Jr. of Industrial Pollution Control 33(2)(2017) pp 1120-1127
www.icontrolpollution.com
Research Article

DESIGN OF SAND FILTER UNIT FOR SURFACE WATER TREATMENT IN GUBRE CITY, SNNPR, AND ETHIOPIA

DAIDA SHARATH *, BERHE TEKLE A AND SUSHMA K

Department of Chemical Engineering, College of Engineering and Technology, Wolkite University, Wolkite- P.O - 07, Ethiopia

(Received 15 June, 2017; accepted 18 June, 2017)

Key words: Surface water treatment, Sand filtration, Design of sand filter unit, Turbidity

ABSTRACT

Surface water is the best source of water that satisfies us from our thirst and used for many other houses hold and industrial applications. It can be polluted by different means of contaminations. The presence of these contaminations may be in the form of soluble, insoluble or with other compounds above its limit could alter the usefulness of the water. In the present study, this project is aimed to design a Sand Filter unit, which deals with impurity problem in surface water, by using Sand Filtration as alternative treatment method for treating surface water for drinking in Gubre-City, SNNPR, and Ethiopia. To achieve this goal, three plastic version Sand Filter units were installed at laboratory and performed about nine experiments with different parameters. The results are analyzed by the efficiency of Sand Filter in removing impurity and compared between units with respect to the key design parameters. Three experimental results were selected and compared which have best impurity removal efficiency. Finally, it is observed that all these three Sand Filter units achieved more than 80% turbidity removal efficiency from surface water. From the experiments, it is clear that the Sand Filter Unit 1 as attained the highest turbidity removal efficiency of 88.4% as compared to the other two Sand Filter units.

INTRODUCTION

The Sand Filter concept was developed in the late-1980s by Dr. David Manz, of the University of Calgary, Department of Civil Engineering. In essence, it is an adaptation of the slow sand filtration (Slow Sand Filter) process to the household scale (Filtronics, 1993; Fox, *et al.*, 1994; Hallberg and Martinell, 1976). Testing in the laboratory and the field began in 1991 and the design was refined; the concrete SF was patented in 1993. A cross-sectional view of a concrete SF designed with a square footprint. The first SFs to be used in homes were installed in Nicaragua in 1993 (European Union, 1998; Fewster, *et al.*, 2004). Laboratory research on their effectiveness for bacterial reductions was conducted later at the University of Calgary and published in a Master's thesis (Buzunis, 1995). Subsequent SF designs include circular designs using concrete and plastic housings. Concrete designs afford the potential for sustainable local production; whereas plastic designs must be manufactured at a central location but are far lighter and can be stacked for shipping. The SF is currently in use in Canada, the U.S., Mexico, Nicaragua, El Salvador, Costa Rica, Brazil, Ecuador, Haiti, Indonesia, Bangladesh, Laos, Vietnam, China, the Philippines, Ethiopia, Kenya, Nigeria, Gabon, Nepal and the list continues to grow (Sims and Slezak, 1991). In fact, SF technology is at its infant stage here in Ethiopia. It is currently estimated that there are more than 270,000 BSFs successfully installed around the world (Huisman and Wood, 1974), predominantly in Asia, Africa and South America. The main source of water in Gubre city is surface water from rivers and ponds. Surface water contaminants typically consist of sediments, bacteria, viruses and heavy metals. Bacteria and viruses are the main causes of waterborne diseases (Collins, 1992; EPA, 1993; Elliott, 2008). Surface water treatment is the process of removing undesirable chemicals, biological contaminants, suspended solids

***Corresponding authors email: daidasharath@gmail.com**

and gases from contaminated water. The goal is to produce water fit for a specific purpose. Most water is disinfected for human consumption (drinking water), but water purification may also be designed for a variety of other purposes, including fulfilling the requirements of medical, pharmacological, chemical and industrial applications (Haarhoff and Cleasby, 1991; Home Water Purifiers and Filters, 2008). The methods used include physical processes such as sand filtration and chemical processes such as chlorination or billing of water. According to a 2007 World Health Organization (WHO) report, 1.1 billion people lack access to an improved drinking water supply, 88 percent of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, while 1.8 million people die from diarrheal diseases each year. In this project, the performance of Sand Filter (SF) to remove impurity will be studied.

