Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.780771

51 (2013) 6210–6217
September

Taylor & Francis
Taylor & Francis Group

Advanced water treatment using a meshed synthetic tube as biological filter media in pilot plant scale

Kwang Soo Kim[a,*], Juhaeng Lee[b], Jungo Park[a], Taehwan Jun[b], Muhammad Sajjad[b]

[a]*Department of Water Resources & Environment Research, Korea Institute of Construction Technology, 283 Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do 411-712, Korea*
Tel. +82 31 910 0279; email: kskim@kict.re.kr
[b]*Department of Construction Environment Engineering, University of Science and Technology, 176 Gajung-dong, 217 Gajungro, Yuseong-Gu, Daejeon 305-350, Korea*

Received 27 October 2012; Accepted 27 December 2012

ABSTRACT

The purpose of this study is to remove suspended solids (SS) and soluble organic matter from waste water using meshed synthetic tubes, made of synthetic poly propylene fiber to allow free water flow from any direction. The capacity of 450 m^3/d pilot plant was operated to treat effluent of secondary settling tank in sewage treatment plant. Removals of SS, soluble organic matter and phosphorus (w/additional chemical treatment), were monitored. As a result, maximum SS-loading rate for the plant was found 3.8 kg SS/m^3 d, and operation time was limited up to 45 h, and the maximum linear velocity was found 16 m^3/m^2 h. The maximum SS removal for each unit reactor was 7.1 kg/cage m^3. With the meshed tube biofilter, not only SS but also soluble organic matter removal and nitrification were observed. Because of its relatively fast filtration rate and high filtration capacity, it seemed to be used properly as a direct filtration.

Keywords: Meshed synthetic tubes; Meshed tube biofilter; Maximum SS-loading rate; Maximum linear velocity

1. Introduction

Contaminants in domestic wastewater include soluble organic matters, suspended solids (SS), and nutrients such as nitrogen and phosphorus, and they are removed mostly through advanced wastewater treatment systems composed of series of anaerobic, anoxic, and aerobic reaction tanks [1,2]. In order to treat to better effluent quality, usually biofiltration system is added after secondary settlement, in addition, for soluble phosphorus removal, physical filtration system can be also used with additional chemical treatment.

Conventional filtration systems have used mainly sand filter, biofilter with plastic or ceramic media, and lately membrane filtration of synthetic material.

Sand filtration should include complex water-collecting system in lower part, its operation system is also complicated, and in addition, it requires large area to built. In plastic and ceramic media case, if used in a fixed bed, most SS and BOD removal is

*Corresponding author.

Presented at The Fifth Desalination Workshop (IDW 2012), October 28–31, 2012, Jeju, Korea

carried out physically through the pores between medium and the media blockage may appear as a result of slime by microbiological activities [3–5]. Lately used microfiltration treats SS but hardly removes soluble organic matters [6]. In addition, conventional filtration systems naturally limit the fluid flow to one direction by the physical shapes of media; however, the meshed tubes show limitless flows by the high pore size so as to provide completely mixed conditions. This is advantageous in the operation of the plants, as the blockage around entry point by contaminants can be lowered.

This study aims to control both the SS and soluble organic matters by meshed synthetic tubes as biological media that provide high interfacial area and free water flows from any direction. It is expected that with the meshed tube media, the treatment efficiency can be enhanced as the tubes perform as sieve and the biofilm on the media helps removing soluble organics.

2. Experimental methods

2.1. Characteristics of meshed synthetic tube biomedia

Fig. 1 shows meshed media woven cylindrically by poly propylene fiber and cut to sizes. Diameter of the tubes is controlled by the thickness and the number of fiber. Various sizes of the meshed tube from 3 to 20 mm were made. Table 1 lists physical characteristics of meshed tubes cut into 2–3 cm on each diameter. With increasing diameter, mesh sizes also increased, and the numbers of packed tubes for unit volume decreased [7]. With the empty meshed cylindrical shapes, porosity for all the sizes are high enough to 85%, and this allows characteristic free water flows from any direction with this filter system.

