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Particle removal properties of stormwater runoff with a lab-scale vortex separator

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ABSTRACT

A lab-scale vortex separator, based on a swirling motion to remove settleable particles, was used to remove suspended solids in urban stormwater runoff. However, the treatment is limited to the removal of large settleable particles. The synthesized stormwater runoff was made with tap water and the addition of road sediment. The vortex separator has internal components designed to enhance vortex separation by minimizing the turbulence, increasing the efficiency, and preventing captured pollutants from washout. As the flow continues to spiral down around the inlet baffle, a low energy vortex motion directs settleable particles into the protected sediment storage zone. Advanced vortex separation provided an extendable and stabilized flow path while protecting the captured pollutants for a wide range of flow rates. The range of the inflow rate was 30–115 l/m, and the size of the influent particles varied from 75 to 200 μm. Overall removal efficiencies of 51.8% for SS, 26.6% for COD, 70.5% for TP, and 35.6% for TN were achieved. The efficiency of particle removal for a high inflow rate was better than for a low inflow rate under the same condition of influent particles. The particle removal efficiency of the inlet baffle improved by about 5–10% compared to without an inlet baffle.

Keywords: Stormwater; Runoff; Separation; Particle removal; Vortex; Baffle

1. Introduction

Stormwater runoff from paved areas such as highways, roads, parking lots and bridges has been identified as a critical non-point source pollution to receiving waters. The typical pollutant constituents of primary concern include: TSS, nutrients, heavy metals, PAHs, oil, and grease [1–3]. The concentration and load of such pollutants are closely related to the land use and rainfall conditions. In order to reduce the impact of stormwater runoff on receiving waters, engineers and managers use best management practices (BMPs): catch basins, sedimentation ponds, swales, filtration systems, and vortex separators [2].

A vortex separator is also known as a dynamic separator, a swirl concentrator, or a hydrocyclone. In Europe and the United states, this technology is used to treat and control urban pollution and combined sewer overflows,

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and it protects the receiving waters from polluted sewage overflow [4]. Recently, the vortex separator has been used in the treatment of stormwater runoff. The vortex separator is a simple device, which causes the centrifugal separation of particles in a fluid stream. Unlike the slow settling within a settling tank, the vortex separator system yields fast separation and utilizes less space. A vortex separator consists of a vertical cylinder, a tangential inlet, and two outlets: one for the concentrated solids and one for the effluent. A vortex separator has no moving parts, and the influent tangentially comes into the separator producing the essential swirling motion. The separation action of a vortex separator treating particles is the consequence of the swirling flow that produces centrifugal force on the fluid and the suspended particles [4,5].

A variety of vortex separators have been developed to treat urban stormwater runoff. The majority of stormwater runoff treatment is trapping particles smaller than 100 μm in diameter. Particles below 100 μm in diameter are not easily separated by conventional types of vortex separators [6,7]. SS removal is limited to the large size of settleable particles.

We developed a lab-scale vortex separator equipped with an inlet baffle to improve the SS removal efficiency. The vortex separator has internal components designed to enhance vortex separation by minimizing turbulence, increasing efficiency, and preventing captured pollutants from washing out. To determine the efficiency of various operation conditions, a series of experiments were performed with different particle sizes and inflow rates.

2. Materials and methods

2.1. Experimental set up

A vortex separator was used as the physical process to separate the particles from stormwater runoff. The vortex separator used in the experiment is shown schematically in Fig. 1. It mainly consisted of four different parts, which were a vortex separator, 0.4 m^3 inflow storage tank, mixing pump, and flow equalization tank. The Inflow to separate the sediment was pumped from the storage tank to the flow equalization tank and injected into the vortex separator. The inflow rate to the separator was adjusted by using a valve located on inlet pipe. The total height of the separator was 480 mm. The diameter of the outside cylinder was 300 mm. The detailed dimensions of the vortex separator are presented in Table 1. The flow entering tangentially into the separator induced swirling motion, which generated the apparent centrifugal force on the fluid and particles. However, the particles received larger force than the fluid due to the density and bumped into the outside cylinder wall. Once at the exterior cylinder wall, the particles settled by gravity. The inlet part of the separator was designed using a spiral waterway called the "inlet baffle". It formed a high vortex velocity, which helped improve the efficiency of particle removal.

