Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.24028

154 (2019) 119–131
June

Laboratory and field application of the synthetic fiber filter for treating turbid stormwater

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Received 31 July 2018; Accepted 25 February 2019

ABSTRACT

To evaluate the performance of a synthetic fiber filter in reducing turbidity in stormwater from construction sites, laboratory experiments were conducted in this study. The impact of different operating parameters including fiber configuration, filter depth, filtration velocity and coagulant dosage on the effluent quality and head loss were investigated. Based on the results, filter configuration can affect the pathway for water flow, which potentially influences the separation of solids. Effluent turbidity was found to decrease with increasing filter depth and increase with filtration rate but the turbidity reduction was still considerable at a filtration rate of up to 1,500 m d^{-1}. Addition of a coagulant enhanced the particle retention and achieved the highest reduction of 72% at 2 mg L^{-1} dosage. Based on the results from laboratory tests, empirical models were developed to estimate the efficiency of the filter in terms of operational factors. Meanwhile, in the field application of fiber filter, the preferable treatment capacity was achieved at the highest flow rate. This discrepancy between laboratory and field test results was attributed by the resuspension of particles as well as the penetration of particles into the fiber filter.

Keywords: Construction sites; Fiber filter; High-speed filtration; Stormwater; Turbidity

1. Introduction

Stormwater from construction sites are considered as one of the main sources of diffuse pollution resulting concerns in the receiving waters [1]. When soil is exposed during construction activities, stormwater runoff washes out substantial suspended materials as well as adsorbed chemical and biological pollutants into the nearest waterway. Additionally, the fine-sized soil particulates can spread to a long distance within streams or keep the water muddy for a period of time, thereby reducing the productivity of the water, decreasing its recreational value, and increasing treatment costs for industrial or drinking water plants [2].

Currently, turbidity is recognized as a regulated indicator of pollution associated with stormwater runoff from construction sites. According to a modelling work on the relationship between level of contamination and turbidity, an increase of five nephelometric turbidity unit (NTU) would decrease gross primary production in receiving water by 3%–13%, while a 25 NTU increase would result in a 13%–50% reduction [3]. In order to minimize the impact, US Environmental Protection Agency (EPA) permitted the discharge of construction-associated stormwater runoff with turbidity less than 280 NTU [3]. In Korea, the government requires the effluent turbidity from best management practices (BMPs) to not exceed 100 NTU [4].

However, highly turbid water results from intense light scattering by fine particles with diameters smaller than 50 μm [5]. The conventional BMPs, including temporary sediment basin, silt fences and rock check dam, cannot effectively remove the turbidity matters with such small size.

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In addition, sediment basins often provide inadequate settling times for small silt and clay-sized sediment particles, resulting in resuspension and subsequent discharge of fine particles during rainfall. Aside from this, intensive precipitation accelerates the flow rate of stormwater runoff, resulting in an impairment of BMPs and release of small particulates. Therefore, further reducing the turbidity in construction-site stormwater runoff is of great importance.

As a newly developed filter media for water filtration, synthetic fiber has recently played a significant role in particle separation [6]. Due to its great abrasion resistance, elasticity, and appreciable porosity, it can be operated under high filtration speed to separate the small particulate matters from suspension [7]. To cope with the regulation in Korea, a non-woven filamentous fiber was selected as a filter media to further remove turbidity matters from stormwater. In this study, laboratory experiments were conducted to evaluate the performance of a synthetic fiber filter under various operational conditions. Meanwhile, field tests were carried out to examine the actual capability of fiber filter on reducing turbidity under varying flow-through rates.

2. Materials and methods

2.1. Synthetic fiber filter and artificial stormwater

The fiber used in this study consists of polyamide tied to a 5 mm diameter polythene core-rope. It was manufactured to have a linear shape as shown in Fig. 1a and has a nominal outer diameter of 45–50 mm. This makes it easy to arrange for field application. It has a specific surface area of 1.0–1.6 m^2 m^{-1} and porosity of 90%–95%. In particular, the surface of fiber filter is negatively charged due to the nature of nylon, and its SEM image is provided in Fig. 1b.

All the experiments were carried out using an artificial stormwater prepared by mixing tap water with yellow soil. The particle size distribution in Fig. 1c shows that 80% by volume of the particles are smaller than 13 μm. The stormwater was prepared such that the turbidity is about 100 NTU, which is commonly found in the construction site after stormwater settling basin [8].

2.2. Laboratory experiment

A lab-scale system consisting of a filter chamber and a feeding tank was constructed as shown in Figs. 2a–e. The dimensions of the feeding and filter tanks were 0.7 m × 1.0 m × 1.0 m (width × length × height) and 0.12 m × 0.20 m × 0.32 m, respectively.

The channel-type filter module, which is the key part of the experimental set-up, was filled with fiber media. Prior to the filter, a gravel wall was installed to direct and distribute water flow. In addition, a separation grid between the gravel and fiber works to ensure that the fiber will not be moved by the water flow.

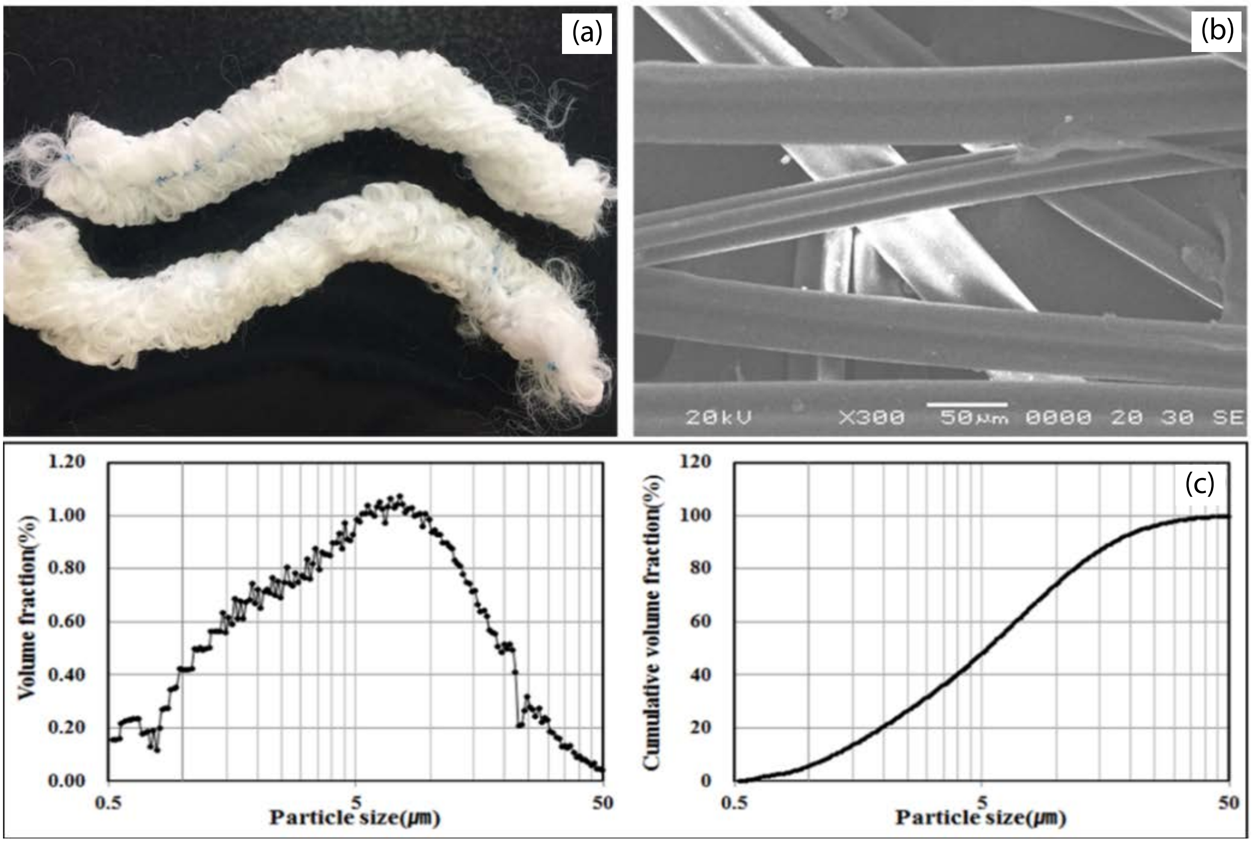

Fig. 1. (a) Bundle type synthetic fiber filter, (b) SEM photo-micrograph of fiber filter and (c) particles size distribution of the stormwater used for this study.

