Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2015.1062427

57 (2016) 7733–7741
April

Taylor & Francis
Taylor & Francis Group

Sustainable technology of trickling biosand filter (TBSF) combined with rock media to reduce organic matters for drinking water

Minsoo Maeng[a], Jaegyun Park[a], Haegyun Lee[b], John E. Tobiason[c], Seok Dockko[a,*]

[a]*Department of Civil and Environmental Engineering, Dankook University, Yongin-si, Gyeonggi-do 448-701, Korea, Tel. +82 31 8005 3479; Fax: +82 31 8021 7213; emails: minsoo13@dankook.ac.kr (M. Maeng), jpark@dankook.ac.kr (J. Park), dockko@dankook.ac.kr (S. Dockko)*

[b]*Department of Civil and Environmental Engineering, Dankook University, Cheonan-si, Choongnam-do 330-714, Korea, Tel. +82 41 550 3526; Fax: +82 41 550 3520; email: haegyun@dankook.ac.kr*

[c]*Department of Civil and Environmental Engineering, University of Massachusetts at Amherst, 18 Marston Hall, Amherst, MA 01003, USA, Tel. +1 413 545 5397; Fax: +1 413 545 2202; email: tobiason@ecs.umass.edu*

Received 6 August 2014; Accepted 30 May 2015

ABSTRACT

Access to safe drinking water is still unavailable to many people in developing countries. Biosand filter (BSF) is one of the most promising emerging point of use technologies. A large amount of organic matters is contained in their water source. The purpose of this study is to develop a hybrid BSF system, called as a trickling biosand filter (TBSF), which is combined with rock media as trickling filter to reduce organic matters ranged from CODcr 50 to 150 mg/L in source water. The effects of TBSF and BSF on the factors as CODcr, flux, turbidity, and DO are analyzed. Results showed that the effluent CODcr of TBSF was obtained 2.3–4.2 mg/L during 41 d. However, that of BSF fluctuated within 13.1–28.6 mg/L. DO in standing water of TBSF increased to average 7.8 mg/L while that of BSF decreased to average 1.2 mg/L. DO played an important role to activate microbial activity in trickling filter and to ripen Schmutzdecke layer to decrease constantly turbidity and *Escherichia coli* (*E. coli*) in TBSF, though shock loading of organic matters occurred. The turbidity could be removed well if it was originated from organic matters. Removal of *E. coli* in BSF was fluctuated because of low DO. This could not provide perfect microbial layer on top sand and allow *E. coli* passing through sand filter, though enough time for ripening.

Keywords: Schmutzdecke; Biosand filter; Drinking water treatment; Point of use; Tricking filter

1. Introduction

Access to safe drinking water is still unavailable to many people in the world, most of who live in rural, dispersed, and often remote communities in developing countries [1]. The World Health Organization recommends point of use (POU) household water treatment as an intervention to address the need, drawing on appropriate low-cost technologies [2,3]. POU water treatments, which allow the purification of

*Corresponding author.

Presented at the 7th International Conference on Challenges in Environmental Science and Engineering (CESE 2014) 12–16 October 2014, Johor Bahru, Malaysia

water at the point of consumption rather than at a centralized location, allow water quality to be improved at the household scale. Already widespread in their usage, 19 million people are estimated to use POU water treatment in 2007 [4].

One of the most promising emerging POU technologies is the biosand filter (BSF), a household scale, which was developed at the University of Calgary by Manz [5]. It is low cost and safe technology that was downscaled from the traditional slow sand filtration. BSF makes it affordable (US $20–$30/unit), accessible, and durable [6,7]. Compared to other chemical disinfection and ceramic jar filter, it is easy for operation and maintenance. As many as 500,000 people worldwide rely on the BSF for safe drinking water and there are several reports that have addressed field implementation, user satisfaction, and percentage removal of *Escherichia coli* (*E. coli*) in the field [8,9]. Micro-organism activity of biofilm growing on top sand is effective to degrade organic matters of source water [10]. BSF could reduce heavy metal ions as well as turbidity [6,8,11–13]. Variations and less than ideal performance in field testing have been reported for BSFs, ranging from negative up to 100% bacterial removal [6–8,11,13,14]. Many researches were performed in the field to reduce waterborne disease using BSF [15]. To get high quality of treated water, low velocity of flow and low concentration of organic matter in source water should be maintained [16]. However, rivers, lakes, and ponds in the cities of developing counties are polluted with highly concentrated organic matter [17,18]. In rainy season, high concentration of organic matter inflows to reservoir called as a water-pan in Africa as well as Asia. The quality of source water was changed from 50 to 150 mg/L of CODcr, depending on season [19]. This deteriorates water quality of effluent and malfunctions BSF with plugging on the top sand. It is important that BSF should be operated without special control or complex maintenance to obtain safe water by household.