Description of the study area

The study will be conducted in SNNPR in Gurage zone at Wolkite University which is located about 20 km away from east of Wolkite town and 180 km south of Addis Ababa. They are located about 7.30′N and 36.20′E. The topography is characterized by slopping and rugged areas with very little plain land. The altitude of the zone varies within the range of 700-3400 meters above sea level. Gubre people use ground, river and pipe water, but most of them used river water. Fig. 1 shows the types of water sources that are used in the Gubre region, Ethiopia (International Development Research Center of Canada, 1998; Nichols, 2008; Ngai, 2009).

Although the sand filter is initially developed for pathogens removal, it is very efficient to remove impurity and other heavy metals from water and waste water (European Union, 1998; Bellamy, *et al.*, 1985; Buzunis, 1995; Campos, 2002; Centre for Affordable Water and Sanitation Technology, 2008; Centre for Affordable Water and Sanitation Technology, 2009a).

The data from previous research work regarding the effectiveness and removal efficiencies of tried sand filter units were presented in Table 1 below:

EXPERIMENTAL PROCEDURE

The experimental procedure is as follows:

1. Pre characterize the surface water by measuring its PH, total dissolved solid and turbidity and filter box is prepared from plastic pot. This pot consists of diffuser plate and lid.

2. The sand is prepared in the required size using sieve analysis and determined its uniformity coefficient and effective and size.

3. The sand is washed repeatedly until the color of water unchanged by using detergent and drying using sun light.

4. The dried sand and sample water put in to the filter pot depends on the required sand thickness and sample water depth.

5. The flow rate is determined by measuring the volume of filtrate per time.

6. The effluent water is characterized to identify which sand size and layer arrangement is effective in the quality of water.

7. The sand filter (SF) is designed at optimum flow rate, sand thickness and sand size (Fig. 2).

Sand filter (SF) construction

The approach was to employ SF units that were exactly as constructed and used in households, but within a controlled laboratory setting. Accordingly plastic filters were constructed inside the process laboratory of the Wolkite University. Filters were of the 20 cm height and 10 cm internal diameters. Considering the time and cost constraint, plastic is selected as the construction material for all filter parts. 4 L plastic bottle was selected to be the suitable

Fig. 1 Children collecting unsafe water for drinking.

Table 1. Effectiveness and removal efficiencies of sand filter

Quality parameter	Percent removal,%	Reference
Viruses	90	[21]
Protozoan parasites &helminthes	>99.9	[21]
Iron and manganese	90-95	[21]
E.coli	95-98, 98.5	[7], [3]
Turbidity	85	[8]
Fecal coliform	70.5, 96	[13], [4]
Heterotrophic bacterial population	80	[22]
Giardia lambia cysts	>99.9	[22]
Organic & Inorganic toxicants	50-90	[22]

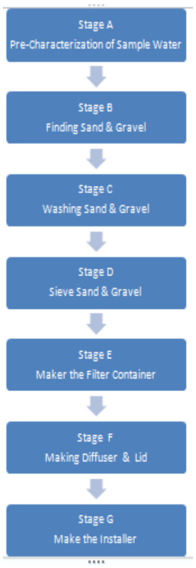

Fig. 2 Flow chart of process description.

material for filter box construction. Similarly, diffuser plate and lid are constructed from the commercial plastic plate.

Filter box construction

The construction was based on the CAWST (Center of Affordable Water and Sanitation Technology) SF design and specification. The specification was scaled down so as to make lab scale SF that performs the same tasks as large scale commercial SF. Plastic outlet tube was prepared from PVC found in laboratory.

Diffuser and lid construction

Based on the availability of material and the duration of the thesis small round plastic plates were selected to be the best construction material. Three identical plastic plate units were bought. The cover can be used as a lid without any modification while the base can be worked into the diffuser (Fig. 3).

The diffuser was constructed using the following procedures.

1. The round plastic plate of the same diameter as the top of the filter box was prepared.

2. A 2.5 cm × 2.5 cm grid was measured and marked on the plastic.

3. A 0.4-2 mm diameter hole was drilled at each intersection on the grid through the plastic.

4. An extra row of holes was added around the circumference of the diffuser. This helps to evenly distribute the water and prevent disturbing the sand near the filter wall.