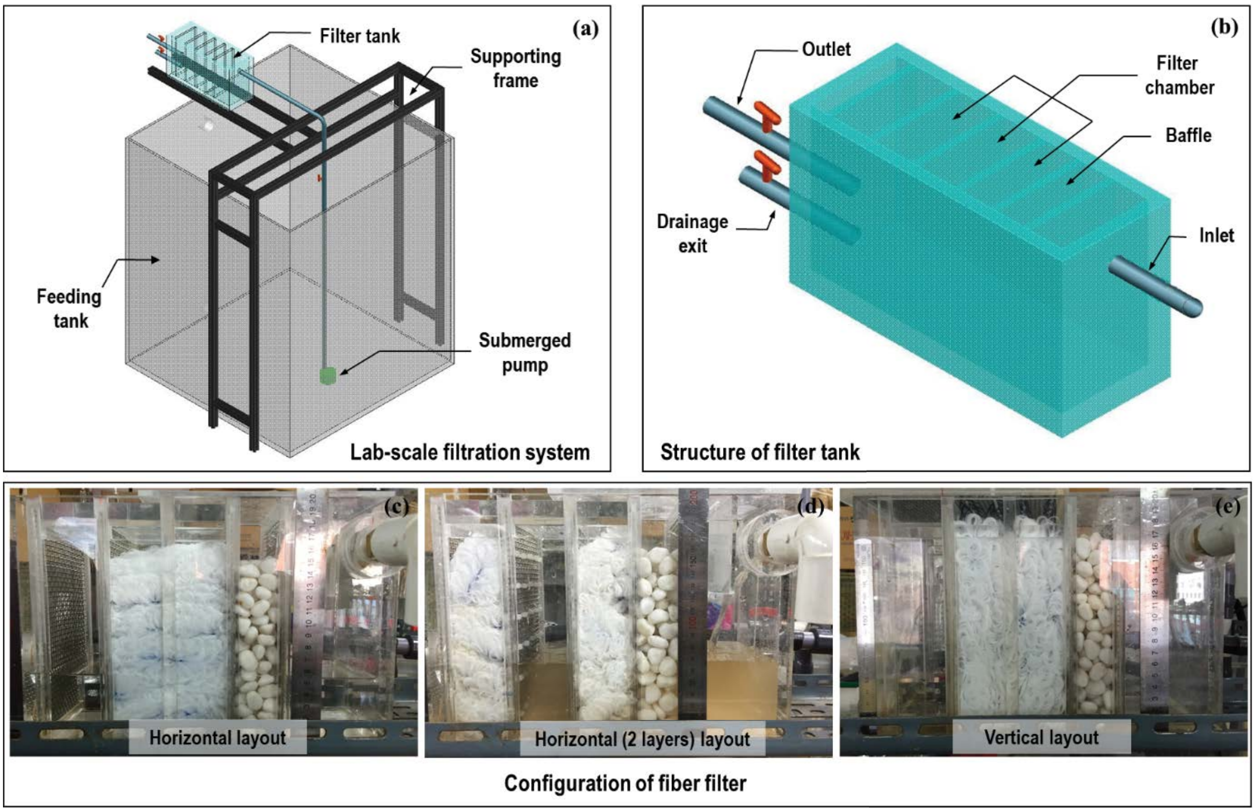

Fig. 2. Experiment setup of laboratory - filter system (a) feeding tank, (b) filter chamber and filter layout, (c) horizontal layout with single layer, (d) horizontal layout with double layers, and (e) vertical layout.

A series of experiments were carried out to assess the filter performance under different conditions including filter depth (5–15 cm), filtration rates (800–1,500 m d^{-1}) and dosages of filter aid (0–10 mg L^{-1}). Meanwhile, the effect of filter configuration was also evaluated by different filter arrangements such as horizontal lay-outs with single layer, double layers with a zone of free water and vertical lay-out (Figs. 2c–e).

In order to verify the reproducibility of the results, every experiment was carried out three times. The inflow and outflow turbidity, flow rate and head loss were measured every 10 min during operation. Turbidity was measured using the 2100N Laboratory Turbidimeter (made by Hach company, Loveland, Colorado, U.S.A) while the particle size distribution was analysed using the Accusizer™ 780 Particle Analyzer.

2.3. Field test

In addition to laboratory tests, a field-scale filter shown in Fig. 3 was installed in a 0.39 m wide and 0.40 m deep drainage channel located at Hanseo University, Seosan City, Korea. The filter has fibers that were fixed on a supporting structure at a packing density of 52 g L^{-1} and was placed between two support rock zones.

Fig. 3f shows a diagram of the filter components and operation in the field. The turbid water was made by mixing yellow soil into tap water and the flows were regulated with a gate valve to give 70, 105 and 140 m^3 d^{-1}. This corresponds to filtration rates of 600, 900 and 1,200 m d^{-1}, respectively.

3. Results and discussion

3.1. Effect of fiber configuration on filter performance

Fig. 4a shows the changes of effluent turbidity by different fiber configurations during the operation. As seen in the figure, single horizontal, double horizontal layers and vertical layouts have similar trends as the filtration persisted. This is due to the same physical retention mechanisms, such as size exclusion and straining, since a repulsive force exists between particles and filter eliminating the possibility of removal by electrostatic mechanisms. This has been confirmed by the previous works on synthetic fiber filter [9,10].

However, a significant difference in effluent turbidity ($p < 0.001$) was observed between single and double lay-outs, which means that double layer with a free-water zone in between gives a higher removal efficiency than a single layer having an equal filter depth (Figs. 4a and b). Typically, head loss is regarded as one of the factor affecting filter performance with respect to media packing or configuration. However, in this study, the difference in head loss is not significant (Fig. 4c). Thus, the result might be related to the hydraulic efficiency induced by different lay-outs. In practice, multiple reactors in series achieve a relatively higher hydraulic efficiency than a single reactor with the same volume [11]. Similarly, double filter layers improved the hydraulic performance, resulting in increased particle retention.

