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상하수처리를 위한 새로운 고효율 응집/여과 장치

A Novel High Rate Flocculator/Filter in Water and Wastewater Treatment

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Abstract

Conventionally used flocculation tanks require large space and high energy requirement for mixing. Static flocculators using gravel bed filter operate at a lower flow rate (5-10 $m^3/m^2 \cdot h$). Further, the cleaning of this system is difficult. A novel high rate static flocculator/filter developed at UTS packed with buoyant media such as polystyrene, polypropylene has been found to operate at higher filtration rates (30-45 5-10 $m^3/m^2 \cdot h$). They can easily be cleaned with minimal energy. Detailed experiments conducted with an artificial kaolin clay solution show that buoyant media is an excellent static flocculator in producing uniform filterable microflocs (12-15 m) even when it is operated at a high rate of 30-40 m/h. Detailed filtration experiments were conducted in a wastewater treatment plant to treat the biologically treated effluent with a floating media of depth of 120 cm. This filter was able to remove majority of phosphorus and remaining solids. It reduced significantly the fecal coliforms and fecal streptoccoci, thus requiring less amount of chlorine for disinfection. The advantage of this system is the low energy and water requirement for cleaning of filter bed. The periodic backwash adopted 30 seconds air and water and 30 seconds water cleaning every 90 minutes filter operation. Thisis equivalent to 1-2% of filtered water production. Mechanical cleaning system on the other hand, requires very low energy requirement (<1% of filtered water production).

Key words: High rate flocculator/filter, water treatment, wastewater treatment, buoyant medium, flocculant, floc size, backwash

주제어: 고효율 응집/여과장치, 상수처리, 하수처리, 부상여재, 응집제, 플록크기, 역세척

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1. INTRODUCTION

In the last two decades, there have been a number of buoyant media filtration and flocculation systems have been tried in water treatment and wastewater treatment as flocculators and filters (Vital et al., 1990; Ishigaki, 1991; Washe et al., 1993; Sugaya, 1993; Sahnoun et al., 1994; Schulz et al., 1994; Ngo and Vigneswaran, 1995, 1996, 1998; Vigneswaran and Ngo, 1998, 1999).

The researchers from the University of Technology, Sydney (UTS) were successful to develop a high rate static floating medium flocculator/filter. This basicconcept involves the passing of destabilized particles through a packed bed of buoyant material (polystyrene or polypropylene) from the top of the filter. During the passage of the particlesthrough the filter, both flocculation and the solid-liquid separation take place within the filter bed itself. The flocculation occurs by the contact of destabilized suspensions within the pores of the medium. This is followed by the separation of particles and flocs by the filter medium. The previous studies showed that the downflow floating medium filter can successfully be used as an excellent static flocculator due to its ability to produce uniform micro flocs and as prefilter dueto its ability to remove pollutants to a certain degree with negligible headloss development. Meanwhile, this system was operated successfully at the high filtration rate under normal complete saturated or complete saturated conditions (without any water remaining in the filter bed during the filter run).

The applicability of this system in water treatment and wastewater treatment was studied in two parts to determine: (i) its ability functioning as a static flocculator, and (ii) its effectiveness as a solid-liquid separation unit. Different models of backwash methods were also studied.

2. EXPERIMENTAL INVESTIGATION

Polypropylene beads (of 3.8 mm diameter and 0.870 g/cm^3 density) and polystyrene beads (of 1.9 mm diameter and 0.05 g/cm^3 density) wereused as the filter medium. The floating beads were packed in the filter column with a porosity of approximately 0.36. A grid (stainless steel coarse mesh) at the top was used to restrain the medium. A rapid mixing device was fabricated by tightly winding 3-6 mm tube around a column to produce a rapid mixing time of approximately 1-second in all experiments. The rapid mixing was provided to uniformly mix the particles with chemical and destabilize them. A schematic diagram of the system is shown in **Fig. 1**. The coagulants used were commercial ferric chloride (from Ajax), polyaluminium chloride (WAC-HB from Atochem) and polysilicato-iron (molar ratio of silica and iron is 3 to 1 from Suido Kiko Kaisha). The optimum flocculant dose was determined by standard jar and filterability tests. The experiments were conducted with an artificial kaolin clay suspension and the effluent from the secondary sewage effluent. During the experiments, the filtration rate in the filter was maintained constant at a known value (e.g. 15, 30, 45 m^3/m^2 · h). The headloss through the bed was directly recorded from the pressure transducers. The filter system was backwashed using air from an air compressor (20-30 kPa) and water of turbidity less than 2 NTU at a rate of 20-30 m^3/m^2 · h. Typical cleaning of column involved a combination of upflow air and water for 30 seconds followed with upwards flow of water for another 30 sec. The mechanical backwash for the floating medium was also tested using a rotating bar with paddles installed to stir the floating medium at a rate of 40 rpm for 30