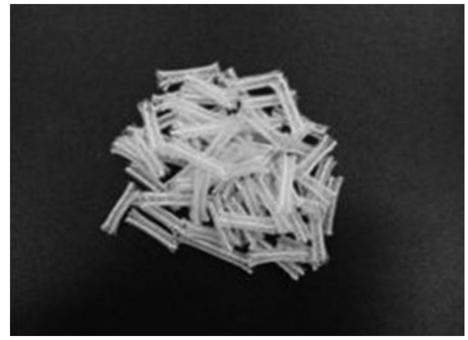

Fig. 1. Meshed synthetic fiber tubes.

2.2. Pilot plant

Fig. 2 illustrates the pilot plant used in this experiment (located in Ilsan domestic wastewater treatment plant, Goyang, Geoynggi, Korea). The plant was designed to control SS by filtration and soluble phosphorus with additional chemical treatment. Influent to the plant was pumped from the secondary settling tank through weir and stored in a storage tank for 2–4 h. Before the filtration, mixing tank of 2–3 min hydraulic retention time (HRT) was provided for chemical pretreatment for soluble phosphorus removal.

Table 1
Characteristics of meshed synthetic fiber tubes used in this experiment

Physical characteristics	∅3 mm	∅5 mm	∅10 mm	∅15 mm	∅20 mm
Length (cm)	2	2.5	3	3.3	3
Porosity (%)	85	90	92	96	97.6
Bulk density (g/cm^3)	0.08	0.06	0.05	0.04	0.03
Packed tubes/vol. (ea/L)	1,392	516	138	103	74
Net size (mm)	0.26 × 0.25	0.75 × 0.85	1.01 × 1.4	1.5 × 1.8	1.8 × 1.9

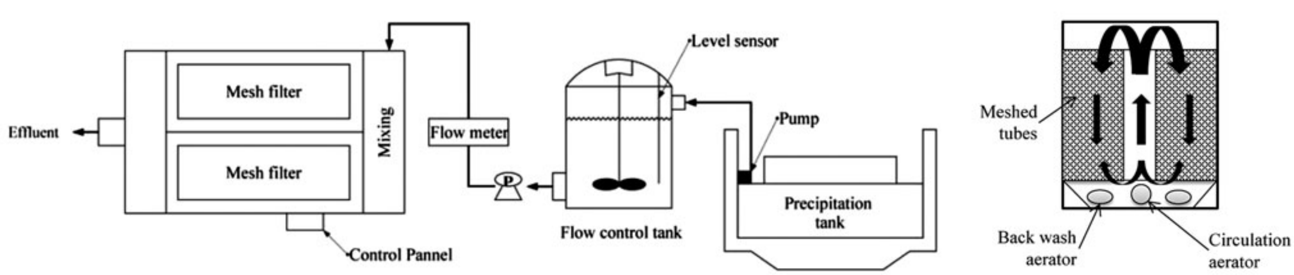

Fig. 2. Schematic diagram of pilot plant.

Fig. 3. Filter bed of pilot plant equipped with meshed tubes.

