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Bonjin Koo

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Ph. D. Dissertation

A Study on the Filtration Efficiency of
Micro particle Pollutants from Non-Point
Source

- Focused on Road Runoff and CSOs -

University of Nice Sophia Antipolis

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ABSTRACT

The impermeable area and the peak discharge volume have been consistently increasing due to widening of city development and renewal. Thus, distortion of water cycle has been serious problem compared to the past. When it comes to NPS pollution, lack of information on the load and characteristics of pollutants led to the insufficient reduction measures.

The purpose of this study is to investigate the effectiveness of filters to control micro particles from non-point sources, especially from road runoff and Combined Sewer Overflows (CSOs). The study first examined the particle size and characteristics of NPS pollutants, and then analyzed the head loss, treatment efficiency and changes in particle size distribution before and after the treatment using device type facilities. The four most commonly used filters - Expanded Polypropylene (EPP), Expanded polystyrene (EPS), and Perlite as floatability filtering materials, and Zeolite as non-floatability - were compared. The upward-type filtering equipment was manufactured for the lab experiment, and CFD modeling was conducted to identify optimized design parameters.

The results showed that the ratio of micro particles ($< 100 \mu\text{m}$), to which the filtering process can be applied, was highest in samples from the road runoff, followed by one from the bridge, and from the parking lot. The results using road runoff displayed that EPP was most efficient with ratio of 89% to treat SS and COD. The removal rate of EPP for Zn and Cu was also high over 80%, which is 7 ~ 40% higher than those of other filters tested. The continuous filtering period calculated was again longest for EPP to reach 163 days. The calculated filtering period for CSOs was apparently shorter than that for road runoff, due to the hydraulic loading and SS quantity. The filters compared were not efficient to remove TN and TP in CSOs. The results from the numerical analysis for the particles over $100 \mu\text{m}$, to which the gravity sedimentation can be applied, showed that sedimentation efficiency can be improved by controlling the inflow velocity through the utilization of the bent pipe or baffle wall. The operation and management can be also easier by placing appropriate facilities such as manhole at the sedimentation point.

This study suggested the best filtration material to treat NPS pollutants tested by road runoff and CSOs samples. The experimental results shown in this study and following discussions may act as base information for proper design and operating parameters of the filtering facilities to control NPS pollutants.

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CHAPTER 1 INTRODUCTION

1.1 Background

The impermeable area and the peak discharge volume have been consistently increasing due to widening of city development and renewal. Thus, distortion of water cycle has been serious problem compared to the past. In Korea, because of urbanization and industrialization followed by rapid economic development, water pollution of public waters became a serious issue. Although the problem by PS pollutants is decreasing by the installation of environment facilities, reduction measure of non-point source (NPS) pollution is insufficient because characteristics and generation rate are difficult to determine.

Point source (PS) pollution does not have large fluctuation in discharges because they mainly consist of home sewage and industrial sewage and are generated consistently at a certain area. On the other hand, NPS pollution are defined as pollution sources that randomly emit water pollutants at unspecified areas such as city, roads, farmland, mountains, constructions sites, etc. according to “Water Quality and Ecosystem Conservation Act” in Article 2, paragraph 2.

NPS pollution generated to watershed at particular time, such as during rainfall event, are generally caused by land-use, and time and source location of occurrence are not clearly identified. Therefore, they are largely affected by environmental and hydrological factors which make efficient management of NPS pollution difficult.

In the United States, it is reported that about 50% of the water pollution of river is caused by NPS pollution.

In case of closed watershed in Korea, about 80% of the water pollution is due to the effect of NPS pollution. (Kim et al., 2004) According to the basis of pollutant loads from Paldang Dam watershed, in case of BOD loads, PS pollutant is 39% and NPS pollutant loads is 61%. For T-N, PS pollutant loads is 19% and NPS pollutants is 81%. For T-P, PS pollutant loads is 30%, and NPS pollutant loads are 70%. Clearly, all pollutants such as BOD, T-N, T-P, etc. are largely affected by pollutants loads of NPS sources. (Lee et al., 2002)

Soil among NPS pollutants is a pollutant that accounts for a large portion of the storm water runoff. It gives catastrophic impact on photosynthesis, respiration, growth, reproduction of aquatic organisms. Nutrients, metals, hydrocarbons, and other contaminants are adsorbed in soil and do move along with soil. Nutrients such as nitrogen and phosphorus can be used as a fertilizer and nutrients are leaked from houses, lawn of golf course, farmland, urban roads, and sewers. Lead, zinc, cadmium, copper, nickel, and other heavy metals are commonly detected substance in urban storm water runoff. 50% of the heavy metals that are flowing into rivers are discharged from soil as a medium.

First of all, as a way to manage such NPS sources, the artificial effect of development of nature should be minimized, and LIDA (Low Impact Development Approaches) should consider rainfall itself as the water source and manage the rainfall on development area. The goal of management should be maintenance of natural resources, soil condition, forest, terrain characteristics, native plants on wetland, etc. to their natural and original states even after development. In other words, rainfall and storm water runoff are managed in developing area by applying small-scale facilities that can reproduce the natural processes such as infiltration, evapotranspiration, and storage in the area.

Second way to manage NPS pollutants is a device type facility as an active way. Among the device type facilities, filtration-type facility is to handle NPS pollution using filter media

such as soil and sand. In case of adoption filter type device, the evaluation of size of pollutant particles is required because filtration efficiency depends on the size of pollutant particles.

To remove NPS pollution through device type facility, it is necessary to full comprehension of occurrence characteristics of NPS pollutants and also evaluation of elimination characteristics of device-type facilities.

1.2 Objectives

In this study, we evaluated filtration efficiency of micro particle from NPS pollutants with a focus on road runoff and Combined Sewer Overflows (CSOs), which are two major representatives of pollutants that largely affect water quality of rivers among NPS pollutants.

To examine the applicability of sedimentation and filtration process as a treatment technology of NPS pollutants, we comprehended the characteristics of generation and sedimentation of pollutants. We intended to propose a method to increase the applicability of sedimentation and filtration treatment process by evaluation of the filter media as a main variable in application of those characteristics to filtration treatment process.

1.3 Content and scope of the study

For the study of the occurrence characteristics of NPS pollutants, occurrence characteristics of existing study were researched. Based on the research, we searched for the characteristics of pollutants by applying NPS pollutant to the filtration treatment process.

For understanding of characteristics of pollutants, road runoff that comes from roads, bridges, and parking lots and CSOs selected from combined sewer and storm overflow chambers were chosen as NPS pollutants.

In previous studies, the main characteristics of NPS pollutants were divided into particulate and soluble parts. Also, sedimentation and filtration treatment process were presented as applied technology for elimination of micro particles. Therefore, in this study, we analyzed the size of pollutant particles at the points of occurrence and suggested the application of filtration process as a treatment technology based on the study.

Since filter media as a key factor of filtration treatment process, floatable filter media and non-floatable filter media that commonly applied were selected to examine the efficiency before and after the filtration process. For non-floatable filter media, Zeolite, which possesses nature of adhesion, and for floatable filter media, Expanded Polypropylene (EPP), Expanded Polystyrene (EPS), and Perlite, considering scope of development and intensity of filter media, were chosen to be examined applicability as filter media.

To evaluate filtration process enduring time as a method to examine the treatment efficiency, the generation time of overflows at designing standard was evaluated. For each filter media, the treatment efficiency of particulate and soluble pollutants was evaluated. In addition, inside the filtration equipment, treatment efficiency was evaluated for each filter-layer for the safety of treatment.

Also, through the modeling of Computational Fluid Dynamics (CFD), for proper treatment as well as sedimentation efficiency of particulate pollutants ($>100\mu\text{m}$) that gravitational sedimentation is possible, we intended to develop an efficient storm water device by means of suggesting the design criteria of optimal shape for treatment facility.

The details of study are followings. :

With literature research of efficiency of filtration treatment process for NPS pollutants and CSOs, we analyzed the generation and discharge characteristics of each pollution sources and such operation of establishment of existing treatment facilities.

In order to progress in research for generation characteristics and filtration treatment of NPS sources, the target research area was first selected. Next, Sample was collected and

analyzed. Then, filter media selection and characteristics analysis were carried out for comparative experiment.

As an analysis of filtration treatment efficiency of road runoff, size distribution curve and generation characteristics of each pollutant were examined. For analysis of sedimentation characteristics, quantity analysis was implemented to suggest result of CFD modeling.

Moreover, to evaluate the efficiency of filtration treatment process from road runoff, head loss, concentration, and process efficiency were checked for each filter media. Through SEM analysis, mechanism of filtration process efficiency was implemented.

For the efficiency analysis of CSOs, flow and water quality at rainfall and dry weather were measured in experimental site. Also, loss of head and treatment efficiency of SS, BOD, COD, T-N, T-P for each filter media were confirmed.

CHAPTER 2 LITERATURE REVIEW

2.1 Characteristics of NPS pollution

Because NPS pollutants flows into rivers through surface during rainfall, condition of nature, such as intensity and amount of rainfall, soil quality and artificial conditions like land-use, types and amount of cumulated pollutants during dry season, population density, development have large impacts. In this section, generation characteristics of NPS pollutants by land-use, generation and discharge characteristics of urban nonpoint pollutions and road runoff are described.

2.1.1 Pollution load by land-use

When we examined the discharges characteristics of NPS classified by land-use, we could sort them as urban land-use and rural land-use metropolitan land-use refers to houses, industrial complexes, and road constructions which increase impermeable surface area. Non-metropolitan land-use refers to type of land-use such as farmland construction, sports facility installation that maintain permeable layer but generate extra environmental loads due to development.

NPS pollutants, depending on land-use condition, differ in generation and emissions characteristics. Therefore, for the efficient reduction of NPS pollution, understanding of NPS pollution properties in relation to land-use. (Ministry of Environment, 2010) Forest area is generally settled, but nutrients and sedimentation are released from the basin by heavy rain in short term and by forest destruction in the long term.

In farmland, most of pollutants that are generated are discharged with rainfall, and the concentration of pollutants is fairly low, but pollutant loads are shown fairly large because of large occurrence surface area.

The main sources of generation are surface soil from cultivation, elimination of vegetation, negligence of soil during non-cultivation, fertilizers, animal wastes for soil improvement, and supply of irrigation.

In urban area, the pollutants that are generated by residential, commercial, industrial and other activities vary in types and are highly concentrated. In other words, the pollutants in urban area have greater loads per unit area compared to other land-use, and they contain not only general pollutants but also various toxic substances, so they can make serious impact on water quality. (Ministry of Environment, 2006)

NPS pollutants might vary due to particular property of the area. However, as chart 2.1 describes, in case of cities, industrial and development project areas, many particulate pollutants and heavy metals that are deposited on surface discharge all together at the beginning of rainfall. In farmlands, nutrients such as soil, nitrogen are commonly released. (Ministry of Environment, 2006)

Lee (2001) compared the nature of NPS outflow that affects critically on water pollution of Paldang Dam water supply. The study showed leakage characteristics in case of NPS pollution that outflow amount and concentration of pollutants varies a lot in accordance with characteristics of the land-use and rainfall type.

For each representative watershed, because pollutants show up similar time as peak flow rather than peak concentration, pollutant loads is more affected by flow rate than concentration of pollutant.

Discharge Characteristics of BOD, COD, SS, and T-P showed a large range of fluctuation depending on runoff during rainfall, but in case of T-N, the fluctuation of concentration by rainfall was the lowest, so that it is affected the least by runoff.

In the case of the BOD loads by land-use, forest/resort area was 1.53kg/ha/year when the rainfall was 140.4mm, farm/field was 1.93kg/ha/year when the rainfall was 84.9mm, and urban area was 22.84kg/ha/year when the rainfall was 72.94mm. Thus, although the rainfall in urban areas was smallest, the BOD loads by NPS pollution were very high, relative to forest/resort area.

Table 2.1 NPS pollution and pollutants by land-uses (MOE, 2006)

Land-use		Detail sources	Main pollutants
Urban Area		<ul style="list-style-type: none"> ▶ Road and Bridge Construction ▶ Transform land-use type ▶ Storm water and CSOs ▶ Surface runoff ▶ Road surface runoff, etc. 	Soil, Impurities, Bacteria, Nutrients, Heavy metals
Agriculture area	Agriculture	▶ Rice paddies, fields, orchards, fish farm, such as slope failure	Sediment, Nutrients, Pesticides
	Farm	▶ Grassland, farm, storage and use of livestock	Sediment, Bacteria Nutrients
Industrial Area		<ul style="list-style-type: none"> ▶ Combined sewer leaks in sewer and solid ▶ Ground and road surface runoff ▶ Industrial waste accidents and leaks ▶ Raw materials and waste are loaded in the field 	Sediment, Nutrients, Oil, Heavy metals
Development Area		<ul style="list-style-type: none"> ▶ Works leaking muddy water ▶ Abandoned waste building materials and various construction waste 	Sediment, Oil, Heavy metals, Impurities

Shin et al. (2001) investigated the amount of NPS pollution runoff per unit area at Paldang Dam water supply, and the amount of runoff of SS, BOD, COD, T-P, and T-N were 423.4, 20.0, 56.6, 2.6, 20.9 kg/ha/year respectively. Moreover, unit measurement by land-uses considering the livestock breeding conditions was suggested. In case of rice field, the runoff of COD, T-N, and T-P were 173.6, 74.26, 7.7 kg/ha/year respectively. For field, the runoff of COD, T-N, and T-P were respectively 63.0, 14.0, 4.2 kg/ha/year.

For mountains, the runoff of COD was 24.8 that of TN were 11.2 that of TP was 0.4 kg/ha/year. And in case of livestock field, the runoff of COD, TN, and TP was 14.7, 3.8, 0.3kg/ha/year respectively.

Lee et al. (2002) suggested basic unit of NPS pollution at the Paldang Dam Water Supply according to land-use by calculating for each water system. According to each water system, the basic unit for each land-use was quite high in Kyung-an stream, but there were not much difference compared to that of the Bookhan River and the Namhan River Basin.

**Table 2.2 Unit value of NPS pollution by land-uses
(Lee, hyeondong, etc., 2002)**

Watershed	Land-use Type	NPS Runoff Loading(kg/ha/year)					
		BOD	COD	SS	TOC	T-N	T-P
North Han River	Forest/Resort	3.4	7.2	333.4	1.0	1.3	0.100
	Crops	19.3	34.5	355.6	5.1	6.8	0.528
	Urban	370.6	1,844.7	9,462.3	72.3	121.0	3.442
South Han River	Forest/Resort	3.2	33.7	325.4	0.9	1.1	0.096
	Crops	18.9	33.7	348.4	5.0	6.6	0.516
	Urban	363.2	1,807.9	9,273.5	70.9	118.6	3.373
Kyung-an River	Forest/Resort	3.7	7.6	342.0	1.0	1.4	0.104
	Crops	19.8	35.4	364.0	5.2	7.0	0.542
	Urban	379.2	1,887.7	9,682.5	74.0	123.9	3.522

Table 2.3 Water pollution load by pollution sources of river watershed

Type	Gum River	Nakdong River	Youngsan River	Han River
Living system	58,044 (37%)	80,905 (41%)	43,685 (34%)	135,433 (50%)
Livestock system	30,203 (19%)	28,723 (14%)	19,812 (16%)	33,309 (12%)
Industrial system	11,988 (8%)	18,294 (9%)	5,042 (4%)	17,561 (6%)
Land-Based	49,967 (32%)	67,799 (34%)	44,346 (35%)	81,044 (30%)
Etc.	6,614 (4%)	3,970 (2%)	13,790 (11%)	5,430 (2%)
Summary	156,816 (100%)	199,690 (100%)	126,676 (100%)	272,776 (100%)

According to 2003 Water environment management Plan, 30~35% of water quality was affected by soil pollutants that occupies most of non-point pollution, and if effects of sewer leakage other than land-based pollution are included, it was expected that the weight of impact would increase by 65~70% in 2015.

2.1.2 Characteristics of NPS in urban area

Because urban area has high ratio of impermeable imperviousness among total river area, rainfall runoff and change of concentrations of water quality changes rapidly.

The runoff flow rate was raised sharply during rainfall, and when rainfall terminated, the flow rate was rapidly decreased and recovered with short amount of time. Hydrological phenomena in urban area are very sensitive to changes of rainfall. Generally, in urban areas,

early stage of runoff phenomena stand out at the beginning of rainfall, so maximum pollution loads runoff proceed maximum flow rate.

Pollution loads per unit area of NPS pollutants, which are discharged in urban areas, are highly concentrated compared to other land-used characteristics, and they contain organic matter, nutrients, heavy matter as well as toxic substances.

In general, compared to pre-development district, the discharges of NPS pollutants such as BOD and SS have been increased 92 times and 24 times respectively. Due to increase of impermeable area by urbanization, large amount of NPS pollution were released to public waters during rainfall, which increase the problem of water pollution. (Choi, 1998)

In addition, in the case of urban areas, due to various development projects and vigorous commercial activity, the increase in traffic, a lot of pollutants have been accumulated in road surface. Also, various shops, traditional market, and gas stations also accumulate heavy metals, nitrogen, organic substances such as petroleum hydrocarbons which become a major cause of ecological destruction like water pollution and death of fish. Within urban areas, the type of land-use is subdivided. Therefore, the outflow of NPS pollutants differs a lot by the types of land-use. In other words, among land-use in urban areas, areas with many parks and grassland release less amount of pollutant compared to the area with many commercial and industrial sites. Those areas have large amount of outflow (runoff) of non-point pollutant due to quite a number of impermeable areas and emissions of pollutants.

In the case of residential areas, depending on the effects of housing density, vegetation, etc., amount of discharge of NPS varies. Table 2.4 demonstrates that according to once case in which the NPS loads were compared by the types of land-use in urban areas, low density and medium-density residential area shows higher concentration of BOD, COD while industrial,

commercial area and roads showed high concentration of micro-particle substances and heavy metals.

Table 2.4 NPS pollution in urban area (unit : mg/L)

land-use	BOD	COD	TSS	TDS	T-P	TKN	Pb	Cu	Zn	Cd
Low-density residential	38	124	70	144	0.52	3.32	0.057	0.026	0.161	0.004
Medium-density residential	38	124	70	144	0.52	3.32	0.180	0.047	0.176	0.004
High-density residential	15	79	97	189	0.24	1.17	0.041	0.033	0.218	0.003
Commercial area	21	80	77	294	0.33	1.74	0.049	0.037	0.156	0.003
Industrial area	24	85	149	202	0.32	2.08	0.072	0.058	0.671	0.005
Road	24	103	141	294	0.43	1.82	0.049	0.037	0.158	0.003

Source: International Erosion Control Association, 2002

In the Jin et al. (2006) through the urban areas of Youngsan River region, combined sewer and Pungyoungjeong stream and YongBong stream property of sewer region the flow loads classified by land-use were calculated. Discharge characterization of NPS pollutants in urban areas were 4.43~14.22mg/L for BOD and EMC, 8.27~18.81mg/L for COD, 35.76~358.86mg/L for SS, 1.61~7.13mg/L for T-N and 0.03~0.46mg/L for T-P, Moreover, the discharge characterization of NPS pollution at sewer drainage areas for BOD was 20.24~32.28mg/L, 38.96~56.17mg/L for COD, 65.87~202.78mg/L for SS, 5.50~6.59mg/L for T-N, 0.33~0.46mg/L for T-P.

2.1.3 Characteristics of road runoff

Due to the fact that road is a social base construction that connects broadband organizations, the pollutants that occurred in certain areas can easily move from one place to another.

Also, many highways and roads pass through water system and cities adjacently. Due to this characteristic, pollutants such as various organic and particulate materials, heavy metals, etc. are cumulated on the highways during dry period, and during rainfall, these pollutants flow through the nearby water system and land which become the permanent internal pollution source and affect seriously to water quality and ground water. The generation type of NPS pollution and the main types of pollutants are shown in table 2.5.

Table 2.5 NPS pollution occurrence types and materials on the road

Parameters	Pollutants	Source
Particulates	Particulates	Pavement wear, the atmosphere and maintenance activities
Nutrients	N and P	Atmosphere and fertilizer application
Metals	Lead	Leaded gasoline from auto exhaust and tire wear
	Zinc	Tire wear, motor oil and grease
	Iron	Auto body rust, steel highway structures such as bridges and guardrails, and moving engine parts
	Copper	Metal plating, bearing and brushing wear, moving engine parts, brake lining wear, fungicides & insecticides
	Cadmium	Tire wear and insecticides application
	Chromium	Metal plating, moving engine parts and brake lining wear
	Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, brushing wear, brake lining and asphalt paving
	Manganese	Moving engine parts
	Cyanide	Anti-caking compounds used to keep deciding salt granular
	Na, Ca, Cl	CaCl ₃ (snow removal)
Hydrocarbon	Sulphates	Roadway beds, fuel
	Petroleum	Spills, leaks, antifreeze and hydraulic fluids and asphalt surface leachate

Source: USEPA, 1994

Table 2.6 summarizes the study of concentration of pollutants in storm water runoff that are caused in roads of commercial and residential area to investigate the concentration of pollutants occurred on roads by types of land-use. The result was that road areas showed 20~80

times higher concentration for particulate substances and 3~10 times higher concentration for heavy metal compared to other areas.

