, Universiti Teknologi Malaysia, 81310, Skudai, Johor Bahru, Malaysia Tel: +(6)07-5531760

ABSTRACT

The main source of water options in most urban and rural areas for Samarinda was well (ground) water. Samarinda is a developing city and most highly populated located in the East Borneo province of Indonesia. Meanwhile, the location and characteristic of land in Samarinda was swampy areas with organic substances concentration ($KMnO_4$) and high turbidity, a poor drinking quality to might have health problem. In this study established potential of BSF for efficiency removal organic substances concentration ($KMnO_4$) and turbidity. (Unit biosand filter was made from 8 mm rectangular glass with the medium used inside BSF reactor as sand local, gravel and supported by aerator for supply O_2 to growing biofilm at the layer of fine sand and also diffuser plate to maintain the flow rate of water into the BSF reactor unit. Then, BSF was using flow rate (0.2 and 0.4 m h^{-1}) and paused period (6 and 12 h). Efficiency decrease in the concentration of organic substances, the fist biosand filter the average efficiency by 76.82%, the second biosand filter average efficiency of 74.17%, at the third biosand filter efficiency by an average of 71.28% and the fourth biosand filter average reduction efficiency is 73.29% and while the turbidity of the average efficiency for the first biosand filter by 96.56%, the second filter biosand average efficiency of 94.08%, the third biosand filter average efficiency amounted to 96.52% and the fourth biosand filter average efficiency of 95.03%. Significant impact of this study was conducted The BSF design, construction, operational and maintained as technology become solution in urban and rural area to provide safe water and drinking water in developing countries.

Key words: Biosand filter reactor, biofilm, organic substances concentration, turbidity, well (ground) water

INTRODUCTION

Waterborne diseases are the main cause of sickness and death in the community with limited access to safe drinking water. And about 80% of infectious diseases in the world are water-borne (Xia *et al*., 2004). World Health Organisation estimated that worldwide, 1.8 million losses arise per year due to lack of hygiene and poor water value (WHO/UNICEF, 2006).

Drinking water polluted by microorganisms can cause dozens of communicable disease in developing countries (Arnal *et al*., 2001). Currently, boiling water is regularly used in several countries as a disinfection technique, however its high cost is a main concern (Sobsey, 2002). There are several methods for water treatment for consumption, including granular activated carbon, anaerobic digestion, coagulation, flocculation, chemical oxidation, membrane separation, electrochemical treatment, filtration, flotation, softening, hydrogen peroxide catalysis and reverse osmosis (Alade *et al*., 2012; Alaboud and Magram, 2008; Magram and Abdel-Azeem, 2008; Bhattacharya *et al*., 2008; Durai and Rajasimman, 2011; Gokturk and Kaluc, 2008; Ibeto *et al*., 2010; Magram and Azeem, 2008; Ramalakshmi *et al*., 2012). However, in poor countries infrastructure and supply of water frequently require suitable management and regulation in the rural communities (Pryor *et al*., 1998). Weedy institutional agreement, lack of financial income and poor practicable understanding hider a feasible water systems (Lenton and Wright, 2004; Momba *et al*., 2005). Financial ability of centralized drinking water management systems are extremely essential in the sparsely settled rural populations and it is furthermore practicable that the fashion is changing in the direction of decentralized solutions in these cases (Peter-Varbanets *et al*., 2009). The World Health Organisation suggested point-of-use household water treatment (POU) as an involvement to discuss need, illustration on inexpensive technologies (Sobsey, 2002; WHO, 2007).

A current evaluation point-of-use household water treatment (POU) choice in developing countries use Slow Sand Filter (SSF), generally called the biosand filter (BSF) where improved water supplies are often difficult and costly to develop, operate or support (Sobsey *et al*., 2008). The BSF was modified for household application from traditional Slow Sand Filter (SSF), making the construction more appropriate for household use (Ahammed and Davra, 2011). In conventional SSFs, during the ripening process a biolayer (schmutzdecke) forms, head loss increases and performance improves. Since the filter is generally charged once daily, a portion of the charged water remains in the BSF until the next charge. It was reported that about 143,000 BSFs were in operation as of June 2007, serving an estimated 858,500 users in 36 countries. For that year, they produced nearly 1.3 billion liters of drinking water (at 25 L/unit/day) (Clasen, 2009). Famous biosand filters are mainly know as an efficient method between the five dissimilar household treatment technologies and as having the most prospect of becoming widely used and sustainable for improving household water quality to decrease waterborne disease and death (Sobsey *et al*., 2008; Stauber *et al*., 2009). Slow Sand Filter (SSF) can reduce 90-99% bacteria, iron (Fe), manganese (Mn) 30-90%, BOD 46-75%, COD<15-25%, pesticide 0-100%, turbidity<1 NTU, Giardia cycts and virus 99% (Smet and van Wijk, 2002).

