Stormwater Runoff Treatment Filtration System and Backwashing System

J. H. Lee(✉), M. J. Lee, and S. H. Yang

Division of Civil, Environmental and Urban-Transportation Engineering,
Korea National University of Transportation,
50 University Road, Chungju, Chungbuk 27469, Korea
jlee@ut.ac.kr

Abstract. This study has been carried out to evaluate the applicability of the pilot scale the hybrid type of stormwater runoff treatment systems (SFS) for treatment of combined sewer overflow. And, to determine the optimum operation parameter such as coagulation dosage concentration, effectiveness of coagulant usage, surface loading rate and backwashing conditions. The SFS system is consisted of hydrocyclone coagulation/flocculation with polyaluminium chloride silicate (PACS) and upflow filter to treat combined sewer overflows. There are two modes (without PACS use and with PACS use) of operation for STS system. In case of without coagulant use, the range of SS, turbidity removal efficiency were 72.0–86.6% (mean 80.0%), 30.9–71.1% (mean 49.3%), respectively. And, the recovery rate of filter was 79.2–83.6% (mean 81.2%) the rate of remained solid loading in filter media was 16.4–20.8% (mean 18.8%) after backwashing. In case of SFS run with coagulant use, The range of influent flowrate and surface overflow rate were 6.8–8.0 m^3/day (mean 7.2 m^3/day), 163.2–191.8 m^3/m^2/day (mean 172.4 m^3/m^2/day), respectively. The influent turbidity, SS concentrations were 59.0–90.7 NTU (mean 72.0 NTU), 194.0–320.0 mg/L (mean 246.7 mg/L), respectively. The range of PACS dosage concentration was 6.0–7.1 mg/L (mean 6.7 mg/L). The range of SS, turbidity removal efficiency were 84.9–98.2 (mean 91.4%), 70.7–96.3 (mean 84.0%), respectively. It was found that removal efficiency was enhanced with PACS dosage. The recovery rate of filter was 92.0–92.5% (mean 92.3%) the rate of remained solid loading in filter media was 6.1–8.2% (mean 7.2%) after backwashing. In case of coagulant use, the particle size of effluent is bigger than influent particle size. The results showed that STS with PACS use more effective than without PACS use in SS and turbidity removal efficiency and recovery rate of filter.

Keywords: Stormwater · Filtration · Combined sewer overflow
Backwashing · Hydrocyclone

1 Introduction

During storm events, many wastewater treatment plants may not be able to achieve the requested effluent quality. In the worst case, untreated CSO may bypass the plant. To overcome and mitigate these problems related to CSO and stormwater runoff, engineers

G. Mannina (Ed.): UDM 2018, GREEN, pp. 886–892, 2019.
https://doi.org/10.1007/978-3-319-99867-1_153

and others are constantly seeking best management practices (BMPs); filtration, sedimentation, chemical flocculation, and vortex separators. Among the BMPS, the upflow direct filtration system is quite outstanding for SSO and CSO treatment (Bernardo 2006). Solid particles smaller than 30 μm in diameter are not easily separated by conventional types of upflow filtration system. To overcome this problem, upflow filter combined with hydrocyclone flocculator has been applied to treatment of the micro particles in urban storm runoff. We have conducted a pilot scale studies on treatable potential of micro particles using stormwater filtration system (STS) which used rectangular shape media made of polypropylene and polyethylene materials. This study has been carried out to evaluate the applicability of the pilot scale SFS and determine the optimum operational parameter such as coagulation dosage concentration, effectiveness of coagulant usage, surface loading rate and backwashing conditions.