Table 2.6 Comparison with the pollutants concentration on the road and elsewhere

Pollutants concentration	Residential Area		Commercial Area	
	road	Elsewhere	Road	Elsewhere
SS (mg/L)	185	8	595	7
Cu (µg/L)	69	22	225	29
Pb (µg/L)	103	26	293	3
Zn (µg/L)	348	120	771	74

Kim et. al. (2004) investigated on discharge characterization of NPS pollutants on the highway in the United States. It was calculate that TSS, COD, and oil & grease represented the range of 5~880mg/L, 13~780mg/L, 0.5~34mg/L respectively.

When EMC's 95% confidence interval was examined, TSS, COD, Oil& grease, and TKN represented 102.8 ~ 216.4 mg/L, 104.5~251.8 mg/L, 5.4~10.6 mg/L, and 2.4~10.2 mg/L respectively.

The heavy metals that are found in high concentration in runoff are mainly Cu, Ni, Pb and Zn, and the range of Cu, Ni, Pb, and Zn were 10~1,000 µg/L, 1~400 µg/L, 1~200 µg/L, and 30~7,000 µg/L respectively.

Kim et al. (2011) concluded that after monitoring the rainfall events at bridge areas for 18 times, the dry period before rainfall showed the range of 1~45 days, and total rainfall sedimentation was 5.0~149mm, and rainfall duration time was 3.0~16.7hr. The result of examination of discharge characterization of NPS pollutants in wider range was that average

EMC represented that value of TSS, COD, T-N, and T-P were 94.94mg/L, 23.37 mg/L, 4.16 mg/L, and 1.01 mg/L respectively.

2.2 Filtration efficiency from road runoff

For the effective prevention of pollutants in road runoff through filtration treatment process, the good grasp of size distribution of particles in runoff is necessary, and many study results on size distribution of runoff are reported in United States, and also few studies are reported in Korea.

2.2.1 Characteristics of particle size distribution

Detention Basin Analysis has reported that the particles in road runoff fall in range of 2~100 μ m, and National Urban Runoff Program reported that 90% of particles were distributed in range of 1~100 μ m.

Municipal Research & Service Center (of Washington) reported that distribution of 90% of bigger size particles falls under 400 μ m.

Figure 2.1 shows the study at three highways in LA for two years by Particle Size distribution of Highway Runoff and Modification Through storm water treatment, and most of number of particles were under 20 μ m, and in quality, those of 400 μ m had the 90% of distribution.

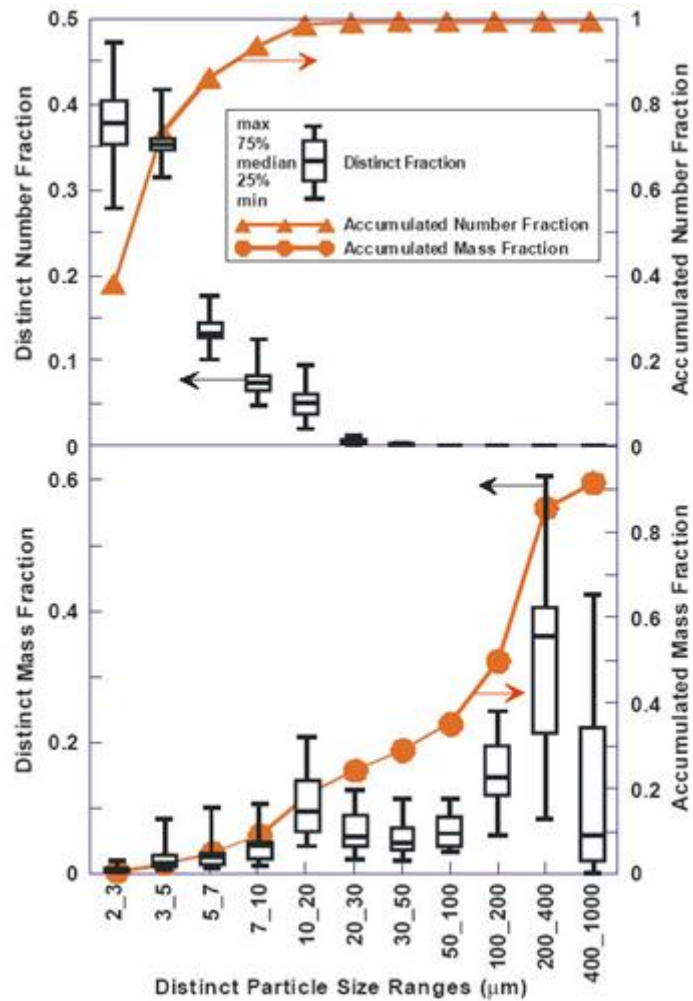


Figure 2.1 Particle size distribution and accumulated mass fraction of highway runoff (LA area)

Figure 2.2 describes the research of particle distribution of solids in storm water inlet and oil-grit separators by Effectiveness of Three Best Management Practices for Highway-Runoff Quality along the Southeast Expressway. The study showed that micro particles (< 100µm) with higher concentration of heavy metal pollution were mostly discharged from first chamber of storm water inlet and oil-Grit Separator. Therefore, highly expensive separation method by sedimentation rather than filtration type device would not give a satisfactory treatment for micro-particles and heavy metals in road runoff.

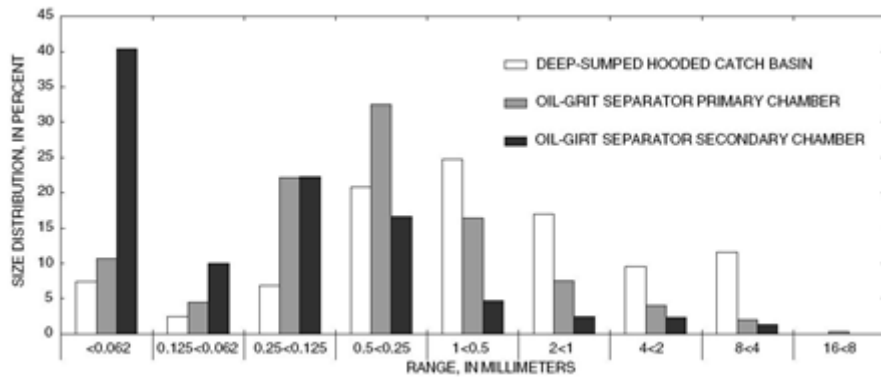


Figure 2.2 Particle-size distribution of a sample of bottom sediment collected from three oil-grit separators located along the Southeast Expressway, Boston

Figure 2.3 describes the movement characterization classified by size of particles and Figure 2.4 describes the size distribution of road runoff during rainfall. Most of particles of road runoff that are in range of $1 \sim 100 \mu\text{m}$ are affected by fluid rather than gravitational sedimentation, and the domestic studies corresponds with studies in foreign countries.

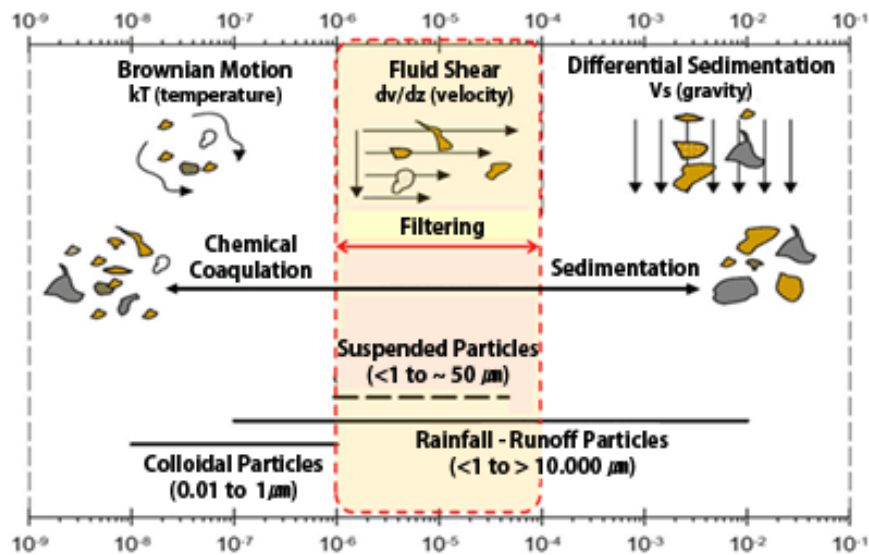


Figure 2.3 Conceptual schematic of movement characterization classified by size of particles

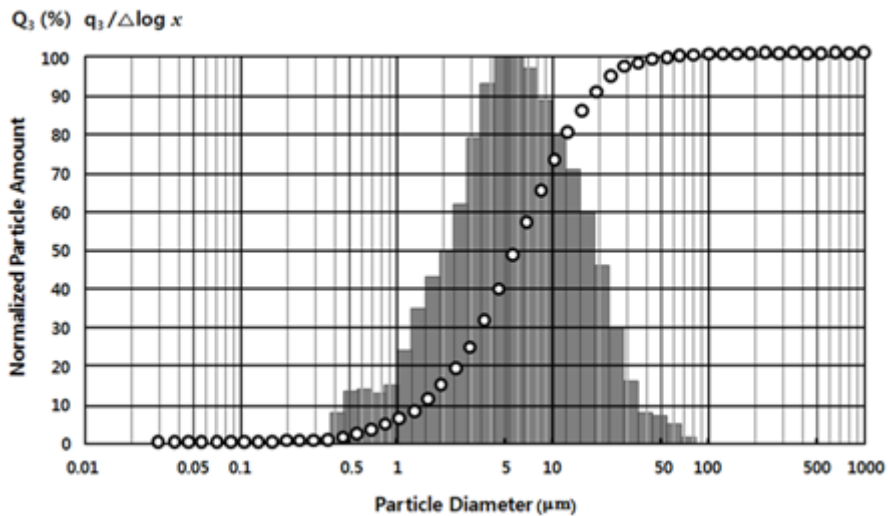


Figure 2.4 Size distribution of road runoff during rainfall

Cho et al. (2007) reported that most of particles in bridge runoff had size of 10~20 μm , and depending on rainfall duration time, the size increased. In details, the size of particles hit the maximum at the beginning of peak runoff and drastically decreased after the maximum point.

Lee et al. (2005) stated that according to the examination of particle size of road runoff, range of Dmean value was 6.7~23.4 μm and range of D90 was 36.2~105.2 μm and the average particle size of road runoff was approximately 20 μm .

2.2.2 Efficiency of filtration devices

In United States, pre and post control techniques have been developed, and mainly passive control method is applied, which ease of securing available land and security of land for installing passive treatment facility when planning of road constructions are on the premise. Therefore, the studies like filtration that can be applied to land with smaller area are comparably small.

In the case of domestic region, as the treatment facilities for NPS pollution were legalized, many studies concerning treatment methods are in progress. With different condition from United State which security of land for facilities are not at ease, consumer demands more for device type facilities which require less land.

In this regard, until recently, vortex-type device such as CDS, DD have been applied a lot, but people perceive vortex-type devices are not suitable for the road runoff with particle size less than 200um, and Ministry of Environment also points out this problem with guidelines.

Kim(2006) experimented on down flow filtration research about EPP (1 ~ 3), zeolite (bi ocell), zeolite (1 ~ 3), Inpakpalm (1 ~ 3), Ferox (1 ~ 3), GAC (2.5 ~ 5). The experiment showed that filtration speed and removal rate were inversely proportional, and SS removal rate were 39.7%, 5.3%, 43.3%, 60.4%, 39.1%, 21.1% respectively. Kim also experimented on EPP, GAC, and Zeolite considering treatment efficiency and filtration speed according to thickness of the filter layer.

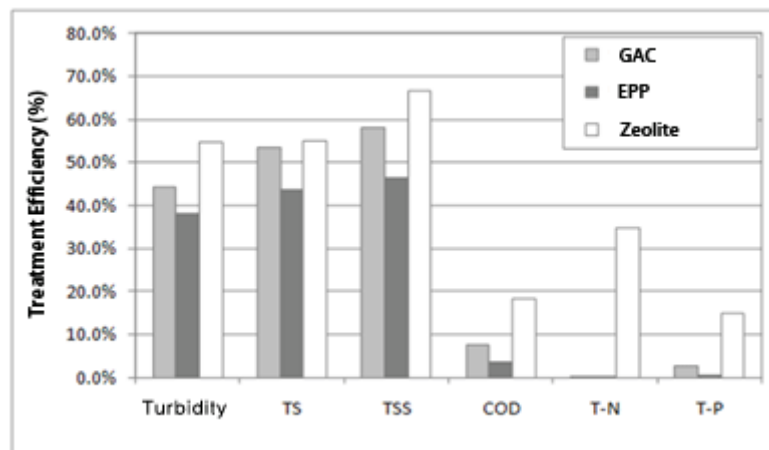


Figure 2.5 Treatment efficiency by filter media (Filter layer of 15cm)

Figure 2.5 shows the treatment efficiency in case of thickness filter layer set as 15cm. Also, the result of filtration duration time test about zeolite that has highest treatment efficiency demonstrated that setting initial stage as 20cm and average inflow SS concentration as 425mg/L, the filtration duration time was about 4 hours 25 minutes, and the relation between filtration speed and time was $Y = -0.0617x^2 + 0.0267x + 1.15886$. When the filtration was continued by $R^2 = 0.8514$, drastic increase in head loss was accompanied which increase was in number of meters.

Bang et al. (2005) researched on fiber, hydro ball, perlite, orchid stone, activated carbon, and sand setting the filtration rate as 200, 400, 600 m/day for each up flow and down flow.

For filtration rate, 200m/day, all filter media was close to or exceed 90% of the removal efficiency, and for 400m/day, 26~87% of removal efficiency was represented additionally, fiber showed the fair treatment efficiency and sand with particle size 38~63 showed bad treatment efficiency (lower than 8%).

SS removal efficiency about filtration duration classified by the filter media showed almost no change for down flow. In case of up flow, sand showed the fastest degradation in treatment efficiency. With fly ash (particle size from 38 to 63mm) as a representative, SS removal with filtration time 200m/day for perlite (3~4mm) showed more than 90% treatment efficiency even after thirty minutes.

2.3 Case study of treatment facilities from road runoff

There are two types of NPS management techniques for water quality of public waters. They are structural method that are based on ecological and engineering technology such as sedimentation, construction of penetration zone and physical treatment facility, and non-structural method such as application of drain water standard and land-use regulation. Among

those, NPS pollution management facilities that reduce NPS by various physical facilities can be classified by storage, penetration, vegetation, device-type facilities. The device-type facilities to remove pollutants in road runoff have methods that are removal by filtration treatment facility, sedimentation, and storm water separation device.

Device-type NPS reduction technology that is to remove pollutants included in road runoff during rainfall uses physical and chemical device. The examples are filtration type using screen and sand and commercialized products (storm filter, storm receptor, Swirl concentrators/Vortex solids separators, and oily water separation device).

Screen is used to remove relatively large floatation or garbage mainly for pre-treatment, but recently they have been used in 1st treatment stage of sewage and waste water due to the advance in screening technology.

Sand filtration consists of filtration layer which is comprised of sand with various particle sizes (from peat to coarse sand) and gravel layer which is for releasing of filtrated water. The removal of pollutants are mainly processed by filtration by filter media, sedimentation from upper layer of sand, but sand filtration has limitation that blockage occurs as time proceeds, so prompt removal of surface sediments, leaves, miscellaneous trash, etc. is required. Therefore, sand filtration is generally used in small areas, and also can be used as pre-treatment in larger areas, but sufficient treatment effects cannot be obtained.

In domestic areas, many devices for reduction of NPS pollution are manufactured and installed, and main products are classified by method using physical flow of rainfall runoff and method using removal such as filtration, coagulation to reduce pollution loads. Among those, the pros and cons of device type facilities that are combined with double filtration facility are shown in table 2.7.

Table 2.7 Analysis of storm water treatment using filtration

Advantages	Disadvantages
<ol style="list-style-type: none"> 1. Attached to suspended solids and solid contaminants can be removed 2. Possible to apply various filter media such as sand 3. Effectively remove bacteria and algae 4. Can be installed in a variety of formats 	<ol style="list-style-type: none"> 1. In a large drainage area unsuitable 2. Because it has a direct impact on the efficiency, filtration layer were required deleting and replacing periodic 3. Inlet to the pre-treatment facilities (sedimentation) is required 4. Management constraints on the installation location 5. This is applicable only in impervious area

Among NPS which occurs during rainfall, the road runoff especially that occurs at impermeable lands or roads have been pointed out with its water quality risk, so the application performances about the practical techniques and domestic and abroad studies have been increasing. Centered on advanced countries, since 1970s, many techniques listed in table 2.8 have been developed.

Table 2.8 shows the rate of removal according to each treatment process monitored by National Management Measures to Control NPS pollution from Urban Areas.

Table 2.8 Pollutants removal rate by storm water treatment devices (USEPA, 2005)

Runoff treatment median pollutant removal(percent) or control practice category	Pollutant removal rate (%)							
	No. of studies	TSS	T-P	OP	T-N	NOx	Cu	Zn
Quality Control Pond	3	3	19	N/A	5	9	10	5
Dry Extended Detention Pond	6	61	20	N/A	31	-2	29	29
Dry Ponds	9	47	19	N/A	25	3.5	26	26
Wet Extended Detention Pond	14	80	55	69	35	63	44	69
Multiple-Pond System	1	91	76	N/A	N/A	87	N/A	N/A
Wet Pond	28	79	49	39	32	36	58	65
Wet Ponds	43	80	51	65	33	43	57	66
Shallow Marsh	20	83	43	66	26	73	33	42
Extended Detention Wetland	4	69	39	59	56	35	N/A	-74
Pond/Wetland System	10	71	56	37	19	40	58	56
Submerged Gravel Wetland	2	83	64	14	19	81	21	55
Wetlands	36	76	49	48	30	67	40	44
Organic Filter	7	88	61	30	41	-15	66	89
Perimeter Sand Filter	3	79	41	68	47	-53	25	69
Surface Sand Filter	7	87	59	N/A	31.5	-13	49	80
Vertical Sand Filter	2	58	45	21	15	-87	32	56
Bio retention	65	N/A	49	16	97	95	-	-
Filtering Practices	18	86	59	57	38	-14	49	88
Infiltration Trench	3	100	42	100	42	82	N/A	N/A
Porous Pavement	3	95	65	10	83	N/A	N/A	99
Ditches	9	31	-16	N/A	-9	24	14	0
Grass Channel	3	68	29	32	N/A	-25	42	45
Dry Swale	4	93	83	70	92	90	70	86
Wet Swale	2	74	28	-31	40	31	11	33
Open Channel Practices	9	81	34	1.0	84	31	51	71
Oil-Grit Separator	1	-8	-41	40	N/A	47	-11	17

2.4 Characteristics of CSOs

At the area of combined sewer where sewage and rainfall runoff are transferred together during rainfall (only sewage during dry period), increase of discharge and change of concentration of pollution are large.

The road runoff that occurred during rainfall inflow to sewage including various pollutants cumulated on surface of road. In case of exceeding capacity of intercepting sewer pipe, that is not carried to sewage treatment plant, and non-intercepting discharge are out flowed to river via storm overflow diverging tank. Likewise, CSOs is discharged to receiving body of water (like river, dam, and etc.) because it exceeds the intercepting sewer capacity. Because CSOs contains road runoff as well as house sewage, it contains various pollutants and the effects on receiving body of water are known to be serious.

Among CSOs, early stage rainfall runoff contains highly concentrated hospital microbes or harmful materials due to the sediment in sewer, and if left untreated, public hygiene and ecosystem can be damaged. It also contains problem in appearance of landscapes due to trash and concomitants. (Japan sewage work association, 2002)

When the characterization of CSOs is examined during dry and rainfall period, dry period shows the variations in 2~3 times of water quality, while the range of variations was more than 10 times in case of during rainfall. According to report of EPA in US, CSOs contains all the contaminants like as organic materials, bacteria, nutrients, ammonia, turbidity, TSS, and toxic substances only except for acidic waste water. Therefore, those pollutants aggravate the water pollution by discharging a lot of amount via overflow drainage, and causes environmental pollution by flowing to river or lakes.