The biosand filter is a water purification process where the water is treated on a medium with low-speed process that is influenced by the diameter of the smaller grains of sand to filter out microorganisms. Biological nitrification and denitrification process processes occur in the BSF (Murphy *et al*., 2010). Above the surface layer of sand medium filters are designed to biosand filter±5 cm height of water stored at all times. Shallow water layer provides sufficient oxygen to the biofilm layer that exists to keep alive and develop and maintain the biolayer (schmutzdecke) so as not to interfere with the speed of water coming. Schmutzdecke is a German word which means 'dirty layer'. This sticky film, which is brownish red in color, composed of organic material decomposed, iron, manganese and silica and therefore acts as a good filter that acts to remove colloidal particles in raw water. Schmutzdecke zone is also a basis for biological activities, among others, such as *Pseudomonas* bacteria, flavobacterium and alcaligenes. After five days, the composition of bacteria in the biolayer will consist of a collection of diverse bacteria, the types of dominant filament. After more than a week, it will be a little overgrown with fungi such as *Fusarium*, *Geotrichum* and *Sporotrichum* will appear and cause the reduction of BOD content and can degrade some soluble organic material in raw water, which is useful for reducing taste, odor and warn (Droste, 1997). Generally, the ideal time was required so that biosand filter can be used for a maximum of 3 months. Therefore with increasing time of usage, the layers will be thicker which requires higher efficiency and effectiveness of the cleaning process during this period (CAWST, 2008).

Several studies have been reported on the performance of the BSFs in reducing bacteria, virus, iron and turbidity from feed water (Ahammed and Davra, 2011; Duke *et al.*, 2006; Earwaker, 2006; Jenkins *et al.*, 2011; Elliott *et al.*, 2006, 2008, 2011; Stauber *et al.*, 2006). With the advantages of the biosand filter it can solve problems that arise from the water wells in a swampy area with high concentration of organic substances, turbidity, iron and manganese etc.

Organic substances need to be removed before the water is disinfected with chlorine, as it reacts with chlorine and produces trihalomethanes, which have recently been found to be carcinogenic and a high turbidity will result in disruption of osmoregulation system, such as breathing the aquatic organisms and can inhibit the penetration of light into the water. The high turbidity values can also complicate efforts to reduce the effectiveness of filtration and disinfection in water purification processes, whereas iron and manganese make the water turns brownish and blackish which can also cause a bad odor (Metcalf and Eddy, 2003).

The objective of this study was to investigate the efficiency and effectiveness of biosand filter (BSF) design in removing organic substances ($KMnO_4$) and turbidity in drinking water supply.

MATERIALS AND METHODS

Biosand filter design: Biosand reactor unit is a rectangular filter unit made from 8 mm glass with dimensions 30×30×100 cm. The use of the glass is in the formation of biofilm layer and for visual observation the filtration process. Each unit has the same height with the filter medium. Total height of the medium from each biosand filter Reactor is 70 and 5 cm above the water level of fine sand. Water prevents the sand from drying also keeps the moisture in the fine sand during the formation of a biofilm layer and prevent the layer of biofilm from damage. Then from 5 cm from the surface of the water, a diffuser plate made from fiber plastic is used. The function of diffuser plate is to maintain the flow rate of water into the BSF reactor unit. The medium used in BSF reactor as sand local and gravel. The water is received through the orifice hole that is placed on the lateral pipe. Locally obtainable river sand was selectively sieved, using a set of sieves for sand analysis and the portion passing through 0.25 mm sieve and retained on 0.150 mm was used in the present study as filter medium. The filter medium had an effective size of 0.23-0.25 mm filled into the reactor with a depth 40 cm on the top and coarse sand (0.60 mm size) and 15 cm in the middle of media. Lastly, in the bottom layers of underdrain have gravel (10-12 mm size) of 15 cm. The sand and gravel was washed several times using tap water until the wash water became clear, the purpose of this washing is to eliminate the pollutants in the filtration media and dried in the oven for 24 h until at temperature of 105°C for a sterilizer, after that the media were put into the reactor sequentially. The filter media were sieved and washed to remove the clay particles, organic contents and other materials according to the standard procedures for BSF developed by CAWST (2008). Schematic diagram of the filter is presented in Fig. 1.