2.2. Experimental methodology

In an ordinary way, the stormwater runoff was made with tap water and the addition of road sediment. The vortex separator operated at a base flow rate of 65 l/m. During the series of experiments, the flow rate

Table 1
Dimensions of the vortex separator

Component of separator	Measurements (mm)
Height of the separator	480
Diameter of the outside cylinder	300
Diameter of the inside cylinder	210
Diameter of the inlet pipe	50
Height of the inlet	400
Height of the inlet	400
Height of the outlet	300

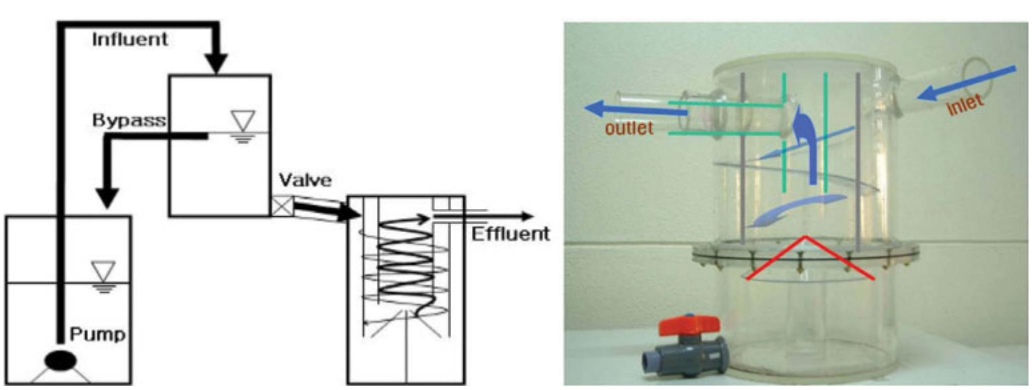

Fig. 1. Schematic diagram of the vortex separator.

was varied from the base condition to study the respective influence on the separation performance. Influent particle sizes were varied from 75 to 200 μm. The size distribution of the particles in road sediment was classified by 75, 90, 150 and 200 μm mesh sieves. The particles retained in each sieve were collected, dried and weighted. The experiment was repeated two or three times for each condition to minimize experimental errors, and the mean values were taken as the result.

3. Results and discussions

3.1. Effect of the inlet baffle

An experiment was performed to investigate the effect of the inlet baffle on the removal of pollutants. A summary of the mean concentration for SS, COD, TN, and TP from each separator are presented in Table 2. The average influent concentrations were 380 mg/l for SS, 7.9 mg/l for COD, 5.8 mg/l for TN, and 2.8 mg/l for TP, respectively. The effluent concentration of SS in the separator with the inlet baffle ranged from 96 to 322 mg/l and the mean value was 183 mg/l, and the overall mean value of SS removal was 51.8%. The effluent concentration of SS in the separator without the inlet baffle varied from 190 to 220 mg/l and the mean value was 207 mg/l, and the overall mean value of SS removal was 45.5%. SS removal efficiency with the inlet baffle improved by about 5–10% compared to the separator without the inlet baffle. Similar results were found in the other pollutant parameters. This might be caused by the enhanced vortex velocity from the inlet baffle. SS removal efficiency increased as the centrifugal force on the fluid and the particles increased (Fig. 2).