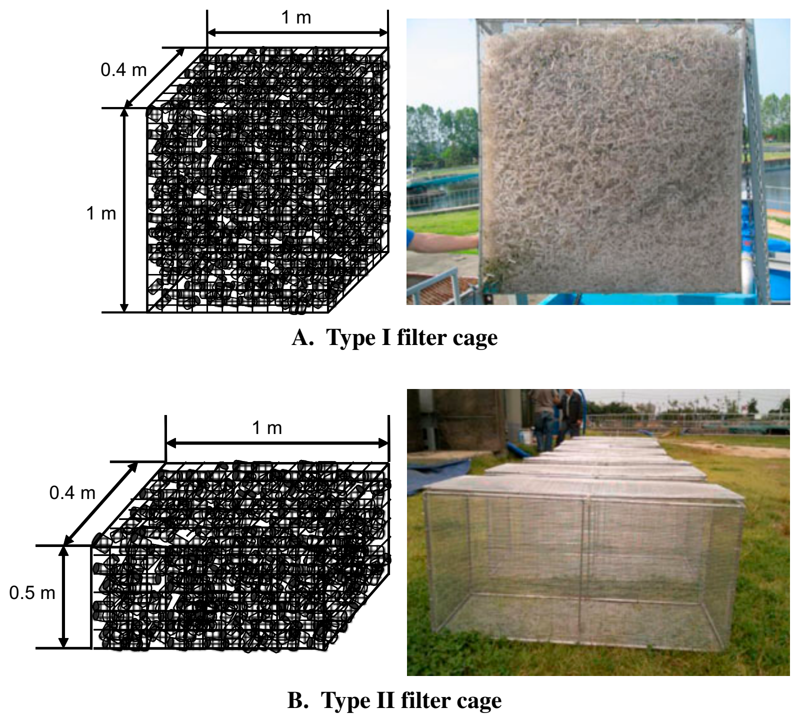

Fig. 4. Filter cage packed with meshed filter tubes.

A rectangular filtration tank was made in size H 1.3 m × W 1 m × L 4 m, with lined aerator in the bottom-center of the tank, cages for the meshed media were equipped in both sides of the reactor (Fig. 4). Air was only provided through the central bottom aerator, and therefore, it formed upward-dispersion-downward air/water movement resulting in turbulence in the meantime contaminants traversing the reactor.

There is 0.3 m space at the filtration tank bed, for backwashing of filtered SS after operation. A total of 16 bar-type aerators were equipped in the center to help moving SS to meshed filter tubes, and for backwashing, 16 circular-type aerators were constructed at the bottom of the reactor. Aeration rate for the main central aerator was 1.44 m^3/min, and for the back-washing aerator, it was 4.75 m^3/min. The SS in the effluent and back-washing water were collected through weir.

2.3. Pilot plant operation

Effluent from secondary settling tank of domestic wastewater treatment plant was used as inflow for whole experiment. Phase I was designed to examine SS removal efficiency, and Phase II for soluble phosphorus removal with additional chemical treatment. Variation in the tube size, HRT and linear velocity was applied to draw standard design factors.

At Phase I-I, meshed tubes of ∅5 mm, ∅10 mm were cut into 5 cm length, mixed to equal volume and put into the Type-I cages (H 1 m × W 0.4 m × L 1 m (vol. 0.4 m^3), Figs. 3 and 4(A)). In total, eight cages of

Table 2
Operation conditions for SS and soluble phosphorus removal of 2nd effluent

	Meshed tube size (mm)	Influent flow (m^3/d)	HRT (h)	Linear velocity (m^3/m^2 h)
Phase I		38.4	2	2
Cage type I	∅5 + ∅10	77	1	4
		154	0.5	8
		461	0.16	24
	∅5	154	0.5 (30 min)	8
		461	0.16 (10 min)	24
Cage type II	∅5	77	0.5 (30 min)	8
		128	0.3 (20 min)	13.5
		226	0.17 (10 min)	27
	∅3	128	0.3 (20 min)	13.5
		154	0.25 (15 min)	16
		226	0.17 (10 min)	27
Phase II			Rapid mixing: 3 min	4
Cage type I	∅5, ∅5 + ∅10	154	Filtration: 0.5 h	
			Rapid mixing: 3 min	8
		77	Filtration: 1 h	

meshed filter (four cages for each side) were equipped to the reactor and operated to treat wastewater. The influent flow rate of pilot plant was varied from 38 to 461 m^3/d. Concurrently, HRT and linear velocity in filter bed changed from 2 h to 10 min, and from 2 to 24 m/h, respectively. At Phase I-II, the efficiency of back-washing was improved by lowering the cage from 1 m (Phase I-I) to 0.5 m (Fig. 4(B)), and the performance was tested for two types of meshed media; ∅5 and ∅3 mm (see Table 2).

Phase II-I aimed to perform chemical soluble phosphorus removal at the same time with SS removal. Rapid mixing tank was attached for chemical treatment before the meshed tube filtration tank which at this time functioned as filters as well as slow mixing tank. Mixture of ∅5 mm + ∅10 mm tube and single ∅5 mm tube were used in this experiment.