Water sources: The water value was observed to suggest the characteristic of ground water in developing countries. The water source from wells (ground water) located in swampy areas tend to contain organic substances and high turbidity. Wells located in Samarinda, Indonesia. The well

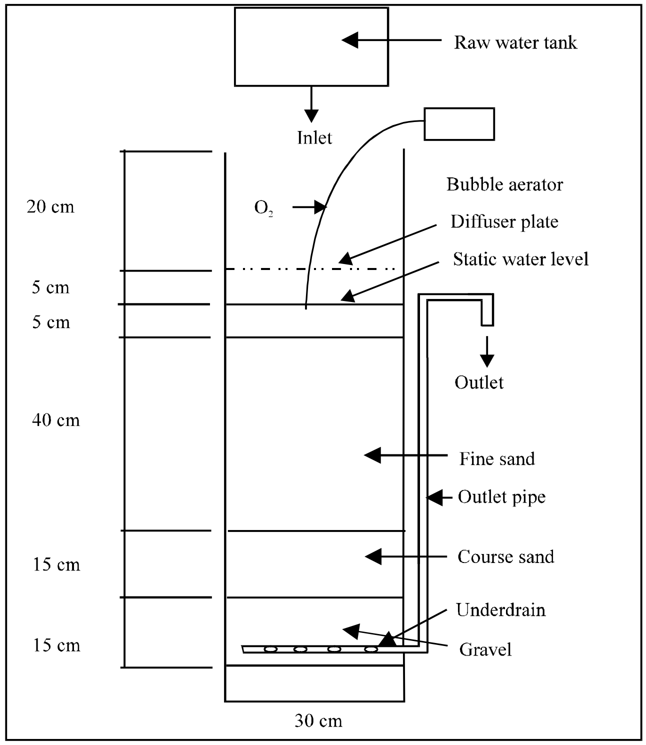

Fig. 1: Schematic biosand filter design

water is used for daily activities such as washing clothes, bathing and for drinking water. Experiment for the duration (7 days) after ripening for 20 days after that well water was collected in 4 samples each BSF every day and 1 sample at the inlet. Experiments conducted from October to November 2010 during the rainy season affected the quality of well water. The characteristics of the well water pre-filtration are shown in Table 1.

Filter operation: The experiments were performed by using 4 units of BSF reactor; four units used well water (ground water) as influent were conducted simultaneously. Each filter was fed a standard batch of 20 L of the influent water mixture per day for 20 days, except during weekly testing. Each valve on the tank was opened and set appropriate discharge that have been planned (BSF 1 and 2 used a flow rate of 0.2 m h^{-1} with a discharge 5×10^{-3} L sec^{-1} while BSF 3 and 4 used the flow rate of 0.4 m h^{-1} with a discharge 1×10^{-2} L sec^{-1}) was then flowed into each reactor. Ripening during 20 day used a continuous system for 24 h, ripening period was 1-3 weeks to growth biofilm layer, this period was allows efficient growth of the biological layer in the sand (Ngai and Walewijk, 2003). After 20 day ripening Schmutzdecke at fine sand layer the processing was no longer using a continuous system, BSF 1 and 3 with periods of pause 6 h and BSF 2 and 4, the pause period that was used is for 12 h, while for the flow it was from morning until the evening. Official testing begin in week 4, allowing an initial 20 days ripening period for the biological zone to be created inside the sand with bubble aerator for the supply O_2 for feeding the biological zone and after that sampling measurements were taken. Samples were taken at the point of inlet and outlet of each BSF reactor samples every day during seven days. The filters were charged once a day with raw water prepared daily.

Table 1: Characteristic of water pre-filtration

Parameter	Result
Organic substances concentration ($KMnO_4$)* (mg L^{-1})	27.4
Turbidity matter (NTU)**	39.0
pH	6.80

*Kalium permanganate, **Nephelometric turbidity unit

Table 2: Characteristic and decrease of organic substances concentration ($KMnO_4$) inlet and outlet using biosand filter treatment

	Sample		Outlet (mg L^{-1})				Efficiency (%)				
	taken	Inlet									
Parameter	(days)	(mg L^{-1})	BSF 1	BSF 2	BSF 3	BSF 4	BSF 1	BSF 2	BSF 3	BSF 4	pH
	1	22.34	5.56	6.67	5.54	5.34	75.2	75.11	70.14	76.09	6.6
	2	21.22	5.74	6.33	4.34	5.39	79.54	72.95	70.16	74.59	6.5
Organic	3	22.31	5.12	6.73	4.22	5.36	81.08	77.05	71.44	75.97	6.5
Substances	4	22.11	6.63	5.31	5.02	5.37	77.29	70.01	75.98	75.71	6.4
concentration	5	21.22	5.45	6.39	5.31	6.32	74.97	74.31	69.88	70.21	6.5
($KMNO_4$)*	6	22.33	5.53	6.64	5.67	6.38	74.60	75.23	70.26	71.42	6.7
	7	22.30	5.67	6.43	5.56	6.89	75.06	74.57	71.16	69.10	6.6
	Averages						76.82	74.17	71.28	73.29	

*Kalium permanganate, BSF: Biosand filter

Table 3: Characteristic and decrease of organic substances concentration ($KMnO_4$) inlet and outlet using biosand filter treatment

