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Removal of Zinc by Vortex Flow Separator as BMPs in Residential Area

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도시주거지역 와류형 비점오염 저감시설에서의 Zn제거특성

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Abstract

본 연구에서는 도시지역의 하나인 주거지역에서 배출되는 강우유출수 내에 중금속이 장치형 비점오염저감시설 중에 하나인 와류형시설에서 제거되는 특성을 파악하고자, 대상 중금속을 Zn으로 삼고 2007년 4월부터 2008년 11월까지 모니터링을 수행하였다. 유출수 모니터링은 와류형 시설의 유입부와 유출부에서 유량과 수질을 각각 시간변화에 따라 측정하였으며, 시설유입부와 유출부, 그리고 시설하부에 쌓인 침전물을 채취하여 침전물 모니터링도 수행하였다. 그 결과, 높은 강우강도에서 발생된 강우유출수는 와류형 시설내에 HRT를 감소시켜 Zn의 제거효율이 낮게 관측되었으며, 특히 HRT가 20분이내의 조건이 될 경우에는 처리효과가 없는 것으로 확인되었다. Zn는 입자성물질과 밀접한 관계를 맺으며 제거되는 특성을 보였으며, 입자성물질이 스크린에 의한 여과 및 침전작용이 일어날 때 입자성물질에 부착되어 거동하는 특성을 보였다. 그 중에 0.075mm 이하의 미세한 입자에 부착된 고농도의 Zn는 제거되지 못하였고, 와류형 시설 후단에 후처리시설로서 저류시설을 두어 충분한 HRT를 제공한 결과, 와류형 시설만을 운전하였을 때와 비교하여 높은 제거특성을 보이게 되었다.

주요어 : Zinc, 와류형 비점오염저감시설, 강우유출수, 침전물, 제거효율

I. Introduction

Runoff from urban areas contains pollutants that reflect human activity and the urban development of the catchment. This non-point source (NPS) pollutant consists of inorganic elements, particularly heavy metals. The presence of heavy metals in urban runoff is of paramount concern

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due to a potential to not degrade in the environment. Former researchers have demonstrated that heavy metals are common pollutants in runoff from urbanized areas during a storm (Barrett *et al*., 1998; Zanders, 2005). Thomson *et al*. (1997) indicated that pollutants such as lead (Pb), zinc (Zn) and other heavy metals attach to Suspended Solids(SS) and are transported over roadways to drainage system and water resources. Contribution of heavy metals to urban runoff is significantly dependant on the land use. Zn is particularly a large proportion of heavy metals in runoff from residential area (Lee and Lee, 2009).

Historically, Pb has been used as an indicator for other toxic pollutants in urban storm water because it is relatively easy to monitor and its dangers are well documented. In this study, however, we focused Zn as a target material to indicate other toxic substances. Zn has been found to have low toxicity to man however prolonged consumption of large doses can result in some health complications (Hess and Schmid, 2002). While Zn does not affect human health, it can be toxic to aquatic life. Furthermore, it is easier to monitor the concentration of Zn in residential area than that of Pb. Zn and Pb were significantly positively correlated in the urbanized estuarine sediments (Ramessur, 2004).

Nowadays, Korean total maximum daily load (TMDL) has been enforced to set BMPs for reducing the NPS pollutants in four main rivers of Korea. It is necessary to accumulate data according to removal characteristics of the NPS pollutants in various means of best management practices (BMPs). The vortex flow separator (VFS), which is one of the BMP facilities, acts as a continuous reducing pollutant unit below ground and mechanism is filtration for solid separation and sedimentation. The VFS works by deflecting the inflow and associated pollutants including heavy metals away from the main flow stream into a separation chamber.

The primary objective of this study was to identify the removal characteristics of Zn discharged from residential area by the VFS as BMPs. To reveal the removal characteristics of Zn, the research approach involved not only monitoring and sampling inlet and outlet of the VFS but sampling sediment in the bottom of the VFS.

II. Methods

1. Study area and unit process of the VFS

The VFS is situated on the riverside of a branch of the Han River. The catchment is small residential area which is a part of apartment complex and runoff from this catchment in rainy season is discharged into the river via rainwater conduit and the VFS. The catchment represents urban land use with 100% impervious area which consists of parking lots and roads paved with asphalt. Detail information of catchment area and design factors of the VFS is shown in Table 1.