3. Results and discussion

3.1. SS removal by Type-I cage

Fig. 5 shows time series of SS concentration in Type-I cage packed with ∅5 mm + ∅10 mm meshed tubes. At the condition of 2 h of HRT, zero SS in the treated water lasted until 677 h of operation. Under 1 h HRT condition, it appeared the effluent SS lasted zero during 201 h of operation, and under 30 and 10 min of HRTs, the SS levels in the treated water rapidly increased.

In order to shorten the HRTs, meshed tube sizes were changed to single ∅5 mm and the same experiment was carried out. Fig. 6 shows that under 30 min

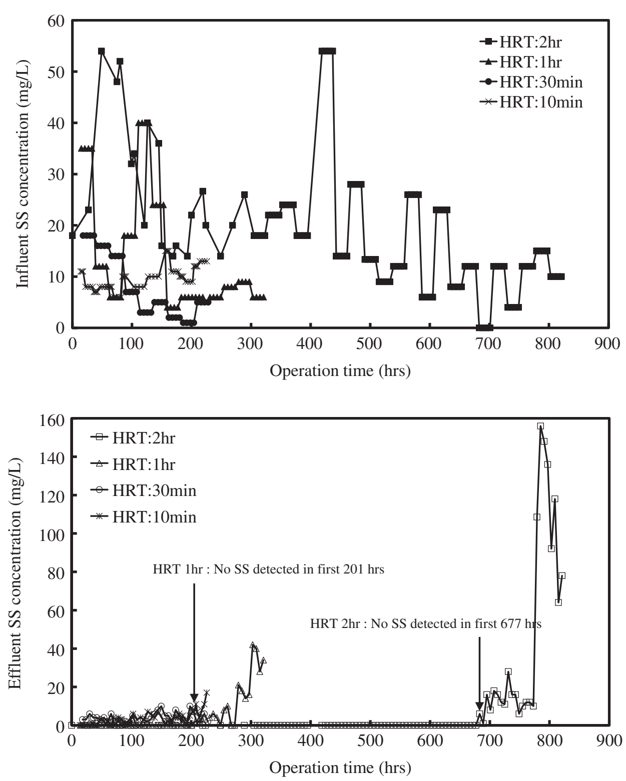

Fig. 5. SS concentrations of influent and effluent to the changes of filter bed HRT (Type-I cage packed with ∅5 mm + ∅10 mm tubes).

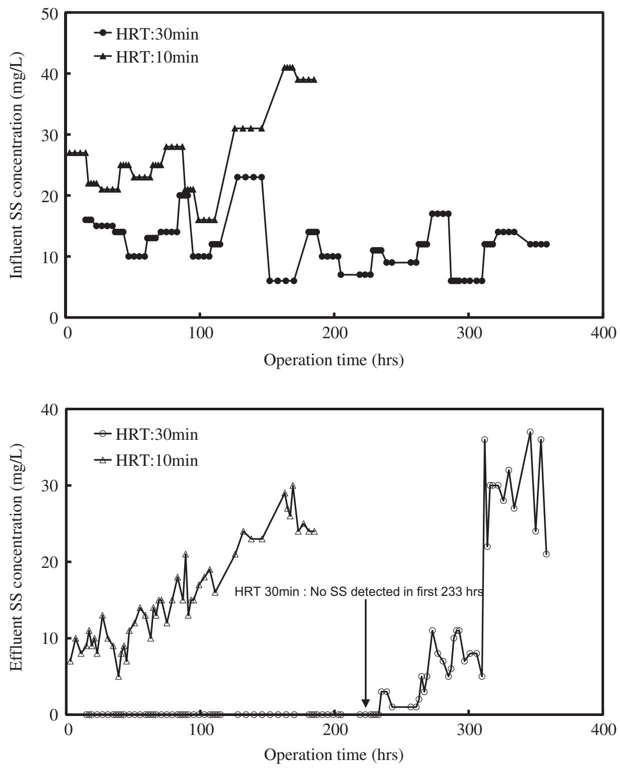

Fig. 6. SS concentrations of influent and effluent to the changes of filter bed HRT (Type-I cage packed with ∅5 mm tubes.