			Outlet (NTU)				Efficiency (%)				
	Sample taken	Inlet									
Parameter	(days)	(NTU)	BSF 1	BSF 2	BSF 3	BSF 4	BSF 1	BSF 2	BSF 3	BSF 4	pH
	1	29	2	1	1	1	96.55	93.10	96.55	96.55	6.6
	2	29	2	2	1	1	96.55	93.10	96.55	93.10	6.5
	3	29	2	1	1	1	96.55	93.10	96.55	96.55	6.5
Turbidity	4	28	1	1	1	1	96.42	96.42	96.42	96.42	6.4
	5	30	2	1	1	1	96.66	93.33	93.33	96.66	6.5
	6	28	1	1	1	1	96.42	96.42	96.42	96.42	6.7
	7	29	2	1	1	1	96.55	93.10	93.10	96.55	6.6
		Averages						96.56	94.08	96.52	96.03

NTU: Nephelometric turbidity unit, BSF: Biosand filter

The schedule of the filter operation is presented in Tables 2 and 3. The test was conducted at room temperature and the water temperature was set at 25-34°C.

Sample and analytical method: Samples were collected at different intervals for analysis, influent water and grab samples. Grab samples were analyzed by APHA standard method for parameter such as organic substance concentration ($KMnO_4$) and turbidity of the filtered water where 1.5 L bottles were used to collect water samples from each reactor. The pre and post-filtration water sampling organic substances ($KMnO_4$), preservation and tests were performed according to the APHA standard methods (APHA, 1992). The turbidity of water was analyzed by a turbidity meter. pH of pre and post-filtration water was recorded by a pH meter.

The statistical analysis of the data was performed using t-test for efficiency of organic substances concentration ($KMnO_4$) and turbidity.

RESULTS AND DISCUSSION

Decrease of organic substances ($KMnO_4$): From this study the average efficiency was determined. From Table 2 it can be seen that the efficiency achieved by the four units of BSF reactors with flow rate variations and pause, did not show any a significant difference. The average efficiency of organic substances ($KMnO_4$) decreased from BSF 1 was 76.82%, 74.17% reduction for BSF 2, 71.28% for BSF 3 and 73.29% for BSF 4. This comparison showed the differences in the efficiency of each BSF, where BSF 1 better than with BSF 2, 3 and BSF 4.

Interaction contact time with period of paused and flow rate had great impact for decrease organic substances ($KMnO_4$) average each unit biosand Filter reactor can decrease organic substances ($KMnO_4$) even in period of paused 6 and 12 h, flow rate of 0.2 and 0.4 m h^{-1}, Biofilm on surface of fine sand had interaction with organic substances influent from well water transform organic substances became energy for growth of biofilm and reduce organic substance. Then, period of paused and aeration for supply O_2 5 cm on the surface of fine sand layer in water was improvement the growth biofilm and decrease of organic substances ($KMnO_4$). Figure 2a-d shows the removal of organic substances ($KMnO_4$) for all four BSF reactors, where a high removal of the organic substances was recorded in treatment period of 21-27 days after ripening and removal of the organic substances was found in all the BSF reactor and Fig. 2 shows all removal of organic substances ($KMnO_4$) from the range of 21.22 mg L^{-1} until 4.22 mg L^{-1}. In water and waste water treatment, BSF showed that the presence of well-developed biofilms and associated microorganism was required for effective nutrient cycling and biodegradation of organic compounds, under both aerobic and anaerobic conditions (Mendoza-Espinosa and Stephenson, 1999). The high concentration of organic substances ($KMnO_4$) of the water contained in the groundwater may indicate or provide information on the location of the wells, because for those near septic tanks and swampy area, organic substance can easily infiltrate into the wells. Pollution of organic substance and turbidity in well water comes from poor sanitation in the form of household and industrial waste.

Organic compounds are compounds composed of atoms of C, H, O, N, S, P and X with the carbon atom as its backbone and the other atoms will bond with the carbon atoms by covalent bonds. There are so many kinds of organic compounds ranging from a short carbon chain (such as trihalomethane, methanol) to long chains (carbohydrates, humid acid and so on). Many types of organic compounds depend on the pollutant source.

Measurement numbers of permanganate ($KMnO_4$) are a measurement of organic substances in water, where organic substances in water are oxidized by strong oxidizing $KMnO_4$ at boiling temperature (±100°C) for 10 min. The more organic matter in the water, the more of oxidant $KMnO_4$ is needed to oxidize organic compounds. The measurement of organic matter in the aggregate (general) is to determine the concentration of organic substances in water in general, without knowing the type of compounds. Basic measurements of the aggregate are based on the nature or characteristics of organic compounds in general.