Chebbo et al. (1992) analyzed the floatable solid in runoff during rainfall, and reported that mostly the distribution of solid (66~85%) was under 100 μm . Also, it was reported that if the sediment was removed up to 3~44 μm (average sedimentation velocity : 4~11m/hr), up to 69~87% of total pollution load (in case of COD) were possible to remove.

Milne et al. (1996) interpreted the size distribution result in order to characterize the mutual effects between large solids and sewer sediments in combined network, and Becker et al. (1996) analyzed that most of particulate COD and total phosphorous sediment under the range of 0.04~0.9cm/s in case of road runoff.

In addition, Chancelier et al. (1998) proposed the mathematical model which represented property of settlement of pollutants by each sedimentation experimental methods. Meanwhile, Lee et al. (2005) reported that range of average particle size was 6.7~23 μm as the result of analysis of size distribution of road runoffs. Also, Han et al. (2002, 2003) studied on variation characteristics of floc size in potable water treatment process.

Yoon et al. (2006) measured the size distribution of CSOs, sewage during dry season, and surface runoff during rainfall by using the laser diffraction measurement method. According to analysis result of particles numbers, the median of particle size by sample type was similar for dry sewer and surface runoff (0.5 μm), but the range of size was 0.3~0.6 μm in sewer during dry season, 0.3~45 μm in combined sewer outflows, and 0.3~313 μm in surface runoff, which showed very big variation in CSOs and surface runoffs. For volume analysis of particles, the median of sewage in the dry season and CSOs were 85 μm and median of surface runoff was 50 μm , which is smaller. For frequency curve of the surface area of particles, it was analyzed that sewage in the dry season was 2.5 μm and CSOs was 15.3 μm and surface runoff was 9.0 μm . It was assumed that size distribution became very diverse because the solids deposited in dry season

and the deposited solids were mixed and flowed with large particles and storm water during rainfall.

Lee (2004) measured the change of water quality of CSOs which flowed into K sewage treatment plant, and the flowing concentration of SS was 14~812mg/L, averagely 228mg/L. Concentration of COD, BOD, TN and TP were 14~812 mg/L, 35~449 mg/L, 28~219 mg/L, 23~93 mg/L, 0~7 mg/L respectively, and SS change curve of CSOs and change of T-N, T-P, COD represented very similar trend.

Lee et al. (2010) proposed that when the flow rate of CSOs was measured, the flow rate rapidly increased 2 hours after the rainfall, which was two times greater than flow rate at same time during dry season. For particle distribution of the dry season, particle range 5~3000 μ m were distributed. There was significant amount of more than the particles size of 180 μ m during rainfall. During dry and rainy season, the concentration of COD, BOD, T-N, T-P did not change, but concentration of SS during rainy season increase 5.7 times greater than dry season due to the inflow of road surface sediments and big size particles by early stage storm water.

2.5 Filtration efficiency from CSOs

Yoon et al. (2006) conducted the sedimentation study by the depth of sedimentation column using CSOs. Sedimentation rate of pollutants by rainfall showed very different results: The range of removal rates was large, and compared to median curve of pollutants of CSOs, sedimentation rate curve of dry season sewage and surface runoff showed the tendency to fall downward. This means that sediment removal of CSOs is possible in despite of larger surface load amount and shorter residence time than dry sewage and surface runoff. Also, by this fact, we can conclude that pollutants by the re-flotation of sewer sediment have significant affect.

COD and SS showed similar sedimentation velocity change proportional to concentration. In other words, the higher the concentration at the beginning of study, the higher the removal rate of settling speed. This showed the similar trend to the study result of Randall et al. (1982) that early concentration and SS removal amount by sedimentation were proportional. For COD, setting 0.1cm/s as average sedimentation velocity, the removal rate of sedimentation velocity was 10% while it was respectively 40%, 20% for CSOs and surface runoff. For SS, CSOs was 50% and surface runoff was 20%.

Lee (2004) introduced DAF (Dissolved Air Flotation) based on the fact that particulate pollutants take up the largest portion among pollutants in CSOs. When CSOs were treated with DAF, SS removal rate was more than 90%, and the particles size greater than 10 μ m were mostly removed. With same operating condition that showed 90% removal by DAF, the SS removal rate by sedimentation and flotation was respectively 53% and 37%.

When separating settlement for CSOs, the SS treatment efficiency was low, so filtration process is introduced (Tanaka et al., 1995). Filtration process was different from potable water treatment in that it has lots of suspended solids and lots of clogging-causing materials that can cause the blocking of filter pores, so introduction of sand filtration was difficult (Maeng et al., 2006).

As an alternative, Son et al. (2010) introduced the fiber filtration device. As the flow rate increase, the removal efficiency of suspended solids is lowered, but at speed exceeding about 750m³/m²/d, the treatment efficiency was not lowered significantly. T-P also showed the similar trend but compared to SS, T-P removal efficiency was relatively low.

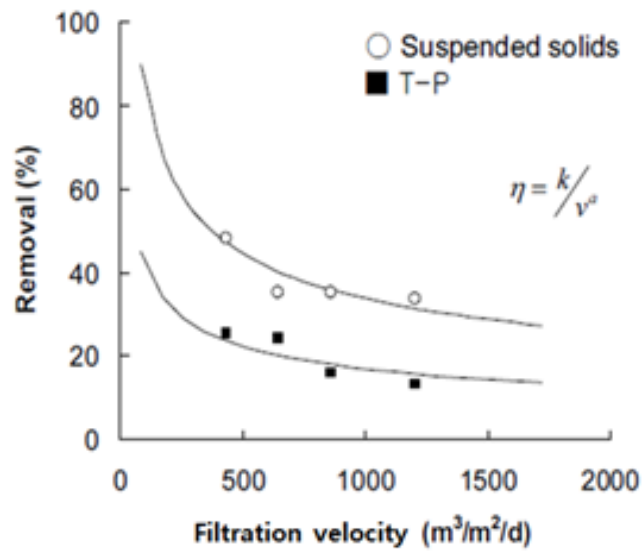


Figure 2.6 Relationship between filtration velocity and removal rate (Son et al., 2010)

Lee et al. (2010) treated CSOs using Vortex separator and continuous filtration process device, and the result was that removal efficiency of COD, BOD, T-N, T-P was 50%, 50%, 8%, 18%, respectively. The removal efficiency of Vortex separator was lower than fiber filtration device, but if fiber filtration device was operated alone, the treatment efficiency rapidly decreased because of fast blocking of fiber filter media by solids.

2.6 Case study of treatment facility from CSOs

The facility to reduce the discharge loads caused by CSOs has limitation in many respects such as efficiency, maintenance, and affordability. As methods to reduce CSOs discharge loads, increase of intercepting pipe capacity, separate sewer system, installment of storage facilities, and real-time control method can be used.

Intercepting pipe capacity expansion is the method to replace sewer pipe with larger capacity one. It is most common way but it increases traffic disorder, increases capacity and lowers efficiency of waste water treatment plant and has high construction cost.

Separate sewer system treats sewage without letting sewage flow into river during dry and rainy season without CSOs, however it is considered the efficiency of treatment plant and the applicability in the area. This is an effective way to reduce the overflows, but factors such as construction costs should be examined beforehand.

In general, more problems such as incorrect house connection to main pipe can occur due to the complex separate sewer compared to existing combined sewer system. Also, first flush in storm water sewer can be discharged into rivers, which become a fundamental problem. Therefore, the solution for this problem is required. (Kong et al., 2004)

Installment of storages at the combined sewer regions can not only reduce the overflow loads but also facilitate the installment and management due to function of reducing rainfall discharge for prevention of flood. Through this, we can cope with change of flow amount at ease. However, because it requires large space, there is a limitation to usage due to narrow land capacity in Korea, and the maintenance cost can be great due to the facility during storage period. In addition, it allows runoff (before discharge into the sewer) to stay at specific region, so the problem regarding public hygiene and public health can be raised (Gong et al., 2004).

Real-time control method uses computer to ensure the operation and control of the system. At the time of rainfall, the goal of real time control method is to cope with the state of flow in sewer and the change of rainfall type. To maximize the amount, it adjusts the pumping rate and location of flood control sluice. In other words, by measuring rainfall at multiple points, right amount of rainfall is calculated. Thus, optimal flow control method is derived. However, compared to general facilities, this method required complex and expensive devices. (Gong et al., 2004)

For managing CSOs, in case of USA, separate sewer system had been promoted to eliminate CSOs. Already in the 1960s, 122 local government 1,755 separate sewer system projects were in progress, but because of technical problems such as incorrect house connection caused by procedure to separate sewer system from combined sewer system and the monetary problem, the projects were changed from full-scale separate sewer system to mixed system. And for the combined sewer with the good condition of the pipeline, and overflow-control facilities were focused to install because it was concluded that it is better to treat first flush in early stage rainfall rather than change to separate sewer system.

In addition, in order to achieve the water quality standard of discharge line according to the CSOs maintenance policy announced by federal government in 1994, Nine Minimum Controls (NMC) was written and Long Term Control Plan (LTCP) were established.

In Japan, in order to reduce the pollution load, the reorganization of combined sewer (Retrofitting CSOs) project has been promoted, and established the policy on the 'Guidelines and construction manual for reduction of CSOs' published in 1982 that the goal was reducing CSOs loads to fewer than 5% of annual generation of BOD loads. In order to achieve this goal, method such as increase of intercepted capacity, improvement of storm overflow diverging

tanks, separate sewer system, inflow/infiltration reduction, construction of storm water storage tank, and outflow treatment facilities were suggested.

According to the revised the Sewerage Act Decree, the generation of overflow is regulated for improvement of sewer in case impact of rainfall is not great, and set discharge amount at its minimum by installment of screen at storm overflow diverging tanks. Also, in case of generation of overflow, the law set limit of event mean concentration (EMC) of BOD to less than 40 mg/L. (Gong et al., 2004)

CHAPTER 3 MATERIALS AND METHODS

3.1 Experimental sites

In this study, before the evaluating head loss, water quality treatment efficiency and particle size distribution for each filter media, we examined the particle size analysis and water quality of road runoff and CSOs generated at combined sewer storm overflow diverging tank in order to evaluate the discharge characterization of NPS during rainfall. In the case of road runoff, one-way four lanes highway, bridges, and three parking lots for each Area A and Area B in Gyeonggi-Do were examined, and for CSOs, storm overflow diverging tanks of Seoul urban area C and D that include drainage area of 33.3ha and 540.1ha were selected as point of analysis.

The overview of investigation points and the field photos of NPS discharge characteristics are shown in Table 3.1 and Figure 3.1.

Table 3.1 Summary of investigation points for capture of NPS pollution

Category		Point	Time	Total Rainfall (mm)	Preceding Dry days (day)	Survey items
Road Runoff	A Site	3 places (Roads, bridges, parking)	2013. 2. 18	6	28	- Water Quality (COD, SS, Pb, Zn, Cu) - Particle size analysis
	B Site	3 places (Roads, bridges, parking)	2013. 2. 25	15	15	- Water Quality (COD, SS, Pb, Zn, Cu) - Particle size analysis
CSOs	C Site	C storm overflow diverging tanks (33.3 ha)	2012. 6. 26	3.5	11	- Flow Measurement - Water Quality (BOD, COD, SS, T-N, T-P)
	D Site	D storm overflow diverging tanks (540.1 ha)	2012. 7. 16	33.5	4	- Flow Measurement - Water Quality (BOD, COD, SS, T-N, T-P)






vision	Fields photos		
Road Runoff			
CSOs		C storm overflow diverging tanks	D storm overflow diverging tanks
			

Figure 3.1 Investigation points for capture of NPS pollution.


The measurement of CSOs were conducted at the diverging tank that consist of various land forms such as residential, commercial, and roads form and has 33.3 ha drainage area and at the diverging thank with macro scale drainage area, 540.1 ha. The date of measurement was June 26th, 2012 when 3.5mm of rainfall occurred and July 16th, 2012 when 33.5mm of rainfall occurred.

3.2 Samplings and analysis

3.2.1 Samplings

In order to determine the First Flush during the rainfall, sampling was conducted at five minute intervals by sequentially increasing the yield interval depending on water quality. To measure discharge, PCM portable flow meter was used, and the details are shown in Table 3.2.

Table 3.2 Portable flow meter specifications

Division	Contents	
Manufacture / Model	NIVUS(Germany) / PCM3	
Details Specifications	Flow	<ul style="list-style-type: none"> · Method: Ultrasound (Doppler) method · Flow range : 1.52 ~ 6.1m/s · Accuracy : $\pm 2\%$
	Level	<ul style="list-style-type: none"> · Type : Fencing fast pressure conversion · Range : 5mm ~ 3.5m · Accuracy : ± 0.085
	Flow rate	<ul style="list-style-type: none"> · Accuracy : $\pm 2\%$

3.2.2 Analysis

Preceding case study for road runoff states that toxic substances such as heavy metals are existed in fine particles.

For water quality check, SS category was measured over time during rainfall, and then COD, Pb, Zn, Cu that contain heavy metals were analyzed for the sample that maximum SS

concentration was observed from each source. Additionally, size distribution analysis was conducted to examine the characteristics depending on size distribution.

The water quality categories about the collected water sample were analyzed according to standard method (APHA, 1995), and particle size analysis was conducted using Malvern's Mastersizer 2000E, measuring from 0.1 ~ 1000µm.

Heavy metals were analyzed using the ICP-MS. In specific, PerkinElmer's NEXION300X was used.

Specifications of each analyzer are shown in Table 3.3 and Table 3.4.

Table 3.3 Specifications of particle size analysis


Division	Contents	
Manufacture / Model	Malvern Instruments / Mastersizer 200E	
Details Specifications	<ul style="list-style-type: none"> . Measuring range - 0.1 ~ 1000 micrometer . Various kinds of measurements - emulsions, suspensions and dry powders . Accordance with the terms of measurable Flexibility - provides a variety of semi-automatic sample dispersion unit, 'plug and play' cassette system applies . An accuracy - Malvern Quality Audit Standard in accordance with the measurement results Dv50 is around ± 1% . Reproducibility - Dv50 measured under 1% RSD is superior in Malvern Quality Audit Standard 	

Table 3.4 Heavy metals analyzers (ICP-MS) specification



Division	Contents	
Manufacture / Model	PerkinElmer / NexION300X	
Details Specifications	<ul style="list-style-type: none"> . Upgraded Sample Introduction System . Automated X, Y, Z Axis Align . Plasma View Windows . Upgraded Main Q-pole and Detection System . New Vacuum System (3 Stage Turbo Pump + 1 Stage Roughing Pump) 	

Table 3.5 SEM (Scanning Electron Microscope) Specifications

Division	Contents	
Manufacture / Model	Hitachi / S-3400N	
Details Specifications	<ul style="list-style-type: none"> .3.0nm @ 30kV(High Vacuum Mode) .10nm @ 3kV(High Vacuum Mode) .4.0nm @ 30kV BSE(6Pa in Low Vacuum Mode) .Mag. Range x5 - x300,000(153 Steps) .Accelerating Voltage Range 0.3kV - 30kV(1,171 Steps) .Analytical WD 10nm, TOA=35 deg. .Vacuum System TMP(210L/sec)x1, RP(162L/min)x1 .VP Range 6-270 Pa 	

SEM (Scanning Electron Microscope) is the representative measurement that we can observe at the level of nanoscale and it is a device that allows observing surface tissue in three-dimensional even for high magnification using electrons. For this study, Japan Hitachi's S-3400N model was used as SEM and the specifications are shown in Table 3.5.

3.3 Selection of filter media and properties analysis

3.3.1 Selection of filter media

Filter media used in this study was selected targeting commonly used filter media at device type NPS reducing facility which lacks domestic installment of filtration. The selected filter media was zeolite as non-floatable filter media and EPP, EPS, perlite as floatable filter media.

3.3.2 Analysis of the physical properties of media





In common, up-flow types are selected for filtration method for NPS pollutants, and considering treatment efficiency and safety in operation, polymerized floatable filter media are largely considered. As a result, the most widely used in the market are Expanded Polypropylene and Expanded Polystyrene.

Perlite is artificial soil made from the perlite formed by the volcanic process which is pulverized, heated, and expanded. As many pores light-weighted soil, it has quality of non-flammable, heat-insulation, sound adsorption, anti-chemical, non-toxic and the volume is very light and has many pores, so that it has excellent drainage and air permeability.

The characteristics of Zeolite are porosity, adsorption performance, and ion exchange performance, and making use of this property, it is mainly used for moist removal, and for changing hard water to soft water.

The physical characteristics of each filter media used in the experiment are shown in Table 3.6.

Table 3.6 Physical properties of filter media

Items	EPP	EPS	Perlite	Zeolite
Picture				
Particle size	1.0 ~ 3.0mm	2.0 ~ 3.0mm	1.0 ~ 3.0mm	1.0 ~ 4.0mm
Specific gravity	0.8	0.8	0.04 ~ 0.25	2.01 ~ 2.20
Porosity	80% over	33%	80%	45 ~ 55%
Specific surface site	Over 800 m^2/m^3	Over 500 m^2/m^3	600 m^2/g	600 ~ 700 m^2/g
Distribution of micro pores	50 ~ 300 μm	100 ~ 500 μm	20 ~ 100 μm	3 ~ 20 Å

The proportion of Perlite which is buoyant filter media is the lowest (0.04~0.24), and EPP and EPS show the same value, 0.8. The Zeolite which is non-buoyant filter media has portion of 2.01 to 2.40 which is quite high.

3.3.3 Adsorption characteristics of filter media

The distribution of micro pores which represents the absorption capacity of filter media was the finest for Zeolite which has the finest void, and EPP and EPS showed the similar results.

In order to determine the nature of adsorption of filter media, the experiment applied to chemical filter media was conducted (Bishop, 1983). 250 ml of Tap water and 25g of waste oil were mixed and 0.5 g of filter media was added into the mixture and was stirred for about 3 minutes. The weight was recorded for selectively chosen filter media which waste oil was absorbed.

Table 3.7 Adsorption characteristics of filter media

Division	EPP	EPS	perlite
Adsorption amount per unit of filter media	9.61	19.94	3.86

Because Zeolite has density greater than 1 and sinks under water, zeolite was excluded in the experiment. Perlite which is buoyant but mineral filter media showed very low oil absorption compared to EPP and EPS which are polymer buoyant media.

EPS showed two times higher absorption than EPP, but in consideration that the foaming capacity of EPP is 15 times and that of EPS are 30~40 times, the absorption is quite similar. In fact, the material used as oil absorption paper in market is PP.

3.4 Experimental methods for filtration efficiency

In this section, the test method for evaluating the treatment efficiency for each filter media and filtration treatment test devices, the manufacturing method of artificial inflow of the filtration device for evaluation of filtration performance of road runoff and CSOs were stated.

3.4.1 Experimental device

The treatment facility using filter media are classified into downstream and upstream depending on the flow type of raw water. Downstream shows higher treatment efficiency due to same direction with gravity that causes filtration and sedimentation to occur at the same time but the filtration residue are easily settled on the upper part of filter layer and has higher risk of exposing filtration residue if discharge is heavy.

On the other hand, upstream system is facilitated in control of treatment amount and the filter residue has no direct impact on the filter layer. Therefore, upstream system fits for the heavy discharge treatment and device-type non-point facility which accompany the By-Pass (rainfall overflow). Thus upstream system was used in this study.

The experimental apparatus had two types: acrylic and STS. The surface area of filter media was 289 cm^2 , the filter layer's height was 50cm, and By-pass was 40cm from the upper part of filter layer.

In the case of acrylic, it was used as the experimental apparatus to test the treatment efficiency of outflow compared to inflow for each filter media, and the STS type was used for evaluating the treatment efficiency according to the change of height of the filter layer by installing outflow valve with intervals of 10cm on the 50cm height filter media outlet.

Each experimental apparatus and diagrams are shown in Figure 3.2.