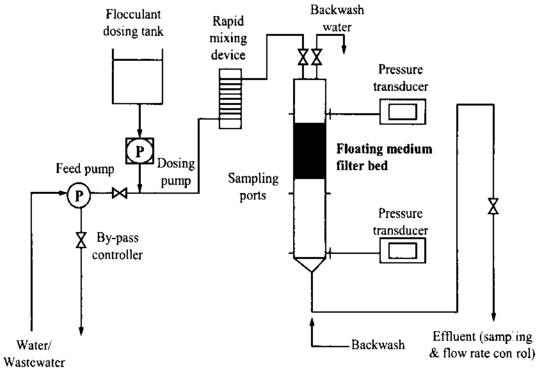


Fig. 1. Experimental set-up.

상하수도학회지. 논문
19권 2호. pp. 149-154. 2005

seconds. The water is then sent from the top (20-30 $m^3/m^2 \cdot h$) for 30 seconds to complete the backwash process. The performance of the floating medium filter was evaluated in terms of filtrate quality (turbidity, suspended solids, phosphorus, faecal coliform and faecal streptoccoci) and headloss development.

3. RESULTS AND DISCUSSION

3.1. In water treatment

3.1.1. Saturated flow condition

An artificial kaolin clay suspension of 54 NTU was used as the feed water. Particle size and density of kaolin clay used were 4.26 m (50 percentile size) and 2.71 g/cm^3, respectively. In most of the experiments, ferric chloride at its optimum dose of 35 mg/L was used. The floating medium depth was kept at 90 cm. The experiments were conducted at different filtration velocities with two different filter media. The flocculation in floating medium filter beds occurs when destabilized particles agglomerate to form micro-filtrable flocs.

The experimental conditions and the corresponding velocity gradient values are presented in **Tables 1** and **2** together with the average floc size. It is interesting to note that although the G value was high, the flocs are uniform and are of filtrable size. It is also clear from the experiments with different depths that the flocs did not change with depth (in other words with different contact time). In most cases, the flocs were more or less remained constant through out the filter run (**Table 2**). This indicated that the ultimate floc size (steady state) has been achieved in a short contact time as a result of very high velocity gradient values. This system can thus be used as an excellent static flocculator in producing uniform filtrable flocs.

Table 1 shows that the flocs produced from the system were uniform and filtrable size. In most cases, the flocs were more or less remained constant through out the

Table 1. Floc sizes at different filter depths, filtration velocities and filter media (saturated condition with in-line FeCl3 addition)

Filter media	Filter depth (cm)	Filtration velocity ($m^3/m^2 \cdot h$)	Ave.velocity gradient (s-1)	Contact mixing time (s)	Ave. diameter of floc df(m)
Polystyrene	45	30	225	54	13.2
Polystyrene	65	30	267	78	13.4
Polystyrene	90	30	289	108	13.8
Polystyrene	115	30	306	138	14.0
Polystyrene	121	30	317	145	14.0
Polystyrene	90	15	163	216	15.6
Polystyrene	90	30	289	108	13.8
Polystyrene	90	45	420	72	12.0
Polystyrene	90	60	608	54	11.2
Polystyrene	90	30	289	108	13.8
Polypropylene	90	30	297	108	13.2

Table 2. Flocculator performance at different filtration times (saturated condition, filter depth = 90 cm, FeCl3 dose = 35 mg/L)

v ($m^3/m^2 \cdot h$)	Floc size (m)				
	0 min	60 min	120 min	180 min	240 min
15a	16.4	16.1	15.3	15.2	15.6
30a	13.5	14.1	13.9	13.5	14.2
45a	11.6	11.5	11.7	12.5	12.8
60a	10.9	11.1	11.2	11.1	11.5
60b	12.6	12.2	12.7	13.8	14.6

Note: a: polystyrene beads, b: polypropylene beads.