The purpose of this study is to develop a hybrid BSF system, called as a trickling biosand filter (TBSF), which is combined with trickling filter to reduce the concentration of organic matters ranged from CODcr 50 to 150 mg/L in source water. We investigate the effects of TBSF and BSF in terms of operating factors as CODcr, flux, turbidity, UV_{254}, *E. coli*, and DO at high concentration of organic matters.

2. Materials and methods

2.1. Design of TBSF and BSF

A diagram of the experimental TBSF and BSF is shown in Fig. 1. The container was constructed by acrylic plate, and the capacity of two systems was 15 L/d for household base. Each filter consisted of 5-cm rock layer at the base, followed by 5-cm gravel, and 30 cm of a single layer of sands. Diameter of sand is in the range of 0.75–1.00 mm. 20 cm of water were maintained above the sand at all times, ensuring saturated conditions. It needs two diffuse plates not to disturb the surface of top layer when pouring.

Apart from BSF reactor, TBSF consisted of a trickling filter box placed on top of BSF to remove organics including in source water as Fig. 1. Dimension of the trickling filter box was 0.2 m (width) × 0.2 m (length) × 0.065 m (depth), in which rock media were filled. The box was located at 3 cm above the surface of water. Source water circulated by a submerged pump, 12 W, to trickle from standing water to the top of the box. The water passed through the biofilm flowing down on the surface of rocks, average dia. 25 mm, in the box.

2.2. Synthetic source water

The influent water quality was designed to roughly simulate a typical surface water source used in reservoir called water-pan of Africa. Concentration of organic matters increases because the biomass of plant and the feces of animals inflows to reservoir in rainy season. Source water was synthesized with distilled water, lake water, and low-fat milk to change CODcr into 50, 100, and 150 mg/L in the lab as shown in Table 1 [20]. Natural pond water was collected from the lake nearby named Anseo Lake from April to June.

Turbidity of synthetic water was mainly produced by low-fat milk which is biodegradable by micro-organisms. *E. coli* was cultured and spiked to the synthetic source water to keep control of 200–300 CFU/mL. Every 15 L of synthetic water per day was constantly supplied to TBSF and BSF by masterflex pumps. Amount of standing water in TBSF, 8 L, is circulated by submerged pump. Concentration of CODcr in influent was controlled by five stages such as 50, 100, 50, 150, and 50 mg/L for 41 d. CODcr, turbidity, UV_{254}, pH, DO, and *E. coli* at each stage were monitored.

2.3. Operation of reactor

The reactor was operated for 41 d with changing influent concentration as step feed ranged 50–150 mg/L CODcr for the test of shock loading. The standing water in TBSF was circulated many times to contact gravel media in the box, then it percolated slowly

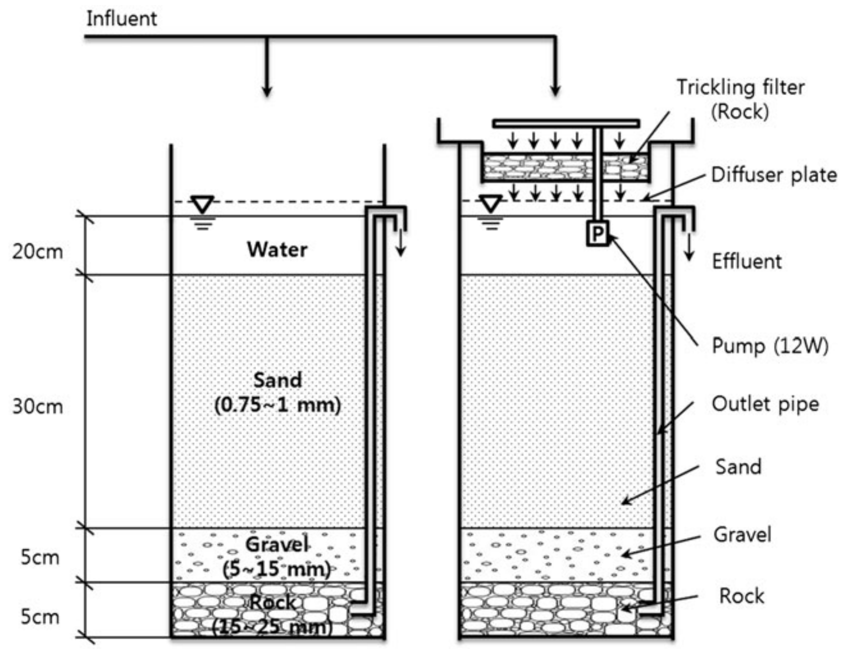

Fig. 1. BSF (left) and TBSF (right).