Sand and gravel preparation

Selecting and preparing the filtration sand and gravel is crucial for the treatment efficiency of the sand filter. Crushed rock is the best type of filtration sand since it has less chance of being contaminated with pathogens or organic material. The sand for this project was obtained from crushing quarried rock. The sand and gravel were brought from wolkite university road construction (Pearce-McLeay, 1996; Salem, *et al*., 2000).

Washing the sand and gravel

Impure materials that found in a filter media affect the efficiency of the SF. Therefore, washing with pure water again and again repeatedly is necessary until it is purified. Since there is no sand and gravel washer, the sand has been washed with hands. The material contained considerable earthy matter and is said to have been fairly well washed by this process. Both the gravel and filtration sand were washed in the process engineering Laboratory. The washed sand and gravel were left in the sun for some time to be dried (Fig. 4).

Sieving sand and gravel

The washed and dried sand was sieved using a set of sieves with different mesh size. The mesh sizes used were: 0.5 mm, 1 mm, 2 mm, 3 mm and 4 mm. This is used us to determine the effective size and uniformity coefficient of the filter media.

The materials used in sand sieve analysis were sand sample, sand container, set of sieves, sieve set lid and catch pan. The procedures used to characterize the sand were summarized as follows (Fig. 5).

Sand sieve analysis

The Sand Filter requires a certain range of sand grain sizes to effectively treat drinking water. Conducting a sand sieve analysis provides the distribution of sand grain sizes for a sample of sand. This information can be used to:

Fig. 3 Filtration sand and gravel.

Fig. 4 Sand and gravel washing and drying.

Fig. 5 Different types of sieves.

1. Determine if the prepared sand (sieved and washed) is within the Effective Size (ES) and Uniformity Coefficient (UC) ranges recommended for the filtration sand in the SF.

2. Determine what useable sand will be produced from a sand source and how much sand will be rejected as too fine or too coarse.

3. Estimate if a sand source would be a good supply to produce filtration sand (once the sand had been prepared by sieving and washing). This is done by determining the Effective Size and Uniformity Coefficient for the portion of the sand sample that would be useable.

The procedures used to characterize the sand were summarized as follows:

1. The sand sieves were stacked with the coarsest (4mm) on top followed by the 3mm,2mm, 1mm, 0.5 mm, and finally the catch pan on the bottom.

2. The 300 gm sample of sand is measured and put in the container.

3. The entire 300 gm sample was poured from the container onto the top sieve (4mm) and the lid placed on top of the sieve.

4. The entire sieve set was shaking both sideways and up and down for about five minutes.

5. The top lid was removed; the sand on the 4 mm was removed and measured the amount and recorded as cumulative sand retained on the sieve for the 4 mm sieve.

6. The next 3 mm sieve was removed and measured (on top of the sand from the 4 mm sieve), and recorded as Cumulative Sand Retained on the Sieve for the 3 mm sieve.

7. Step 6 was repeated for the 2 mm, 1 mm sieve, then the 0.5 mm sieve mesh, and finally the catch pan.

8. The percent retained on the sieve and the percent passing through the sieve for each sieve were calculated and recorded.

9. The percent passing through the sieve value for each sieve size was plotted on the graph.

10. Finally the effective size and uniformity coefficient of the sand were determined.

Set-up and installation of sand filter units

The main purpose of this experimental work is to identify the design parameters that affect the SF performance and impurity removal capabilities. Three different set up of the SF were installed. Each set up has three experiment units were installed. Since the other parameters have not that much significance effect on the efficiency of the SF, three parameters of great importance are selected. The three parameters are standing water height, filtration sand depth and media sand effective size (ES).

The two filter units SF1 and SF2 differ only by the height of the standing water (supernatant). From these set ups the effect of clear water depth on the efficiency of SF to remove impurity will be investigated. SF3 is different from SF1 and SF2 in all parameters. Such as, filtration sand depth and water height. The difference in impurity concentration of the effluent water sample from the three SF units shows the effect of the filtration sand depth (Fig. 6).