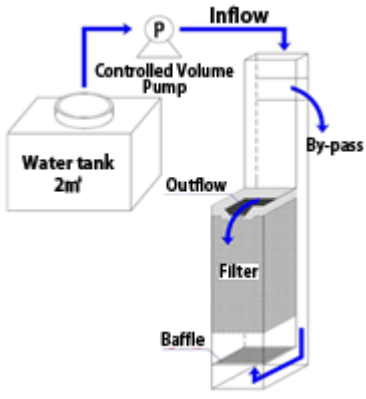
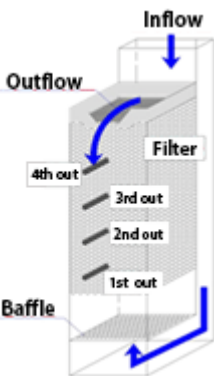
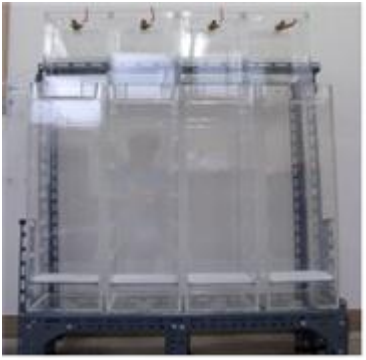

Division	Experiment Device 1 (acrylic material)	Experiment Device 2 (STS material)
Experiment Diagram		
Experiment Device		

Figure 3.2 Experimental device and schematic diagram for the evaluation of filtration efficiency

3.4.2 Manufacturing samples of road runoff and CSOs

For the evaluation of filtration performance for road runoff and CSOs, inflow was manufactured in order to re-enact the water quality during real rainfall.

The concentration of road runoff was modified similar to that of inflow by mixing the tap water to the dust collected from the road surface which was filtered by 850 μ m sieve to remove the excess particles. CSOs were used with modifying concentration of inflow by mixing proper amount of dust to the daily waste water of diverging tank at fine weather.

Figure 3.3 describes the manufacturing process of inflow raw water according to generation source of non-point pollution. Dusts of road surface are collected and filtered. Then road surface inflows are made by mixing Dusts and tap water, and inflow of CSOs are made by mixing Dusts with sewage during fine weather.



Figure 3.3 Manufacturing process of test samples from NPS pollution

3.4.3 Experimental methods

The linear velocity of inflow for the test experiment of treatment efficiency of NPS for each filter media was set as 950m/day which is the maximum linear velocity presented by the Ministry of Environment. In order to reach that velocity, standard pump was used, and in order to reproduce the water quality characteristics of CSOs, road dust was mixed into the tap water and waste water during rainfall. The SS concentration of this mixture representing the inflow raw water was in range of 931~1,450 mg/L.

In order to keep the conditions at constant, the separate agitator was placed in two-ton water tank to mix the dust and inflow consistently, and for each filter media, inflow and outflow were collected and the size particle and water quality was analyzed in 10 minutes interval.

In each experiment, the measurement range of head loss limit by hydraulic loads was set on 40cm considering the economics and field applicability of device-type non-point reduction facilities with filtration and if more than 40cm of head loss occurs for each filter media, the experiment was terminated.

Also, for the filtration performance evaluation for road runoff, the filter layer treatment water were additionally collected on 1-hour intervals in order to test the treatment efficiency according to the filter height, After all the experiments were finished, additional particle analysis were conducted on the filter media washing water in order to identify the property of particles that are present in each filter media.

CHAPTER 4 EVALUATION OF SEDIMENTATION AND FILTRATION EFFICIENCY FROM ROAD RUNOFF

4.1 Characteristics of road runoff in the study site

The road runoff filtration characteristics of device-type NPS reduction facilities using filtration process were analyzed at roads, bridges, and parking lots in urban site A and B in Gyeonggi-Do during winter time. The road runoff pollution generation and particle characteristics were analyzed as the followings.

4.1.1 SS

In order to examine pollutants characteristics of road runoff, site A and site B were chosen. Site A showed the total rainfall of 6mm and intensity was 3mm/hr. Site B's total rainfall was 15mm and intensity was 2.5mm/hr.

Overview of the measurement is shown in Table 4.1.

Table 4.1 Overview of captured samples by each site

Category	Point	Preceding dry days (day)	Total rainfall (mm)	Duration of rainfall (min)
A Site	3 places (Roads, bridges, parking)	28	6	120
B Site	3 places (Roads, bridges, parking)	15	15	420

SS monitoring result at each point are shown in the Figure 4.1 ~ 4.2 and Table 4.2.

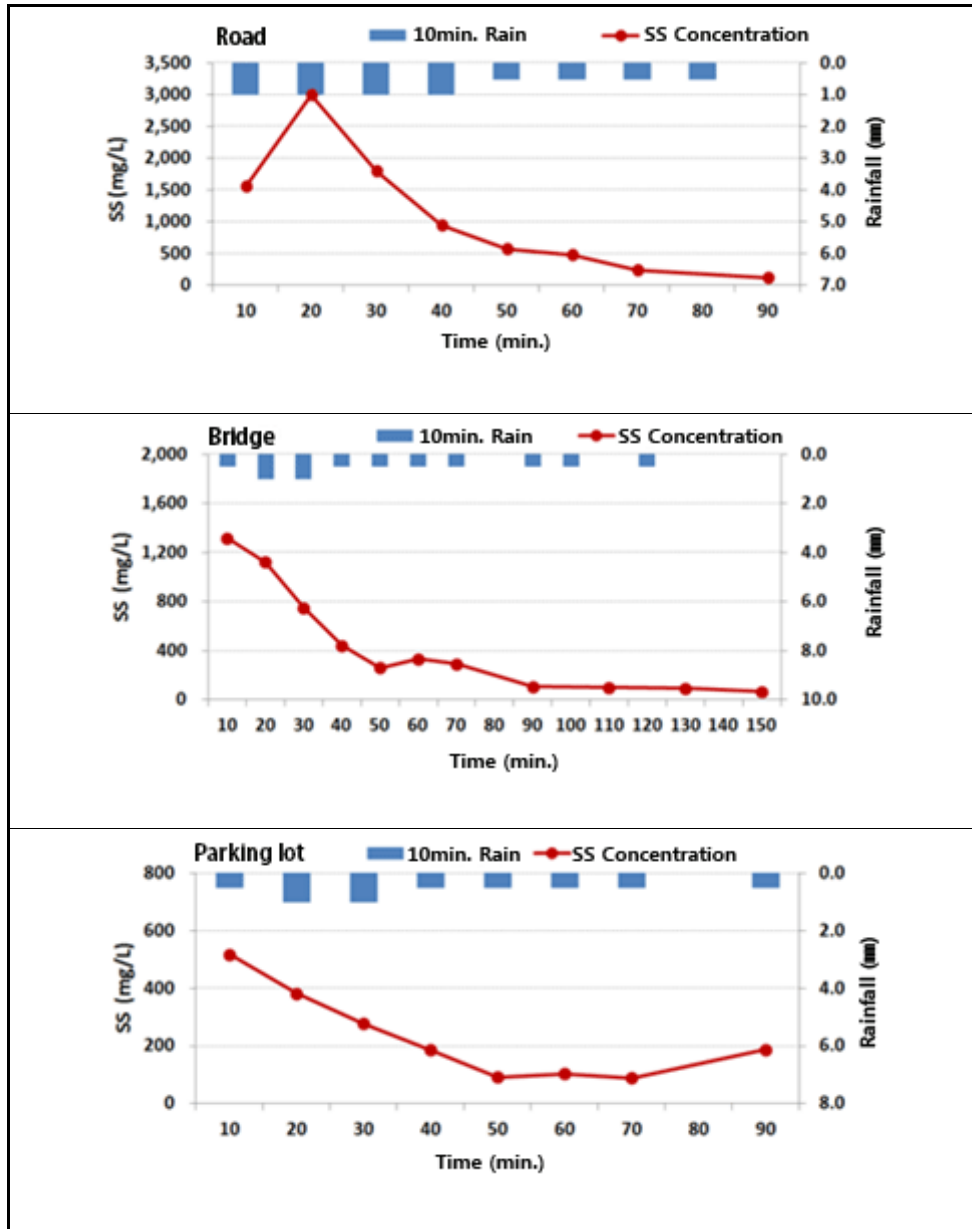


Figure 4.1 SS monitoring result by road runoff (A site)

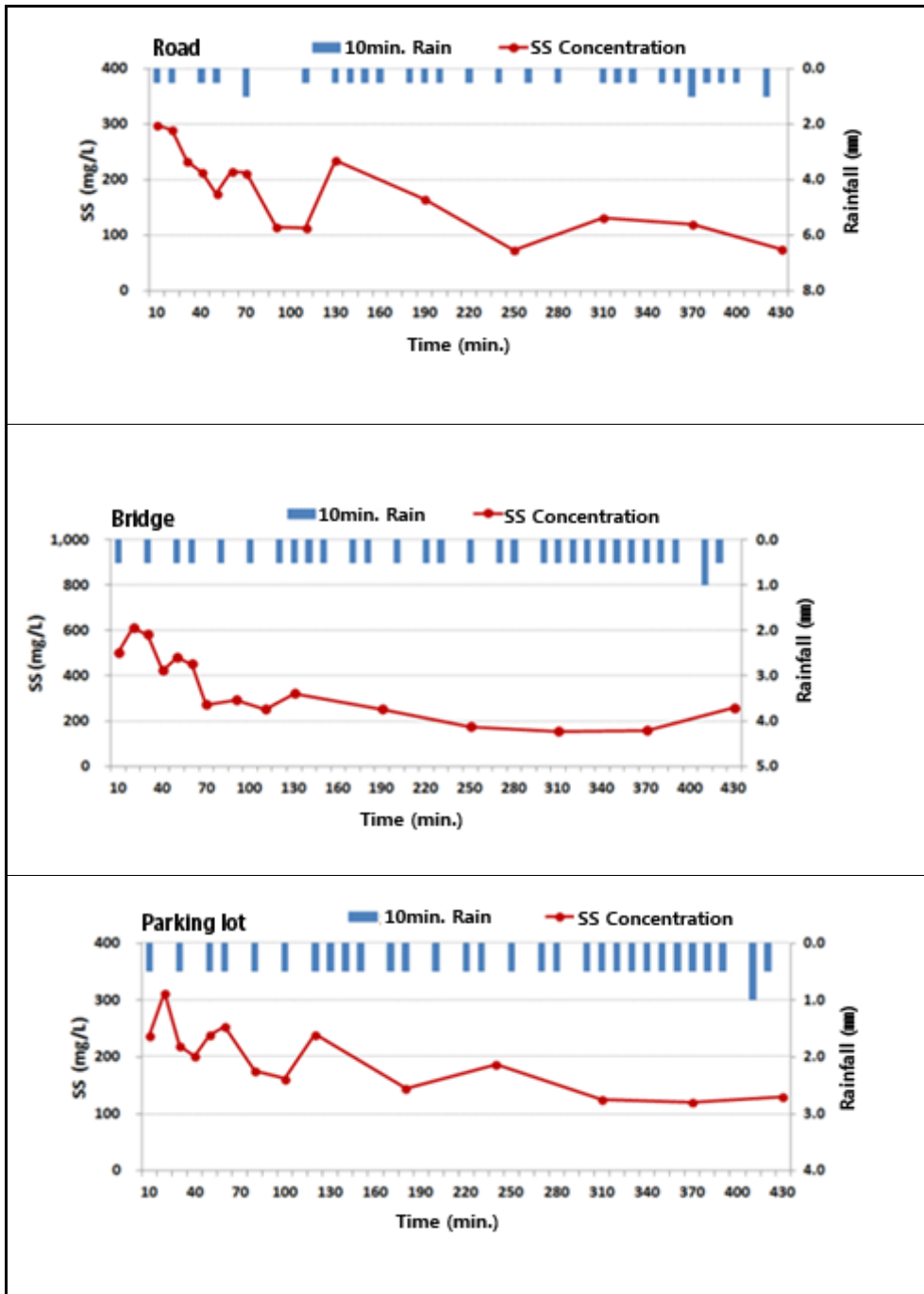


Figure 4.2 SS monitoring result by road runoff (B site)

Table 4.2 SS monitoring result by road runoff source

Division	Source quantity	SS concentration(mg/L)			
		Minimum	Maximum	Average	
A Site	Roads	8	117	3,004	1,091
	Bridges	11	68	1,320	445
	Parking	8	87	518	229
B Site	Roads	16	74	298	178
	Bridges	15	154	611	345
	Parking	14	121	313	197

The monitoring result for each generation source about the rainfall runoff in urban area showed that region wise, roads and bridges had higher SS concentration than parking lots overall in site A. In case of site A, it is assumed that higher SS concentration was shown because antecedent dry days (28 day) are longer than 15 days of Site B, which allows more pollutants to be aggravated on the roads. Point wise, it is assumed that roads and bridges showed higher concentration because they have more pollutant generated due to a lot of vehicles driving in high speed compared to parking lots.

As shown in Table 4.2, SS concentration change over time showed that in spite of small amount of rainfall, as the rainfall intensity of Site A and Site B was respectively 3.0mm/hr and 2.2mm/hr, the maximum SS concentration was occurred within ten to twenty minutes and then decreased drastically. The regional concentration of roads, bridges, and parking lots during the monitoring period were 4.0~25.7 times, 4.0~19.4 times, and 2.6~6.0 times respectively and it was confirmed that the longer antecedent dry days and the more traffics, the greater the difference in concentration of rainfall road runoff.

4.1.2 Water quality analysis

As shown in Table 4.1, the result of SS monitoring for each generation source about rainfall road runoff in urban area demonstrated that Site A, in general, had the higher concentration than Site B. Therefore additional water quality analyses are conducted on Site A on items such as COD, Cu, Zn, Pb. The results are shown in Figure 4.3.

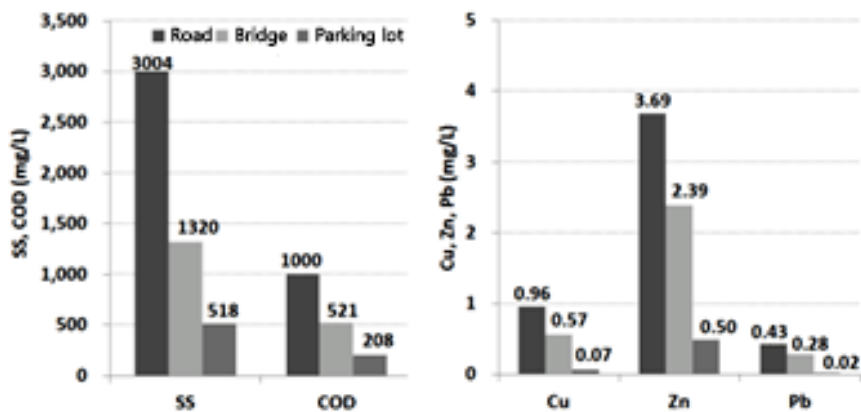


Figure 4.3 Water quality analysis result at the time of maximum SS occurrence

Five water quality parameters, including heavy metals, showed the concentration order as SS : Roads > bridges > parking lots. The COD concentration in road runoff was 1,000mg/L, 521mg/L, 208mg/L for roads, bridges, and parking lots respectively. This indicates that because the organic material concentration is mainly consisted of particulate substances, as the SS concentration becomes higher, the organic material concentration becomes higher. Cu, Zn, Pb were examined for heavy metal components, and among those, Zn components were the highest. For roads, Cu, Zn, and Pb's concentration were 0.96mg/L, 3.69mg/L, and 0.43mg/L respectively. For bridges, they were 0.57mg/L 2.39mg/L 0.28mg/L for Cu, Zn, and Pb in order. Lastly, for parking lots, concentration of Cu, Zn and Pb, were respectively 0.07mg/L, 0.50mg/L, 0.02mg/L.

These results showed the higher value compared to existing research result of Kim. et al. (2004) which showed concentration of Cu 0.01~1.0mg/L, and Pb 0.01~0.3mg/L. It is assumed that the result is higher compared to other research because the time of investigation was in the mid of February when the antecedent dry days were longer as 28 days and at the time of monitoring, the pollution loads were accumulated in snow of road. Regional wise, roads and bridges have more vehicles running at high speed, thus have more impurities on roads caused by tire and engine wear. Therefore it was concluded that concentration of not only SS but also COD, heavy metal were higher detected.

4.1.3 Particle size distribution

According to the SS monitoring result generated road runoff, the most highly concentrated site A was selected as the representative area and the result of SS concentration analysis on this site showed concentration on roads, bridges, and parking lots are respectively 1,320mg/L, 3,004mg/L, and 518mg/L. From this result, additional particle size analysis was conducted.

The particle size distribution result about maximum SS generation onset of road runoff during rainfall is shown in Figure 4.4 and Table 4.3.

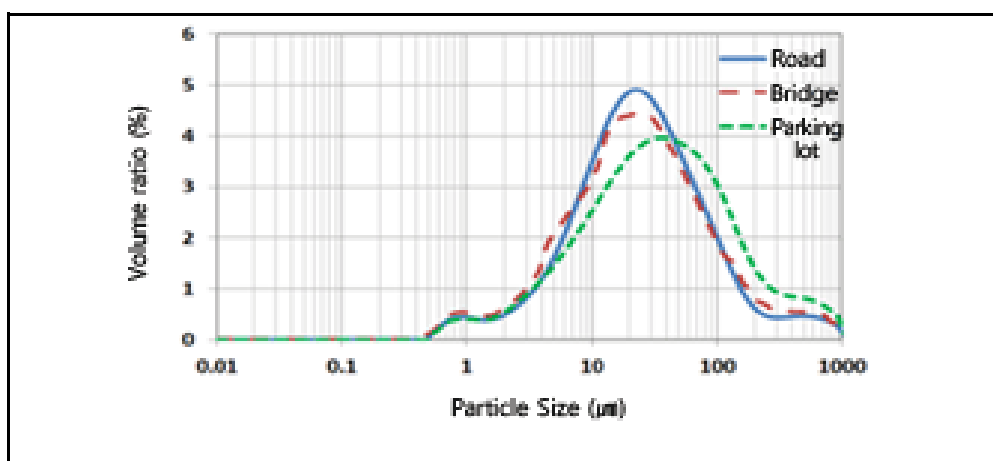


Figure 4.4 Particle size distribution result at the time of maximum SS occurrence

Table 4.3 Particle size distribution result about road runoff

Division	Particle size(μm)		
	Roads	Bridges	Parking Lot
D(0.1)	4.70	4.08	4.65
D(0.25)	10.74	9.35	12.33
D(0.5)	21.99	21.43	31.56
D(0.75)	49.09	56.36	74.31
D(0.9)	102.34	129.13	184.34

The particle size that corresponds to 50% for each region showed similar result for road and bridge: $21.99\mu\text{m}$ and $21.81\mu\text{m}$ in order, but parking lots showed the difference which value was $31.55\mu\text{m}$. The size representing 75% was also similar in roads ($49.09\mu\text{m}$) and bridges ($56.36\mu\text{m}$), but again parking lots' particles size, 74.31 showed a big difference. This was resulted from the fact that parking lots contain more particles that are greater than 100 compared to roads and bridges.

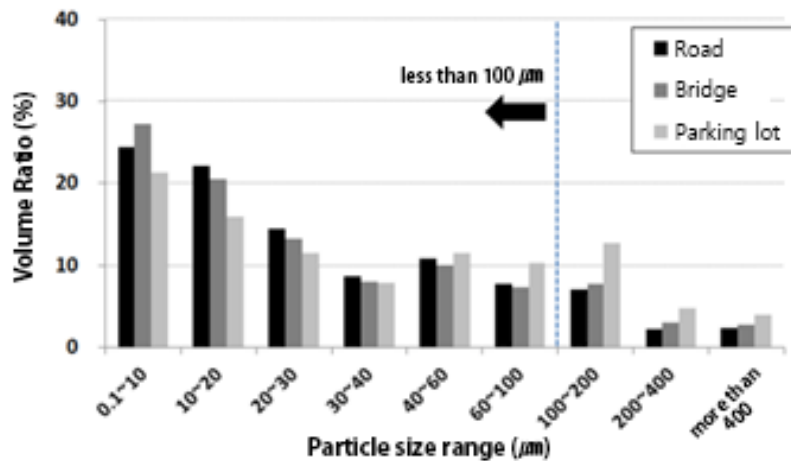


Figure 4.5 Particle size range-volume ratios at the time of maximum SS occurrence

Table 4.4 Volume ratios by each particle size range

Particle size range	Volume ratio (%)		
	Roads	Bridges	Parking Lot
less than 10 μ m	24.4	27.2	21.3
10 μ m ~ 60 μ m	56.2	51.8	46.9
60 μ m ~ 100 μ m	7.8	7.3	10.3
100 μ m or more	11.6	13.5	21.5

As shown in Figure 4.5 which represents the particle size analysis in ratio of volume by each size range, the volume ratio of particles under 10 μ m was 24.4%, 27.2%, and 21.3 % for roads, bridges, and parking lots respectively. The volume ratio of particles under 100 which is very hard to remove in short retention time of sedimentation process was 88.4% for roads, 86.3% for bridges, and 78.5% for parking lots which indicates that they consists of mostly micro particles.