To understand the factors affecting the removal of particles in the separator, the size distribution of the particles in the effluent was measured [8]. Fig. 3 shows the results for the influent and effluent at each separator. Most particles in the influent were in the size range of 100–1000 μm. The distribution of the particles in the influent was compared with the effluent, which is passed through each separator. The vortex separator with the inlet baffle completely trapped particles larger than 150 μm. Moreover, most of the particles were in the size range of 1–100 μm. Without the inlet baffle, it effectively trapped particles larger than 270 μm. Particles below 100 μm in diameter are hardly separated by conventional types of vortex separators, and remained in the suspension of the effluent [6,8]. The vortex separator with inlet baffle was more effective in the removal of fine particles.

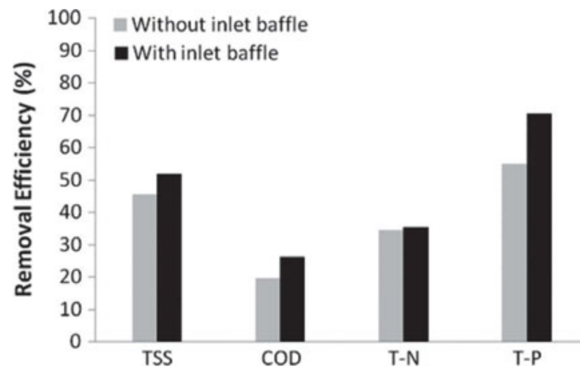

Fig. 2. Comparison of the mean removal efficiency.

3.2. Removal of SS classified by particle diameter

To evaluate the performance of the vortex separator mainly based on SS removal, it was necessary to reproduce the ranges of the particle size using road sediment. The particle size ranges were $d_p < 75$ μm, $90 < d_p < 150$ μm, $150 < d_p < 200$ μm and $d_p > 200$ μm. The influent was simulated SS concentration by mixing with tap water to represent rainfall runoff as much as possible. The operational results of the vortex separator in the range of 30–115 l/m in regard to the inflow rate are presented in Table 3. As a result of the experiment, the efficiency of SS removal was 26.7–34.5%, 66.0–70.6%, 93.3–96.5% and 96.8–98.3% for particle size ranges of $d_p < 75$ μm, $90 < d_p < 150$ μm, $150 < d_p < 200$ μm and $d_p > 200$ μm, respectively. When the larger particles ($d_p > 150$ μm) were observed, the efficiency of SS removal was high compared to the fine particles ($d_p < 150$ μm).

Table 2
Effect of the inlet baffle on the pollutant removal efficiency

Item	Inflow (mg/l)	Separator with inlet baffle			Separator without inlet baffle		
		Range (mg/l)	Mean (mg/l)	Removal (%)	Range (mg/l)	Mean (mg/l)	Removal (%)
SS	380	96–322	183	51.8	190–220	207	45.5
COD	7.9	5.0–6.4	5.8	26.6	6.1–6.8	6.3	19.2
TN	5.82	3.60–4.02	3.75	35.6	3.26–4.48	3.80	34.7
TP	2.81	0.61–1.02	0.83	70.5	1.12–1.52	1.27	54.8