The SF3 Units was installed to investigate the effect of filtration sand size on the removal of impurity. All SF units were installed as shown in the following Table 2.

Pre-characterization of sample water

The sample water was taken from Gubre river and

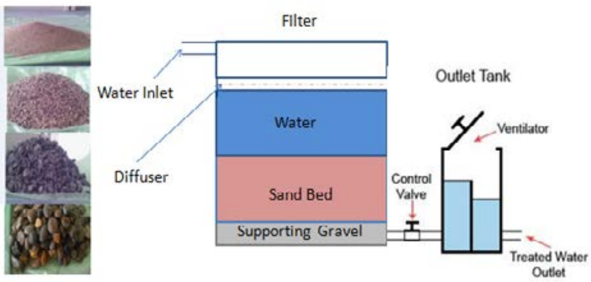

Fig. 6 Sand filter units' construction.

Table 2. Different sand filter unit set ups

Parameters(mm/cm)	SF1	SF2	SF3
Fine Sand Effective Size(mm)	1.1	1.1	1.1
Gravel Depth(cm)	1.5	1.5	1.5
Coarse Grain Depth(cm)	6	6	10
Fine Sand Depth(cm)	6	6	10
Mixture Sand Depth(cm)	6	6	10
Standing Water Height(cm)	9	6	4
Shell Diameter(cm)	10	10	10
Total Sand Filter Height(cm)	22	22	22

the sample water contains impurity was measured in Chemistry laboratory. The measured parameters are turbidity, PH, TDS, Cl and TSS. Our experimental design objective is to reduce the impurity of water (Sharma, 2001).

RESULTS AND DISCUSSION

Results

The Results are presented in four sub section. Sand sieve analysis, pre and final characterization of laboratory results, design calculation and concentration results and impurity removal.

Sand sieve analysis results

The results from sand sieve analysis are presented as follows. The same sand is used for the first sand filter units so that their media characteristics are the same. The result is presented in Table 3 To determined the cumulative sand retained on the sieve(A), percentage retained on the sieve (C),percent pass through the sieve and cumulative sand retained by catch pane(B) Percent retained on the sieve (c) = $\frac{A}{B}\times 100\%$

Percent pass through the sieve = 100% - C

The media a characteristic is determined from (Figs. 1-5).

The effective size, d10 (ES) value is read from the graph where the line crosses through the sieve line at 10% and the uniformity coefficient, (UC) = d60/ d10 where d60 is read from the graph where the line crosses the passing through the sieve line at 60%. The uniformity coefficient and effective sand size can be determined in the sand size versus percentage sand pass through each sand sieve graph shown in Fig. 7.

Where;

X axis =sand thickness,

Y axis= percent pass through the sieve.

Therefore, the media characteristic is determined from the above (Fig. 7) have the following values.

The effective size, d10 (ES) value is read from the above graph where the line crosses through the sieve line at 10%.

ES=1.1 mm.

The uniformity coefficient, (UC)=d60/d10 where d60 is read from the graph where the line crosses the passing through the sieve line at 60% (d60=1.9 mm). Therefore, the uniformity coefficient (U c) =d_{60}/d_{10}

$$Uc = \frac{1.9mm}{1.1mm} = 1.7$$

The media characteristic result is summarized and presented below Tables 4-6.

Pre and final characterization from Laboratory result

In the Table 7, three of the sand filter units are selected, which have the best turbidity and TDS removal efficiency. This efficiency has achieved in the sand size of fine sand, medium Sand and mixture

Table 3. Cumulative sand retained on the sieve for each sieve size

Sand size(mm)	*A(gm)	*C = (A/B)*100	*(100-C)
3	0	0	100
2	34	36.6	63.4
1	84	90.3	9.7
0.5	89	95.7	4.3
Catch Pan	93=B	100	0

*A (gm) = Cumulative sand retained on the sieve
*C = Percent Retained on the sieve
*(100-C) = Percent pass through the sieve

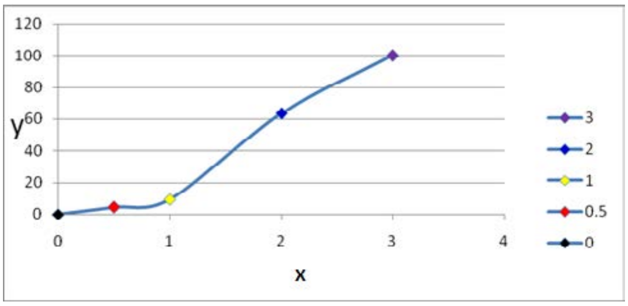

Fig. 7 Determination of media effective size and uniformity coefficient for SF1, SF2 and SF3.