Figure 1 shows the unit process of the VFS

Table 1. Summary of the catchment area and design factors of VFS

BMPs	Catchment area (ha)	Land use	Impervious -ness (%)	Design factors of VFS			
				Design flow rate (m^3/day)	Volume (m^3)	Screen perforation diameter (mm)	Inlet & outlet diameter (m)
VFS	1.75	Residential area	100	3,900	7.65	2.4	0.3

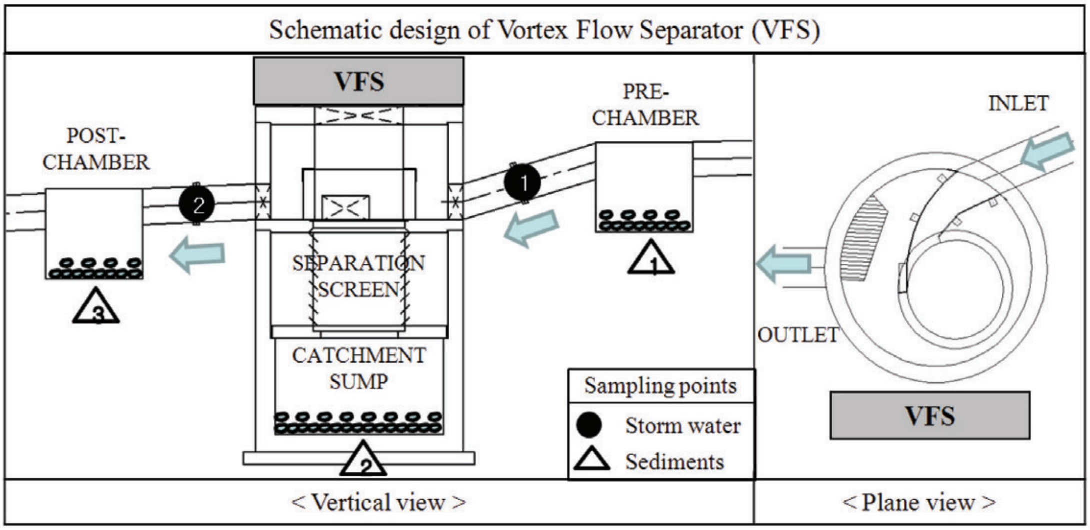

Figure 1. Schematic design of Vortex flow separator and its unit process

and its schematic design. Storm water runoff with particulates flow into the pre-chamber. Storm water is discharged to the detention tank via separation screen. In the case of the particulates, however, they make sediments in the pre-chamber because of their specific gravities and in the catchment sump because of separation screen. Small paticulates less than screen perforation size passing it through the screen are settled on the bottom of the post-chamber.

2. Sampling and experimental methods

Prior to any analysis, storm water runoff monitoring data and samples were collected form 12 storms between April 2007 and November 2008. A storm was defined as having 2 antecedent dry days. Monitoring and sampling were performed at the inlet and outlet of the VFS as shown in Figure 1. Every monitoring point was equipped with a number of flow meters so that flow rate data was stored automatically. Samples were collected at the same points as monitoring points of the VFS from the beginning of runoff to the point when runoff ceased. The first sample was collected at the beginning of runoff. Early several samples were collected at 5 or 10 minute's intervals when runoff flow rate sharply increases due to the first flush phenomenon. After peak of flow rate, Sampling intervals were extended until the end of runoff. On average 12 samples were collected in every event. A variety of water quality parameters was measured, including TSS, CODmn, BOD_5, DOC, TN, TP and Zn used the Standard Methods. Precipitation and antecedent dry day data were collected from a meteorological observatory which was 500 meters from the study site.

Sediments with the high concentration of pollutants are easily generated in the VFS because of its own mechanism treating pollutant so that this kind of BMP has to monitor the sediments. In this study, heavy metals including Zn concentration in sediments and particle size were analyzed to reveal the runoff and removal characteristics of particles in the VFS. Sediment samples were collected from three points on October 2007 after the sixth storm event monitoring. Sampling was conducted at the bottom of the pre-chamber and post-chamber as well as at the bottom of the catchment sump in the VFS using a suction pump as shown in Figure 1. These sediments had been accumulated for ten months from the end of the 2006. In terms of the concentrations of heavy metals in sediments, various heavy metal parameters such as Zn as well as cadmium(Cd), lead(Pb), copper(Cu), chrome(Cr), Nickel(Ni) and arsenic(As) were examined by ICP(Inductively Coupled Plasma) analyzer.