2 Materials and Methods

2.1 Setup of the Pilot Scale Stormwater Filtration System

The pilot scale stormwater filtration system (STS) was installed at the municipal wastewater plant serving the city of Cheongju (CWTP) Korea. CWTP has an average flow of 2.8 million cubic meter a day The STS influent submersible pump was installed at the existing grit chamber. The pilot scale stormwater filtration system (STS) used for experiments is shown in schematically in Fig. 1. During a storm event, the discharge of untreated sewage and stormwater are inflow of CWTP. STS consisted of two hydrocyclones for coagulation and flocculation, filter column, backwash blower and pump, air flow meter, pressure gauge, valve fitting, centrifugal pump, submersible pumps, automatic switch controller, chemical flowrate gauge, injection pump, electromagnetic flow meter, effluent and underflow storage tank. Influent submersible pumped from grit chamber was transfer to the storm water storage tank. Influent from storm water storage tank was injected to hydrocyclone with coagulant to hydrocyclone and underflow returned to the influent pipe to improve flocculation ballasting.

2.2 Process Operation and Measurement Method

Graded particle size(<100 μm) materials were vigorously mixed with grit chamber wastewater and stored at storage tank and mixed continuously using a mixer in order to obtain homogeneity. A laser diffraction particle size analyzer (Shimadzu model SALD-2101) was used to determine the particle size and distribution. To determine the removal efficiency for various influent SS concentrations and turbidity (NTU), a series of tests were performed. The range of surface loading rate for filtration was 453.6–528.0 m^3/m^2/day (mean 496.0 m^3/m^2/day), and the filtration retention time was 3.8–4.4 min (mean 4.1 min). The influent SS concentrations, turbidy were varied ranging from 118.0 to 366.0 mg/L (mean 238.8 mg/L), and 39.6 to 114.0 NTU (mean 76.2 NTU).

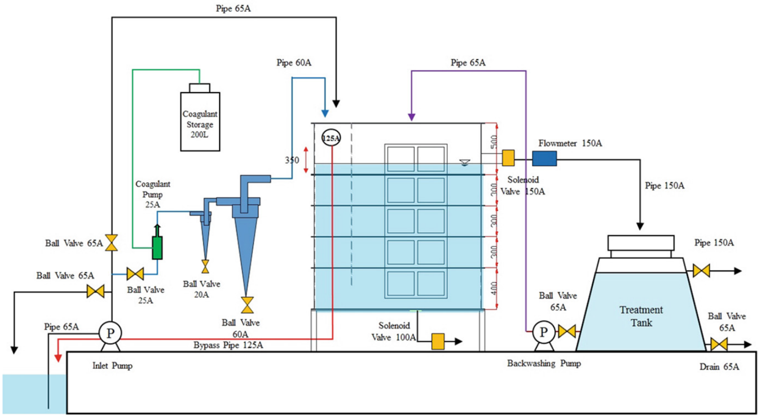


Fig. 1. Schematic diagram and installed photo of the pilot scale stormwater filtration system.

3 Results and Discussion

3.1 STS Operation Without Coagulant

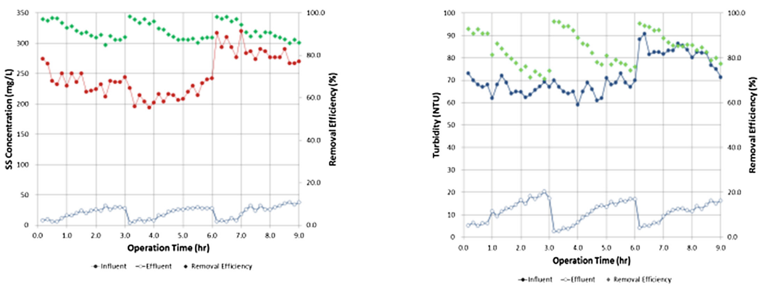
The STS run without coagulant dosing had a total operation time of 14.8 h. Through more than 6 experiments were carried out with various conditions such as different SS concentration. Results calculated in terms of SS and turbidity removal efficiency are shown in Table 1. Results showed that the range of SS, turbidity removal efficiency were 72.0–86.6% (mean 80.0%), 30.9–71.1% (mean 49.3%), respectively. The variation of surface overflow rate, retention time, head loss, and SS solid loading rate were shown in Fig. 3. When solid loading increased, SS removal efficiency was rapidly decreased. The calculated average solid load was 12.4 kg/m^2. There has uncorrelated between removal efficiency and head loss were shown in Fig. 4. A number of samples were analyzed for particle size distribution. The range of D_{Mean} for influent and effluent were 4.6–35.8 µm (mean 18.3 µm), 2.7–24.5 µm (mean 8.3 µm) respectively.