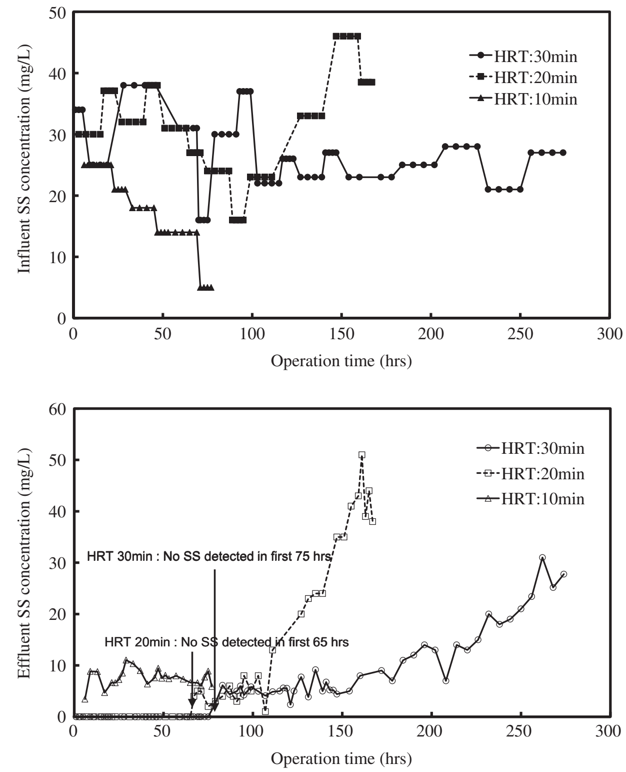

Fig. 7. SS concentrations of influent and effluent to the changes of filter bed HRT (Type-II cage packed with ∅5 mm tubes.

of HRT condition SS was perfectly treated until 233 h of operation, but with 10 min of HRT, it hardly removed SS from the beginning.

Therefore, with Type-I cage, the shortest available HRT was found 30 min, and proper tube size was ∅5 mm.

3.2. *SS removal by Type-II cage*

Fig. 7 shows the SS concentration changes in the water treated by Type-II cage, packed with ∅5 mm-size meshed tubes of half the amount packed in Type-I cage. Under conditions of 30 and 20 min HRTs operation, the effluent SS levels lasted zero until 75 and 65 h, respectively. At 10 min HRT condition, SS was not treated even from the beginning.

Fig. 8 seek for shorter available HRTs, so that smaller meshed tube size was applied. With ∅3 mm meshed tube media packed in Type-II cage, it was shown that 43 and 25 h of operation were possible for SS removal under the HRT conditions of 20 and 15 min. With 10 min HRT condition, SS was detected in the treated water from the beginning.

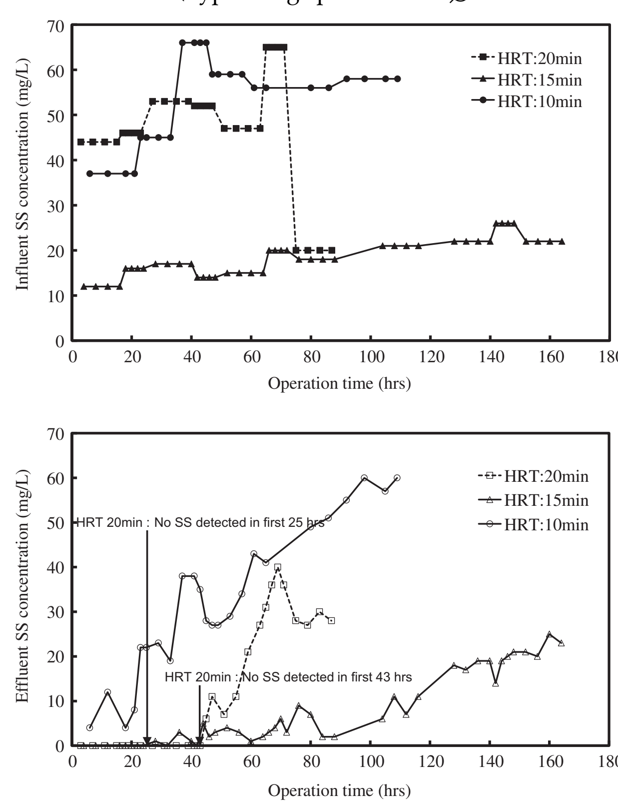

Fig. 8. SS concentrations of influent and effluent to the changes of filter bed HRT (Type-II cage packed with ∅3 mm tubes).