The result on pollution load and particle size distribution of road runoff was similar to that of previous research conducted by Lee et al. (2005). The study of Lee et al. (2007) also showed that the particle size range mostly falls in nearby 20 μ m in case of road runoff, and they reported that the smaller the particle size, the higher the concentration of heavy metal.

Based on the result of particle size and SS water quality analysis, the particle size was converted to weight ratio according to the region. All particle were assumed all particles to be spherical regardless of size, and the weight for each particle size according to size analysis were 2.14~2.60 referencing the specific gravity range of dust generated on roads presented by USEPA.

The SS load ratio about particle size in range of 60~100 μm according to region are shown in Figure 4.6 and Table 4.5

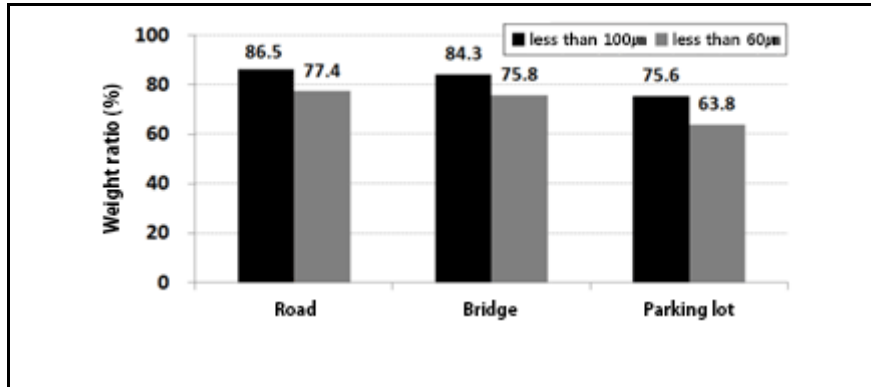


Figure 4.6 Weight ratio of particle at the time of maximum SS occurrence

Table 4.5 Load ratio by each particle size range

Particle size range	Load ratio (%)		
	Roads	Bridges	Parking Lot
< 10 μm	23.4	26.1	19.9
10 μm ~ 60 μm	54.0	49.8	43.9
60 μm ~ 100 μm	9.1	8.5	11.8
> 100 μm	13.5	15.7	24.4

As shown in Figure 4.6, weight ratio of particle that are under 100 μm were 86.5% for roads, 84.3% for bridges, and 75.6% for parking lots. For particles under 60 μm , weight ratio calculated was 77.4% for roads, 75.8% for bridges, and 64.8% for parking lots, thus confirmed that micro particles takes up most of total SS pollution loads

According to particle size distribution result, the volume ratio is greater as particle size is smaller. In case of roads and bridges, the SS pollution loads takes up 75% of total pollution loads in the range of micro particles under 60 μ m. Thus the treatment of micro particles is an important factor in filtration performance evaluation of storm water treatment.

4.2 Sedimentation as pre-treatment

4.2.1 Pre-treatment process

The basic treatment process of filtration type reduction facility which is device-type NPS pollution reduction facility is shown in Figure 4.7.

The road runoff which is generated from impervious surface such as roads moves through the storm sewer, flows into the NPS pollution reduction facility on the edge and is treated. Once it is flowed into treatment facilities, the pollutants with relatively bigger particle size are processed with chemical sedimentation in sedimentation storage tank, and the pollutants with smaller particles that flow along the current are processed by filtration and collection when passing through the filter layer outlet.

Here, the sedimentation storage chamber is where pre-treatment process occurs and filtration treatment chamber is where actual treatment process occurs.

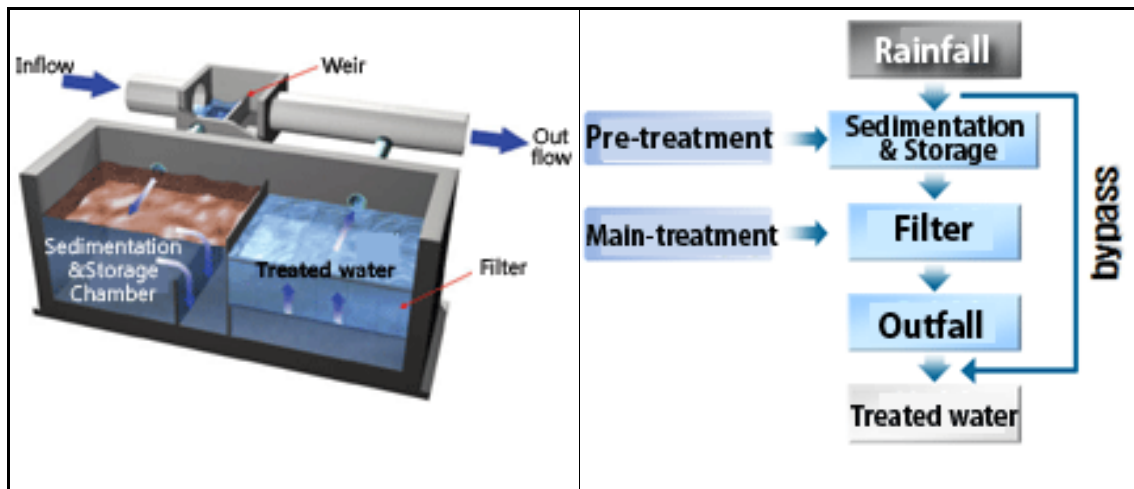


Figure 4.7 Treatment facilities and process diagram

4.2.2 Design criteria

The sedimentation storage which is pretreatment process has the basic role which is filtration of coarse impurities and pollutants that gravity sedimentation occurs due to high specific gravity. It was expected that the pollutants with particle size greater than $100\mu\text{m}$ would be treated in the sedimentation storage chamber, and in order to confirm, the sedimentation treatment characteristics were analyzed through numerical analysis.

Table 4.6 shows the calculation formula for each design parameters of settling basin based on the sewage system standards, and Figure 4.8 is the example of device-type reduction facility with $500\text{ m}^3/\text{hr}$ handling capacity. Grit chamber generally reduces the non-perishable inorganic materials and buoyant materials with large particle size ($\geq 100\mu\text{m}$) among influent.

Table 4.6 Formula of each design parameters in grit chamber

design parameters	Formula	
Velocity limit	$V_c = \left[\frac{8\beta}{f} \cdot g(S-1)D \right]^{1/2}$	f : Coefficient of friction(≈0.03) β : Constant(≈0.06) g : Acceleration due to gravity (9.8 m/s ²) S: specific gravity (2.65) D: particle diameter(m)
Effective length	$L = V \cdot T$	L : Grit Chamber effective length(m) V : Average velocity(m/s)
Effective width	$W = \frac{Q}{V \cdot T \cdot v}$	T : Settling Time(s) W: Grit Chamber Effective width(m)
Effective depth	$H = T \cdot v$	Q : Influent(m ³ /s) v : Surface loading rate(m ³ /m ² · s) H : Effective depth of Grit Chamber (m)

The calculation result for grit chamber of reduction facilities using formulas shown in Figure 4.8 with assumption that flow of fluid is laminar flow was that average flow rate was 0.03m/s, and retention time was 140 seconds, and surface loads were 1.043 m³/m² · s.

The grit chamber of non-point reduction facilities do not have the stable condition about the sedimentation of soil particles compared to sewage facilities. Therefore, according to the shape of influent chamber and flow of fluid within reduction facilities, the sedimentation effect can be reduced due to unidirectional flow and short-circuit flow, so the flow of fluid was examined according to shape of treatment facilities and flow board using CFD simulation

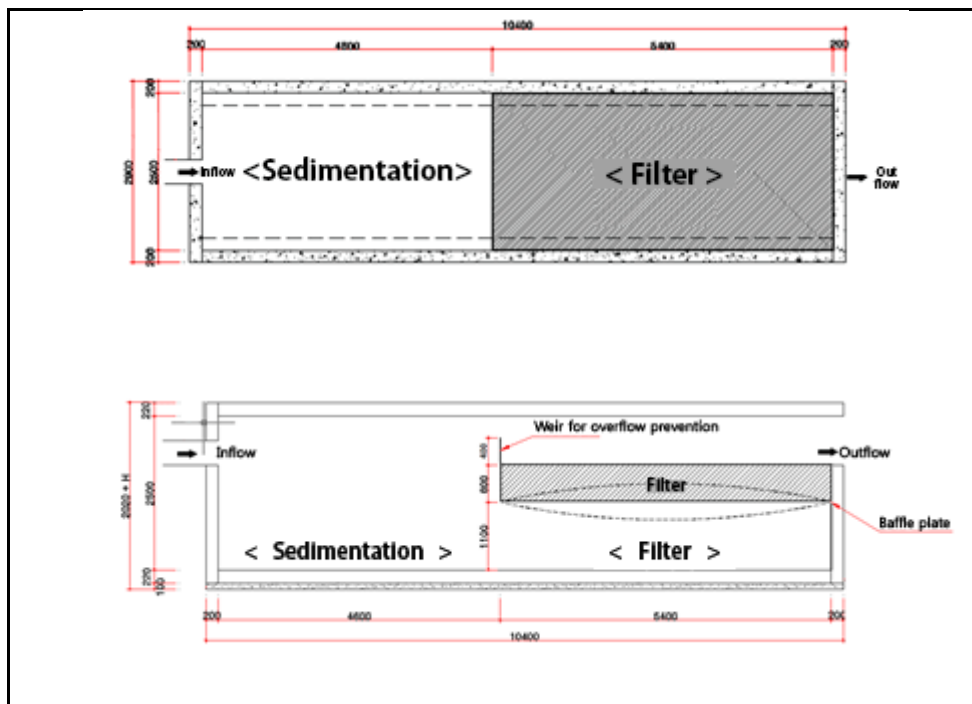


Figure 4.8 Storm water treatment facilities

4.3 Numerical analysis for sedimentation

Because the particles with size over 100 in road runoffs can go through gravitational sedimentation, they are controllable in grit chamber according to the structure of NPS pollution reduction facilities. In this section, using CFD model, the behavior of fluid and particle distribution according to structure characteristics of reduction facilities will be simulated and the optimal condition for successful treatment in grit chamber will be calculated.

4.3.1 Model

(1) Interpretation method

When trying to interpret the behavior of the fluid, there are many cases that the experiments are hard to carry out due to the difficulty in measurement and production of experiment devices, enormous time consumption and expenses, and difficulty in experimental technique requirements. In these cases, whole experiment or part of experiments can be anticipated using computers. In other words, the experiment can be substituted by numerical simulation.

Numerical prediction of flow phenomenon based on the theory of fluid mechanics received a lot of attention as a new method to replace the model test method as the numerical prediction enable us to do macro-scale calculation with the rapid development of computer technology. Numerical prediction method has many advantages. It has lower uncertainty and we can set variety of variables that dominates flow field randomly. Also, it has complete reproducibility and we can obtain temporal and spatial details which cannot be acquired by experiments.

Nowadays, the basic principle behind the CFD (computational Fluid Dynamics) models, which are mostly used in temperature distribution and air current analysis are k- ϵ model which is composed of two energy transfer equations. In k- ϵ model, K represents the kinetic energy of turbulent flow and ϵ represents the diffusion of kinetic energy. Because of such simplicity of k- ϵ model, it has limitation to interpret very complicated figuration perfectly, but for now it is evaluated as the most suitable theory for computer programmed.

In addition, numerical analysis, the governing equations entire analysis site for the finite volume method (FVM, Finite Volume Method) and the non-staggered grid mesh (Non-staggered grid) methods dioxide was interpreted as a tool the commercial code, STAR-CCM +

7.04 to be used. In this study, using the STAR-CCM + 7.04 heat transfer, air flow, phase change and chemical reaction is developed for numerical simulation of related phenomena as the program design, pollutant propagation and is applied to the study of combustion phenomena.

For heat transfer and aerodynamics calculation using STAR-CCM + 7.04, implicit scheme and segregated solver were used. Moreover, Non-staggered grid system that vector quantity (ex. velocity) and scalar quantity (ex. temperature, pressure) exist in the same place was used. In order to treat pressure field of Momentum equation, SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithms, which is known to predict the pressure field accurately in spite of relatively less calculation involved, was used. In real program management, upwind differencing scheme to treat convection term was used and to treat diffusion coefficient harmonic mean was used.

The governing equations, when integrated about each finite volume after the equations are converted into general equations in terms of ϕ , the following linear algebraic equations are obtained about control volume P.

$$a_P \phi_P = a_E \phi_E + a_W \phi_W + a_N \phi_N + a_S \phi_S + a_T \phi_T + a_B \phi_B + b \quad (1)$$

Here, each coefficient is defined as follows:

$$b = S_c + S_p \phi_i$$

$$a_E = D_e A(P_e) \quad a_W = D_w A(P_w)$$

$$a_N = D_n A(P_n) \quad a_S = D_s A(P_s) \quad (2)$$

$$a_T = D_t A(P_t) \quad a_B = D_b A(P_b)$$

$$a_P = a_E + a_W + a_N + a_S + a_T + a_B \quad (3)$$

In equation (1) to (3), the capital letters of E (e), W (w), N (n), S (s), T (t) and B (b), used as a subscript, indicates the control volume that is placed in control volume which is adjacent to east, west, north, south, top and bottom. The lower case indicates sides of east, west, north, south, top and bottom. Peclet number is defined as follows.

$$\begin{aligned}
 P_e &= F_e/D_e & P_w &= F_w/D_w \\
 P_n &= F_n/D_n & P_s &= F_s/D_s \\
 P_t &= F_t/D_t & P_b &= F_b/D_b
 \end{aligned}
 \tag{4}$$

Here, F and D each represent convection term and diffusion terms.

In Equation (2), the function A (P), if upwind scheme is used, is expressed as follows as function of Peclet number

$$\begin{aligned}
 A(P) &= A(|P|) + -[P, 0] \\
 &= 1 + [-P, 0] \dots
 \end{aligned}
 \tag{5}$$

Because the governing equations are non-linear, convergence of solution by the repeated calculation is required. When repeatedly calculated, Residual R value defined below was investigated to check degree of convergence. For each dependent variable, if the residual value was less than 10^{-3} , it was considered to be converged.

$$R = \sum_{\text{cells } P} \left| \sum_{n\delta} a_{n\delta} \phi_{n\delta} + b - a_P \phi_P \right|
 \tag{6}$$

Here, represent general variable a present coefficient of discretization equation b represent source function and subscript p, nab represent grid point of calculation control volume and adjacent control volume respectively.

(2) Governing equations.

The continuity equation :
$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \quad (7)$$

Momentum equation:

$$\frac{\partial}{\partial x_j}(\rho u_j u_i) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left\{ (\mu + \mu_t) \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) \right\} + S_{u_i} \quad (8)$$

Energy equation:

$$\frac{\partial}{\partial x_i}(\rho u_i h) = \frac{\partial}{\partial x_i}(k \text{ grad } T) + S_h \quad (9)$$

Turbulent kinetic energy equation:

$$\frac{\partial}{\partial x_i}(\rho u_i k) = \frac{\partial}{\partial x_i} \left\{ \left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right\} + G_k - \rho \epsilon \quad (10)$$

Turbulent kinetic energy dissipation rate equation:

$$\frac{\partial}{\partial x_i}(\rho u_i \epsilon) = \frac{\partial}{\partial x_i} \left\{ \left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_i} \right\} + G_k C_{1\epsilon} \frac{\epsilon}{k} - C_{2\epsilon} \rho \frac{\epsilon^2}{k} \quad (11)$$

Here,

$$G_k = \mu_t \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) \frac{\partial u_i}{\partial x_i}, \quad C_\mu = 0.09, C_{1\epsilon} = 1.44, C_{2\epsilon} = 1.92$$

$$\sigma_k = 1.0, \sigma_\epsilon = 0.9, \sigma_l = 1.0, \sigma_z = 1.0$$

(3) Model used for CFD analysis

The model used in the analysis is a multi-phase flow scheme. Various ways are used to simulate separation phenomena of mixture of solid and liquid. Lagrangian and DEM model are used to see the behavior of particles.

This is interpreted by considering gravitational sedimentation and calculating drag force of particles without taking up volume by the size and density of particles that are assumed to be completely spherical in the base fluid.

Model applied in this analysis are shown in Table 4.7.

Table 4.7 Model used for CFD analysis

Items	applied models
Phase	Lagrangian multiphase
Time	implicit unsteady
Turbulence	Standard K-Epsilon model
Density	Constant
Multiphase-Interaction	Drag force
Domain	Three dimensional
Mesh	Trimmed mesh

4.3.2 Concept and the input parameters

In case of NPS treatment facilities with filtration device, they are divided into grit chamber and filtration chamber to facilitate the cleaning and maintenance. Also inlet was set to let most of particles with large particle size to be settled on grit chamber. Shape and design of the structure was set for filtration to be easy.

Influent that is subject to be treated shows volume and weight ratio classified by particle size as shown in Table 4.8. Those values were calculated with assumption that SS concentration is 341.4 mg/L and based on investigation result about particle distribution. The ratio of number of particles was calculated with assumption that the maximum particles size of 700 μm or more is 1.

Table 4.8 Input parameters for CFD analysis

Influent particle size distribution range (μm)	Average particle size (μm)	Particle volume ratios by size per 1L (%)	Weight by size per 1L(mg/L)	Weight ratio by size (%)	Number of particles
0 ~ 10	5	3.59	13.88	4.06	3,079,923
10 ~ 20	15	7.62	27.48	8.05	225,853
20 ~ 30	25	10.91	37.96	11.12	67,408
30 ~ 40	35	10.19	34.98	10.24	22,529
40 ~ 60	50	17.82	60.75	17.79	13,420
60 ~ 100	80	21.79	73.79	21.61	3,291
100 ~ 200	150	14.93	49.29	14.44	333
200 ~ 400	300	8.79	28.30	8.29	24
400 ~ 1,000	more than 700	4.36	15.02	4.40	1
Total		100	341.4	100	

4.3.3 Result by various inlet types

Table 4.9 shows the six conditions for optimal image simulation of grit chamber influent such as shape of inlet, presence of baffle, presence of porous baffle wall, etc. Figure 4.9 shows the diagram according to each condition.

Table 4.9 Conditions for optimal image simulation of device

Simulate conditions	Inlet pipe shape	Presence of baffle	Presence of porous baffle wall
Condition 1	Horizontal inlet	No	No
Condition 2	Horizontal inlet	Yes	No
Condition 3	Curved inlet	No	No
Condition 4	Curved inlet	Yes	No
Condition 5	Horizontal inlet	No	Yes(25% of the opening parts)
Condition 6	Horizontal inlet	Yes	Yes(25% of the opening parts)

For optimal image simulation of grit chamber influent, stimulation was conducted for six conditions such as shape of inlet, presence of baffle, presence of porous baffle wall, etc. The overview and diagram according to each condition are shown in Figure 4.9 and Table 4.9.