3. Definition of removal characteristic and data analysis

Removal characteristic was defined as a property of pollutants treatment and those behavior by BMP facilities in this study because BMPs have different treatment processes to reduce runoff pollutants. As mentioned in the introduction, the VFS mechanism consists of filtration and sedimentation and is operated by hydraulic vortex flow. So we considered that removal Zn which contained storm water by filtration mechanism, and that which contained sediment by sedimentation mechanism in the VFS.

Removal efficiency was considered to grasp the removal characteristics of VFS. It was calculated by using the differences in the rates of influent and effluent pollutant mass, which is represented as shown in Eq. (1).

$$RE = \frac{\sum_{t=1}^{T} C_{in}(t) \times Q_{in}(t) - \sum_{t=1}^{T} C_{out}(t) \times Q_{out}(t)}{\sum_{t=1}^{T} C_{in}(t) \times Q_{in}(t)} \qquad (1)$$

Where, RE is removal efficiency (%); $C_{in}(t)$ is the time variable concentration in inlet of facilities (mg/l); $Q_{in}(t)$ is the runoff flow rate in inlet of facilities (m^3/min); $C_{out}(t)$ is the time variable concentration treated in outlet of facilities (mg/l); $Q_{out}(t)$ is the runoff flow rate treated in outlet of facilities (m^3/min).

We expected that removal characteristics of Zn in storm water are determined by influent condition such as flow rate and velocity. Therefore, correlation analysis was used to reveal the relationship between removal efficiencies of contaminant parameters and storm factors. Moreover, removal characteristics of Zn in the sediment are determined by particle size. Sieve test was used to analyze particle size and samples were sequentially classified through sieves with pore sizes of 4.75, 2.0, 0.85, 0.425, 0.15 and 0.075mm.

III. Results and discussion

1. EMCs and runoff characteristics of Zn

Total 12 storm events were monitored at sampling points of the VFS located in residential catchment. Table 2 denotes the characteristics of the events monitored in detail, such as total rainfall, runoff duration, average rainfall intensity and antecedent dry days (ADD). The rainfall varied from 6 to 67 mm and the runoff duration time from 1.0 to 13.8 hr. The average rainfall intensity was recorded from 2.5 to 12.4 mm/hr and ADD was determined from 2 to 26 days.

EMCs were calculated to quantify the concentration of Zn in each rainfall event. EMCs at the inlet and outlet of the BMPs are summarized in Table 2. Inlet EMCs as a runoff EMCs ranged from 0.084 to 0.169 mg/L for Zn in the inlet of the VFS. The wide distribution of EMCs depends on various storm factors. High rainfall intensity and long ADD of storm condition of catchment might be a cause of the high EMC. We assumed that EMC is usually related with rainfall intensity and ADD in this study. In the case of Zn, however, these factors did not show consistent corre-

Table 2. Summaries of storm events and analyzed monitoring results

Events	Total rainfall (mm)	Storm duration (hr)	Rainfall intensity (mm/hr)	Antecedent dry days (day)	Zn		
					Inlet of VFS EMCs (mg/L)	Outlet of VFS EMCs (mg/L)	Removal efficiency (%)
Event 1	14	5.6	2.5	4	0.131	0.068	48.1
Event 2	29	8.5	3.4	4	0.116	0.070	40.0
Event 3	13	2.8	4.7	3	0.109	0.112	-2.7
Event 4	12	1.0	12.4	4	0.117	0.133	-12.8
Event 5	7	1.8	4.0	3	0.157	0.125	21.3
Event 6	6	1.3	4.5	12	0.137	0.117	14.7
Event 7	27	3.5	7.7	6	0.131	0.147	-6.7
Event 8	52	4.8	10.8	3	0.116	0.118	-10.3
Event 9	67	13.1	5.1	2	0.084	0.074	12.8
Event 10	45.5	13.8	3.3	7	0.114	0.099	13.1
Event 11	7	2.0	3.5	2	0.169	0.138	18.3
Event 12	21	7.8	2.7	26	0.140	0.093	29.2

lation with the EMCs in this study. Other researchers also did not reveal statistically significant correlations between runoff EMCs and storm factors (Ha and Lee, 2008; Lau *et al*., 2009).