As a result, with ∅5 mm size meshed tube media, the shortest available operation time was 20 min, and it becomes 15 min with smaller ∅3 mm tubes.

3.3. Linear velocity, HRT- and SS-loading rate for zero SS in the treated water

Figs. 9 and 10 show the operational conditions for optimal SS removal in the water treated by meshed tube filtration system. The highest SS-loading rate for the SS conc. to be zero in treated water was found 3.8 kg SS/m^3 d and the highest treatable SS level was 7.1 kg/cage m^3. The shortest available HRT was around 15 min. Conventional water works applies linear velocities of 1–2 m^3/m^2 h for slow filtration and 5 m^3/m^2 h for rapid filtration [8]. However, the meshed tube filtration system showed as high as 16 m^3/m^2 h linear velocity, and this clearly proves high SS removal performance of the filtration system.

3.4. BOD and NH_3–N removal

Fig. 11 illustrates the changes of organic matters, nitrogen, and phosphorus concentrations. The mean influent BOD level was 25 mg/L and treated to 3 mg/L after filtration. Ammonia–nitrogen concentration was also introduced around 1.5–5 mg/L levels, and lowered down to 0.5–1.5 mg/L after filtration. As shown in Fig. 3, after long enough operation when the tube media required back-washing, biofilm on the media surface was observed in the entire tube media regardless of depth, and also the thin biofilm was distributed on the entire media surface even after back-washing. This explains that not only the SS removed within the sieve, but also the large portion of organic matters could be consumed by the biological oxidation through

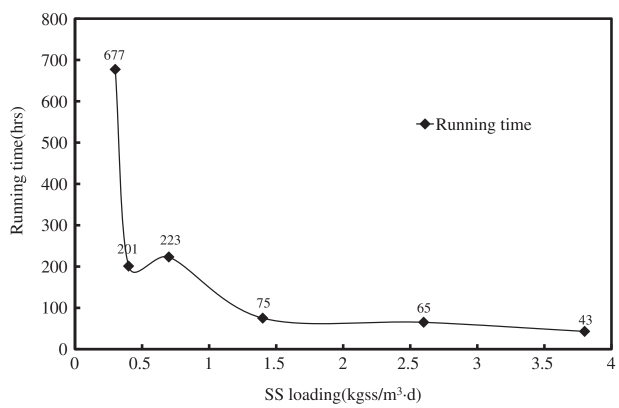

Fig. 9. Variations of running time to the changes of SS loading rate of filter bed for advanced SS treatment.

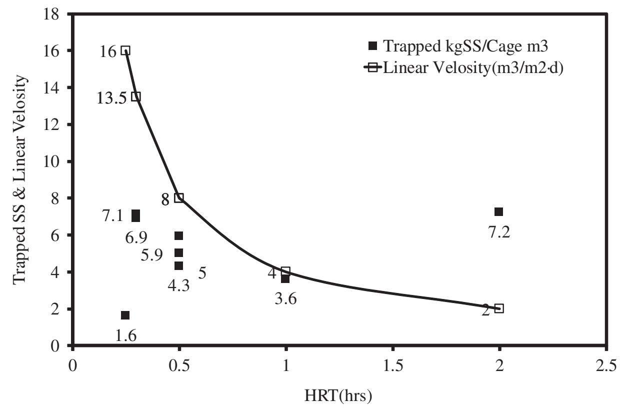

Fig. 10. Results of linear velocity and trapped mass of SS per tube cage volume to the changes of HRTs of filter bed.

the biofilm, and this was the same with NH_3-N. However, neither denitrification nor soluble phosphorus removal was detected. In spite of very short HRT conditions, BOD removal and NH_3-N oxidations were considered the attached microorganisms on the tube surface contributed biofilm for pollutant removal. On the other hand, the poor removal efficiencies of nitrogen removal as nitrogen gas and phosphorus arose