Meanwhile, the effluent turbidity from the filters with horizontal and vertical layout was 62.7–72.4 and 44.9–63.2

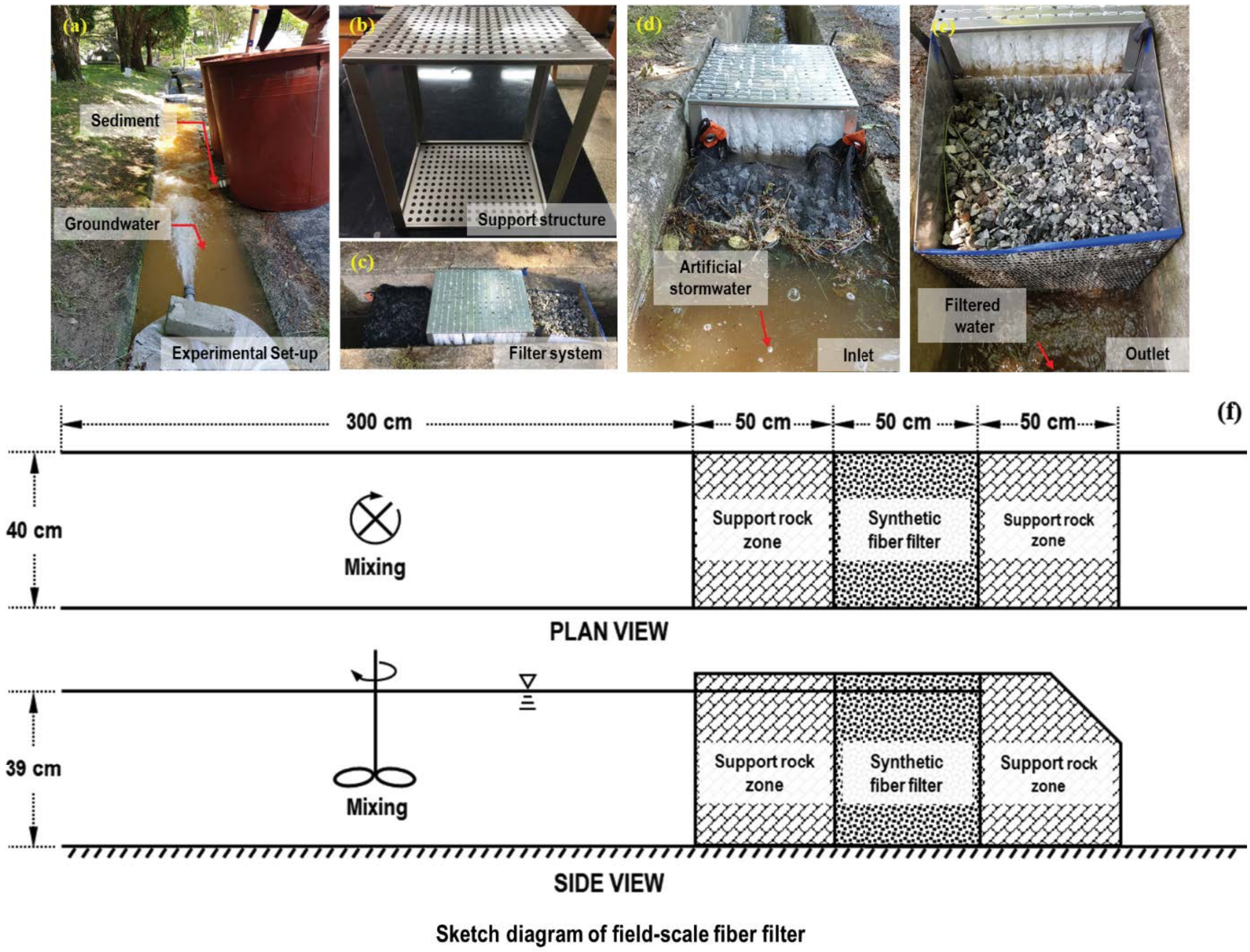

Fig. 3. Experimental setup and sketch diagram of field-scale fiber filter (a)–(e) are the photos of experimental setup and (f) sketch of fiber barrier.

NTU, which are equivalent to removals of 31.9% and 43.0%, respectively. The higher separation capacity of vertical layout was probably caused by the decrement of flow velocity. The interstices in horizontal layout are in the same direction as that of water flow, which is susceptible to the detachment of retained particles. Conversely, the fiber filter was perpendicular to the direction of flow in vertical lay-out, offering a more complex pathway for water flow. In this case, the fluid spends much time to channel through the fiber filter, providing more chances of collision between filter and particles. As a result, interception, attachment, sedimentation and impaction would be enhanced.

In terms of the head loss, a great difference was not observed among the three packing configurations ($p > 0.05$). Due to the higher reduction on turbidity matters in a vertical lay-out, it was finally chosen as the optimal packing configuration for field application.

3.2. *Effect of filter depth on filter performance*

The thickness of filter bed is one of the influential factors affecting depth filtration. However, its effect can be changed with different types of filter bed or properties of filter media [12]. Hence, the performances of fiber filter with different filter depths were investigated, and the results are summarized in Fig. 5.

In Fig. 5a, the effluent turbidity in the 5, 10 and 15 cm filter ranged from 60.6 to 72.7, 51.7 to 58.5 and 41.3 to 52.7 NTU, respectively. Additionally, in term of 5 cm fiber filter, the effluent turbidity was fluctuated at high filtration speed during the entire operation. This indicates that the longer filters not only produced effluent with fewer suspensions but were also more stable. This was attributed to the enhanced re-deposition of detached particles in the longer filters, hence, delaying the breakthrough. As a result, the turbidity removal efficiency increased with the thickness of the fiber filter, which is consistent with most studies on depth filtration.

However, the incremental removal tends to stagnate with increasing filter depth. Similar result was also reported in the study by Wegelin et al., [12] wherein the concentration of suspended solids from roughing filter was no longer reduced with increasing the length of filter bed. In fact, substantial particulate matters were primarily captured by the previous filter layer, and the turbidity was mainly diminished herein. Therefore, the removal efficiency was stagnated with thickening filter.

On the other hand, the increased thickness also led to an elevation of head loss (Fig. 5c) due to the increased

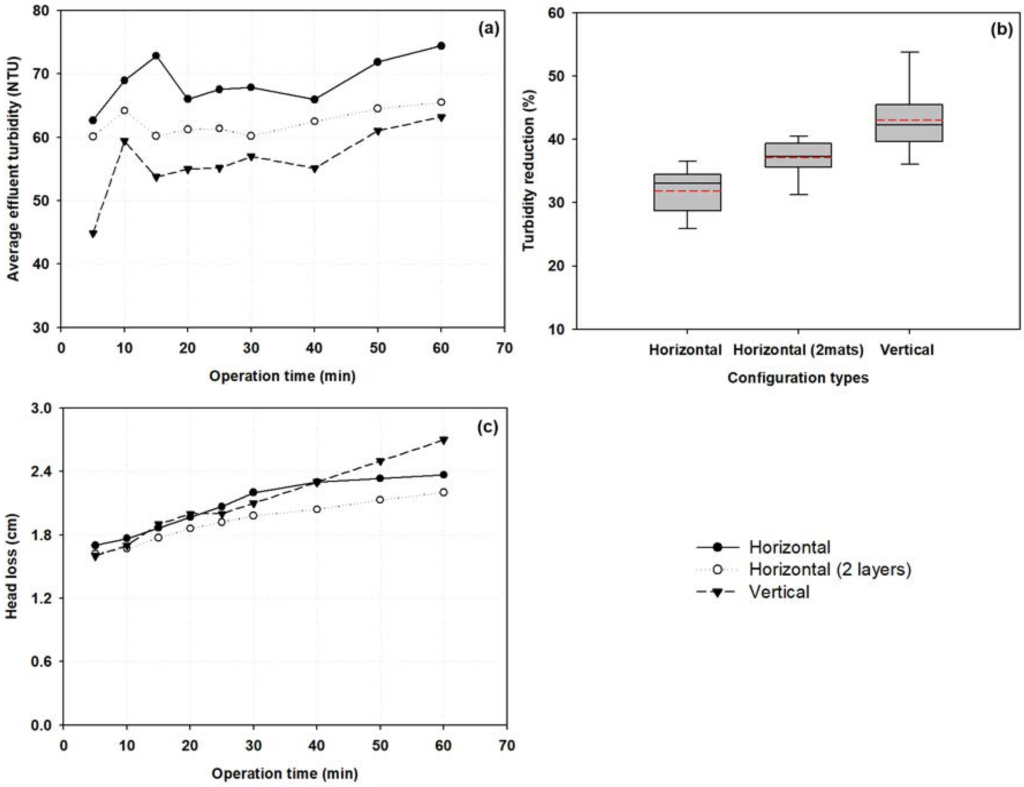

Fig. 4. Effect of filter configurations on (a) effluent turbidity, (b) turbidity reduction and (c) head loss during operational period (filtration rate = 1,150 m d^{-1}, filter depth = 10 cm).