Table 1. Summary results operation condition and SS and turbidity removal efficiency without coagulants

Test No	Duration (hr)	Range	Flowrate (m^3/day)	Linear Velocity (m/hr)	Retention Time (min)	SOR ($m^3/m^2 \cdot d$)	Influent Turbidity (NTU)	Influent SS (mg/L)	Effluent Turbidity (NTU)	Effluent SS (mg/L)	SS Load (kg/m^2)	Head Loss (mm)	Turbidity Removal (%)	SS Removal (%)
		Min	18.9	18.9	3.8	453.6	76.2	200.0	30.4	38.0	-	-	58.9	79.6
1st	1.3	Max	22.0	22.0	4.4	528.0	114.0	260.0	34.7	42.0	5.8	80.0	71.1	85.4
		Mean	20.6	20.6	4.1	494.4	90.3	226.8	32.4	40.3	-	-	63.4	82.1
		Min	19.0	19.0	4.1	456.2	64.5	204.0	34.1	40.0	-	-	38.6	79.6
2nd	1.3	Max	20.7	20.7	4.4	495.6	82.1	246.0	41.0	46.0	5.0	73.0	55.4	83.2
		Mean	19.8	19.8	4.2	476.3	74.4	224.8	38.1	42.0	-	-	48.4	81.2
		Min	19.4	19.4	3.9	465.6	39.6	118.0	20.1	28.0	-	-	31.7	74.6
3rd	1.4	Max	21.6	21.6	4.3	518.4	51.9	150.0	28.6	32.0	4.1	64.0	58.1	80.0
		Mean	20.7	20.7	4.1	496.3	44.6	133.8	23.7	29.6	-	-	46.3	77.8
		Min	19.7	19.7	3.9	472.8	63.2	200.0	35.0	40.0	-	-	31.3	73.0
4th	3.6	Max	21.5	21.5	4.3	516.0	74.6	228.0	43.4	54.0	16.0	110.0	53.1	81.3
		Mean	20.7	20.7	4.1	495.7	69.2	216.0	39.3	46.1	-	-	43.1	78.4
		Min	20.1	20.1	3.9	482.4	70.5	222.0	34.6	42.0	-	-	30.9	67.6
5th	3.6	Max	21.8	21.8	4.2	523.2	84.4	310.0	49.8	72.0	19.4	145.0	56.9	85.2
		Mean	21.0	21.0	4.0	502.9	78.0	260.8	41.9	52.8	-	-	46.1	79.2
		Min	20.2	20.2	3.9	484.8	85.2	286.0	37.7	46.0	-	-	44.9	72.0
6th	3.6	Max	21.8	21.8	4.2	523.2	108.7	366.0	49.8	88.0	24.0	155.0	62.0	86.6
		Mean	20.9	20.9	4.0	500.9	93.5	315.3	43.4	58.9	-	-	53.4	81.3
		Min	18.9	18.9	3.8	453.6	39.6	118.0	20.1	28.0	4.1	64.0	30.9	72.0
Total	14.8	Max	22.0	22.0	4.4	528.0	114.0	366.0	49.8	88.0	24.0	155.0	71.1	86.6
		Mean	20.7	20.7	4.1	496.0	76.2	238.8	37.8	47.0	12.4	104.5	49.3	80.0

3.1.1 Filter Backwashing and Solid Mass Balance in Case of Without Coagulant Use

To backwash a filter, the influent value is closed, and drained whole wastewater. After drain column as filled with effluent and 1st backwashing by blowing air 3 min, and repeat twice in the same way. The SFS system was backwashed by blowing air with effluent water through for 3 min at a rate of 60 $m^3/m^2/h$ after two times backwash, whole drained wastewater was collected for mass balanced analysis. 6 series of backwashing experiments were conducted to determine the effectiveness of air blowing. The recovery rate of filter was 79.2–83.6% (mean 81.2%) the rate of remained solid loading in filter media was 16.4–20.8% (mean 18.8%) after backwashing (Fig. 2).