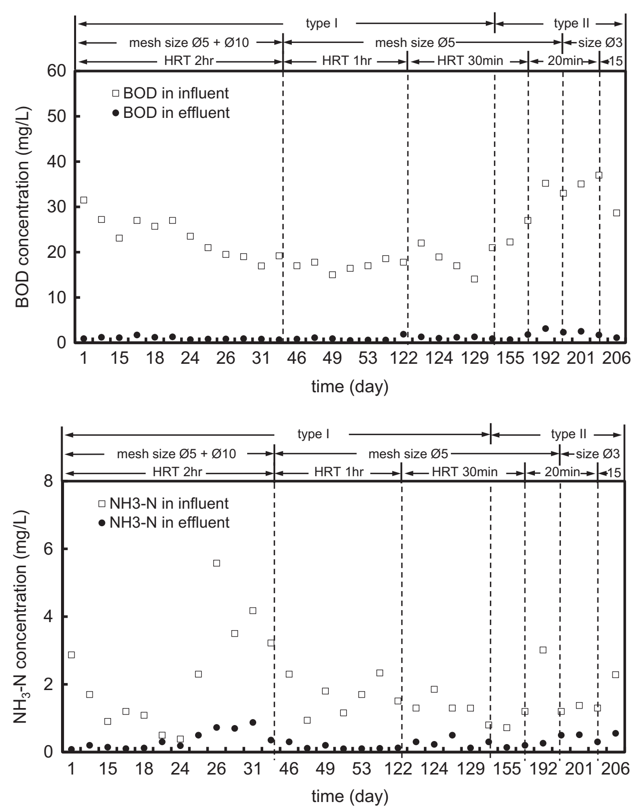

Fig. 11. BOD and NH_3–N concentrations of influent and effluent of filter bed.

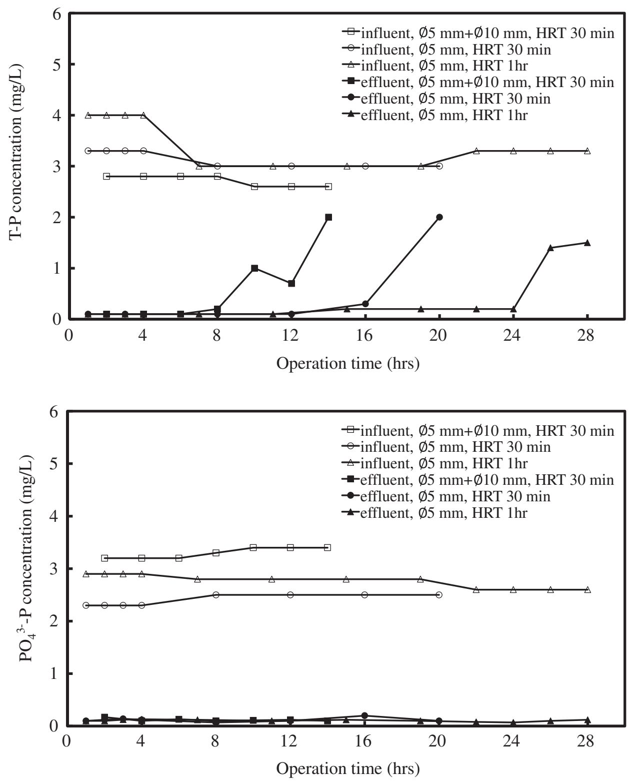

Fig. 12. T-P and S-P concentrations of influent and effluent of filter bed with chemical treatment.

from the aerobic condition in tube beds, hindered denitrification and phosphorus released biologically.

3.5. Sludge filtration after chemical treatment

Fig. 12 shows total and soluble phosphorus concentration changes after treatment with aluminum sulfate addition as a flocculating agent. The influent SS level was originally around 40 mg/L, but after chemical treatment, the formation of $Al(OH)_3$ resulted in the increment of SS levels in the influent of meshed tube filtration system [9]. Around 60 mg/L of SS was flown into the filtration system. Under the various tube-size conditions, the longest available operation times were determined; 6 h at 30 min of HRT with ∅5 mm + ∅10 mm tube mixture, 13 h at 30 min of HRT with ∅5 mm tubes, and 24 h at 1 h of HRT with ∅5 mm tubes.