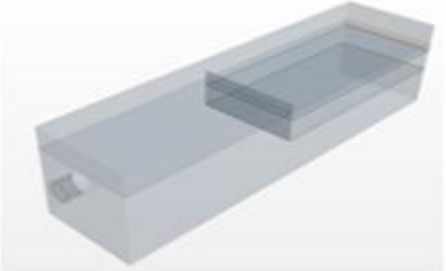
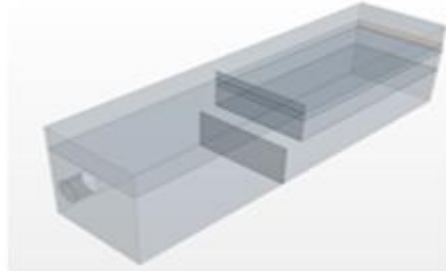
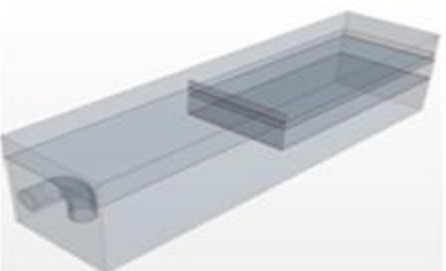
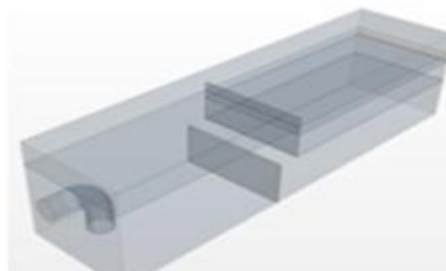
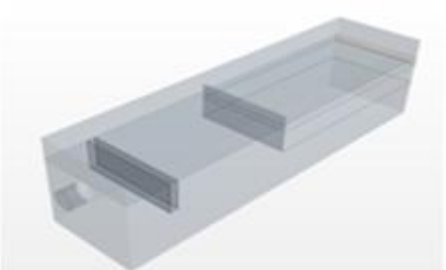
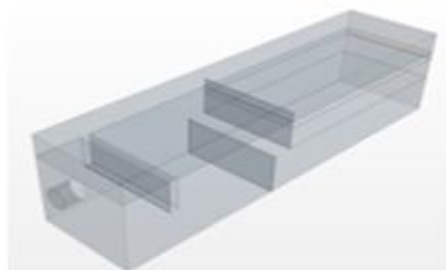
Condition 1 (Horizontal inlet)	Condition 2 (Horizontal inlet, baffle)
	
Condition 3 (Curved inlet)	Condition 4 (Curved inlet, baffle)
	
Condition 5 (Horizontal inlet, porous baffle wall)	Condition 6 (Horizontal inlet, baffle, porous baffle wall)
	

Figure 4.9 Diagrams for optimal image simulation of device

(1) Simulation result of cross-section velocity distribution

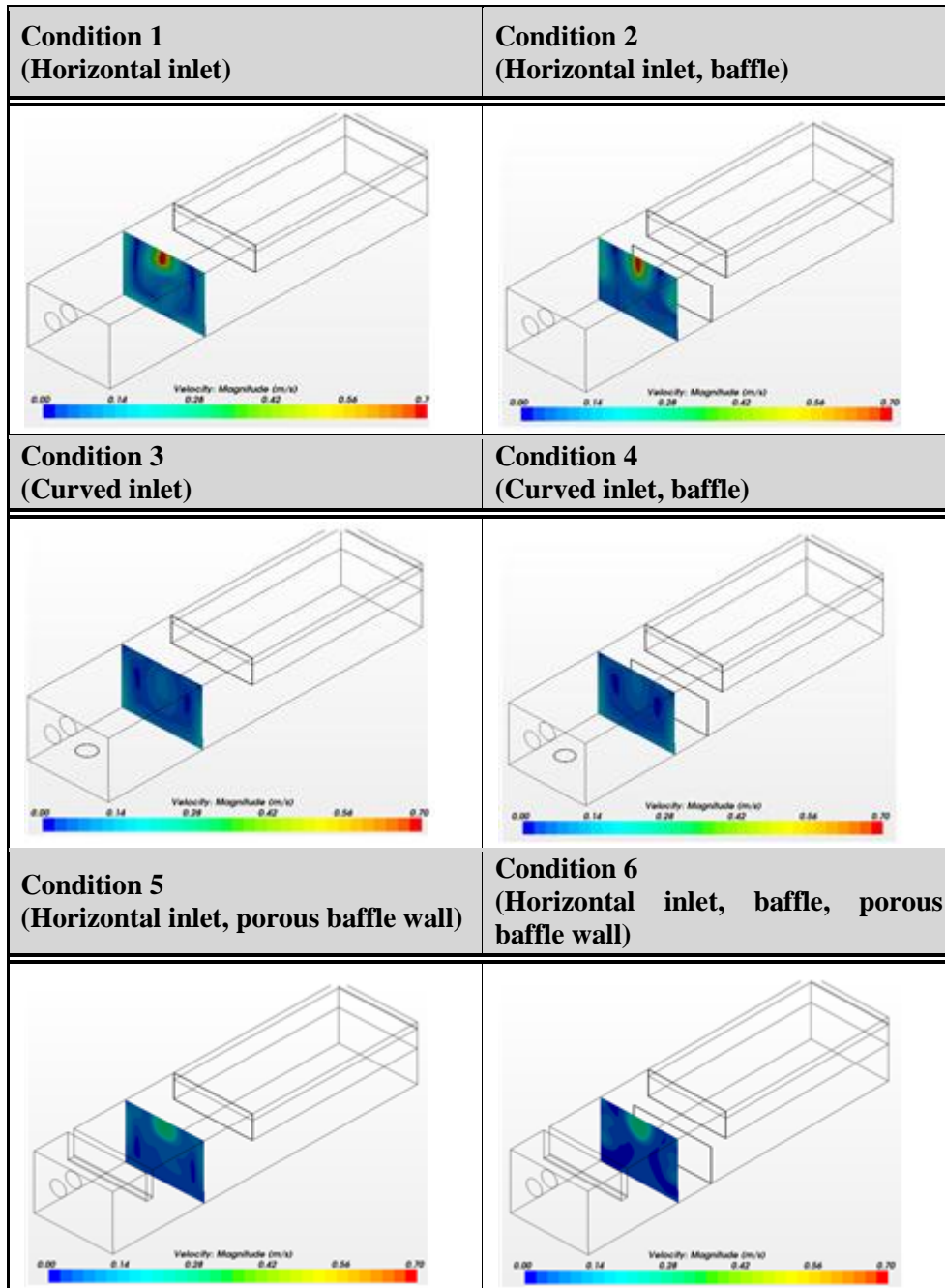


Figure 4.10 CFD simulation results by the inlet conditions
(Cross-section velocity distribution)

For 6 conditions total, the cross-section velocity distribution result of grit chamber cross-section within treatment facilities by CFD simulations are as shown in Figure 4.10.

As shown in Figure 4.10, in case of condition 1 and 2 which separable porous baffle wall was absent and sewage influent was parallel current through straight inlet, horizontal velocity was maintained at 0.7 m/s throughout grit chamber. For condition 5 and 6 where porous baffle wall was installed on straight shape inlet, horizontal velocity decrease by 0.3 m/s due to baffle wall, but flow of sewage was not evenly spread throughout cross-sections and short-circuit flow phenomena was detected.

Finally, for condition 3 and 4 where the inlet was bended, horizontal velocity was formed the least compared to other conditions and short-circuit flow phenomena was not detected, and thus condition 3 and 4 were the most favorable.

(2) Longitudinal velocity distribution simulations

The simulation result of conditional longitudinal velocity distribution and vector distribution are shown as Figure 4.11~4.14.

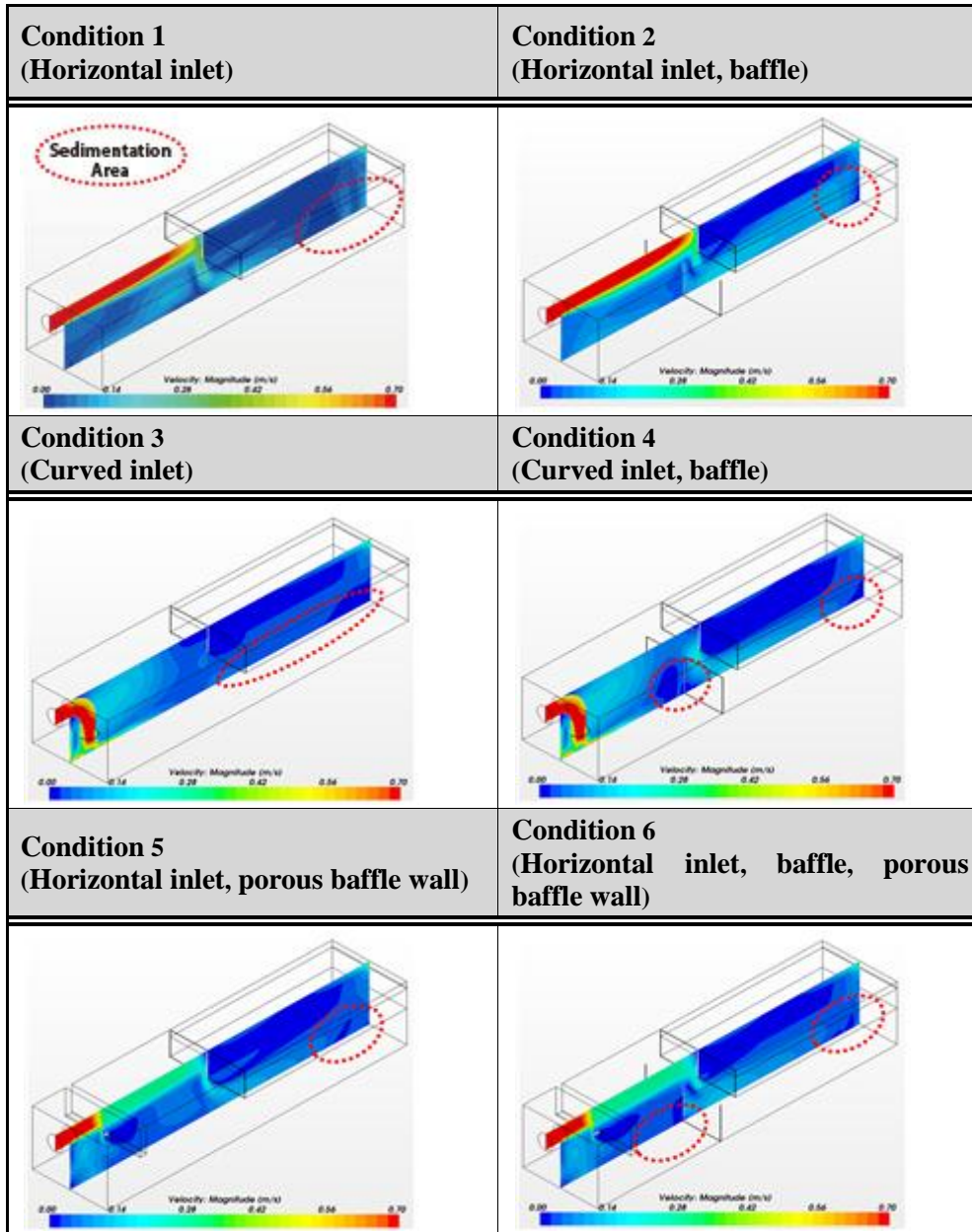


Figure 4.11 CFD simulation results by the inlet conditions (Longitudinal velocity distribution)

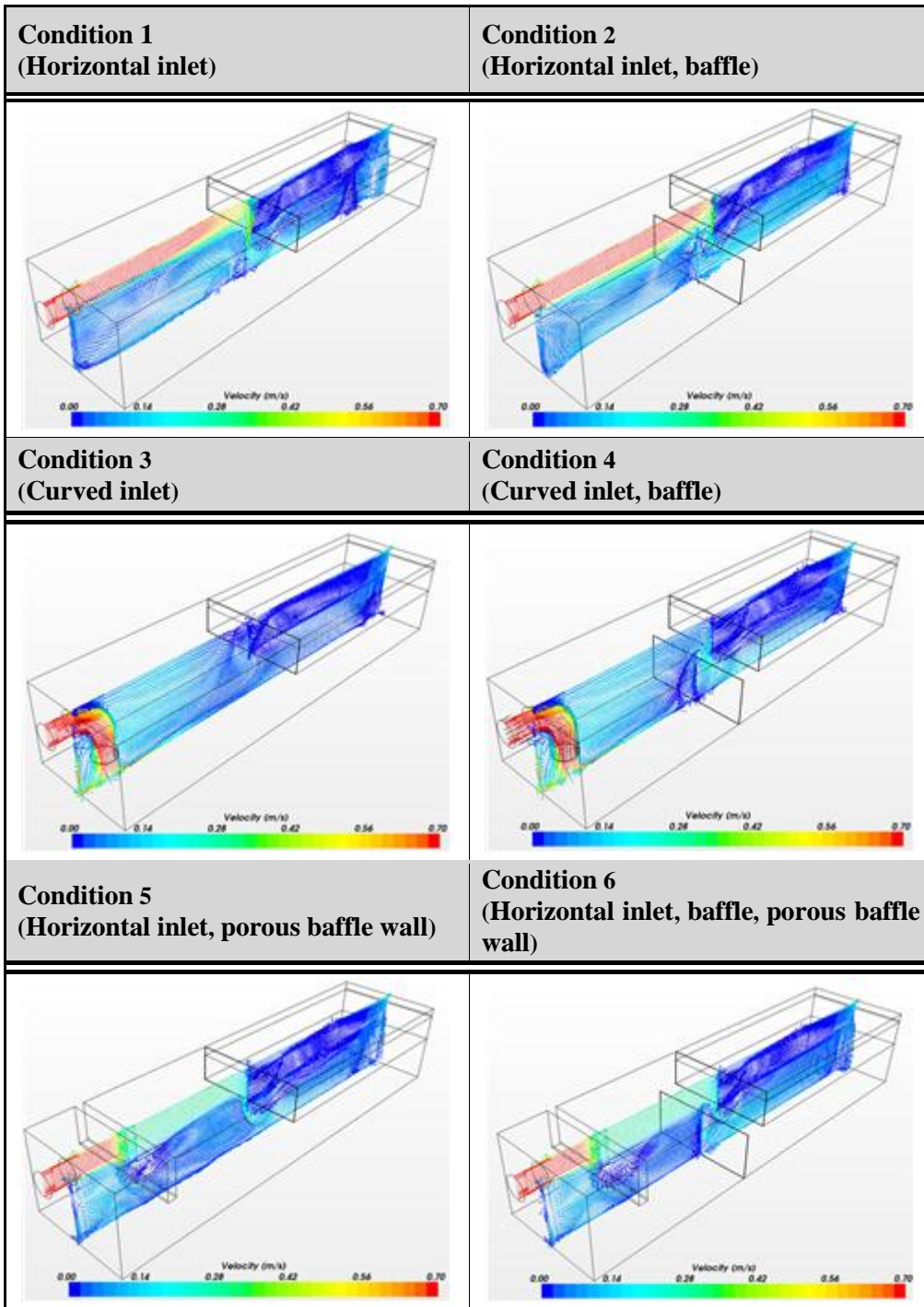


Figure 4.12 CFD simulation results by the inlet conditions
(Longitudinal velocity vector distribution)

As shown in Figure 4.11, the points at which sedimentation is expected are in existence. It is judged that the position will vary depending on the particle size. Also, they present at different place depending on presence of grit chamber, height, and distance.

Most of the sedimentation is believed to be form in front and rear side of baffle and the particles with smaller size is expected to be precipitate at the end of settling basin. However, most of particles are expected to be settled on the bottle of grit chamber due to the effect of entrance with straight influent. In case the inlet is bended, it is anticipated that the sedimentation would occur mostly at the end of grit chamber rather than the front side of chamber.

As shown in Figure 4.12, we can anticipate the direction of fluid flow by distribution of velocity vectors. For condition 1 and 2, the horizontal fluid flow is maintained on upper part due to inlet and strong downward current occurs due to wall of filter paper on the lower part. Thus, as shown in the result of condition 5 and 6 which opening holes were installed to utilize opening hole used in grit chamber, there are not much difference compared to condition 1 and 2.

As shown in Figure 4.13, the analysis of velocity distribution of flat cross-sections shows that condition 1 and 2 with horizontal influent show high speed in the middle and the velocity of both sides of wall are high due to the effect of circulation by filter paper wall. It is expected that sedimentation will form in the middle and at the end of grit chamber for condition 3 and 4 like analysis on vertical cross-sections. Condition 5 and 6 where baffle wall was installed are expected to show poor sedimentation efficiency because it is expected that the velocity will be lowered at bottle part of baffle wall or velocity component in the direction of z will be greater.

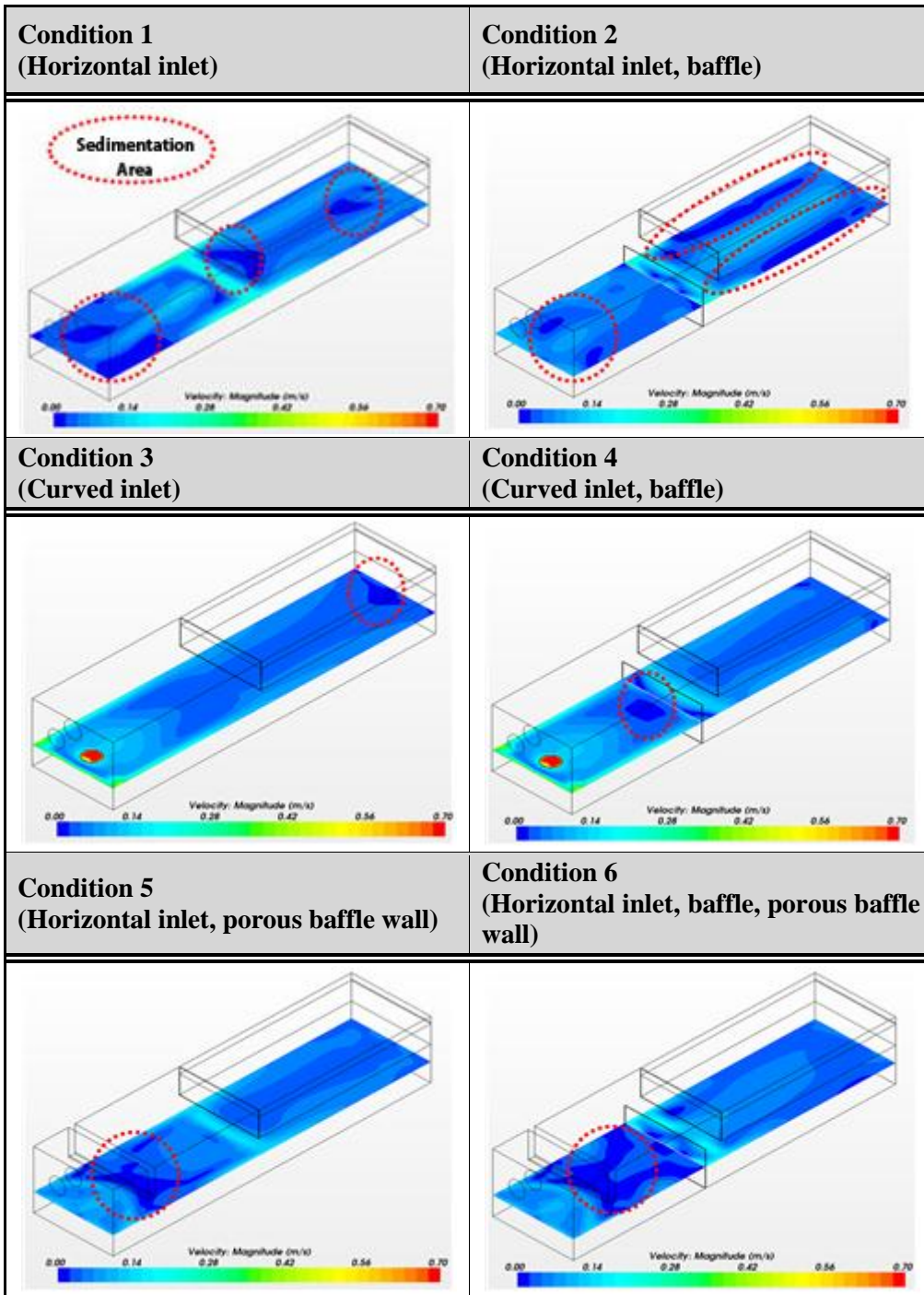


Figure 4.13 CFD simulation results by the inlet conditions
(0.6m height of the longitudinal velocity distribution)

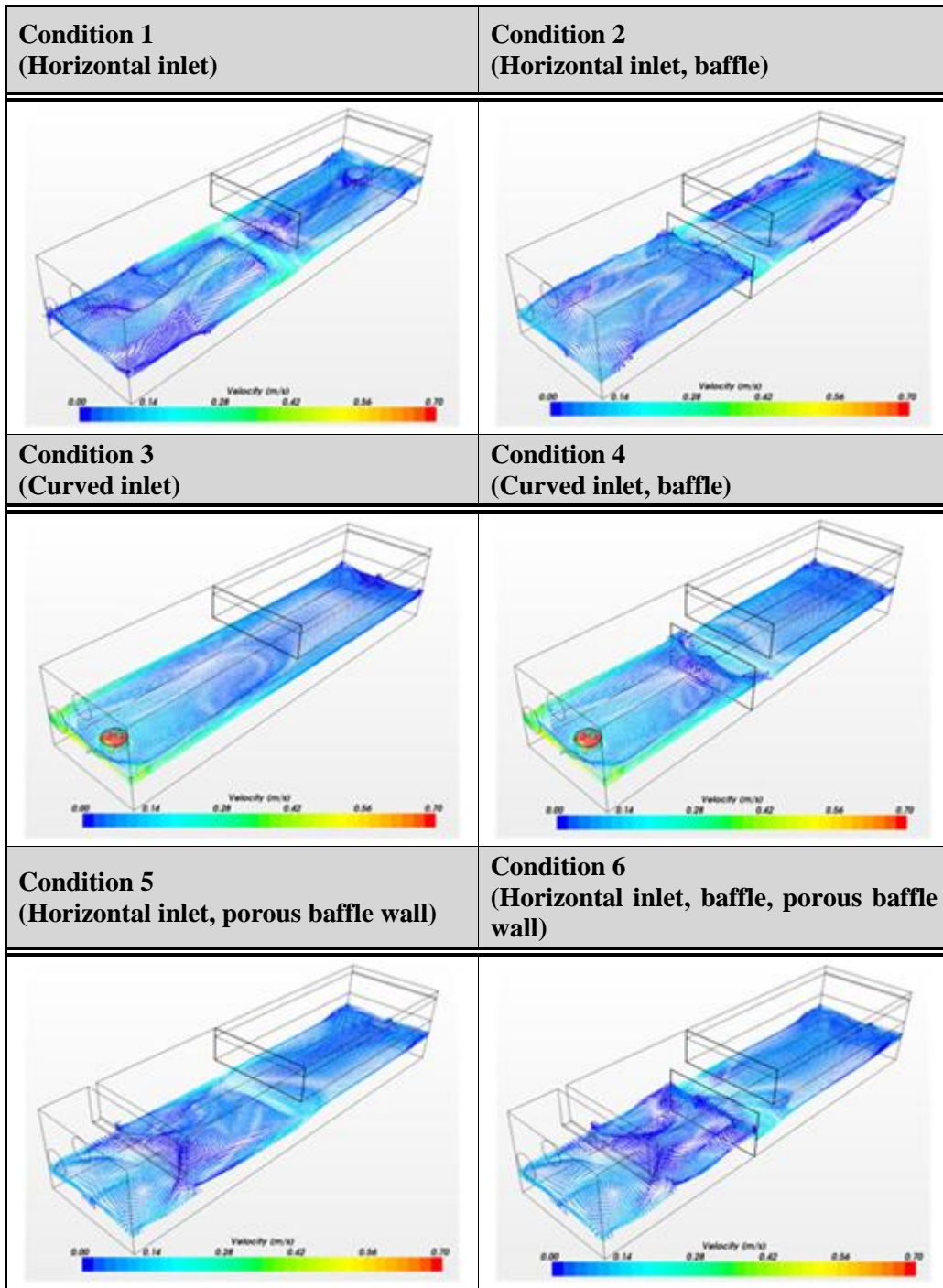


Figure 4.14 CFD simulation results by the inlet conditions
(0.6m height distribution of the longitudinal velocity vector)

As shown in Figure 4.14, soil particles settle on parts that flow velocity is relatively slow. The simulation result of longitudinal velocity distribution demonstrated that for condition 1 and 2 where influent is in horizontal flow without porous baffle wall, the flow velocity, 0.7m/s which started from inlet was maintained until the end of grit chamber and it was expected that the sedimentation occurring in grit chamber is unlikely because the particles in fluid would move along the fast velocity. For condition 5 and 6 with porous baffle wall, the flow velocity decreased only when passing the baffle wall and the velocity was maintained at 0.3m/s~0.4m/s. Thus it was concluded that the sedimentation effect in grit chamber due to decrease of velocity was negligible.