(a) SS (b)Turbidity

Fig. 2. The results of filtration pilot test in CWTP: with hydrocyclone coagulation.

3.2 SFS Operation with Coagulant

The SFS run with coagulant dosing had a total operation time of 4 h. Among the several types of coagulants, polyaluminium chloride silicate (PACS) was selected for stormwater treatment. As the results of Jar test showed that PACS optimum dosage was 7.0 mg/L, which these conditions left residual turbidity to less than 2.0 NTU. Through more than 3 experiments were carried out with various conditions such as different SS concentration. The range of influent flowrate and surface overflow rate were 6.8–8.0 m^3/day (mean 7.2 m^3/day), 163.2–191.8 m^3/m^2/day (mean 172.4 m^3/m^2/day), respectively. The influent turbidity, SS concentrations were 59.0–90.7 NTU (mean 72.0 NTU), 194.0–320.0 mg/L (mean 246.7 mg/L), respectively. The range of PACS dosage concentration was 6.0–7.1 mg/L (mean 6.7 mg/L). Results showed that the range of SS, turbidity removal efficiency were 84.9–98.2 (mean 91.4%), 70.7–96.3 (mean 84.0%), respectively. The range of DMean for influent and effluent were 13.1–27.2 μm (mean 18.6 μm), 14.3–31.9 μm (mean 22.0 μm) respectively. The correlation coefficient (R2) between SS and turbidity was 0.90 as shown in Fig. 3.

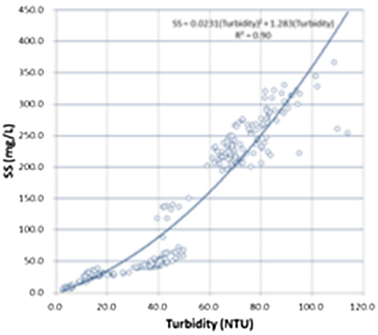


Fig. 3. The correlation coefficient (R^2) between SS and turbidity

3.2.1 Filter Backwashing and Solid Mass Balance in Case of with Coagulant Use

Backwashing begins when the drainage pipe valve at the filtration tank bottom is completely open (backwashing stage 1). Backwashing stage 2 was using air bubbles and water jet washing the media for 3 min and open the drainage valve. After backwashing stage 1, 2, 92.0–92.5% (mean 92.3%) of SS loading was discharged from filtration tank. 3 series of backwashing experiments were conducted to determine the effectiveness of air blowing. The results of 3 series of the backwashing experiments and SS loading mass balance analysis are summarized in Fig. 4. The recovery rate of filter was 92.0–92.5% (mean 92.3%) the rate of remained solid loading in filter media was 6.1–8.2% (mean 7.2%) after backwashing.

Influent		
Item	Value	Unit
Q_{in}	7.2	m³/hr
T_{in}	3.00	hr
SS_{in}	246.7	mg/L
	5.3	kg
	100.0	%

Pilot Plant			
Item	Settling Part	Filtration Part	Unit
Q	7.2		m³/hr
V	0.6	1.4	m³
Retention Time	1.7	11.7	min
Filtration Area	0.4	1.0	m²
Linear Velocity	35.5	7.2	m/h
SS Load	-	5.3	kg/m²
SOR	-	172.4	m³/m² · day
PACS	-	6.7	mg/L
Head Loss	-	63.3	mm
Residual SS	-	0.4	kg
	-	7.2	%

Effluent		
Item	Value	Unit
Q_{Out}	7.2	m³/hr
T_{out}	2.78	hr
V_{Out}	20.0	m³
SS_{Out}	21.0	mg/L
	0.4	kg
SS_{Out} / SS_{in}	7.9	%
SS_{REM}	92.3	%

Backwashing 1 - Stagnant Water		
Item	Value	Unit
Air Q	10.0	m³/hr
Air T	5.0	min
Air V	0.8	m³
Air Injection Rate	10.0	m³/m²·hr
Backwashing 1 V	1.9	m³
SS_{BW1}	1663.3	mg/L
	3.2	kg
SS_{BW1} / SS_{in}	58.9	%