Table 1
Water quality of synthetic source water at five stages

Stage	Period (d)	CODcr (mg/L)	Turbidity (NTU)	UV_{254} (cm^{-1})	pH	DO (mg/L)	*E. coli* (CFU/mL)
1st	1–12	49 ± 2	10 ± 1.5	0.10 ± 0.016	7.36 ± 0.2	7.04–7.89	200–300
2nd	13–15	95 ± 4	18 ± 0.7	0.18 ± 0.005	7.24 ± 0.8		
3rd	16–31	50 ± 3	10 ± 1.9	0.10 ± 0.015	7.35 ± 0.18		
4th	32–34	150 ± 3	28 ± 0.7	0.29 ± 0.01	7.19 ± 0.7		
5th	35–41	49 ± 2	10 ± 1.3	0.10 ± 0.008	7.37 ± 0.29		

through the porous sand medium. The level of standing water of two systems provided a head of water that was sufficient to drive the water through the filter bed, while retention time was 20 h at each filter. The experiments were performed at 20 ± 2℃ and pH 7 ± 0.3. To remove bacteria, BSF has thin layer of biofilm on the top sand with ripening. It takes two weeks for biofilm to grow on the sand to uptake pathogens and bacteria in source water. It is called as Schmutzdecke layer known to form 1 mm on the surface of the sand bed after 27 d [21]. In this experiment, monitoring started on 6 d since source water was fed. After operation in high concentration of influent, the surface of a BSF becomes clogged due to the deposition of suspended solids. The BSF was cleaned by removing the top 2–3 cm of the sand bed including the Schmutzdecke layer after withdrawal of standing water. New sand was covered on the top sand instead. High concentration of influent was injected to the two systems for three continuous days as 100 and 150 mg/L of CODcr, respectively. Operating condition and water quality of source water are shown in Table 1.

2.4. Sampling and analysis

After one-week start-up for ripening of biofilm on the surface of media, experimental measurements were conducted every day at different CODcr influents. Influent and effluent samples were collected in 50-ml tube bottles for analysis of CODcr, turbidity, UV_{254}, DO, *E. coil*, flux, pH, and temperature. The UV_{254} and CODcr were measured with a UV spectrophotometer (DR5000^{TM}, Hach Co. USA). Turbidity was measured with a turbidimeter (2100N, Hach Co., USA). *E. coli* was analyzed by 3M$^{™}$ Petrifilm.

3. Result and discussion

3.1. Overall performance

CODcr, turbidity, flux, UV_{254}, and DO of effluent were analyzed at each stage as shown in Table 2. All factors of TBSF were constant and stable; however, those of BSF were unstable and fluctuated at shock loading of organic matters. Researchers reported BSF has a reliable efficiency if the water quality of inflow is limited to surface water [11,13,14,22]. When shock loading occurred, it affected DO and UV_{254} directly according to the result.

3.2. Organic matters

The results of organic matter reduction by two filters are presented in Fig. 2. The ordinate scale is expressed in days based on load of organic matter. The CODcr of influent was average 49 mg/L at first stage of TBSF. It was reduced to 1.4 mg/L though it was fluctuated 3.0–9.4 mg/L during a couple of days at the beginning operation. At the same period, the effluent of BSF was changed to 11.2–19.0 mg/L. In case of operation in slow sand filter, turbidity and BOD_5 of influent are recommended as less than 10 NTU and 2–3 mg/L, respectively. The concentration of organic matter of influent used in this experiment was about 10–30 times high for shock loading test. At second stage, in which CODcr was increased to 100 mg/L for 3 d, the effluent from TBSF went up 3.5 mg/L while that from BSF increased to 28.6 mg/L. When the influent was supplied as 50 mg/L after 3-d shock loading, CODcr of TBSF was also reduced to 2.3 mg/L. However, that of BSF was still 17.8 mg/L within 2 d.

On 25th day's monitoring since starting up, flux was dropped from 15.0 to 4.5 LMH in BSF. At this moment, we replaced 2–3 cm of BSF top sand for cleaning with new sand. Then, the flux was recovered to 15.0 LMH and CODcr of effluent reduced to 2.48 mg/L. At fourth stage of CODcr 150 mg/L for 3 d, the concentration of TBSF changed from 2.0 to 4.03 mg/L, while that of BSF increased from 8.48 to 21.6 mg/L. Effluent of TBSF reduced from 5.9 to 2.1 mg/L during 3 d after influent concentration returned to 49 mg/L. However, BSF took seven more days to become 18.9 mg/L. Fig. 3 shows the effects of CODcr and DO in two filters. CODcr of standing water in TBSF showed 80% removal; that in BSF was 46%. This is because rock media played key role to decompose organic matters in standing water. Dissolved oxygen of standing water in TBSF increased from average 7.5 mg/L of source water to average 7.8 mg/L, while that in BSF decreased average 1.2 mg/L. Especially, DO in BSF dropped to 0.38 mg/L at the injection of 100 mg/L of CODcr; 0.27 mg/L at the injection of 150 mg/L of CODcr. It is known that different biochemical reactions including oxidation of organic matter occur in BSFs [23].