According to sedimentation-expected area simulation result, for cases of absence of baffle in between grit chamber and filtration chamber, it was appeared that sedimentation occur in filtration chamber in priority regardless of the shape of inlet and the condition whether the baffle wall is present or not. Although the baffle is present, condition 2 where porous baffle wall was absent and inlet was vertical showed that sedimentation occurred first at filtration chamber. Thus it was simulated that baffle does not perform its function successfully.

In addition, according to the longitudinal velocity distribution simulation result at height, 0.6 m, which was the middle point between inflow and bottom of filter layer in reduction facility for condition 3 and 4 where the inlet is bended shape, it was simulated that it was difficult for soil to precipitate first in grit chamber due to the effect of flow velocity which forms around 0.3m/s at the bottom and sides.

Based on the velocity distribution formed for each condition, it was expected that sedimentation occurring at grit chamber would be only possible for condition 4 where the influent was through bended inlet and the wall was consisted of baffle.

(3) Streamline distributed simulations

Streamline distribution simulation result for each condition is as shown in Figure 4.15.

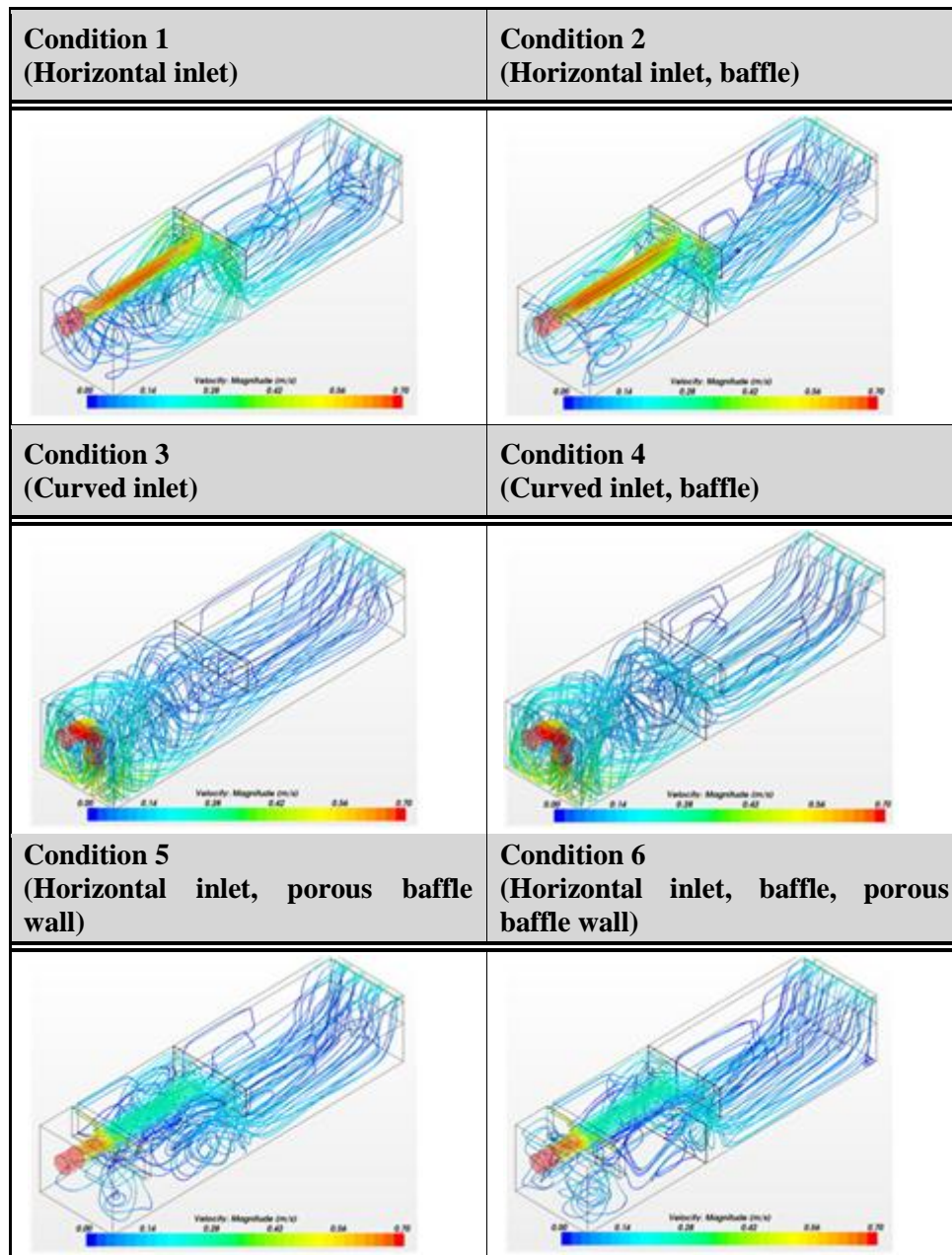


Figure 4.15 Streamline distribution simulation result for each inlet condition

Based on the simulations according to streamline distribution for each conditions, conditions 1,2,5,6, with horizontal flow show the short-circuit flow which pass to filtration chamber because the streamline is most concentrated on the upper part of grit chamber where the flow velocity is high regardless of presence of porous baffle wall or baffle. For condition 3 and 4 where inlet is bended, the complex turbulence occurs inside the grit chamber due to the high flow velocity from the inlet and thus it was concluded that the soil would not be easily precipitated on the settling basin.

4.3.4 Result by baffle types

According to CFD simulation result for total six conditions classified by presences of baffle and the geometry of inlet inside the device-type NPS treatment facilities combined with filtration equipment, condition 1,2,5,6 did not show successful sedimentation of particles with big size in the grit chamber due to the formation of short-circuit flow in the facility. For condition3 and 4, even though short-circuit flow phenomena was not appeared, due to the effect of flow velocity, the turbulence was formed in grit chamber which made the sedimentation unfavorable and thus it was confirmed that appropriate solution was necessary.

Therefore, in order to prevent the formation of turbulence inside the grit chamber, the baffle with height of 1.1m were additionally installed at the front end, and for checking of optimal geometry for existing baffle between grit chamber and filtration chamber, another CFD simulations according to six conditions classified by height and distance from filtration chamber were conducted.

The overview and diagram for each condition for examination of height and optimal installment location of baffle are as shown in Figure 4.16 and Table 4.10.

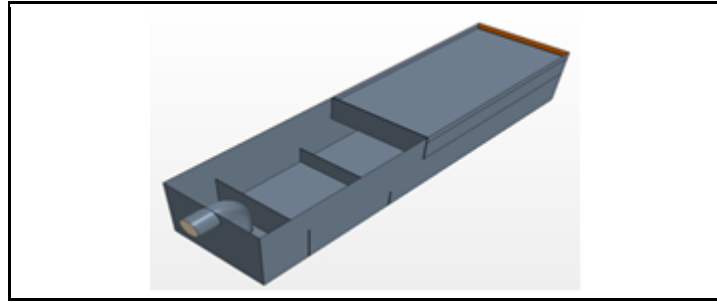


Figure 4.16 Diagram for installment of baffle

Table 4.10 Simulation conditions by installment shape of baffle

Simulation conditions	Separation distance between baffle with filter material, L_2 (mm)	Height of baffle, H_2 (mm)
Condition 1	1,100	550
Condition 2	1,100	750
Condition 3	1,100	1,100
Condition 4	700	550
Condition 5	700	750
Condition 6	700	1,100

(1) Longitudinal velocity distribution simulations

The longitudinal velocity distribution and vector distribution of longitudinal velocity of six conditions for installation of baffle to make stable sedimentation conditions inside the grit chamber are as shown in Figure 4.14~4.20.

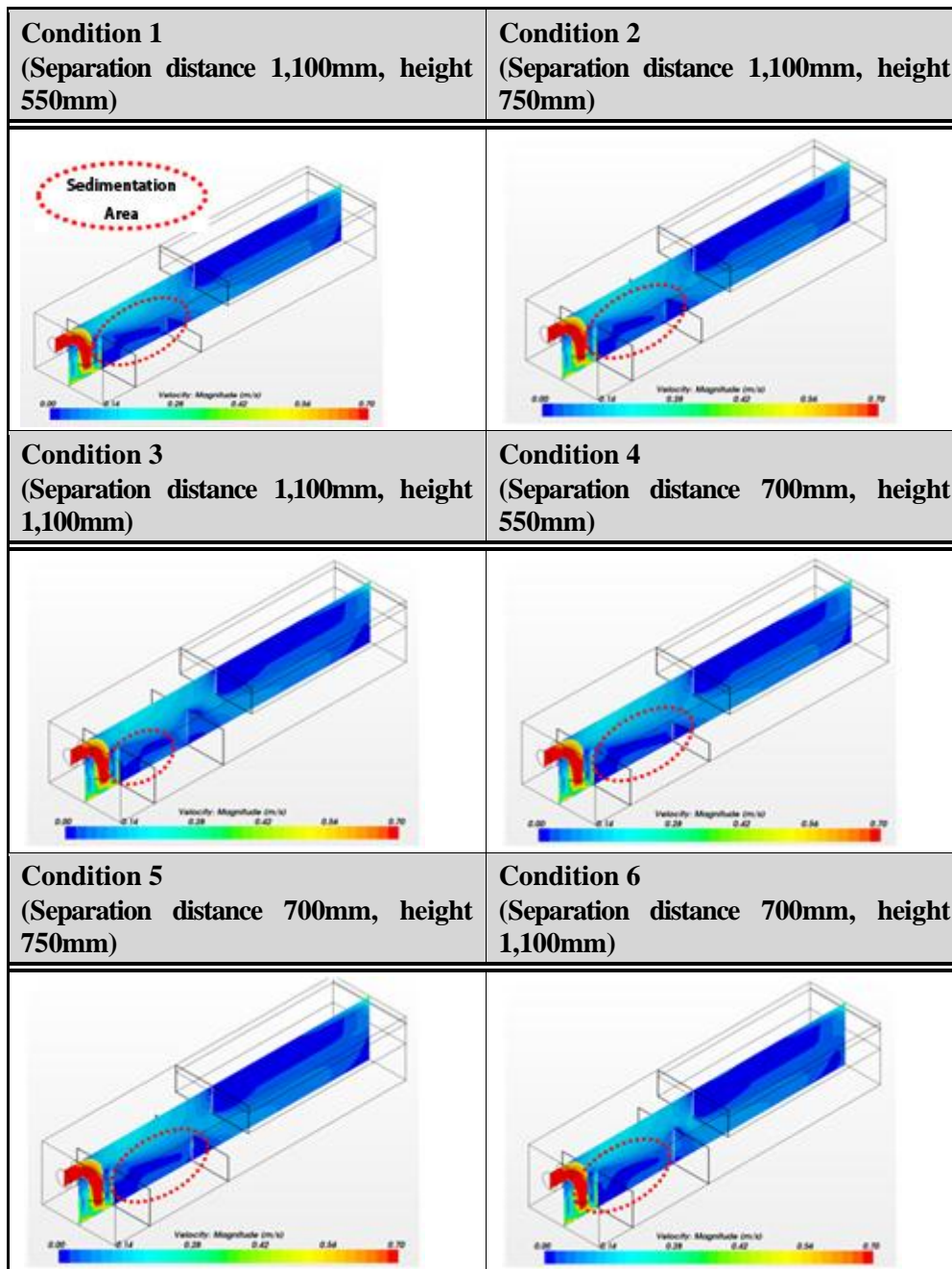
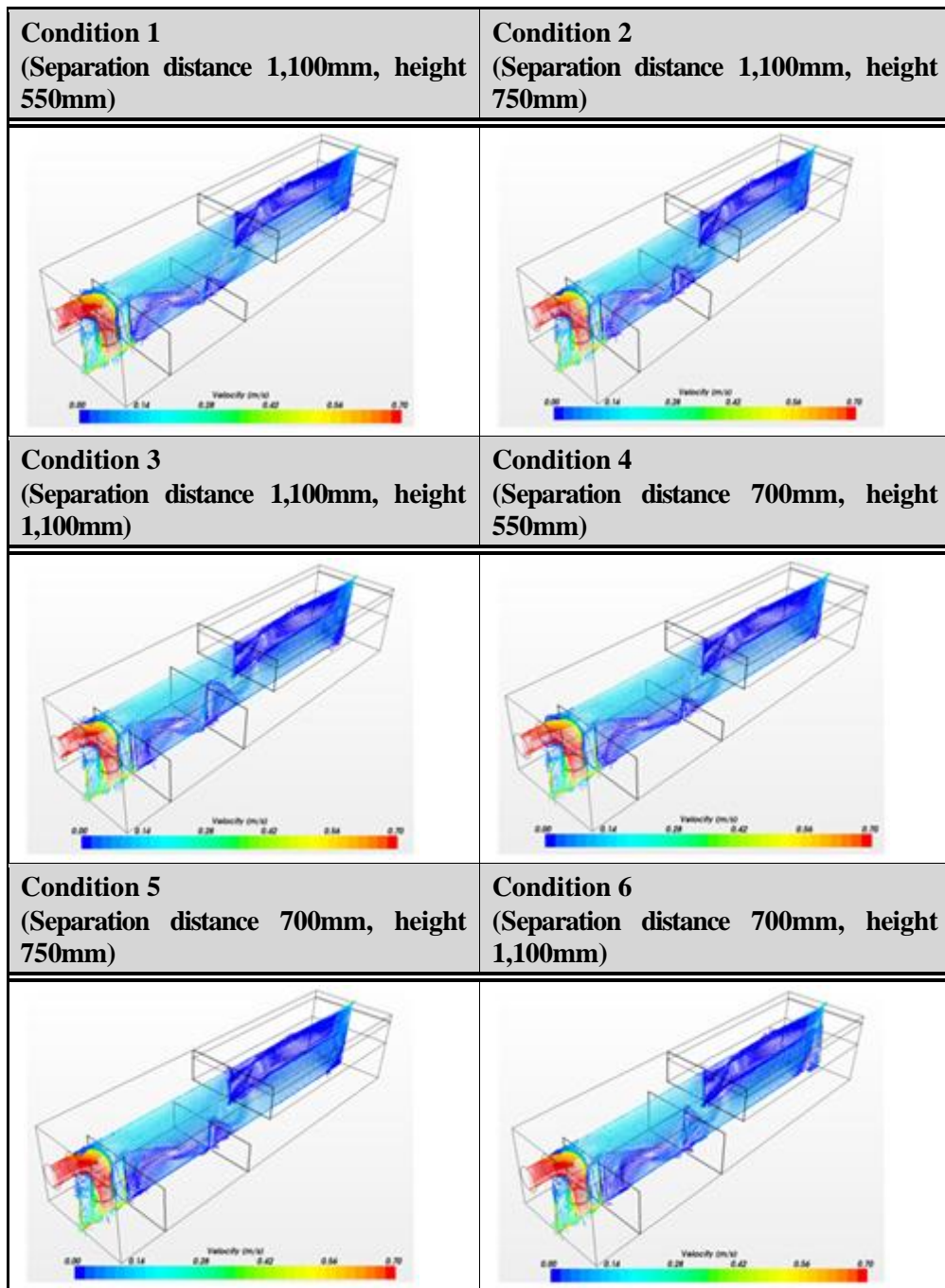


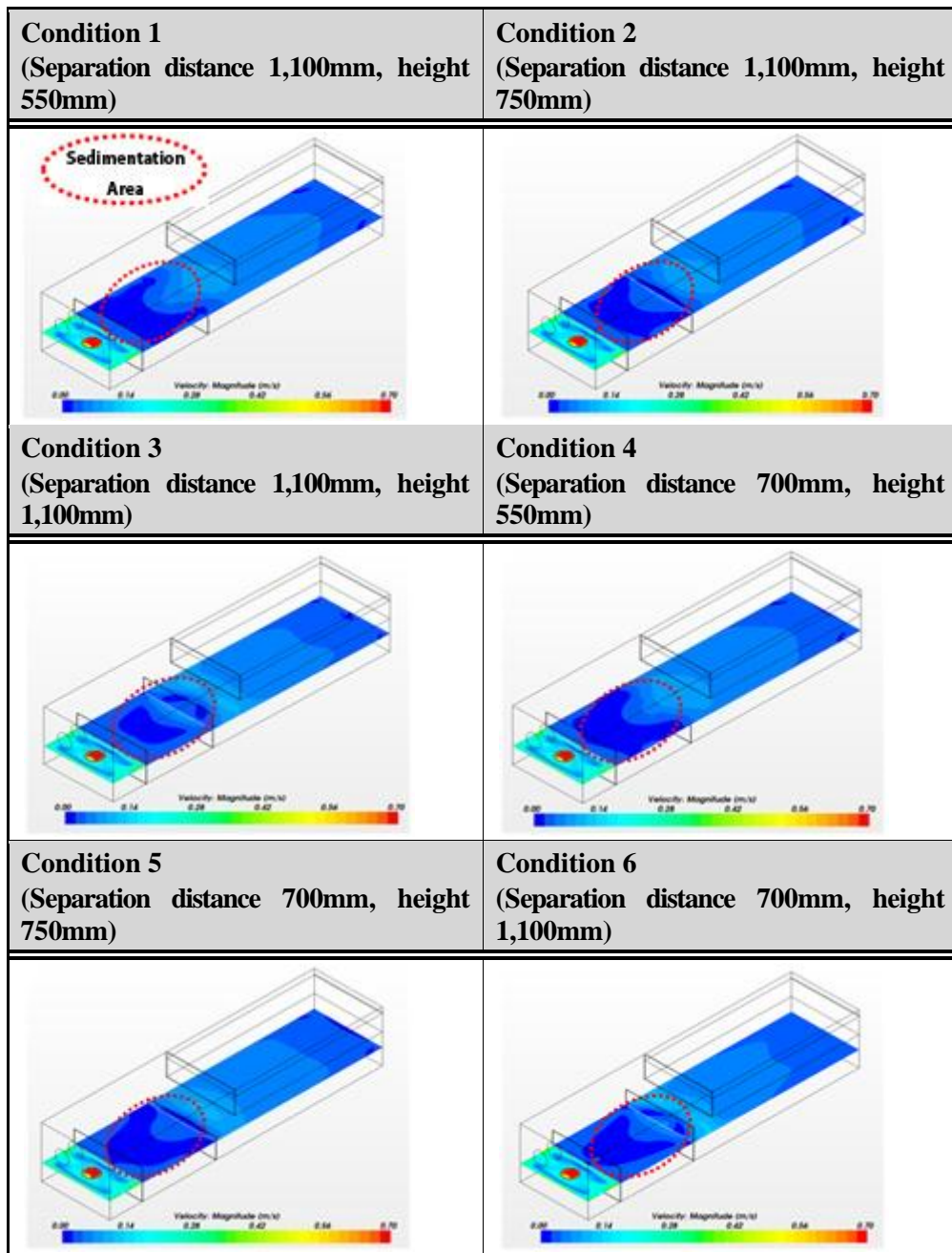
Figure 4.17 CFD simulation results by baffle condition (Longitudinal velocity distribution)

Although the simulation results showed some differences, all six conditions showed the velocity distribution that sedimentation of particles was possible. The baffle installed on inlet properly blocked the flow velocity that occurred at inlet.