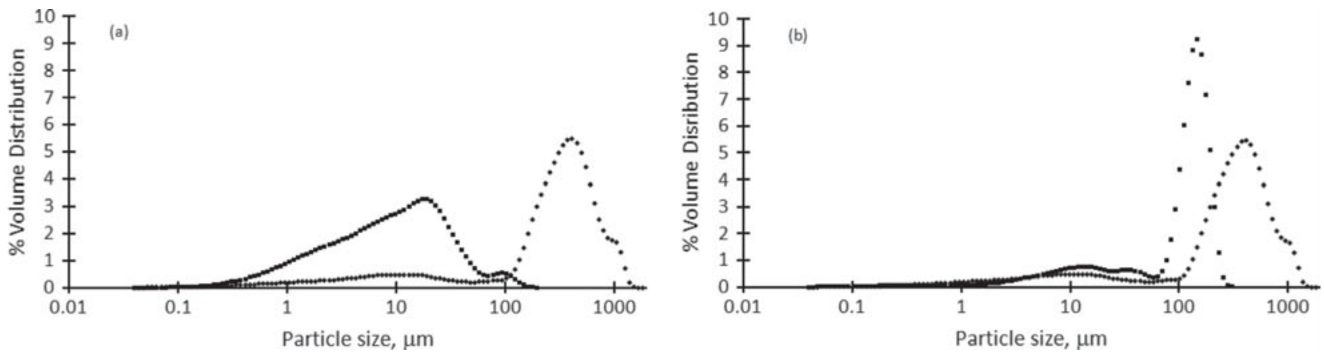

Fig. 3. Comparison of the size distribution of the particles in the influent and effluent which were treated (a) by a separator with an inlet baffle; (b) by a separator without an inlet baffle. (♦) influent; (■) effluent.

Table 3
Removal efficiency for different ranges of particle sizes and inflow rates

Items	Particle size											
	$d_p < 75$ mm			$90 < d_p < 150$ mm			$150 < d_p < 200$ mm			$d_p > 200$ mm		
Inflow rate (l/m)	30	65	115	30	65	115	30	65	115	30	65	115
Min	20.6	22.9	29.3	58.2	59.2	67.1	94.8	89.8	92.3	96.4	95.5	96.7
Max	40.4	37.0	38.7	78.0	71.9	73.0	99.2	97.9	94.4	99.4	99.2	99.2
Mean	26.7	28.3	34.5	66.0	67.0	70.6	96.5	94.2	93.3	98.3	96.8	98.1

For the fine particle (d_p < 75 µm) separation test, the efficiency of SS removal increased at the higher inflow rate. But this was not observed in the larger particles (d_p > 150 µm). There are two main forces that remove particles from the water: the centrifugal force was induced by the swirling motion, which forces the particles to move to the outside of the separator wall, and the gravitational force made the particles pulls down. The movement of the particles to the sidewall depends on both the flow rate and the particle size [7]. Increasing the inflow rate implies increasing the centrifugal force. The improvement in the efficiency of SS removal when the inflow rate increased from 30 to 115 l/m in the fine particle (d_p < 75 µm) separation test can be explained by the higher centrifugal force. Meanwhile, the efficiency of SS removal for larger particles (d_p > 150 µm) increased at a lower inflow rate. Decreasing the inflow rate implies reducing the centrifugal force. Therefore, the results indicate that the centrifugal force was not the major force in the separation of the larger particles (d_p > 150 µm). Therefore, the separation mechanism was mainly driven by gravity [4]. The box plot results of the SS removal are shown in Fig. 4. The effect of the hydraulic retention time on the SS removal is shown in Fig. 5. The results showed that the SS removal efficiencies for particle sizes below 150 µm decreased according to the increase in the hydraulic retention time. The SS removal efficiencies for particle sizes over 150 µm were more than 90% for all inflow rates. It was assessed that both particle size and its specific gravity mainly affected the separation of the particles (d_p > 150 µm).

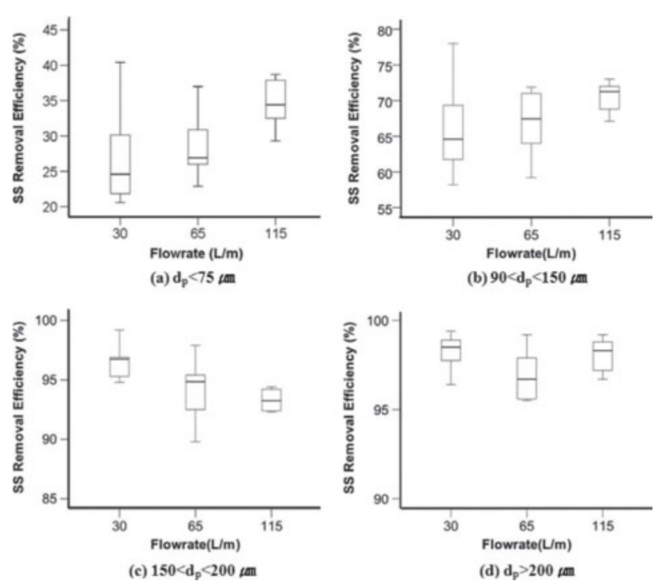

Fig. 4. Box plots of SS removal efficiency.