3.3. Turbidity removal

Turbidity of influent was about 10 NTU at first stage, and then the effluent of TBSF was settled down as 0.2–0.4 NTU since 2 weeks of operation. However, turbidity of BSF was monitored from 1.9 to 4.4 NTU at same period as Fig. 4. It was a bit high turbidity of effluent in other results [24] because it was not ripened enough at first stage. At second stage, 18 NTU of influent was supplied to two filters for 3 d. Turbidity of effluent in TBSF was not changed at all for increased influent. However, that in BSF increased from 3.2 to 5.6 NTU.

Although the influent was reduced to 10 NTU after 3 d, the effluent of BSF was fluctuated from 3.9 to 13.4 NTU during third stage. Flux was decreased as

Table 2
Result of average water quality of effluent on five stages

Analyses	Stage Filter	1st	2nd	3rd	4th	5th
CODcr (mg/L)	TBSF	4.2	3.5	2.3	4.0	3.1
	BSF	13.1	28.6	17.8	21.6	23.6
Turbidity (NTU)	TBSF	1.1	0.4	0.3	0.6	0.4
	BSF	2.7	3.4	4.7	6.5	4.1
Flux (LMH)	TBSF	14.9	15.0	14.8	14.7	14.7
	BSF	13.7	10.9	9.4	10.5	2.8
UV_{254} (cm^{-1})	TBSF	0.021	0.013	0.014	0.017	0.014
	BSF	0.067	0.181	0.222	0.217	0.156
DO (mg/L)	TBSF	7.90	7.29	7.91	7.39	7.65
	BSF	1.64	0.37	1.43	0.6	0.79

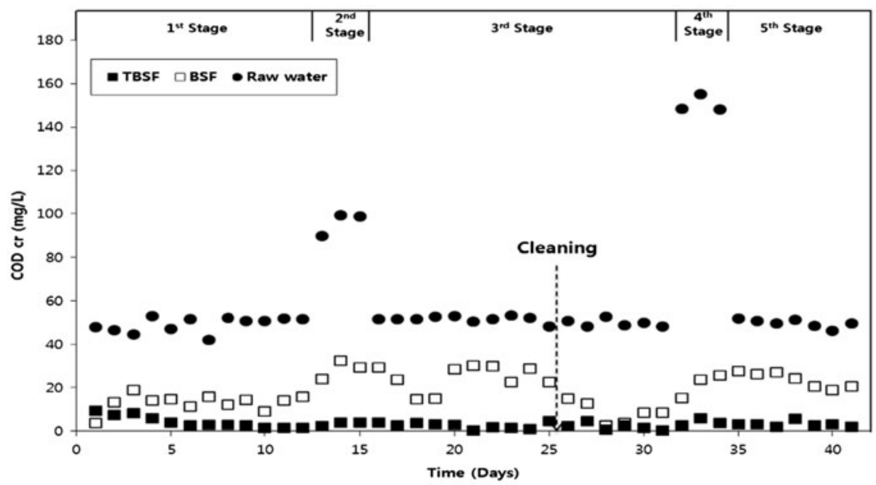

Fig. 2. Result of CODcr in TBSF/BSF operation.

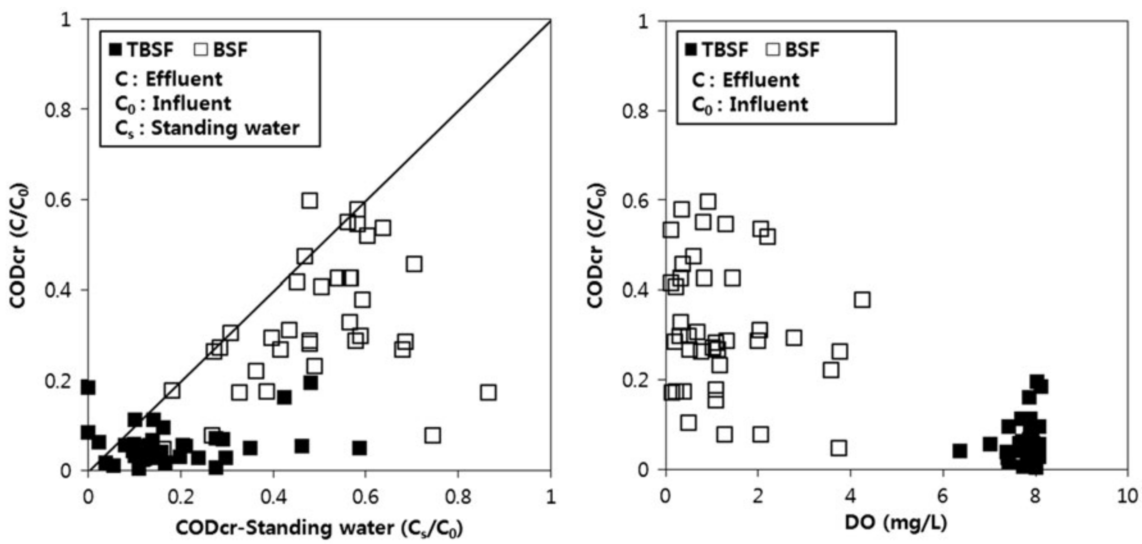

Fig. 3. CODcr and DO effects in standing water quality.