Table 4. Summarized results from sieve analysis

S.No	Sand depth (L)(cm)	Water height (cm)	Volume flow rate(l/s)	Turbidity (NTU)	TDS (mg/l)
Fine sand depth(cm)	10	4	0.009	5	1.1
Medium sand depth(cm)	10	4	0.013	7.4	1.7
Mixture sand depth(cm)	10	4	0.012	5.8	1.62

SF unit NO	Uniformity coefficient	Effective size in mm
SF 1	1.7	1.1
SF 2	1.7	1.1
SF 3	1.7	1.1

sand size at 10 cm sand depth and 4 cm water height.

Design calculation and construction results

The head loss, filtration time and media volume for each Sand Filter units are calculated based on the parameter used at laboratory scale. The flow rates of all sand filter units were measured. The flow rates of the filters and filtration loading rate (V) of each sand filter (SF) units are presented in Table 8.

A Sand Filter unit Constructed at Wolkite University has the following construction specifications (Table 9).

TDS and turbidity removal efficiency

The effluent water TDS, Cl, TSS and turbidity values are presented and summarized in Table 10.

DISCUSSION

Impurity concentration exceeding 5NTU of turbidity should be removed from the water sample before use. To this, sand filter (SF) is designed and constructed in the laboratory. In this section the absorption regarding the medium characteristics, design and construction, comparison of different steps of SF units for impurity removal will be interpreted**.** In this project, most of the factors that affecting the performance of sand filter such as filter media characteristics (effective size and uniformity coefficient), filter media depths (filter sand depth), and standing water depth are considered. Some other factors like variation in turbidity of the water, flow rates and filtration rates are considered to have a little or no effect on the SF performance. The performance of SF increases with decrease in effective size. This is because smaller size filter media resulted in smaller pores openings which lead to better removal efficiency. It should be noted that this incremental in efficiency is achieved in expense of increase in head loss. Larger size of filter sand indicates that the media is more porous and the head loss becomes lower. However, the removal efficiency of such media is low as many of small particles in the influent will pass directly through the porous bed. For the first three SF units, the effective size determined from (Fig. 7). Using sieve analysis is found to be 1.1 mm. This value is reasonably agreed with the recommended standard range 0.5-1.35

Table 5. Sample water before treatment of SF

	TDS(mg/l)	TSS(mg/l)	Turbidity	PH	Cl
sample water	8.52	9	43	7.8	5

Table 6. Results of sample water after treatment

Parameters(cm)	Sand depth(cm)	Water height in (cm)	Volume flow rate in (L/s)	Turbidity (NTU)	PH	Total dissolved solid (TDS)(mg/l)
Fine sand depth (cm)	6	9	0.016	7.02	6.92	1.4
	6	6	0.011	6.1	6.96	1.3
	10	4	0.009	5.0	7.01	1.1
Medium sand depth (cm)	6	9	0.019	9.8	7.86	2.1
	6	6	0.014	8.1	7.02	1.9
	10	4	0.013	7.4	6.93	1.7
Mixture of sand depth(cm)	6	9	0.018	7.26	7.12	1.9
	6	6	0.013	6.9	7.04	1.87
	10	4	0.012	5.8	7.02	1.62

Table 7. Best three sand filter unit results from LAB

S.No	Sand depth (L)(cm)	Water height (cm)	Volume flow rate(l/s)	Turbidity (NTU)	TDS (mg/l)
Fine sand depth(cm)	10	4	0.009	5	1.1
Medium sand depth(cm)	10	4	0.013	7.4	1.7
Mixture sand depth(cm)	10	4	0.012	5.8	1.62