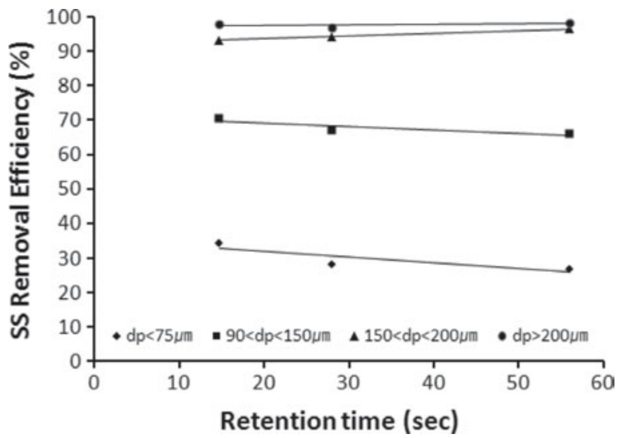

Fig. 5. The relationship between the retention time and SS removal efficiency.

4. Conclusions

A novel structure for the inflow inlet was equipped with a vortex separator. Such an inlet called the inlet baffle was found to the increase the removal of fine particle (d_p < 75 μm) by enhanced centrifugal force. The SS removal efficiency increased nearly 10% due to the inlet baffle, compared to a conventional vortex separator. The vortex separator with the inlet baffle trapped particles larger than 150 μm completely, and fine particle were effectively removed by a higher inflow rate. However, this was not observed for larger particles (d_p > 150 μm). The removal of fine particles was mainly controlled by centrifugal force. Otherwise, the removal of larger particles was controlled by the particle size and gravity. To improve overall suspended solid removal, the vortex separator needed to have an ample hydraulic retention time and high inlet velocity.

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References

[1] M. Fuerhacker, T.M. Haile, B. Monai and A. Mentler, Performance of a filtration system equipped with filter media for parking lot runoff treatment, Deasalination, 275 (2011) 118–125.
[2] Y.C. Jang, P. Jane, T. Tolaymat, B. Dubey, S. Singh and T. Townsend, Characterization of roadway stormwater system residuals for reuse and disposal options. Sci. Total Environ., 408 (2010) 1878–1887.
[3] M. Kayhanian, C. Suverkropp, A. Ruby and K. Tsay, Characterization and prediction of highway runoff constituent event mean concentration, J. Environ., 85 (2007) 279–295.
[4] J.P. Veerapen, B.J. Lowry and M.F. Couturier, Design methodology for the swirl separator, Aquacult. Eng., 33 (2005) 21–45.
[5] R. Gupta, M.D. Kaulaskar, V. Kumar, R. Sripriya, B.C. Meikap and S. Chakraborty, Studies on the understanding mechanism of air core and vortex formation in a hydrocyclone, Chem. Eng. J., 144 (2008) 153–166.
[6] J.H. Lee, K.W. Bang, Y.J. Cho and S.J. Joh, The hydrodynamic filter separator for removal of urban storm runoff, Water Sci. Technol., 53(7) (2006) 243–252.
[7] M.C. Andral, S. Roger, M. Montrejaud and L. Herrenas, Particle size distribution and hydrodynamic characteristics of solid matter carried by runoff from motorways, Water Environ. Res., 71(4) (1999) 398–407.
[8] F.M. Menezes, R. Amal and D. Luketina, Removal of particles using coagulation and flocculation in dynamic separator, Powder Technol., 88 (1996) 27–31.