Backwashing 2 - Treatment Water		
Item	Value	Unit
Air Q	10.0	m³/hr
Air T	5.0	min
Air V	0.8	m³
Air Injection Rate	10.0	m³/m²·hr
Backwashing 2 V	1.9	m³
SS_{BW2}	723.3	mg/L
	1.4	kg
SS_{BW2} / SS_{in}	26.2	%

Fig. 4. SS solid loading mass balance in case of coagulant use.

4 Conclusions

This study has been carried out to evaluate the applicability of the hybrid type of stormwater runoff treatment systems (SFS) and determine the optimum operational parameter such as coagulation dosage concentration, with or without coagulants, surface loading rate and backwashing conditions. The results of Jar test showed that PACS optimum dosage was 7.0 mg/L, which these conditions left residual turbidity to less than 2.0 NTU. In case of SFS run with coagulant use, The range of influent flowrate and surface overflow rate were 6.8–8.0 m^3/day (mean 7.2 m^3/day), 163.2–191.8 m^3/m^2/day (mean 172.4 m^3/m^2/day), respectively. The influent turbidity, SS concentrations were 59.0–90.7 NTU (mean 72.0 NTU), 194.0–320.0 mg/L (mean 246.7 mg/L), respectively. The range of PACS dosage concentration was 6.0–7.1 mg/L (mean 6.7 mg/L). The range of SS, turbidity removal efficiency were 84.9–98.2 (mean 91.4%), 70.7–96.3 (mean 84.0%), respectively. It was found that removal efficiency was enhanced with PACS dosage. The recovery rate of filter was 92.0–92.5% (mean 92.3%) the rate of remained solid loading in filter media was 6.1–8.2% (mean 7.2%) after backwashing. In case of coagulant use, the particle size of effluent is bigger than influent particle size. The results showed that STS with PACS use more effective than without PACS use in SS and turbidity removal efficiency and recovery rate of filter. The SFS system, which came out to solve the problems of low efficiency of removing micro particles of upflow filtration type stormwater treatment devices, therefore SFS is considered as an alternative system.

Acknowledgements. This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. 2017R1D1A1B03033724).

References

Balmforth, D.J.: The pollution aspects of storm-sewage overflows. Water Environ. J. **4**(3), 219–226 (1990)

Chow, M.F., Yusop, Z.: Characterization and source identification of stormwater runoff in tropical urban catchments. Water Sci. Technol. **69**(2), 244–251 (2014)

Chaters, F.J., et al.: Particle size distribution variance in untreated urban runoff and its implication on treatment selection. Water Res. **85**, 337–345 (2015)

Sartor, J.D., et al.: Water pollution aspects of street surface contaminants. J. WPCF **46**(3), 458–467 (1974)

Ebeling, J.M., et al.: Evaluation of chemical coagulation-flocculation aids for the removal of suspended solids and phosphorus from intense recirculating aquaculture effluence discharge. Aquaculture Eng. **29**, 23–42 (2003)

El-Gendy, A.S., et al.: Treatment of combined sewer overflow using retention treatment basin assisted with polymer chemical coagulation. Water Environ. Res. **80**(9), 763–774 (2008)

El Samrani, A.G., et al.: Chemical coagulation of combined sewer overflow: heavy metal removal and treatment optimization. Water Res. **42**, 951–960 (2008)

Filtration + Seperation (March/April 2010): Wastewater treatment: enhanced biological treatment of storm flows

Ma, Y., Zhu, D.Z.: Improving sediment removal in standard stormwater sumps. Water Sci. Technol. **69**(10), 2099–2104 (2014)

Shimadzu Corporation: Particle Size Analyzer Model: SALD-2101

Torres, A., Bertrand-Krajewski, J.L.: Evaluation of uncertainties in settling velocities of particles in urban stormwater runoff. Water Sci. Technol. **57**(9), 1389–1395 (2008)