2. Removal efficiencies of the VFS in storm water

Removal efficiencies of Zn were calculated using differences between the inlet and outlet EMCs to indicate the characteristics of Zn reduced by the VFS in each rainfall event. Average removal efficiencies of heavy metals in the VFS are 8% for Cu, 11% for Pb and 17% for Zn(Caltrans, 2004) as well as 2.1% for Pb and 21.8% for Zn(Gil *et al*., 2006).

In this study, Removal efficiencies ranged from -12.8 to 48.1 % in the VFS. Some removal efficiencies of Zn are less than zero in certain storm events. To establish the cause of the negative removal efficiencies, we focused on the HRT change and therefore calculated average hydraulic retention time(HRT) in every storm event and analyzed relationship between HRT and rainfall intensity. Figure 2 shows the relationship between HRT and rainfall intensity and between HRT and removal efficiencies of Zn.

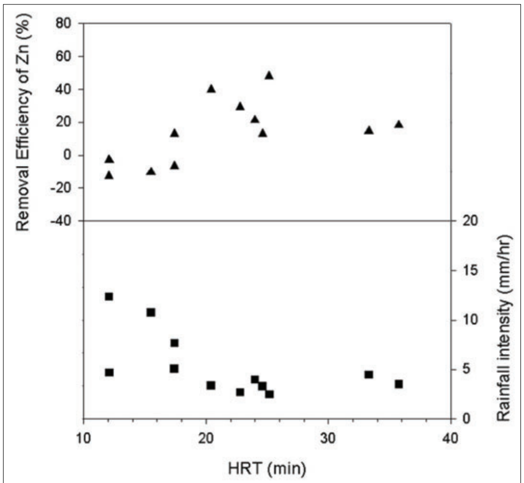

Figure 2. Graphs for relationship between HRT and rainfall intensity and between HRT and removal efficiencies of Zn

When rainfall intensity is high, HRT is decreased in the VFS because this facility works by inflow hydraulic energy. Moreover decreased HRT has a negative effect on removal efficiency of Zn. But if this HRT has decreased below 20 minute especially, removal efficiency of Zn shows less than zero. Therefore, it should be considered to maintain HRT more than 20 minutes for removal of Zn in the VFS.

Table 3 is a Pearson correlation matrix showing the relationships between removal efficiencies of Zn and removal efficiencies of other water contaminant parameters and between removal efficiencies of Zn and storm factors. This table shows correlation coefficients above the diagonal and confidence values (P values) below the diagonal. Storm water contaminant parameters of Zn as well as TSS, BOD, COD, DOC, TN and TP and storm factors of rainfall intensity (RainINT), storm duration (RainDT), total rainfall (Rainfall) and Antecedent dry days (ADD) are included. Removal efficiencies of storm water contaminant parameters such as BOD, COD, DOC, TN and TP in the VFS are not correlated with removal efficiency of Zn, with the exception of TSS. Zn is closely correlated to TSS and they show positive relationships with each other. This means that the removal characteristics of Zn are similar to TSS in the VFS. From this result, it is possible to confirm that Zn, one of the heavy metals, is attached to the suspended solids as defined by former researchers (Thomson *et al*., 1997; Zanders, 2005).

The removal efficiency of Zn is not correlated to storm duration, total rainfall and ADD, with the exception of rainfall intensity, which is negatively correlated. It means that the removal efficiency of Zn is low when storms which have high rainfall intensities occur and we confirm that there is an insufficient HRT in the VFS to treat pollutants under high rainfall intensities.

3. Particle size and Zn concentration in sediments

In this study, particle size and heavy metal concentration of sediments were examined to determine runoff characteristics of Zn in residential catchment and removal characteristics of Zn in the VFS.

The particle size distribution of sediments which settled in the bottom of the pre-chamber, post-chamber and catchment sump in the VFS are shown in Figure 3. The sediment in the pre-chamber consists relatively of bigger particle sizes than the sediment in the bottom of the VFS and this is obviously bigger than sediment in the post-chamber. The distribution of the particle size larger than 0.85mm accounts for almost 74% of

Table 3. Correlation matrix between removal efficiencies of water contaminant parameters with Zn and storm factors