In terms of total phosphorus (T-P), within the available operational times that treats SS levels to be zero, effluent T-P levels were around 0.2 mg/L, but with SS coming out in the effluent, T-P also increased rapidly. On the other hand, soluble phosphorus (S-P) levels in the effluent were consistently very low regardless of HRTs. This proved that soluble phosphorus can be successfully treated with the system consisted of rapid mixing and meshed tube filtration.

Consequently, phosphorus contained in the effluent of secondary settling tank of domestic wastewater, can be treated as low as 0.2 mg/L, without rapid/slow mixing and settling tank, but only with the meshed tube filtration unit.

3.6. Particle size distribution and SS concentration changes by removal efficiencies

Fig. 13 illustrates the particle size distribution by removal efficiencies for ∅5 mm + ∅10 mm tubes packed in Type-II cage. In the secondary settling tank effluent, particles of 20–200 μm were observed mostly. Although there is no SS in the effluent from the secondary settling tank, small as 8–30 μm particles were observed, and in addition, where the removal efficiency was low, it appeared that the particles were

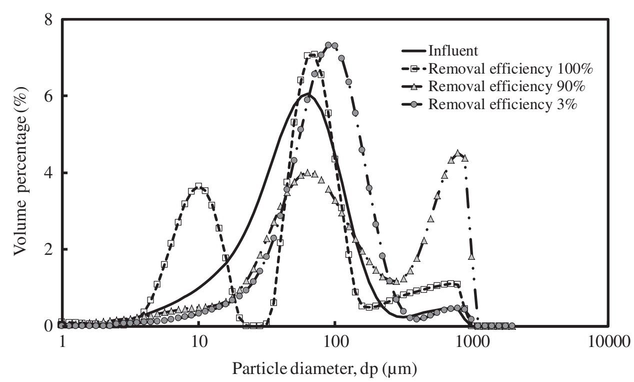

Fig. 13. Distribution of particle size at different removal efficiencies of SS of filter bed.

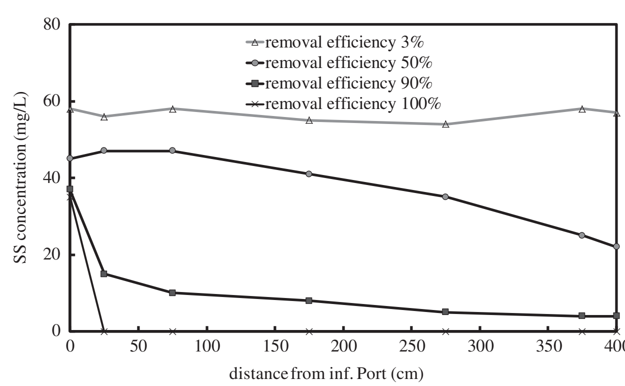

Fig. 14. Variations of SS concentration over the length of filter bed to the changes of SS removal efficiency.

accumulated within the meshed filter media than outflow as bigger than inflow particles.

Fig. 14 shows the SS concentration changes by reactor length from inflow port at various removal efficiencies. Unlikely to most conventional upflow fixed bed biomedia plants that remove contaminants in the lower bed part, this meshed filter plant is operated parallel and aerated at the center therefore reactor length functions more importantly than bed depth in its removal efficiency.

4. Conclusions

(1) When the effluent from secondary settling tank of biological domestic sewage treatment plant is treated by meshed synthetic tube filter, no SS were observed in the treated water until the maximum SS-loading rate 3.8 kg SS/m^3 d. Maximum operation time was found 43 h, and the highest linear velocity was 16 m^3/m^2 h. Maximum SS removal capacity for each filtration unit was found 7.1 kg/cage m^3, and its hydraulic-loading rate was 15 min.

(2) After filtration by meshed tube media, BOD in the effluent ranged between 2 and 3 mg/L, and nitrification was also observed. This clearly shows that meshed tube media not only remove SS but also soluble organic matters as well as nitrification along with the biofilm formed on the surface of media.

(3) It was found that soluble phosphorus removal to the levels lower than 0.2 mg/L was possible by single meshed tube filtration system, after chemical pre.

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