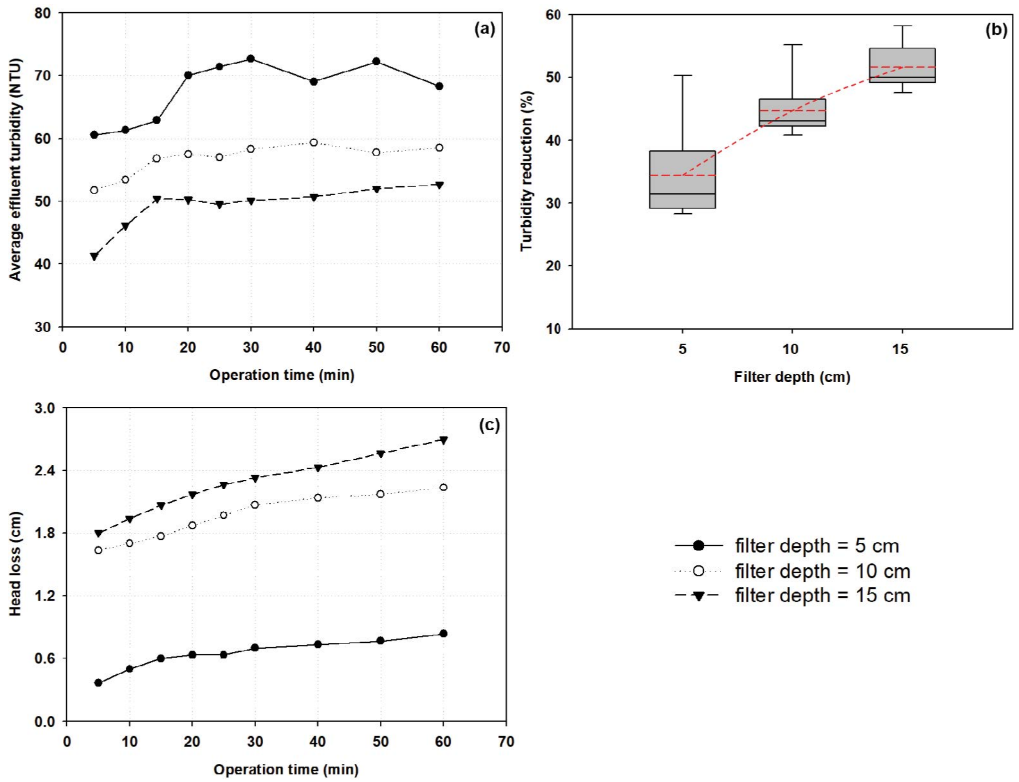

Fig. 5. Effect of filter depth on (a) effluent turbidity, (b) turbidity reduction and (c) head loss during operational period (filtration rate = 800 m d^{-1}).

resistance to flow [13]. Thus, the design of filter depth should be optimized depending on the requirements in site and limits for effluent quality.

3.3. Effect of filtration rate on filter performance

The speed of fluid filtering through the filter bed can pose a significant impact on the particle retention. However, there is limited supporting experimental data on how the removal changes with filtering speed in highly porous filter media. Lee et al. [7] indicated that the effect of filtration speed on nylon fiber was similar to that of on granular media, whereas Gao et al. [9] found that the incremental rate moderately enhanced the solids separation by fiber ball. In this study, three filtration rates (i.e., 800; 1,150; 1,500 m d^{-1}) were chosen to evaluate its effect on filter performance. The results are presented in Fig. 6.

As expected, the degradation of effluent quality occurred since the filtering velocity elevated, resulting in a turbidity reduction of 51.6%, 41.2% and 34.2% at the velocity of 800, 1,150 and 1,500 m d^{-1} (Figs. 6a and b), respectively, which is in agreement with the results from previous studies [10,14]. In addition, the effluent turbidity was found to be stabilized around 50 and 60 NTU under the velocity of 800 and 1,150 m d^{-1}, respectively. Meanwhile, the increment of turbidity persisted at the velocity of 1,500 m d^{-1}. The highest filtration velocity contributed to the greatest shearing force acting on trapped particulates, which may far exceed the hydrodynamic drag force within the filter pores [15]. Hence, those particles would no longer retain in the filter, resulting in a significant breakthrough.

The filtration velocity also influenced the build-up of head loss across the fiber filter. As shown in Fig. 6c, the head loss that reached 2.4, 3.3 and 4.2 cm corresponding to the rate of 800, 1,150 and 1,500 m d^{-1}, respectively, after the filters were operated for 60 min. The head loss is not changed with a great extent, in comparison with that documented in the current studies in which head loss can reach to 1.0–1.4 m [9]. This result suggests that the application of fiber filter have a great potential for treating turbid runoff because it might greatly minimize the possibility of overflow and ponding.

3.4. Effect of coagulant dose on filter performance

Filter aids, such as polyacrylamide, aluminous and ferric salts, have been reported as an effective approach to improve the effectiveness of BMPs. In the present study, polyaluminum chloride (PAC) was selected to investigate its improvement on filtration efficacy. Three PAC doses (2, 5 and 10 mg L^{-1}) were performed with 15 cm fiber filter under the filtering speed of 800 m d^{-1}.

As shown in Fig. 7, the effluent turbidity diminished significantly ($p < 0.001$) and maintained around 30 NTU after 30 min as dosed 2 mg L^{-1} of coagulant. In this aspect, particles can be destabilized and their surface charge is neutralized, the repelling forces between particles and between particle and filter were eliminated [16]. Therefore, a better turbidity removal was achieved. When the dose was