Correlation coefficients	Confidence value (P-value)										
	TSS	BOD	COD	DOC	TN	TP	Zn	RainINT	RainDT	Rainfall	ADD
TSS		0.456	0.951	0.964	0.067	0.572	0.000	0.006	0.562	0.361	0.319
BOD5	0.238		0.006	0.040	0.228	0.760	0.281	0.190	0.216	0.826	0.180
COD	0.020	0.739		0.001	0.067	0.212	0.583	0.536	0.587	0.895	0.261
DOC	-0.015	0.597	0.828		0.133	0.229	0.823	0.493	0.814	0.542	0.473
TN	0.545	0.376	0.545	0.459		0.375	0.056	0.130	0.747	0.298	0.063
TP	-0.182	0.099	0.389	0.376	0.282		0.817	0.719	0.457	0.486	0.157
Zn	0.939	0.339	0.177	0.072	0.564	-0.075		0.001	0.354	0.575	0.477
RainINT[1)]	-0.740	-0.407	-0.199	-0.219	-0.463	0.116	-0.816		0.270	0.589	0.383
RainDT[2)]	0.186	0.385	0.175	-0.076	0.104	-0.238	0.294	-0.347		0.002	0.731
Rainfall[3)]	-0.290	0.071	0.043	-0.196	-0.328	-0.223	-0.18	0.174	0.788		0.646
ADD[4)]	0.315	0.415	0.353	0.229	0.552	-0.435	0.228	-0.277	0.111	-0.148	

[1)] Rainfall intensity (mm/hr) [2)] Storm duration (hr) [3)] Total rainfall (mm) [4)] Antecedent dry days (day)

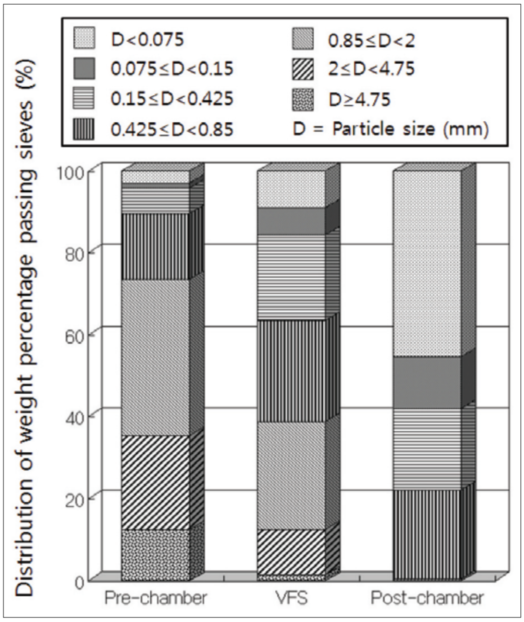

Figure 3. Distributions of the particle size fractions in residential sediments

the sediments in the bottom of the pre-chamber. However, there is no particles lager than 0.85mm in the sediments which settled on the bottom of the post-chamber. It means that the these particles are captured by separation screen and settled on the bottom of the catchment sump in the VFS when comparing between distribution of particle sizes in the VFS and that in the post-chamber.

Even though designed separation screen perforation diameter of VFS is 2.4mm, the particles less than 2.4mm could not be easily passed through the screen because of the characteristics of VFS facility which is deflecting the inflow and associated particles away from the main flow stream. Minute particles which are less than 0.075mm could not distinguished the exact figure in this study. However, the distribution of the particle size less than 0.075mm accounts for upper 45% of the sediments in the post-chamber. this means that minute particles were not filtered and discharged directly into the river.

Washed off particulates with storm water were transported to the VFS so that the concentrations of Heavy metals in sediments which had been settled at the pre-chamber and post-chamber and the bottom of the VFS were examined as shown in Table 4. Zn is the most washed off heavy metal from a residential area as the same with former researches. Zn concentration of sediment in the bottom of the pre-chamber is the lowest and gradually increases through the VFS process.

Sansalone and Buchberger (1997) studied solids from urban highway storm water and found the highest concentrations of Zn in the 25?45μm size range. Lee *et al*. (2007) reported a large proportion of Zn associated with particles lower than 75 μm in size in storm water. Considering particle size analysis as shown in Figure 3, this result shows that the sediment which is composed of the most particles larger than 4.75mm is relatively low concentration of Zn in the pre-chamber. The sediment which is composed of the most particles less than 0.85mm, especially, 0.075mm and passed through the VFS with no treatment is relatively high concentration of Zn in the post-chamber. As a result, these analyses confirm that

Table 4. Summaries of the heavy metal concentration in sediments in each sampling point

Sampling point	The heavy metal concentrations of sediments (mg/kg)						
	Zn	Cu	Pb	Cr	Ni	As	Cd
Pre-chamber	917.1	319.1	128.4	34.8	35.9	4.1	2.1
VFS	1110.8	614.2	149.0	48.0	40.1	3.7	2.3
Post-chamber	1458.0	424.6	375.0	65.3	41.5	5.0	3.5

small silt-sized particles can be a primary vehicle for metals transport in some systems.