Table 8. Flow rate and filtration rate

SF unit no	Flow rates, L.second-1	Filtration Loading Rate, m3 $s^{-1}.m^{-2}$ (V=Q/A)
SF1(from fine sand depth)	0.009	1.15*10^-3
SF2(from medium sand depth)	0.013	1.70*10^-3
SF3(from mixture sand depth)	0.012	1.53*10^-3

mm (CAWST, 2007). Narrowly graded filter media has low uniformity coefficient (UC) with large pore space which contributes to low removal efficiency. Filter media of high uniformity coefficient (widely graded filter media) involves inclusion of small particles filling interspaces between large particles that encourages clogging. This in turn increases the removal efficiency by reducing the pore openings of the filter media. The uniformity coefficient of SF1, SF2 and SF3 is 1.7. This value is agreed in the range (<4) suggested by previous works (Classmen, 2008). The sand depth increases, the water retention time in filter media also increases undergoing further quality improvements. The three constructed sand filter units achieved the maximum removal efficiency of impurity and able to reduce the concentration below WHO guides lines which is 5NTU turbidity. Among the three sand filter units, SF1 is the most efficient units that achieved removal efficiency of 88.4% which is reasonably above and agrees with past works (Salem, 2000). Using the constructed sand filter units, the effects of media characteristics (effective size and uniformity coefficient), standing water height, and filter sand depth on filtration media is considered. Comparing the removal efficiency of the three sand filter units SF1 looks more efficient than SF2 and SF3 which are presented in the Table 11.

SF1 is the most efficient filter unit with efficiency of about 88.4% followed by SF2 and SF3 with removal efficiency of 82.8% and 86.5%, respectively as indicated in Table 11. The sand filtration units constructed in laboratory are considered for turbidity and TDS removal (University Technologies International, 1998; USEPA; 1999).

CONCLUSION AND RECOMMENDATIONS

Conclusion

Now-a-days the short of safe water for drinking water is hot issue the world, especially developing countries like Ethiopia. Surface water often is the only source; thus, water contaminations are hard to avoid. Unsafe drinking water causes health problem. Surface water treatment is the process of removing undesirable chemicals, biological contaminants and suspended solids. SF is an efficient and affordable alternative technology for impurity removal of water. The goal is to produce water fit for a specific purpose. The SF can be constructed from cheap materials. The capital cost is very low and negligible compared to other impurity removal technologies. Moreover, all costs including operating cost, maintenance and utility cost are negligible. Coming through all the ways of the project, it is concluded that with well-established and careful design parameters, SF is a promising technology for removing turbidity from surface water. In fact, the SF units are constructed at laboratory scale and all parameters are analyzed accordingly (Wilson, et al., 1999). The observation encourages that it can be used for house hold purposes by scaling up the main design parameters. The standing water height, sand depth and effective size are the key determinant factor for good SF performance. The set up with optimum design parameters achieved turbidity removal efficiency of 88.4%.

Recommendations

It is recommended that the removal efficiency enhancement should be studied further. May enhance its removal efficiency and should be

Table 9. Construction results

Diffuser hole diameter(mm)	0.4
Shell diameter(cm)	10
Total SF height (cm)	22

Table 10. Summarized results

SF unit No.	TDS(mg/l)	TSS	Cl	Turbidity(NTU)
SF1	1.1	-	4.5	5.0
SF2	1.7	0.001	4.85	7.4
SF3	1.62	0.05	4.95	5.8
Initial sample water	8.52	9	5	43.0

Table 11. Effluent TDS and Turbidity values at LAB

SF unit No.	TDS(mg/l)=[initial value –final value]*100 / Initial value	Turbidity=[initial value-final value]*100% / Initial value
SF1	87	88.4
SF2	80	82.8
SF3	81.2	86.5

considered during SF design in future studies. In order to implement SF for house hold water further work should be done. Since boiling water is the most effective method to disinfect any harmful bacteria and viruses, it is also recommended to boil the water after filtering to ensure that the water is safe to drink.