25% compared to initial stage, then removal of plugged sand by cleaning was performed. By this cleaning, the flux was recovered to initial condition. Effluent of turbidity was recovered from average 5.3 NTU to average 2.9 NTU in BSF. TBSF has same turbidity without fluctuation. As shown in Fig. 5, CODcr has a correlation with turbidity removal because this turbidity was mainly originated from low-fat milk, organic matters. This was why high DO condition increased high removal of turbidity unlike other water sources that could not be easily decomposed for inorganic clay inside. Normally, colloidal particles as low-fat milk could not pass in pore of sands and blocked inside top sand layer. This could make anaerobic condition in the case of insufficient oxygen in standing water. This explained the result that DO recovered in Fig. 7(b) after cleaning reduced turbidity efficiently at the same period as shown in Fig. 4.

3.4. Flux

The fluxes of TBSF and BSF are shown in Fig. 6. Initial fluxes of those filters started from 15 LMH at first stage. Flux of TBSF was decreased to 2% after 4 weeks of operation. And it was not changed at all to the last although CODcr increased to 100 and 150 mg/L in source water. However, flux of BSF decreased

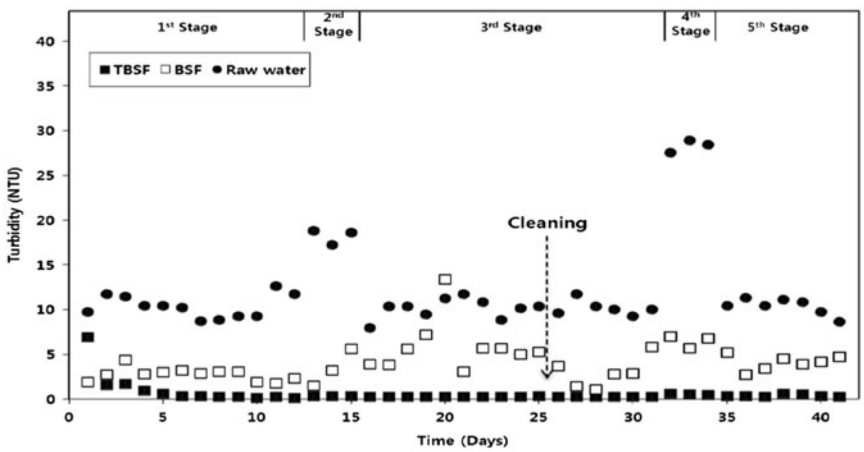

Fig. 4. Result of turbidity in TBSF/BSF operation.

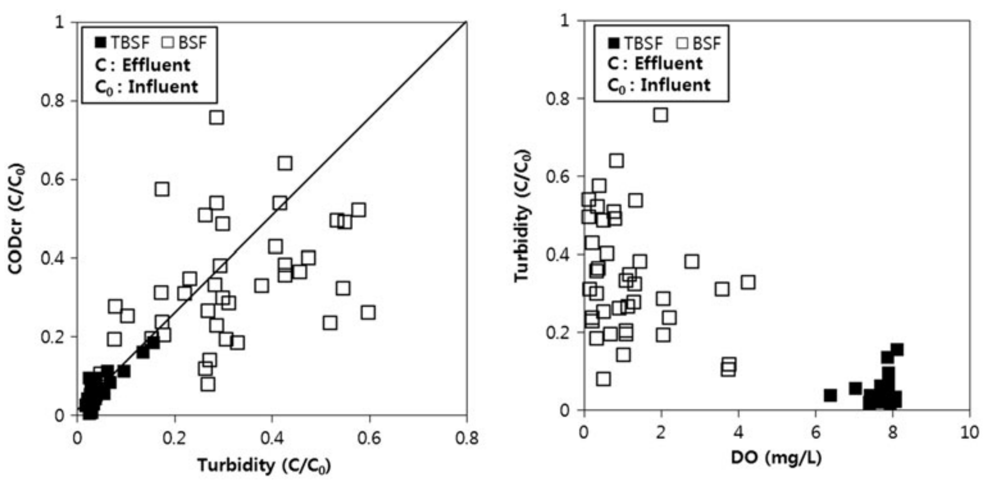

Fig. 5. Turbidity, CODcr vs. DO in standing water.

18% at first stage before CODcr was injected. After CODcr increased, flux decreased from 12.3 to 4.5 LMH as half of initial flux in Fig. 6.

Cleaning on top sand was performed because the flux was too small. Flux was recovered as initial flux as 15 LMH after removal of clogged sand.

It decreased to 4.5 LMH again after CODcr 150 mg/L injected. Finally, it reached to 1.5 LMH after 41 d operation. Total volumes of effluent during operation were 583 L in TBSF and 385 L in BSF, respectively. Shock loading of organic matters was vulnerable to BSF operation.