4. Discussion about the improvement of the VFS

The importance of pollutant particle size distribution is acknowledged in storm water treatment by BMPs and other facilities. This VFS was designed to affect water quality improvement and rely on pollutant removal by settling. Minute particles less than 0.85mm, particularly, 0.075mm with heavy metals especially Zn have no treatment in the VFS and those are discharged with storm water into the river caused by removal characteristics we revealed.

We added post processing after VFS process to improve the removal efficiency of Zn by the VFS. Post processing was conducted to settle the minute particles as giving sufficient HRT to the storm water treated by the VFS. In this study, HRT was given as 24 hours, as well as we observed the concentration of Zn after post processing and calculated removal efficiency in each event. There is no post processing data in the first event only of the whole monitored 12 events.

Figure 4 shows the result of comparison between removal efficiencies of the VFS and those of the VFS with post processing. On the average, the removal efficiency of Zn by the VFS is 13.8 percent As shown in table 2. The removal efficiency of Zn by the VFS with post processing is ranged from 3.5 to 80.4 percent in the monitored 11 events, and this is increased by almost 30 percent. In the case of operating the VFS only, minute particles are passing through the screen without sedimentation in the VFS. In conclusion, it is necessary to operate post processing after VFS process to improve removal efficiency of the VFS for Zn, such as installation of retention tank which offers particles to sufficient HRT for sedimentation.

IV. Conclusions

This study has presented removal characteristics of Zn discharged from residential area by the VFS as BMPs. To reveal the removal characteristics of Zn, this research involved not only monitoring storm water in the inlet and outlet of the VFS but sampling sediment on the bottom of the pre-chamber, post-chamber and VFS.

The removal characteristics of the Zn were defined as follows:

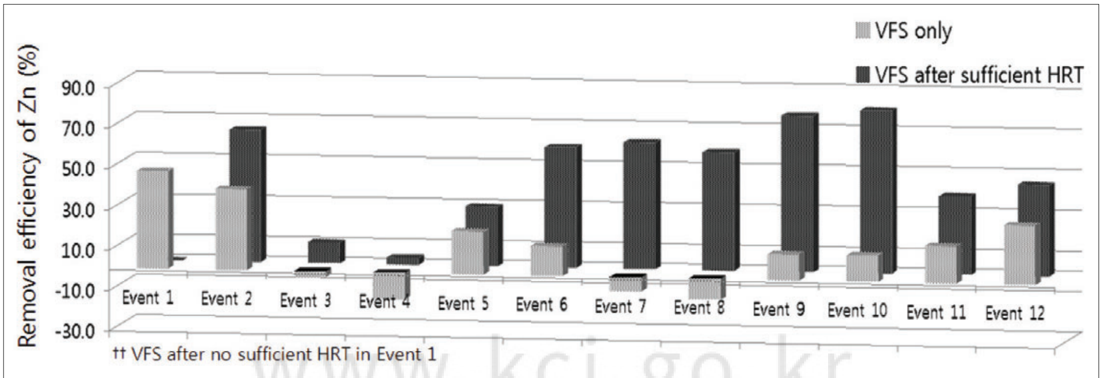

Figure 4. Comparison between removal efficiencies of VFS only and those of VFS with post processing

First, When rainfall intensity was high, HRT was decreased in the VFS and decreased HRT had a negative effect on removal efficiency of Zn. Therefore, there was no effect to treat Zn in the VFS when this HRT had decreased below 20 minute especially. Second, Zn was closely correlated to TSS with positive relationships and when the suspended solids were filtered and settled by the VFS, Zn was settled with attaching to the suspended solids. Third, Minute particles especially less than 0.075mm accounted for upper 45% of the sediments and passed through the VFS with no treatment which were relatively high concentration of Zn in the post-chamber. Finally, When post processing which had 24 hours HRT was conducted, the removal efficiency of Zn was increased compared to operating the VFS only.

In conclusion, when minute particles attached with pollutants such as heavy metals are passing through the BMP facilities, it is necessary to operate post processing such as installation of retention tank which offers particles to sufficient HRT to improve removal efficiency of the BMP facilities.

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