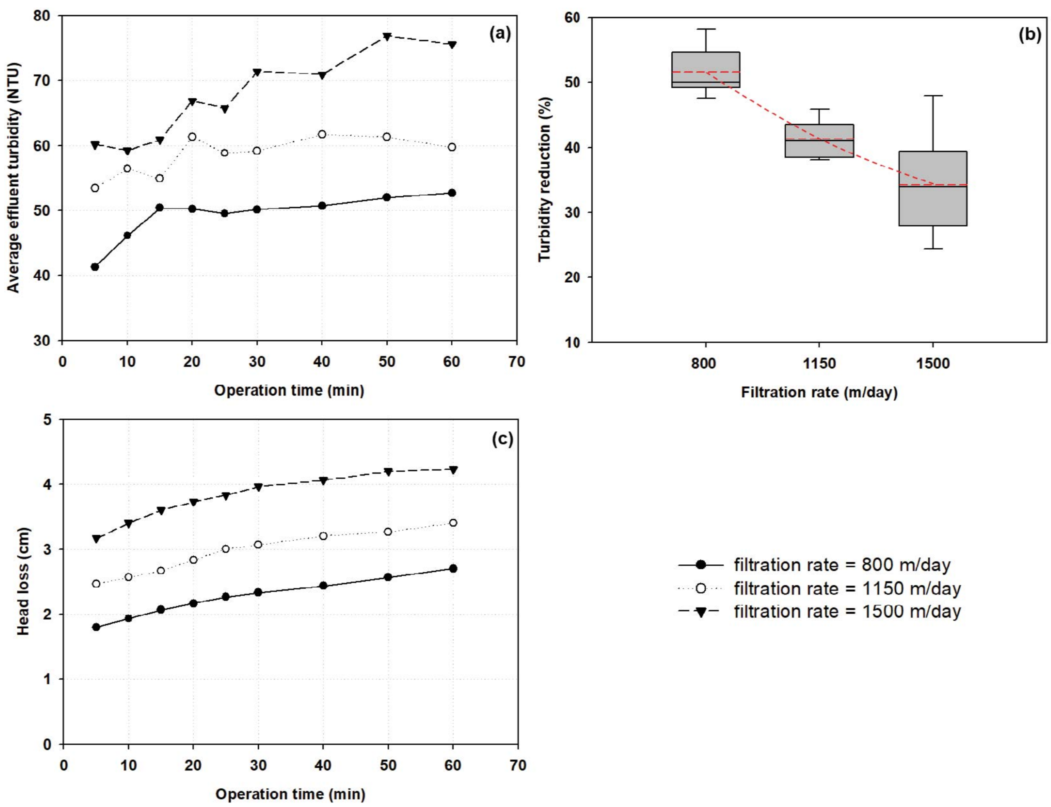

Fig. 6. Effect of filtering speed on (a) effluent turbidity, (b) turbidity reduction and (c) head loss during operational period (filter depth = 15 cm).

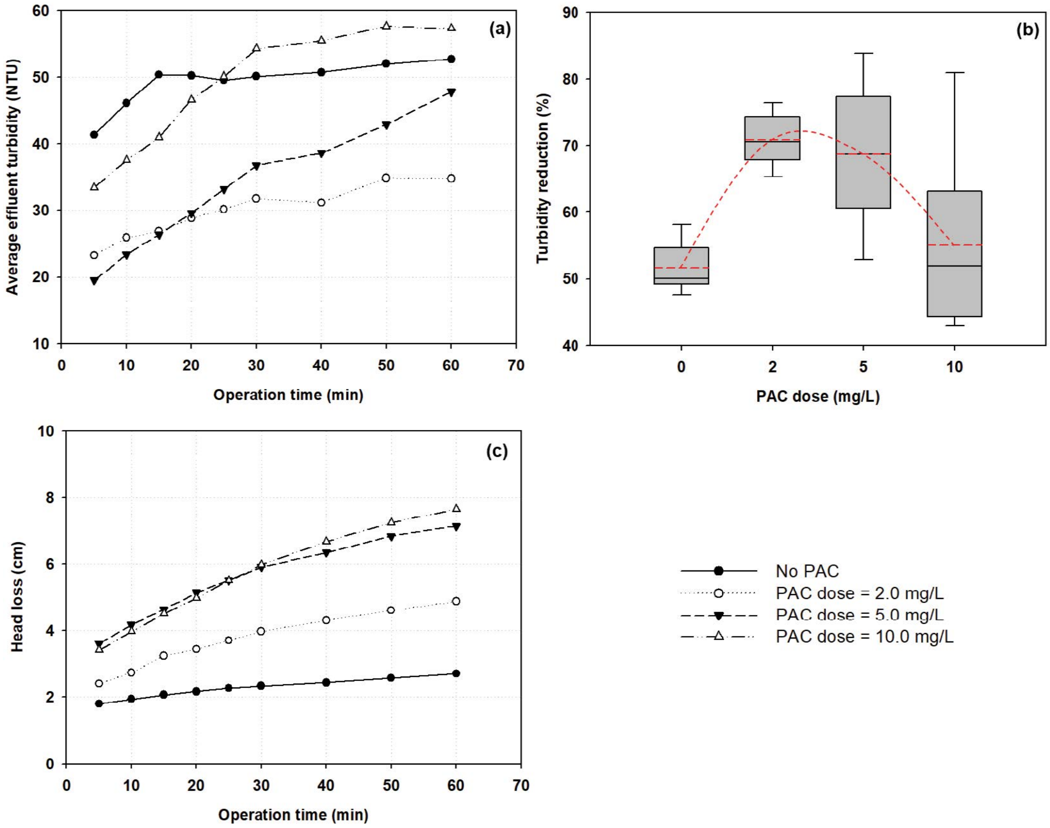

Fig. 7. Effect of PAC dosage on (a) effluent turbidity, (b) turbidity reduction and (c) head loss during operational period (filtration rate = 800 m d^{-1}, filter depth = 15 cm).

5 mg L^{-1}, the minimum effluent turbidity occurred within 20 min, thereafter, it exceed that of dosing with 2 mg L^{-1} of PAC and increased continuously. With highest dose, significant increase of turbidity was appeared in the initial stage. Meanwhile, the effluent turbidity even exceeded that of with no PAC as the run time reached to 25 min. It suggested that the increased PAC dose could accelerate particulate breakthrough in the filtrate, and probably resulting in a generation of aluminum hydroxide, which can potentially affect the effluent turbidity [10]. In this aspect, the surface charge of particulates can be immediately changed from negative to neutral and finally became positive [10,16]. Those solids can be readily intercepted by attraction to negatively charged fiber filter, thereafter, the inflow particles can be repelled away when they moved toward the filter since the repulsion appeared between particles.

In terms of turbidity reduction, the highest dose of PAC resulted in a minor improvement of filtration efficacy. The different observation was reported by Gao et al. [9], wherein the turbidity removal by fiber ball was enhanced since the coagulant dose increased from 5 to 15 mg L^{-1} at the filtration rate of 720 m d^{-1}. This difference can be possibly resulted by the different size of particles in raw water. Comparing with the present study, the majority of inflow particles in Gao et al.'s [9] study were extremely small (<2 μm). These particulates with a smaller size can be more sensitive to surface electric charge. Hence, more cations were required to completely neutralize the particles in suspension.

Fig. 7c exhibits the relationship between the dosage of PAC and head loss, it indicated that an increment of coagulant dose resulted in an increase of head loss, particularly for the dose of 5 and 10 mg L^{-1}. In terms of PAC dose of 2 mg L^{-1}, the water head increased gradually and approximated to 2.5 cm. Based on the above results, 2 mg L^{-1} of PAC was thereby chosen as the optimum dose for treating the stormwater with 100 NTU.

3.5. Predicting the performance of fiber filter

Prediction of particle removal by filters is of practical interest in substantial engineering applications, in particular, the design of BMP facilities. The model establishment associates with several factors, which are chosen based on two considerations: first, these factors can be easily obtained or determined from the practical application; second, these factors have a significant effect on filter performance [17]. Based on this purpose, a prediction model proposed by Hudson [18] was applied in the present study. The model equation (Eq. (1)) is basically developed for depth filtration, which includes the filtration rate factor (V), filter media property factor (d and p), head loss factor (h and S) and filter depth factor (L).

$$\frac{C_e}{C_0} \cong \frac{Vd^3p^4hS}{L} \tag{1}$$

In this study, since the head loss and surge amplitude were small, and the porosity and effective size of fiber filter were consistent in all the filtration experiments, filtration rate (V) and filter depth (L) were considered as the main factors in model development, whilst the equation is amended as follows:

$$\frac{C_e}{C_0} \cong K_f \times \frac{V^a}{L^b} \tag{2}$$

where K_f, a and b are empirical filtration constants.