3.5. DO and UV_{254}

The average UV_{254} of synthetic source water was 0.120 cm^{-1} as shown in Fig. 6. The standing water and effluent of TBSF were average 0.045 and 0.016 cm^{-1}, respectively. Dissolved organic matters were reduced 62.5% in standing water and 37.5% in TBSF filtering process. It is because DO in TBSF was high enough to activate microbial activity in trickling filter as Fig. 6(b).

In BSF, however, the standing water and effluent of BSF were 0.123 and 0.167 cm^{-1}, respectively. Those results were higher than synthetic source water. At first stage, the effluent of UV_{254} was normal as TBSF. However, it increased abruptly than synthetic source water after CODcr 100 mg/L at second stage. Flux decreased and turbidity increased at this moment. DO abruptly decreased from 1.09 to 0.31 mg/L as well. The standing of dissolved organic matters accumulated increased. The concentration of dissolved organic matters in effluent has increased more than that of

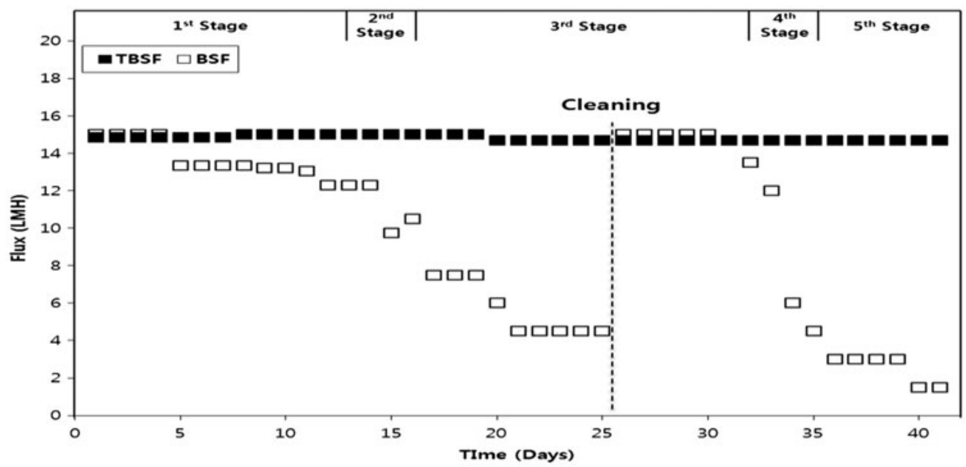

Fig. 6. Flux decline with operation.

Table 3
Log removal of coliform

	Log removal of coliform			
	2nd	3rd	4th	5th
TBSF	1.99–2.00	1.98–2.00	1.99–2.00	1.98–1.99
BSF	0.0	0.0–1.96	1.74–1.85	1.79–1.87

standing water because the plugged organic foulants on sand surface deteriorated the effluent water quality. This could be referred from that the UV_{254} of effluent in BSF was recovered to 0.012 cm^{-1} after removing the plugged organic foulants on sand surface when cleaning. DO also increased from 0.77 to 3.74 mg/L for cleaning even though it decreased below 0.22 mg/L at shock loading of CODcr 150 mg/L.

3.6. E. coli *removal*

Removal of *E. coli* in BSF has shown its great efficiency after ripening Schmutzdecke layer in sand surface [5]. It is reported that 63–99% of *E. coli* was normally removed by BSF, but average 94–96% was removed [8]. In this experiment, 241 CFU/mL of the average *E. coli* was spiked to the influent. After 2 weeks of ripening on sand surface, reductions of *E. coli* were attained to 98.9% in TBSF and 60% in BSF, respectively. Though the researchers have reported