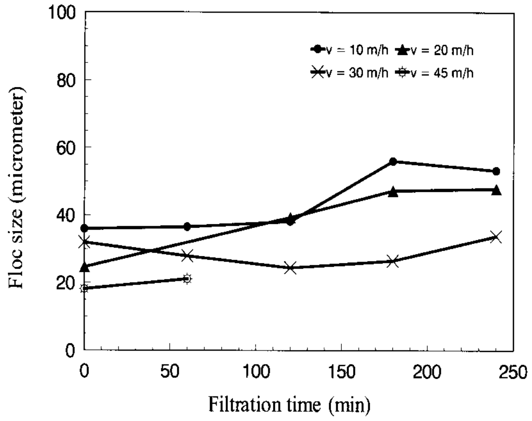


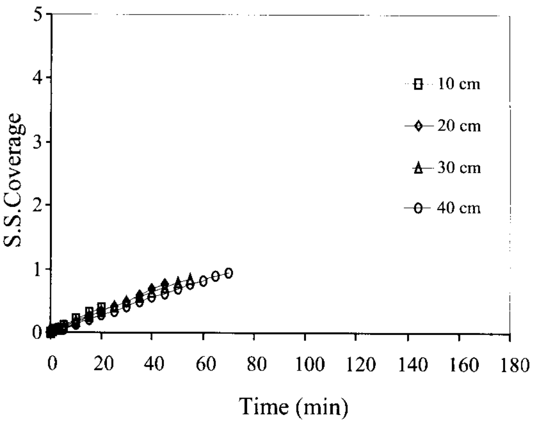
Fig. 2. Variation of floc size at different filtration velocities (unsaturated condition, polypropylene medium (d = 3.8 mm), filter depth = 40 cm; PSI = 2.5 mg/L).

filter run. This indicated that the ultimate floc size (steady state) has been achieved in a short contact time. This system can thus be used as an excellent static flocculator in producing uniform filtrable flocs. Both the media produced uniform flocs of size of 12-15 m.

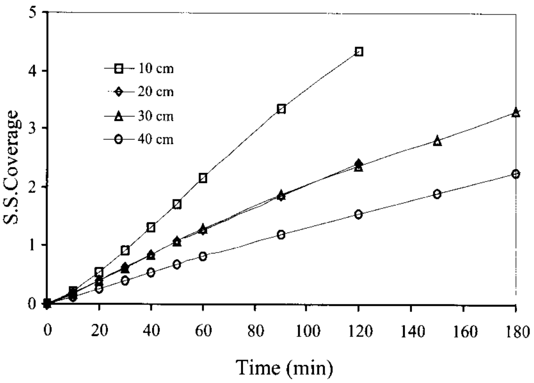
3.1.2. Unsaturated flow condition

Experiments were also conducted with unsaturated conditions at different velocities of 10, 20, 30 and 45 $m^3/m^2 \cdot h$. The polypropylene filter depth was kept at 40 cm. The coagulants used were polysilicato-iron (molar ratio of silica and iron is 3 to 1 from Suido Kiko Kaisha). The optimum flocculant dose was 2.5 mg/L (determined by standard jar test and filterability testing). The experiments were conducted with an artificial kaolin clay suspension (a mixing of 67 mg/L of kaolin clay with tap water). During the experiments, the filtration rate in the filter was maintained constant at a known value (e.g. 10, 20, 30, 45 $m^3/m^2 \cdot h$). In all cases, this unsaturated system functioned as an excellent flocculation system in producing uniform microflocs. As can be seen from **Fig. 2**, the floc size decreased as the filtration velocity increased. The floc size was much larger (43.7 m) at the filtration rate of 10 $m^3/m^2 \cdot h$ compared to the velocity rate of 45 $m^3/m^2 \cdot h$ (19.6 m). The floc size was uniform but slightly increased with filtration time.

Deterioration in effluent quality (increase in C/Co with



a) Saturated



b) Unsaturated

Fig. 3. Temporal variation of specific surface coverage for different filter depths (Polystyrene medium (1.9 mm) PSI 2.5 mg/L; filtration velocity = 30 m/h).

time) was observed in all cases when the velocity was increased. The decrease in floc size with the increase in the filtration velocity can be attributed to the increase in the deterioration of filtrate quality.

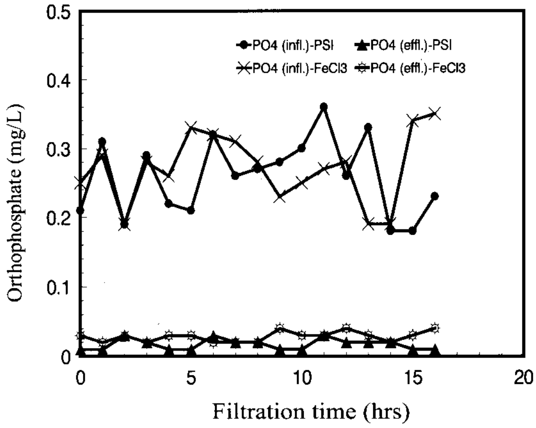
Fig. 3 shows a comparison between saturated and unsaturated flow mode filter in terms of specific surface coverage. As can be seen from the figure, the floc deposition is uniform throughout the filter bed under saturated conditions while for unsaturated flow conditions, majority of the deposition of flocs occurs at the top layer of the filter bed. However, surface coverage was higher when the filter was operated under unsaturated conditions.