Eq. (2) was calibrated using 54 data sets to determine the following empirical models for two different operational conditions.

$$\frac{C_e}{C_0} \cong 0.02425 \times \frac{V^{0.39225}}{L^{0.22395}} \text{ (Filtration without PAC)} \tag{3}$$

$$\frac{C_e}{C_0} \cong 0.01349 \times \frac{V^{0.37417}}{L^{0.44280}} \text{ (Filtration without PAC)} \tag{4}$$

The correlation of measured and calculated values (C_e/C_0) was pursued in Fig. 8. As shown, the slopes of the best-fit line are over 0.99, whilst the correlative relationships are significant ($R^2 = 0.864$, $p < 0.001$; $R^2 = 0.8617$, $p < 0.001$). In addition, the increases and decreases of predicted values well correspond with the observed values. These results also indicate that the turbidity removal by fiber filter can be well simulated by using two factors. On the other hand, the index of filter depth gave an obviously higher value, suggesting that the thickness of fiber filter exerts a more important influence on coagulation–filtration.

3.6. Assessment of field-scale fiber filter

A field experiment was designed to decide the filter performance of fiber by using artificial stormwater. Fig. 9 shows an example of operating field-scale fiber filter. Throughout the operation, the influent turbidity was in the range of 103–131 NTU, and the flow rate and filtration velocity were kept constant at 1.61 L sec^{-1} and 1,200 m d^{-1}, respectively. It was apparently observed that the head loss increased with increasing filtration rate during the initiating filtration period, and it stabilized at 5.3 cm after 40 min operation. On the other hand, the effluent turbidity ranged from 31 to 57 NTU, resulting in an average removal of 63.5%. The decline of effluent turbidity occurred as the head loss elevated within 40 min, which is ascribed to the expansion of filtration area. Typically, the process of depth filtration is composed by three distinct stages with respect to ripening, working and breakthrough stage [18]. However, in present study, the breakthrough of turbidity matters was not significant during the whole run, relating with the abundant internal space inside the synthetic fiber.

Table 1 summarizes the results of field-scale fiber barrier at the designed rate of 600, 900 and 1,200 m d^{-1}. As to the turbidity reduction, it was decreased from 50.2% to 38.6% as the velocity raised from 600 to 900 m d^{-1}. However, the removal efficiency increased to 59.6% as the filtration rate reached to 1,200 m d^{-1}, whilst similar result was obtained from the repetitive testing (4th and 5th experiment). This observation differs from most of the studies on high-speed filtration of fiber

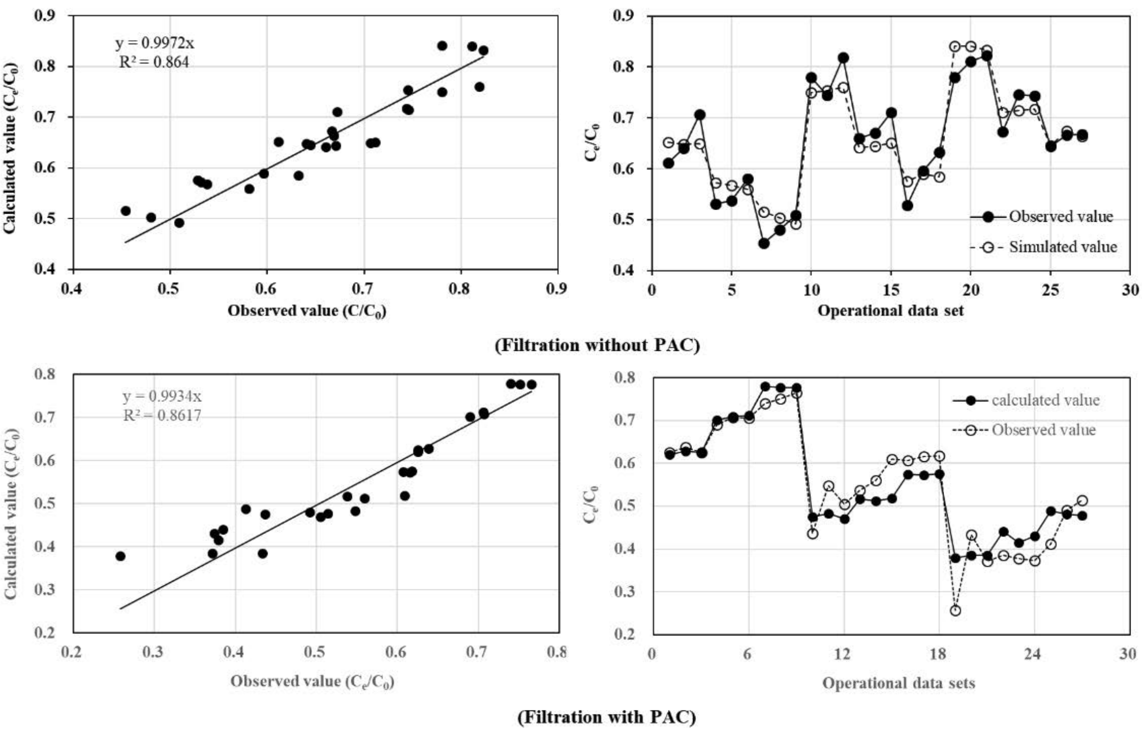

Fig. 8. Relationship between the observed and simulated data.