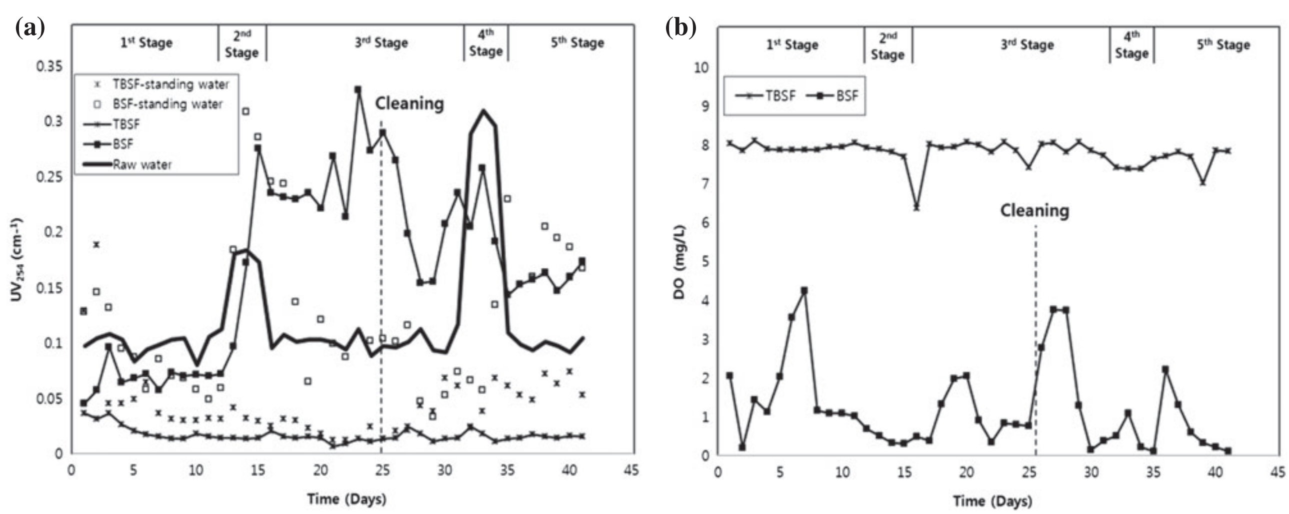

Fig. 7. UV_{254} and DO changes for operation. (a) UV_{254} to standing water and effluent and (b) DO changes for operation.

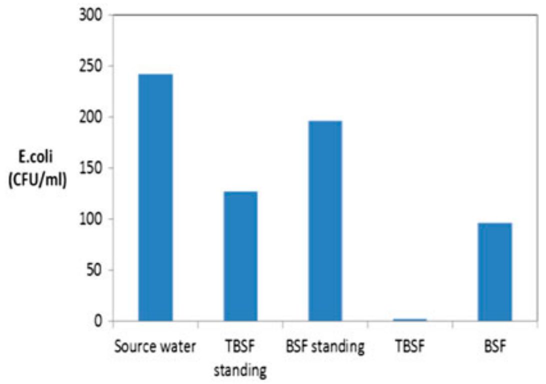

Fig. 8. Removal of *E. coli*.

that the buildup of organic matter and development of the biological layers known as ripening results in a more effective BSF [8,22], BSF showed low *E. coli* removal in Table 3. As shown in Figs. 7 and 8, E. *coli* in TBSF decreased well by microbial activity for high DO concentration.

However, DO in BSF was low DO and high organic matters in influent. This condition decreased microbial activity in standing water and in surface sand which could reduce *E. coli* in BSF. Namely, high concentration of organic matters in influent hindered supplying oxygen to micro-organism for ripening of Schmutzdecke layer, though time for ripening was enough.

4. Conclusions

This study was to develop a hybrid BSF system, called as a TBSF, which is combined with rock media as trickling filter to reduce highly concentrated organic matters. As mentioned before, high concentration of organic matters inflows to source water such as reservoir and lakes in the rainy season. When the CODcr of influent was changed from 50 to 150 mg/L, the effluent of TBSF was obtained 2.3–4.2 mg/L during 41 d. However, that of BSF fluctuated 13.1–28.6 mg/L. TBSF was efficient way rather than BSF. Dissolved oxygen of standing water in TBSF increased to average 7.8 mg/L while that in BSF decreased to average 1.2 mg/L. This increased microbial activity in Schmutzdecke layer on sand surface to decrease constantly turbidity and *E. coli* in effluent, though shock loading of organic matters were introduced. Even though standing water of TBSF was long depth, oxygen of standing water was retained as average 7.9 mg/L. Turbidity of influent was completely reduced from 10 NTU to 0.2–0.4 NTU in TBSF while 1.9–4.4 NTU in BSF. This turbidity was mainly originated from low-fat milk, organic matters, in this experiment. This was why high DO condition increased high removal of turbidity. Through measuring DO in standing water, we could expect efficiency of turbidity removal in the case of turbidity originated from dissolved organic matter. Removal of *E. coli* in BSF has a correlation with ripening of Schmutzdecke layer on sand surface. Enough DO concentration should be provided for ripening. If not, however, standing water and surface sand layer in BSF were changed to low DO and high organic matters. This could not provide perfect microbial layer on top sand and allow *E. coli* passing through sand filter, though enough time for ripening.

Acknowledgments

This research was supported through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (013-2011-1-D00071) and partially funded by Korea Ministry of Environment (MOE) as “Advanced Technology Program for Environmental Industry” (E314-00015-0412-1).