The removal of organic substances in BSF reactor that takes place is a biochemical process. The pollutants are degraded in the waste by organisms that accumulate in the lining fine sand called Schmutzdecke or biofilm. Biochemical processes occurred due to decomposition of microorganisms/ aerobic bacteria that used oxygen to break down pollutants (Metcalf and Eddy, 2003) in the reaction shown below:

$$\text{Organic compounds} + O_2 + \text{microbes} + N + P \rightarrow \text{new microbes } H_2O + CO_2 + NH$$

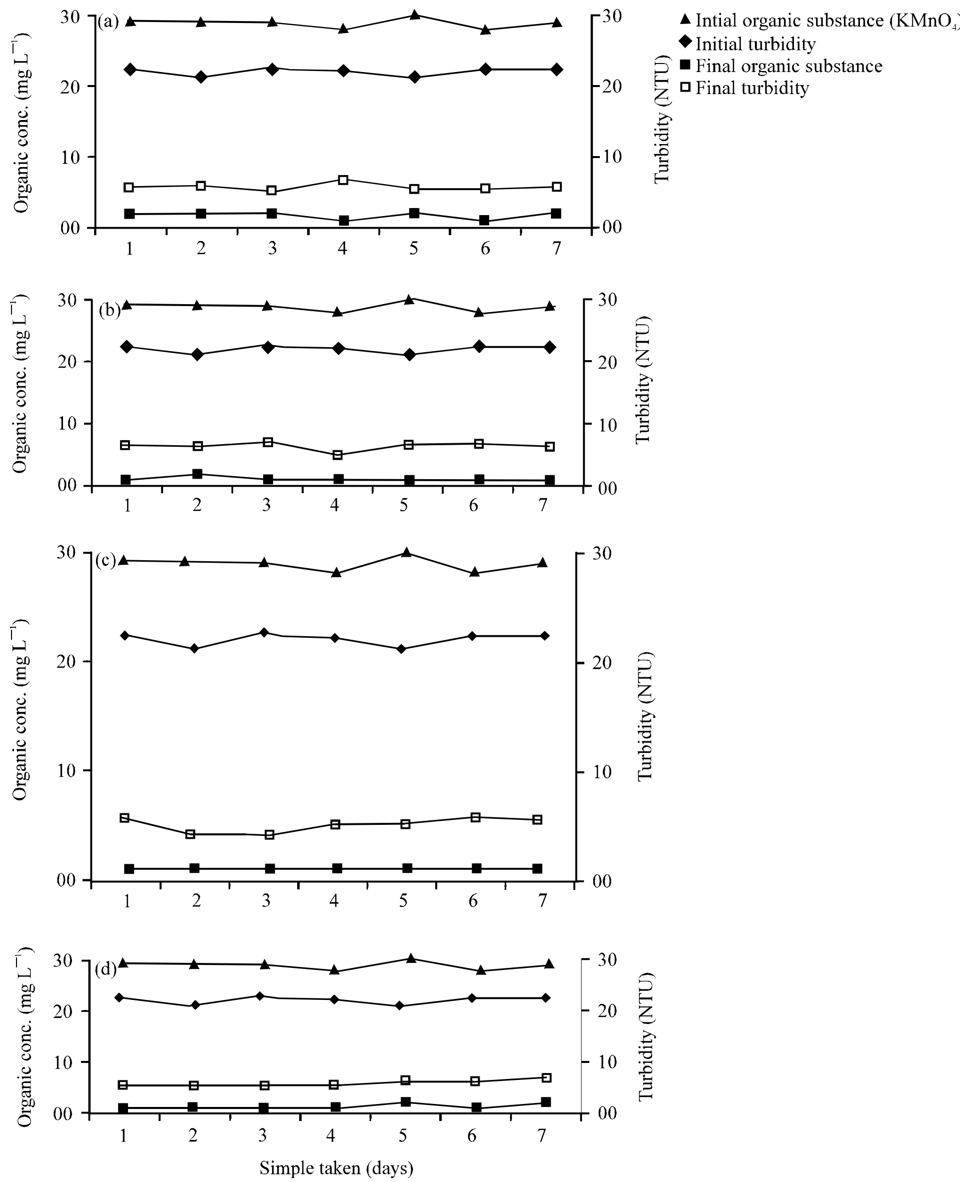

Fig. 2(a-d): Decrease in organic substances ($KMnO_4$) and turbidity using biosand, (a) Filter 1, (b) Filter 2, (c) Filter 3 and (d) Filter 4

According to Metcalf and Eddy (2003) the growth of microorganisms and the reduced concentration of organic substances, indicates that the microorganisms/microbes are capable of degrading and utilizing the concentration of organic substances as carbon sources, energy or sulfur for growth. This study an important and significant positive effect of decrease organic substance using biosand filter with connection flow rate and period of pause has been identifying. Although, biofilm on surface fine layer had not measured in this research because is very complicated.