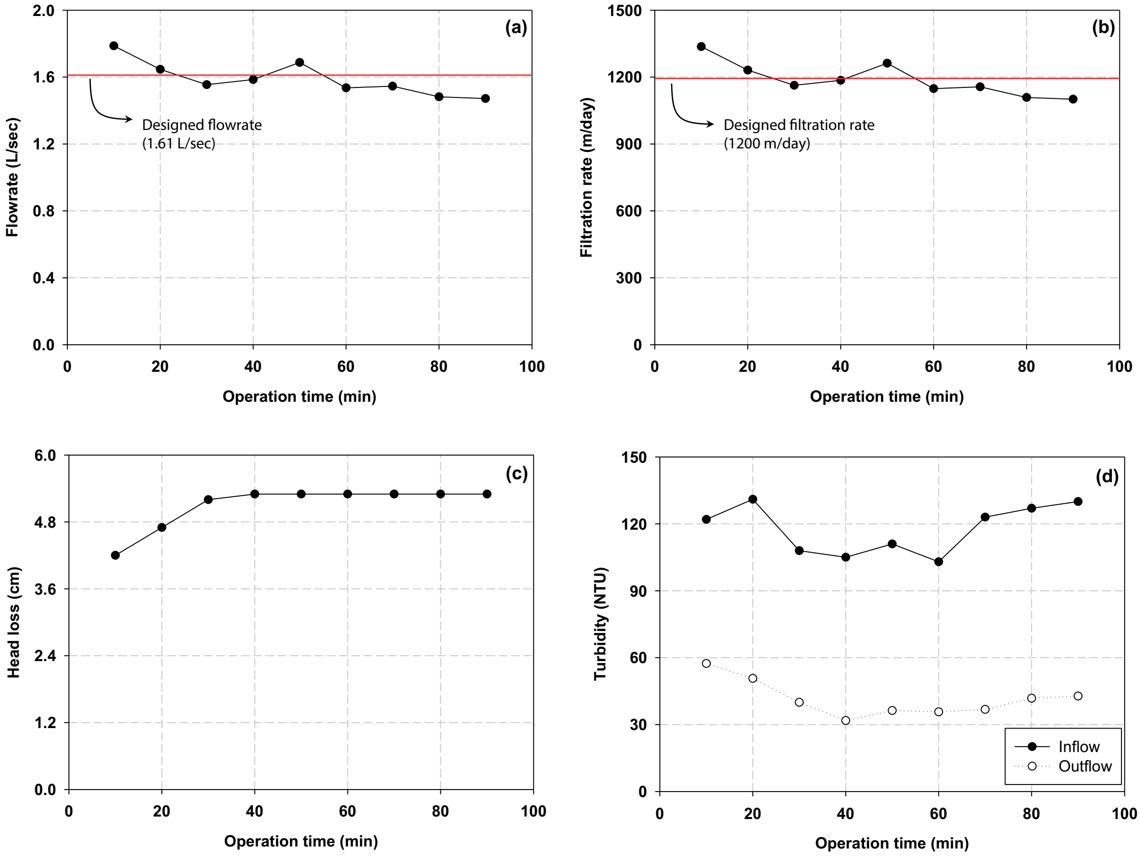

Fig. 9. Illustration of field-scale fiber barrier operating at filtration rate of 1,200 m d^{-1} (a) change of flow rate; (b) change of filtration rate; (c) change of head loss in fiber barrier; and (d) change of influent and effluent turbidity.

Table 1
Overall filtration performance of field-scale fiber filter

Experiment No.	Flow rate (L s^{-1})		Filtration rate (m d^{-1})		Turbidity (NTU)				Removal efficiency (%)		Head loss (cm)
					Influent		Effluent				
	Average	S.D.	Average	S.D.	Average	S.D.	Average	S.D.	Average	S.D.	
1	0.77	0.07	578	55	109	39.0	54.7	23.8	50.2	8.5	0.5
2	1.28	0.05	954	38	119	43.0	74.6	34.6	38.6	11.5	2.9
3	1.38	0.15	1,203	114	112	22.0	45.9	17.3	59.7	9.2	5.5
4	1.31	0.08	982	61	125	29.6	72.3	19.2	42.4	7.0	3.0
5	1.47	0.13	1,212	91	119	10.4	43.5	9.5	63.5	6.2	5.3

filter, in which the filtering efficacy was negatively related with filtration rate [10,14,17]. This aspect is further discussed in the next section.

3.7. Discrepancy between lab-scale and field-scale fiber filter

In summary, solids separation from stormwater is extremely sensitive to the environmental conditions. Its performance can be greatly influenced due to the uncertainty of sediment source as well as the stormwater hydrology. According to the results from laboratory test, the removal efficiency of synthetic fiber is mainly suppressed with an increase in flow rate. In contrast, the turbidity removal was improved as the filtration conducted with the highest flow rate in field test. This finding was not solely subject to filtration rate but also contributed by several factors including packing density, flow field in filter system and particle behaviour.

Fig. 10 shows the possible scenarios in field-scale fiber filter. The increment of turbidity reduction under 1,200 m d^{-1}, it could be roughly related with two reasons. For one thing, it could be accounted for the expansion of effective filtration area. In case of the relatively lower speed filtration (600–800 m d^{-1}), the suspended matters are more concentrated on the bottom due to the density current caused by different levels of turbidity (Figs. 10a and c). With the increment

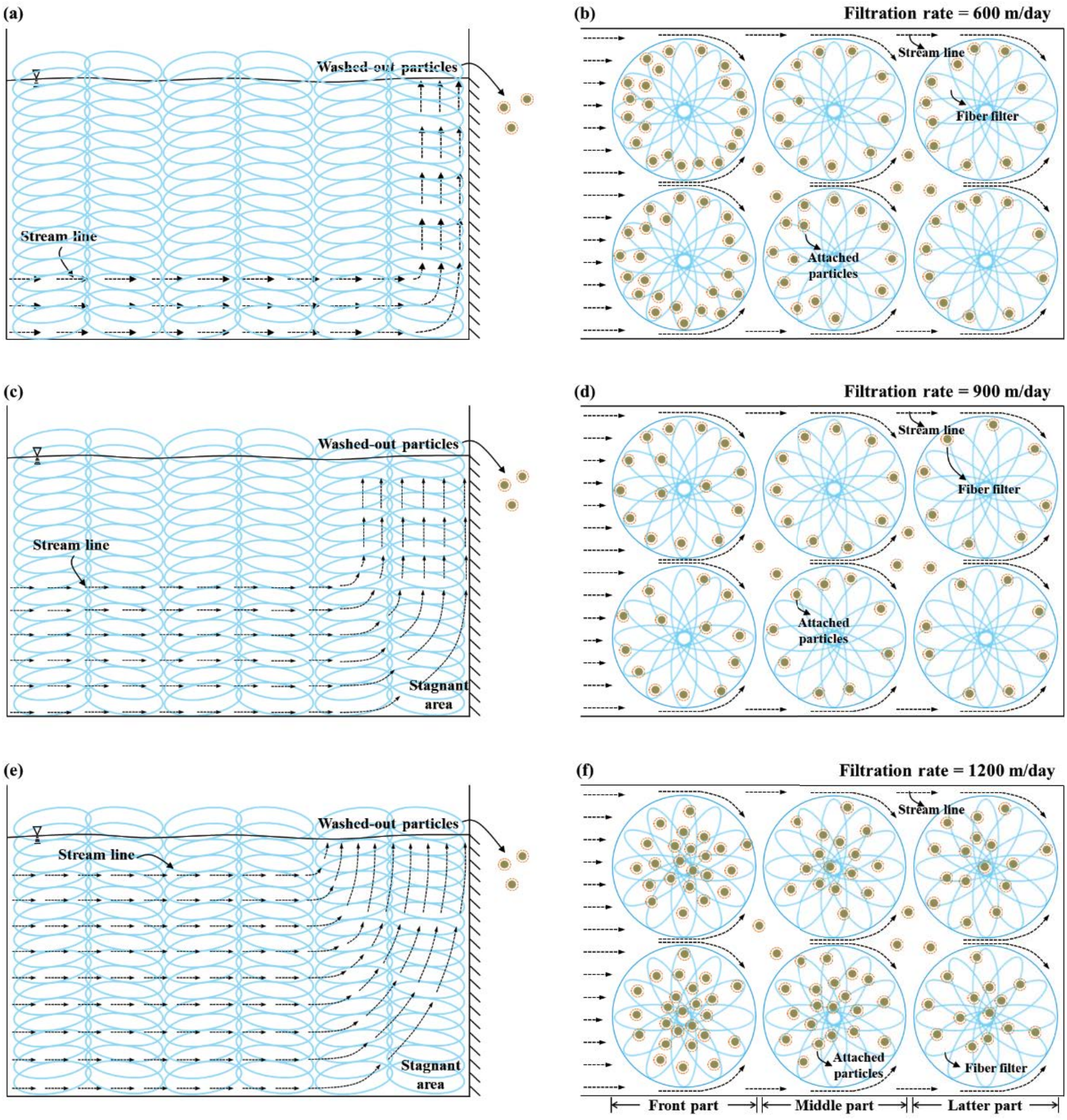

Fig. 10. Pathway of water through the fiber filter under the different filtration rate ((a), (c) and (e) are side views; (b), (d) and (f) are plan views).

of flow rate, the turbulence induced by water flow was enhanced, the pre-settled particles were re-suspended in water column (Fig. 10e). Therefore, the area for accommodating particulates was enlarged when the filter operated under highest filtering velocity.