References

[1] WHO/UNICEF. Progress on Sanitation and Drinking Water: 2010 Update. WHO/UNICEF Supply and Sanitation, World Health Organization, Geneva, Joint Monitoring Programme for Water, 2010.
[2] M.D. Sobsey, Managing Water in the Home: Accelerated Health Gains from Improved Water Supply, World Health Organization, Geneva, 2002.
[3] WHO, Combating Waterborne Disease at the Household Level, World Health Organization, Geneva, 2007.
[4] T. Clasen, W.P. Schmidt, T. Rabie, I. Roberts, S. Caimcross, Interventions to improve water quality for preventing diarrhea: systematic review and meta-analysis, Br. Med J. 334 (2007) 7597–7782.
[5] G. Palmateer, D. Manz, A. Jurkovic, R. McInnis, S. Unger, K.K. Kwan, B.J. Dutka, Toxicant and parasite challenge of Manz intermittent slow sand filter, Environ. Toxicol. 14 (1999) 217–225.
[6] W.F. Duke, R.N. Nordin, D. Baker, A. Mazumder, The use and performance of BIOSAND filters in the Artibonite Valley of Haiti: A field study of 107 households, Rural Remote Health 6 (2006) 1–19.
[7] E. Fewster, A. Mol, C. Wiesent-Brandsma, The long term sustainability of household biosand filtration, in: People Centered Approaches to Water and Environmental Sanitation: 30th WEDC International Conference, Vientiane, 2004, pp. 558–561.
[8] C.E. Stauber, M.A. Elliott, F. Koksal, G.M. Ortiz, F.A. DiGiano, M.D. Sobsey, Characterisation of the biosand filter for *E. coli* reductions from household drinking

water under controlled laboratory and field use conditions, Water Sci. Technol. 54(3) (2006) 1–17.
[9] M.M. Ahammed, K. Davra, Performance evaluation of biosand filter modified with iron oxide-coated sand for household treatment of drinking water, Desalination 276 (2011) 287–293.
[10] K.B. Fox, R.J. Miltner, G.S. Logsdon, D.L. Dicks, J.J. Drolet, Pilot-plant studies of slow-rate filtration, J. Am. Water Works Assn. 76(12) (1984) 62–68.
[11] P. Earwaker, Evaluation of Household Biosand Filters in Ethiopia [Dissertation], Univ. of Cranfield, Bedfordshire, 2006.
[12] M.W. Jenkins, S. Tiwari, J. Darby, N. Nyakash, W. Saenyi, K. Langenbach, The bioSand filter for improved drinking water quality in high risk communities in the njoro watershed, Kenya, Research brief 0906SUMAWA, Global Livestock Collaborative Research Support Program, 2009.
[13] C. WiesentBrandsma, E. Fewster, A. Mol, Medair Kenya Biosand Filter Project Evaluation Interpretation of Results, Medair, Ecublen, 2004.
[14] N. Kaiser, K. Liang, M. Maertens, R. Snider,, Biosand household water filter evaluation 2001: A comprehensive evaluation of the Samaritan's purse biosand filter (BSF) Projects in Kenya, Mozambique, Cambodia, Vietnam, Honduras, and Nicaragua, Samaritan's purse Canada, Calgary, 2002, p. 1213.
[15] A.M. Fabiszewski de Aceituno, C.E. Stauber, A.R. Walters, R.E. Meza Sanchez, M.D. Sobsey, A randomized controlled trial of the plastic-housing biosand filter and its IMPACT on diarrheal disease in Copan, Honduras, Am. J. Trop Med. Hyg. 86(6) (2012) 913–921.
[16] S.L. Gary, Slow Sand Filtration, ASCE, New York, NY, 1991.
[17] F. John, J.N. Mark, Contaminants in drinking water environmental pollution and health, Br. Med. Bull. 68 (2003) 199–208.
[18] J. Haarhoff, B.B. Mamba, R.W. Krause, I.B. Matsebula, Monitoring natural organic matter and disinfection byproduction at different stages in two South African water treatment plants, Water SA 35(1) (2009) 121–127.
[19] B.B. Mambai, R.W. Krausei, B. Matsebulai, J. Haarhoff, Monitoring natural organic matter and disinfection byproducts at different stages in two South African water treatment plants, Water SA 35(1) (2009) 122–128.
[20] A.A.M. Langenhoff, N. Intrachandra, D.C. Stuckey, Treatment of dilute soluble and colloidal wastewater using an anaerobic baffled reactor: Influence of hydraulic retention time, Wat. Res. 34(4) (2000) 1307–1317.
[21] L.C. Campos, M.F.J. Su, N.J.D. Graham, S.R. Smith, Biomass development in slow sand filters, Water Res. 36 (2002) 4543–4551.
[22] M.A. Elliott, C.E. Stauber, F. Koksal, F.A. DiGiano, M.D. Sobsey, Reductions of *E. coli*, echovirus type 12 and bacteriophages in an intermittently operated household scale slow sand filter, Water Res. 42(10–11) (2008) 2662–2670.
[23] H.M. Murphy, E.A. McBean, K. Farahbakhsh, Nitrification, denitrification and ammonification in point of use biosand filters in rural Cambodia, J. Water Health 8(4) (2010) 803–817.
[24] B.J. Buzunis, Intermittently Operated Slow Sand Filtration: A New Water Treatment Process [Dissertation], MSc Thesis, Univ. of Calgary, Canada, 1995, p. 544.