Decrease of turbidity: Table 3 shows the average efficiency as determined by the removal of turbidity. From Table 3 it can be seen that the efficiency achieved by the four units of biosand filter with flow rate variations and pause, which differed did not showed a significant difference. Average efficiency of turbidity decrease in BSF 1 was 96.56 and 94.08% in BSF 2, 96.52% in BSF 3 and 96.03% in BSF 4. From this comparison despite having the same average efficiency, the two variations can reduce the turbidity with an efficiency that was quite large and effective. It the reduction reached >50% indicate that the biosand filter reactor can remove turbidity in the well water with a fairly effective variation occurring in BSF 1.

Extensive moment contact are reflected in batch organize process make decrease and effluent quality of water. Varying form period of paused (6 and 12 h) and flow rate BSF 1 and 2 used a flow rate of 0.2 m h^{-1} with a discharge 5×10^{-3} L sec^{-1} while BSF 3 and 4 used the flow rate of 0.4 m h^{-1} with a discharge 1×10^{-2} L sec^{-1}) operation improved decrease turbidity. The utilize of fine and coarse sand comparison the filter medium had an effective size of 0.23-0.25 mm filled into the reactor with a depth 40 cm on the top and coarse sand (0.60 mm size) and 15 cm in the middle of media improvement significant in effluent turbidity. Figure 2a-d shows turbidity removal with ranges from 28-30 NTU of the well (ground) water, during the 7 days of experiment after ripening for 20 day for all BSF reactors. From this result the removal ranges from 2 to 1 NTU. The reduction of turbidity is a physical process (physical, sedimentation and adsorption) which generally are a very effective method for reducing levels of turbidity that cannot be removed (Gerba *et al.*, 1988). Decrease in turbidity in the BSF reactor was influenced by the layer of sand. In each unit of reactor there were layer of fine and coarse sand serving as a layer of biofilm growth as well as a buffer layer and also functions in removing suspended materials, organic and inorganic from well water (ground water), that caused turbidity after the passing sand layer decreased quite significantly. Numerous studies shown the relationship between turbidity reduction and microbial contamination of raw water and treatment (LeChevallier *et al.*, 1991; Clark *et al.*, 1992; LeChevallier and Norton, 1993) and a few documented waterborne illness epidemics were related by high turbidity levels (Schwartz *et al.*, 2000). The experimental positive result for turbidity decrease by biosand filter was had good performance for used in developing countries where this technology is needed the most, since a lot of BSF-target households tend to be more urban and rural area depend on water sources especially ground or well water sources that may experience elevated levels of cyclic or year round turbidity.

pH values: The seeding process was carried out to form a layer, the layer of the biofilm (biological zone) to be formed on top of filter medium (fine sand) that are expected to degrade the organic substances concentration and turbidity to be used as intended. In this process many factors that must be considered such as temperature, pH and nutrients so that the microorganisms can produce an optimal biofilm layer. In the seeding process the addition of oxygen (O_2) supply is to help accelerate the formation of a biofilm layer. Biofilm growth is heavily influenced by environmental factors such as the interaction between bacteria, plastered surfaces, surface moisture, food available, ionic bonds, Van der Waals bonding, surface tension and condition (Yung, 2003). In addition, the supply of oxygen, pH and temperature and contact time must also be considered. This seeding process used aerobic microorganisms, their need a supply oxygen for growing and then we addition bubble aerator for the oxygen supply of raw water. pH was also monitored in order to maintain in neutral state, because the microorganisms especially bacteria can grow well in this environment at pH range of 5-7 during the seeding process that shows the growth of microorganisms on the filter media. Temperature between 25 to 28°C was good for microorganism because microorganisms can grow well at these temperatures (mesotherm temperatures). This study was measured pH and no significant result small negative for relationship between flow rate and period of paused. Characteristics of pH in the well water during study period are presented in Table 2 and Table 3.

CONCLUSIONS

Based on the results of research and discussion, it can be drawn some conclusions based on research objectives are the results obtained in laboratory testing that the concentration of organic substances ($KMnO_4$) and turbidity with the average value of the overall efficiency more than 50% this proves that with biosand filter can be promising tool and variations flow rate 0.2 m h^{-1} and a pause period 6 h at biosand Filter reactor 1 shows the efficiency decreased concentrations of organic substances ($KMnO_4$) and turbidity in well water most effective when compared to the another variation of flow rate and paused period. This study was conducted The BSF design, construction, operational and maintained as technology become solution in urban and rural area to provide safe water and drinking water in developing countries.

ACKNOWLEDGMENTS

This research was carried out with the support and special thanks for Laboratory of Faculty of Forestry, Faculty of Agriculture and Faculty of Engineering, University of Mulawarman, Indonesia.

REFERENCES

APHA, 1992. Standard Methods for the Examination of Water and Wastewater. 18th Edn., American Public Health Association, Washington, DC.