As to another, the arrangement of synthetic fiber in field-application was much more loose (packing density = 52 g L^{-1}) as compared with that of in laboratory experiment (about 105 g L^{-1}). With lower packing density, the resistance of the media was decreased, which made it easier for the water to go through the fiber and reduce the velocity in voids [19]. Therefore, the particulates, which have been given with greater kinetic energy under highest filtering speed, can penetrate deeply into fiber (Figs. 10b–f). Once those particles deposited into the core of filter, the detachment would be retarded because the external filaments of synthetic fiber offset the hydraulic shearing acting upon them. This has also been suggested by Wegelin et al. [12] in the operation of granular bed filter, wherein the increased filtering speed cause notable penetration of particles. However, it clogged the finer-sized filter grain and re-suspended the deposited particles, resulting in a decrease of filter efficiency. In this regard, the fiber filter that has a great void fraction can highly reduce the chances of blockage, allowing to accept particles continuously.

Meanwhile, the preferable filter performance with an incompact arrangement of fiber filter occurred under high flow rate, expanding the applicability for the extreme storm-flow. In this regard, the amount of fiber can be also reduced as it installed in drainage structure with given dimensions, resulting in minimized operating cost. It should be noticed that the efficacy was not improved at lower flow rate, so that there is a need to identify the range of filtering speed to which the improvement of filter performance is effective. As such, the optimal packing density is necessary to be determined with respect to the designed flow rate. However, it is currently impossible based on the present available data, thus, further study is required to be carried out to identify the effective flow rate and optimize the packing density.

3.8. Comparison of filter performance with other studies

During the last several decades, numerous types of stormwater runoff management have been invented and applied in construction site. The passive treatment system was considered to be a low-cost detention technology for turbidity reduction on construction site, which separates the sediment-laden runoff into two parts, that is one being captured by filter barrier, and the other one being discharged into a drainage channel that connects to the receiving waterway after passing through the filter media.

However, those facilities have been widely used due to its simplicity and cost-effectiveness. Meanwhile, it can converge the runoff and promote the sedimentation of soil particles during severe storm events by restricting water flow, thus diminishing the excessive discharge of sediment. However, it is not able to retain the fine-sized particles because these suspensions are too small to be gravitationally separated within a short time. In this respect, these facilities may achieve a considerable efficacy for treating the stormwater from a site which lack erosive protection or soil stabilization, because coarse particles (sand and silt) are primarily dominated and generated from infinite source of exposed soil during rainfall [3]. Alternatively, they can be useful for a site where coagulation/flocculation technologies or pressurized filtration system were equipped.

On the other hand, the efficiency of reducing turbidity is greatly determined by the initial concentration of sediment as the stormwater received by treatment facility. The conventional filter media can obtain prominent reduction as highly turbid runoff appeared. This is because BMPs are generally more effective in treating stormwater with higher concentration than lower one [20,21]. Even the turbidity in sediment-laden runoff can be reduced greatly, the effluent concentration is still considerable due to the substantial residues with small size. Table 2 summarizes the performance of different BMP facilities, the effluent turbidity was even up to 3,000 NTU as the stormwater filtered from silt fence [22]. Additionally, it was also over 200 NTU as the flocculants applied in compost check dam [23]. This is the limit of the sediment control technology as regards not only what we propose in this study but also those that are being used.

In this respect, the synthetic fiber media can guarantee a further turbidity reduction for the stormwater discharged from the passive treatment system, thus attaining the requirement for the effluent from construction site. The principle of this filter is mainly focused on separating the small-sized particles from stormwater by employing an additional filtration process, which was not effective among the typical sediment control barriers [21,26]. According to the previous

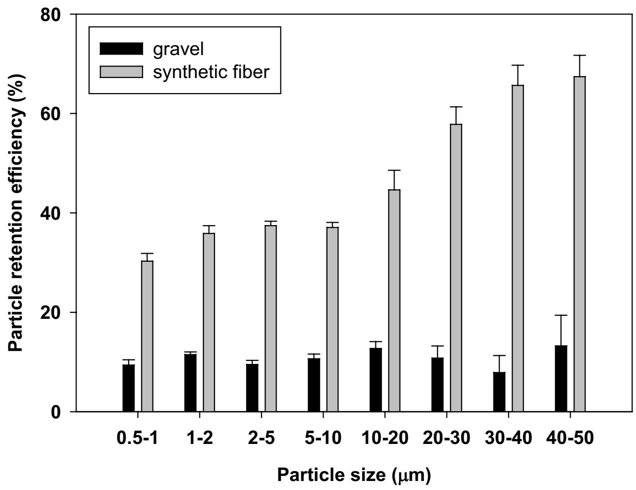

Fig. 11. Particle size range vs. the retention capacity of fiber and gravel filter (filtration rate = 1,150 m d^{-1}, filter depth = 10 cm).

Table 2
Turbidity removal performance for different conventional BMPs

Stormwater controls	Inflow turbidity (NTU)	Outflow turbidity (NTU)	Reduction (%)	Literature
Silt fence	8,805–16,371	3,929–4,843	45.0–76.0	[22]
Compost filter socks (with polyacrylamide)	1,847	940	49.1	[24]
Fiber filtration tubes	15,000	300	98	[25]
Compost check dam	3,813	202	94.7	[23]
Excelsior wattle	–	225–400	90.0–95.0	[1]
Rock check dam	–	858–900	70–89	[1]

study [27], the performance of conventional gravel and fiber filter was investigated, and the relationships between the sizes of small particles (<50 μm) and retention efficiency are shown in Fig. 11. High capture capacity obtained by the employed fiber filter is closely related with the separation of particles less than 10 μm, which has been recognized as the main contributor of turbidity. Fig. 11 also shows that even though the removal efficiency gradually declines as the particle size decreased, more than 30% of the micro-particles (smaller than 1 μm) were removed. Comparing with synthetic fiber, the removal efficiency by granular media was poor among all size ranges. Their detention was even below 10% due to the limited interception capacity of gravel.

4. Conclusions

In present study, the performance of a synthetic fiber for further entrapment of fine particulates in construction stormwater was evaluated under varying operational conditions. For the different filter configurations, vertical layout achieved the highest capacity of capturing turbidity matters under the same operational condition.

On the other hand, the synthetic fiber was found to have the commonality of deep bed filtration. Increasing the thickness of fiber filter not only had a significant impact on improving turbidity removal but also producing more stable effluent quality. Although increasing filter rates resulted in a degradation of performance, removing 35% of small-sized turbidity matters under 1,500 m d^{-1} still was acceptable due to the strong affinity between those particles with pollutants. The addition of coagulant enhanced the turbidity reduction, whereas the excessive dosage of PAC weakened the improvement of removal efficiency. The empirical model was developed, the fibre filtration can be simulated well under a high filtration rate.

In field-scale filtration experiment, the preferable separation of turbidity matters appeared at the highest flow rate, relating with the increased amount of penetrated particles. The experimental results also demonstrate that the synthetic fiber has a great potential for treatment of turbid water at extreme storm flow condition. In this respect, further studies are still required to improve and optimize the filter design and performance.

Acknowledgement

This research was partially supported by a grant (2016 000200002) from Public Welfare Technology Development Program funded by the Korean Ministry of Environment.

Symbols

C_e	—	Turbidity in filtered water, NTU
C_0	—	Turbidity in raw water, NTU
V	—	Filtration rate, m d^{-1}
d	—	Effective size of filter media, mm
p	—	Porosity of the filter bed
h	—	Loss of water head through the filter bed, m
S	—	Surge amplitude in percent of head lost
L	—	Thickness of the filter bed, m
K_f, a, b	—	Empirical filtration constants

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