Table 3. Mean percent bacteria removal for various filtration rates

Filtration Velocity ($m^3/m^2 \cdot h$)	Mean % removal (faecal coliforms)	Mean % removal (faecal streptoccoci)
15	96.4	97.1
30	95.4	95.3
45	57.8	61.3

3.2. In wastewater treatment

In this study, the experiments were conducted using the effluent from the secondary settler of a sewage treatment plant. The experiments were conducted at different filtration velocities of 15, 30 and 45 $m^3/m^2 \cdot h$ with the depth of 120 cm. The results show that the floc sizes that produced from the system was in a good range of filterable size (14-25 m). The highest phosphorus removal efficiency (93%) was achieved at the rate of 15 $m^3/m^2 \cdot h$. Even at the filtration rate of 45 $m^3/m^2 \cdot h$, the filter system still could remove more than 80% of orthophosphate. The headloss development was lower than 24 cm for all cases. The results also indicated that the variation in filtration rates had no significant effect on the faecal coliform and faecal streptococci removal (up to 30 $m^3/m^2 \cdot h$) (**Table 3**). The filter system is just as effective at removing bacteria when operated at a filtration velocity of 15 $m^3/m^2 \cdot h$, as it is when operated at 30 $m^3/m^2 \cdot h$. However, a lot more number of FC and FS escaped through the filter bed when the filtration rate went up to 45 $m^3/m^2 \cdot h$. The bacterial removal was found to be about 30% lower compared to the other two cases. As shown in **Fig. 4** and **Table 3**, the system is extremely effective in removing phosphorus and bacteria from the secondary sewage effluent. During 16 hours of filter run, the number of faecal streptoccoci in the treated effluent were much lower than the effluent discharge standard of 200 No./100mL whilst the removal of faecal coliform was higher than 90%. The chlorine dose required can significantly be reduced. The phosphorus (as orthophosphate) was also removedup to 90%. Since the effluent from the filter system was only 0.01-0.07 mg/L, it not only can meet the criteria of the effluent discharge for nutrients in treatment plant effluent (< 0.3 mg/L total phosphorus) but also fully satisfy the quality requirement for water reuse (< 0.07 mg/L).



($FeCl_3$ conc. = 15 mg/L; PSI conc. = 2.5 mg/L)

Fig. 4. Bacteria removal efficiency with filtration time at different flocculants (v = 30 $m^3/m^2 \cdot h$; L = 120 cm; backwash cycle - every 90 min).

3.3. Backwash method

The suitable filter backwash method for floating medium filter was operated at a combination of upflow air and water (a combination of air (30 kPa) and water (20-30

Table 4. Performance of the floating medium filter at different backwash conditions (polypropylene beads, bed depth = 1200 mm, no flocculant addition, filtration rate = 20 $m^3/m^2 \cdot h$; backwash method = air (30 kPa, 30 sec) + water (30 $m^3/m^2 \cdot h$, 30 sec) from the bottom; water backwash for another 30 sec at the same rate)

Backwash Frequency (min)	Filtered water production (6 h-filter run, m^3)	Backwash water volume (6 h-filter run, m^3)	Suspended solids removal TSS (%)	Total phosphorus (%) (cm)	Headloss after 6 h
90	1.357	0.0226	67.8	35.7	14
120	1.357	0.0169	57	33.2	19.5
150	1.357	0.0113	52.2	37.1	46

$m^3/m^2 \cdot h$) in upwards direction for 30 seconds then followed with upwards flow of water (20-30 $m^3/m^2 \cdot h$) for another 30 seconds. The backwash frequency of 90-120 min was found to be suitable for a long filter run (**Table 4**). The consumption of backwash water was only 1.2-1.8% of filtered water production. Later on, an option of mechanical backwash using rotating paddles; followed by downflow water backwash appears to be the cheapest. In this backwash method, no air is necessary and water requirement can be reduced by another 35%.

4. CONCLUSIONS

As evident from the results, the system was not only successful as a static flocculator but also a filter. It produced uniform filterable flocs (around 15 m) through out the bed and most of these flocs were retained in the bed itself. The operation of frequent but a short duration of backwash is necessary. The backwash would need very little water and the energy requirement is minimized, especially when adopted the mechanical backwash using rotating paddles, followed by downflow water backwash. Hence, this flocculator/filter system could be a techno-economical alternative to treat water and wastewater as well as wastewater recycling or reuse at high filtration rates (up to 60 m^3/m^2.h). On the other hand, this system is easy to maintain and operate. A complete system with an automation backwash system can lead to the continuous filter run without termination.

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