Ahammed, M.M. and K. Davra, 2011. Performance evaluation of biosand filter modified with iron oxide-coated sand for household treatment of drinking water. Desalination, 276: 287-293.

Alaboud, T.M. and S.F. Magram, 2008. A discourse on feasibility of the membrane bioreactor technology for wastewater reuse in Saudi Arabia. Res. J. Environ. Sci., 2: 445-455.

Alade, A.O., O.S. Amuda, A.O. Afolabi and F.E. Adelowo, 2012. Adsorption of acenaphthene unto activated carbon produced from agricultural wastes. J. Environ. Sci. Technol., 5: 192-209.

Arnal, J.M.A., M.S. Fernandez, G.M. Verdu and J.L. Garcia, 2001. Design of a membrane facility for water potabilization and its application to third world countries. Desalination, 137: 63-69.

Bhattacharya, A.K., S.N. Mandal and B. Bhattacharya, 2008. Bio-augmentation technology in textile mill wastewater management: A case study. Res. J. Environ. Sci., 2: 32-39.

CAWST, 2008. Biosand filter Manual: Design, Constructions, Installation, Operation and Maintenance. Centre for Affordable Water and Sanitation Technology (CAWST), Canada.

Clark, S.C., D.F. Lawler and R.S. Cushing, 1992. Contact filtration: Particle size and ripening. J. Am. Water Works Assoc., 84: 61-71.

Clasen, T., 2009. Scaling up household water treatment among low-income populations. Public Health and Environment Water, Sanitation, Hygiene and Health, World Health Organization, Geneva, Switzerland. http://whqlibdoc.who.int/hq/2009/WHO_HSE_WSH_09.02_eng.pdf

Droste, R.L., 1997. Theory and Practice of Water and Wastewater Treatment. John Wiley and Sons, New York.

Duke, W.F., R.N. Nordin, D. Baker and A. Mazumder, 2006. The use and performance of biosand filters in the Artibonite Valley of Haiti: A field study of 107 households. Rural Remote Health, Vol. 6.

Durai, G. and M. Rajasimman, 2011. Biological treatment of tannery wastewater-A review. J. Environ. Sci. Technol., 4: 1-17.

Earwaker, P., 2006. Evaluation of household Biosand filters in Ethiopia. Master's Thesis, University of Cranfield, Bedfordshire, UK.

Elliott, M.A., C.E. Stauber, F. Koksal, K.R. Liang, D.K. Huslage, F.A. DiGiano and M.D. Sobsey, 2006. The Operation, Flow Conditions and Microbial Reductions of an Intermittently Operated, Household-Scale Slow Sand Filter. In: Recent Progress in Slow Sand and Alternative Biofiltration Processes, Gimbel, R., N.J.D. Graham and M.R. Collins (Eds.). International Water Association (IWA) Publ., London, UK., ISBN-13: 9781843391203, pp: 268-277.

Elliott, M.A., C.E. Stauber, F. Koksal, F.A. DiGiano and M.D. Sobsey, 2008. Reductions of *E. coli*, echovirus type 12 and bacteriophages in an intermittently operated household scale slow sand filter. Water Res., 42: 2662-2670.

Elliott, M.A., F.A. DiGiano and M.D. Sobsey, 2011. Virus attenuation by microbial mechanisms during the idle time of household slow sand filter. Water Res., 45: 4092-4102.

Gerba, C.P., K. Hou and M.D. Sobsey, 1988. Microbial removal and inactivation from water by filters containing magnesium peroxide. J. Environ. Sci. Health Part A: Environ. Sci. Eng., 23: 41-58.

Gokturk, S. and S. Kaluc, 2008. Removal of selected organic compounds in aqueous solutions by activated carbon. J. Environ. Sci. Technol., 1: 111-123.

Ibeto, C.N., N.F. Oparaku and C.G. Okpara, 2010. Comparative study of renewable energy based water disinfection methods for developing countries. J. Environ. Sci. Technol., 4: 226-231.

Jenkins, M.W., S.K. Tiwari and J. Darby, 2011. Bacterial, viral and turbidity removal by intermittent slow sand filtration for household use in developing countries: Experimental investigation and modeling. Water Res., 45: 6227-6239.

LeChevallier, M.W. and W.D. Norton, 1993. Treatments to Address Source Water Concerns: Protozoa. In: Safety of Water Disinfection: Balancing Chemical and Microbial Risks, Craun, G. (Ed.). ILSI Press, Washington, DC., USA.

LeChevallier, M.W., W.D. Norton and R.D. Lee, 1991. Occurrence of giardia and cryptosporidium in surface water supplies. Appl. Environ. Microbiol., 57: 2610-2616.

Lenton, R. and A. Wright, 2004. Interim report on task force 7 on water and sanitation. Millennium Project, UNO, United Nations Development Group, New York, USA.