REFERENCES

AWWA. (1991). Manual of design for slow sand filtration, Hendricks, D. (Ed), AWWA Research Foundation and American Water Works Association. Denver. CO. USA

Bellamy, W.D., Silverman, G.P., Hendricks, D.W. and Logsdon, G.S. (1985). Removing

Giardia cysts with slow sand filtration. *Journal of American Water Works Association*. 77 : 52-60.

Buzunis, B.J. (1995). Intermittently operated slow sand filtration: A new water treatment process, University of Calgary Master of Engineering Thesis, Calgary, AL, Canada

Campos, L.C. (2002). Modeling and simulation the biological and physical parameters of

slow sand filtration.

CAWST. (2007). Bio-sand concrete filter. Center for Affordable Water and Sanitation Technology

Centre for Affordable Water and Sanitation Technology (CAWST). (2008). Bio-sand Filter Manual. Calgary. Canada.

Centre for Affordable Water and Sanitation Technology (CAWST). 2009a. Personal Communications.

Classmen, T.F. (2008). World Health Organization Guidelines for Drinking-water Quality Scaling up Household Water Treatment.

Collins, R.M., Eighmy, T.T., Fenstermacher J.M. and Spanos, S.K. (1992). Removing Natural Organic Matter by Conventional Slow Sand Filtration. *Journal of the American Water Works*. 84 : 80-90.

Elliott, M.A., C.E. Stauber, F. Koksal, F.A. DiGiano. and Sobsey, M.D. (2008). Reductions of E. coli, echovirus type 12 and bacteriophages in an intermittently operated household-scale slow sand filter.

El-Araby R, Hawash S. and El- Diwani G. (2009). Treatment of impurity and manganese in simulated surface water via sand technology.

EPA. Preventing Waterborne Diseases," epa.gov, April, 1993. [Online]. Available: http://www.epa.gov/nerlcwww/h2odis.pdf [Accessed: November 2, 2008]

European Union. (1998). Richtlinie 98/83/EG des Rates.

Fewster, E., Mol, A. and Wisessent-Brandsma, C. (2004). The long term sustainability of household sand filtration.

Filtronics. (1993). Impurity Filtration Systems.

Fox, K.R., Graham, N.J.D. and Collins, M.R. (1994). Slow Sand Filtration Today: An Introductory Review. In Slow Sand Filtration. Edited by M.R. Collins and N.J.D Graham. American Water Works Association. Denver, CO

Hallberg, R.O. and Martinell, R. (1976). Vyredox- In situ purification of Surface water. Surface water. 14.

Haarhoff, J. and Cleasby, J.L. (1991). Biological and Physical Mechanisms. In Slow Sand Filtration. Edited by G.S. Logsdon. American Society of Civil Engineers. New York.

Home Water Purifiers and Filters, "Compare water filters, purifiers, and purification technologies," home-water-purifiers-and-filters.com, 2008. [Online]. Available: http://www.home-water-purifiers-and-filters.com/water-purification.php [Accessed: November 2, 2008].

Huisman, L. and Wood, W.E. (1974). Slow sand filtration, World Health Organization, Geneva, Switzerland

International Development Research Center of Canada. (1998). Module 5 Slow sand filters, Revelo, L.A. and Escalante, E.R. (Eds), Fundacion Tecnologica de Costa Rica, Cartago, Costa Rica France. *Jour.AWW*. 84(4) : 158.

Nichols, D. (2008). Samaritan's Purse. Personal communication with Susan Murcott.

Ngai, T. (2009). CAWST. personal communications.

Pearce-McLeay, S. (1996). Filter Offers Healthy Hope for Safer Water Supply Association. 84 : 80-90.

Salem M.H., Eweida A.E. and Farag Azza. (2000). Impurity in drinking water and their environmental impact on human health. 542-556.

Sims, R. and Slezak, L. (1991). Slow Sand Filtration: Present Practice in the United States.

Sharma, S.K. (2001). Adsorptive Impurity Removal from Surface water.

University Technologies International. (1998). Clean Drinking Water to the World.

USEPA, (1999). Method 1622: Cryptosporidium in Water by Filtration/IMS/FA. United States Office of Water EPA-821-R-99-001.

Wilson, A., Parrott, K. and Ross B. (1999). Impurity in house-hold water. *Virginia Cooperative Extension*. 356-478.