Magram, S.F. and M. Azeem, 2008. Evaluation of the performance of dynamic sand filtration under real working conditions. Res. J. Environ. Sci., 2: 52-57.

Magram, S.F. and M.M. Abdel-Azeem, 2008. Efficiency of anaerobic digestion of low-strength sludge under different thermophilic conditions. Asian J. Scientific Res., 1: 510-517.

Mendoza-Espinosa, T. and T. Stephenson, 1999. A review of Biological Aerated Filters (BAFs) for wastewater treatment. Environ. Eng. Sci., 16: 201-216.

Metcalf and Eddy, 2003. Wastewater Engineering Treatment and Reuse. 4th Edn., McGraw Hill, New York, America.

Momba, M.N.B., N. Makala, B. Zani and B.M. Brouckaert, 2005. Key Causes of Drinking Water Quality Failure in a Rural Small Water Supply of South Africa. In: Water Encyclopedia-Domestic, Municipal and Industrial Water Supply and Waste Disposal, Lehr, J.H. and J. Keeley (Ed.). John Wiley and Sons, New York, USA.

Murphy, H.M., E.A. McBean and K. Farahbaksh, 2010. Nitrification, denitrification and ammonification in point-of-use biosand filters in rural Cambodia. J. Water Health, 8: 803-817.

Ngai, T. and A.S. Walewijk, 2003. The Arsenic Biosand Filter (ABF) project: Design of an appropriate household drinking water filter for rural Nepal. Rural Water Supply and Sanitation Support Programme, Environment and Public Health Organization, Kathmandu, Nepal.

Peter-Varbanets, M., C. Zurbrugg, C. Swartz and W. Pronk, 2009. Decentralized systems for potable water and the potential of membrane technology. Water Res., 43: 245-265.

Pryor, M.J., E.P. Jacobs, J.P. Botes and V.L. Pillay, 1998. A low pressure ultrafiltration membrane system for potable water supply to developing communities in South Africa. Desalination, 119: 103-111.

Ramalakshmi, S., K. Muthuchelian and K. Swaminathan, 2012. Comparative studies on removal of fast green dye from aqueous solutions by activated carbon prepared from *Gloriosa superba* waste and *Alternaria raphani* fungal biomass. J. Environ. Sci. Tech., 5: 222-231.

Schwartz, J., R. Levin and R. Goldstein, 2000. Drinking water turbidity and gastrointestinal illness in the elderly of Philadelphia. J. Epidemiol. Community Health, 54: 45-51.

Smet, J. and C. van Wijk, 2002. Multi-Stage Filtration Technology. In: Small Water Community Water Supplies: Technology, People and Partnership, Smet, J. and C. van Wijk (Eds.). IRC International Water and Sanitation Centre, Delft, The Netherlands, ISBN-13: 9789066870352.

Sobsey, M.D., 2002. Managing water in the home: Accelerated health gains from improved water supply. Water, Sanitation and Health Department of Protection of the Human Environment, World Health Organization, Geneva, Switzerland. http://www.who.int/water_sanitation_health/dwq/WSH02.07.pdf

Sobsey, M.D., C.E. Stauber, L.M. Casanova, J.M. Brown and M.A. Elliott, 2008. Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world. Environ. Sci. Technol., 42: 4261-4267.

Stauber, C.E., M.A. Elliott, F. Koksal, G.M. Ortiz, F.A. DiGiano and M.D. Sobsey, 2006. Characterisation of the biosand filter for *E. coli* reductions from household drinking water under controlled laboratory conditions and field use conditions. Water Sci. Technol., 54: 1-7.

Stauber, C.E., G.M. Ortiz, D.P. Loomis and M.D. Sobsey, 2009. A randomized controlled trial of the concrete biosand filter and its impact on diarrheal disease in Bonao, Dominican Republic. Am. J. Trop. Med. Hyg., 80: 286-293.

WHO, 2007. Combating Waterborne Disease at the Household Level. World Health Organization, Geneva, Switzerland, ISBN-13: 9789241595223, Pages: 34.

WHO/UNICEF, 2006. Meeting the MDG Drinking Water and Sanitation Target: The Urban and Rural Challenge of the Decade. World Health Organization and United Nations Children's Fund, Geneva, Switzerland, ISBN-13: 9789241563253, Pages: 41.

Xia, S., J. Nan, R. Liu and G. Li, 2004. Study of drinking water treatment by ultrafiltration of surface water and its application to China. Desalination, 170: 41-47.

Yung, K., 2003. Biosand filtration: Application in the developing world. Civil Engineering (CE) 401 Project, University of Waterloo, Ontario, Canada. http://www.sswm.info/sites/default/files/reference_attachments/YUNG%202003%20Biosand%20Filtration.pdf