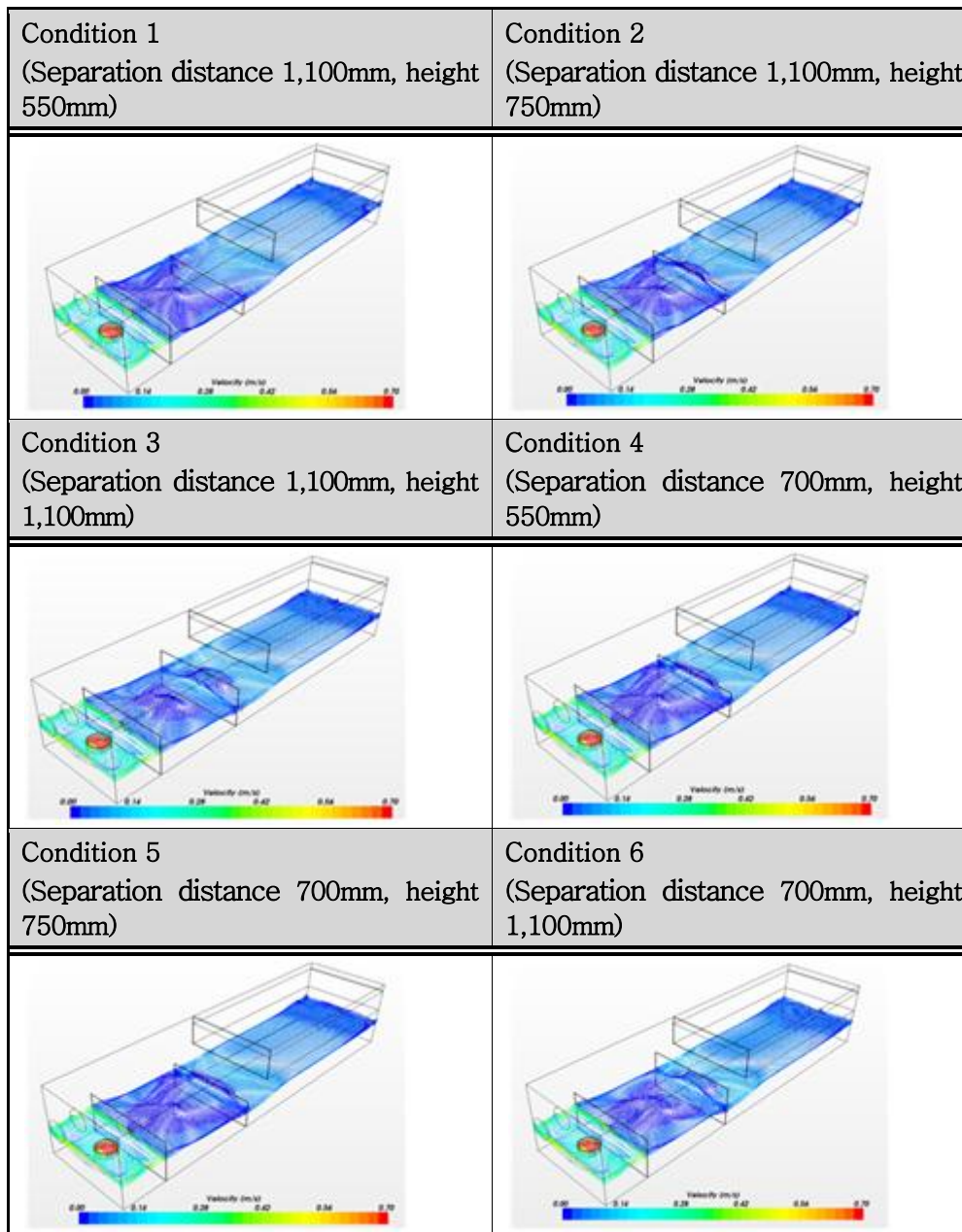
**Figure 4.18 CFD simulation results by baffle condition
(Longitudinal velocity vector distribution)**

In the velocity vector distribution in Figure 4.18, the favorable condition for sedimentation was formed due to the appearance of laminar flow less than 0.15m/s at the top of the grit chamber regardless of geometry of baffle.



**Figure 4.19 CFD simulation results by baffle condition
(Longitudinal velocity distribution at height of 0.6m)**

As the velocity distribution at height of 0.6m from the bottom shows in Figure 4.19, the possible sedimentation area where velocity is low throughout the grit chamber can be detected even in the plane.



**Figure 4.20 CFD simulation results by baffle condition
(Longitudinal velocity vector distribution at height of 0.6m)**

The result of CFD simulation for reviewing of installation location and height of the baffle to provide a stable sedimentation condition inside the settling basin has suggested that sedimentation of soil were most likely at settling area for all six conditions and regardless of height and distance of baffle, the flow velocity in settling basin was maintained under 0.15 m/s which was the fine distribution.

(2) Streamline and particle size distribution simulations

The simulation result of streamline and particle distribution for each condition is shown as the Figure 4.21.

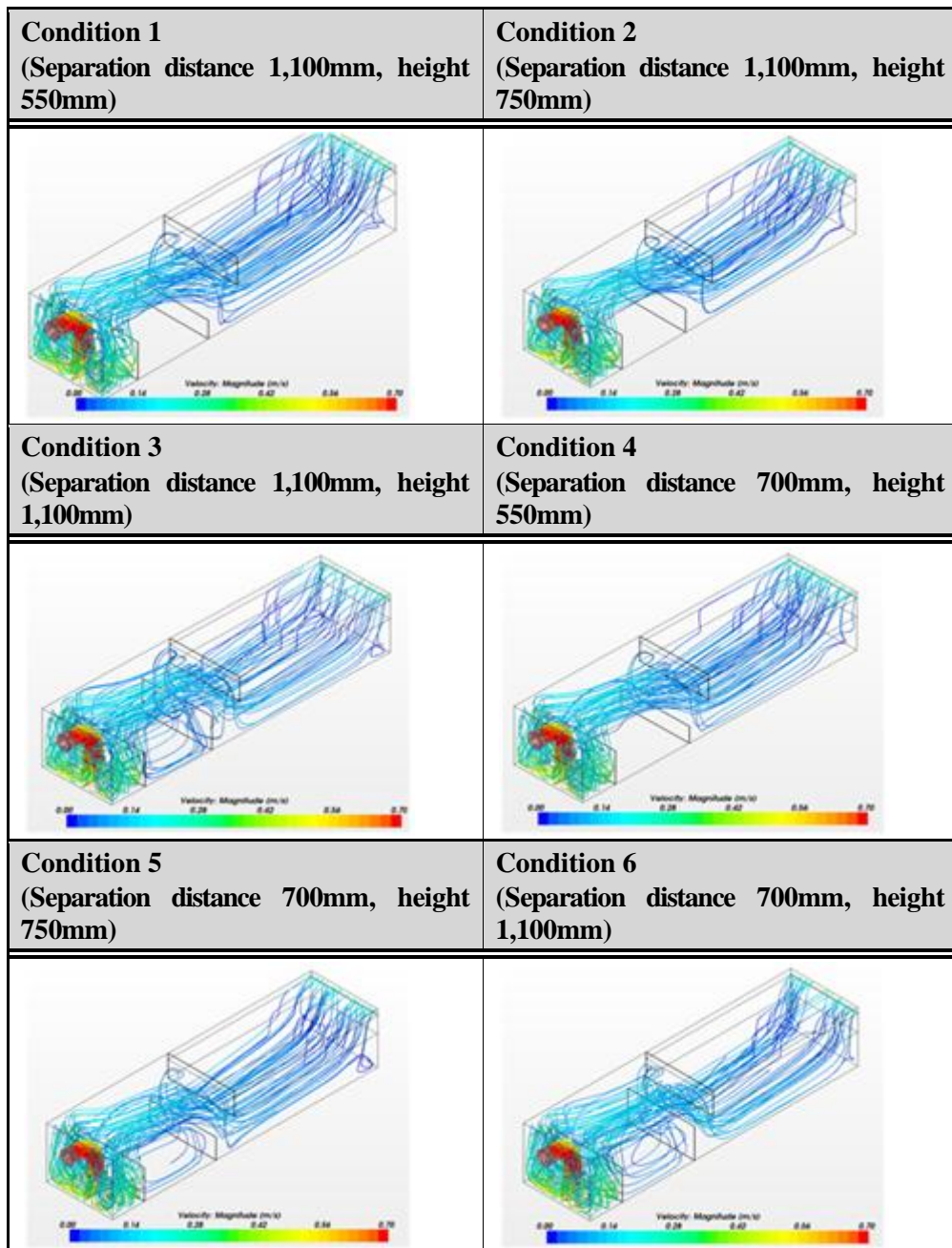


Figure 4.21 Simulation result of streamline by baffle conditions

In streamline distribution for each conditions as shown in Figure 4.21, due to the effect of 1.1m height baffle that was installed in frond end of grit chamber, the turbulence was formed in baffle but for areas after baffle showed an favorable condition for sedimentation because the flow velocity was decreased under 0.15m/s and laminar flow was appeared.

4.3.5 Suggestion for optimal sedimentation conditions

Throughout the simulation of longitudinal/cross-section velocity and streamline according to various conditions such as geometry of inlet, presence of porous baffle wall, position and height of baffle, the optimal condition of grit chamber was calculated. Also, based on the longitudinal and cross-section velocity distribution result for each condition, sedimentation behavior of particles classified by particle distribution was simulated and the result is as shown in Figure 4.22.

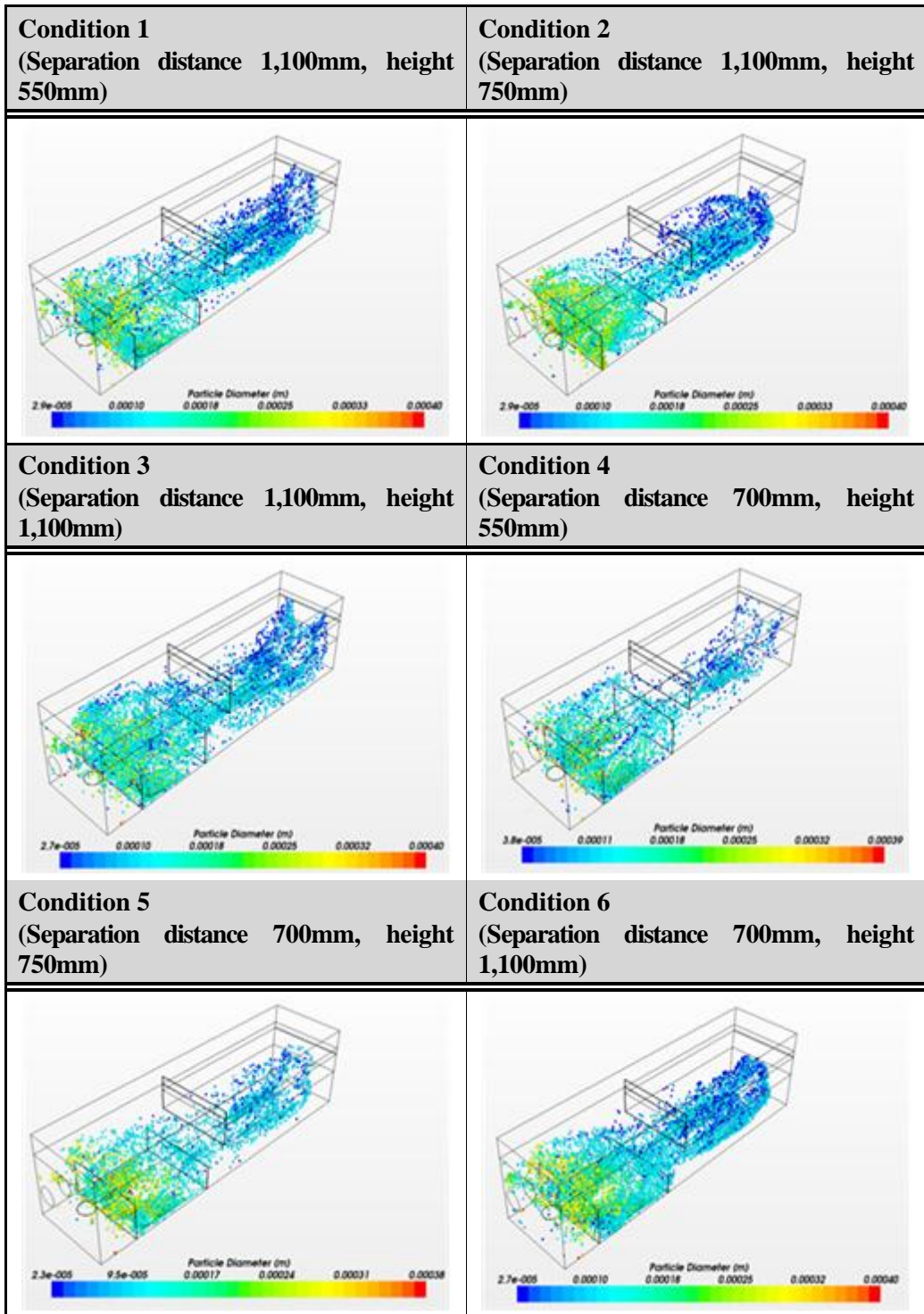


Figure 4.22 Motion simulation result of particle sedimentation by baffle conditions

As Figure 4.23, the treatment facility was divided into three sections: A,B, C and the precipitated particles for each condition were counted by subdividing the particles by particle size into two groups: $100\mu\text{m} \sim 15\mu\text{m}$ and $150\mu\text{m} \sim 400\mu\text{m}$.

As Table 4.10 shows, for the case 3 where the distance from the baffle of filtration chamber and height were set to 1.1m, it was observed that 60.45% of particles with size, $100\mu\text{m} \sim 150\mu\text{m}$, and 95.65% of particles with size $150\mu\text{m} \sim 400\mu\text{m}$, was precipitated in area A. From this result, it was found that heavier particles were prone to precipitate in area A.

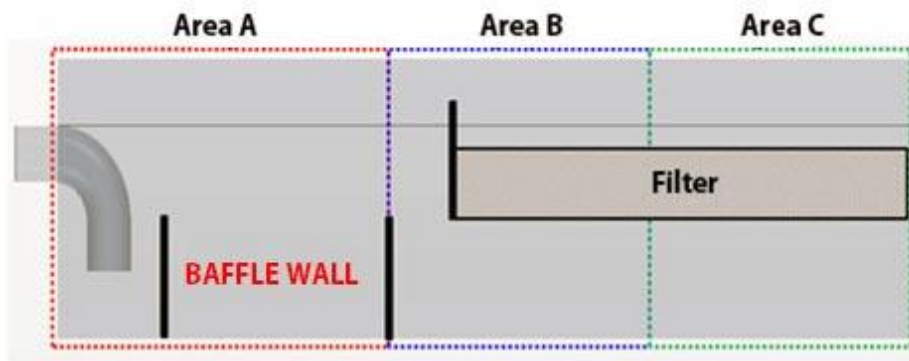


Figure 4.23 Separating area for motion simulation of sedimentation behavior in facilities

Table 4.11 Distribution of particle sedimentation by baffle condition (unit:%)

Division		Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6
$100\mu\text{m}$ ~ $150\mu\text{m}$	A Area	53.73	53.43	60.45	50.75	54.75	55.53
	B Area	12.13	12.51	11.00	14.52	13.45	12.52
	C Area	34.14	34.07	28.55	34.72	31.80	31.95
$150\mu\text{m}$ ~ $400\mu\text{m}$	A Area	85.90	89.08	95.65	82.05	78.45	85.18
	B Area	7.96	11.56	1.49	14.09	13.67	10.10
	C Area	6.14	2.42	2.85	3.86	7.87	4.72

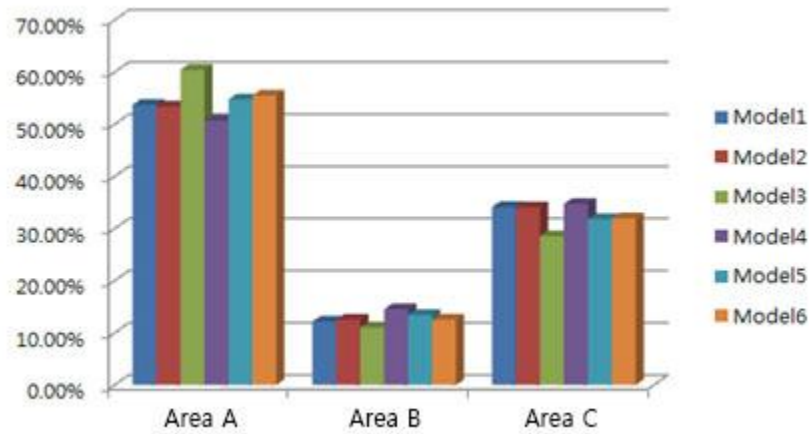


Figure 4.24 Distribution of particle (100 ~ 150µm) sedimentation by baffle conditions

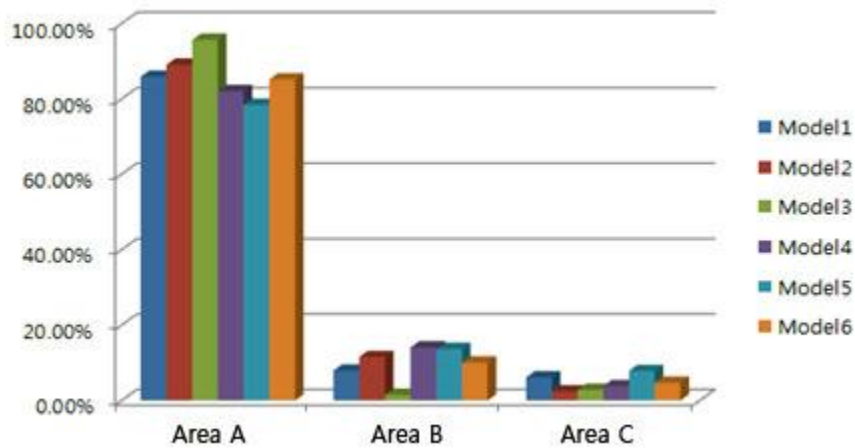


Figure 4.25 Distribution of particle (150 ~ 400µm) sedimentation by baffle conditions

Taken all simulations of sedimentation behavior for each condition in treatment facilities together, the following results can be obtained.

First, the bended type inlet pipe should be installed and short-circuit flow should be prevented by minimizing the behavior of particles caused by horizontal flow velocity with baffle.

Second, when the height of baffle and the distance to filtration chamber is about 1.1 respectively, the heavier particles are mostly precipitated in area A of the grit chamber.

Thus, the positioning of facilities such as manholes to remove the sediments on grit chamber will make maintenance more efficient.

4.4 Evaluation of filtration efficiency

For four selected filter media (EPP, EPS, perlite, zeolite) to test the filtration treatment efficiency for road runoff, the filtration linear velocity was set to 950m/day which is the maximum velocity of filtration treatment facility proposed by Ministry of Environment and the limitation head was set to 40cm considering the economic condition and field applicability condition of the treatment facilities.

For each filter media, change in head loss over time, four water quality parameters (SS, COD, Zn, Cu) before and after the treatment and particle size analysis were conducted.

Experiment conditions were the same for each filter media except that the concentration of inflow raw water differed according to the difference in road surface dust mixed in the course of the experiment.

4.4.1 Changes of head loss by media

(1) Change of Head loss over time classified by filter media

The rate of inflow for each filter media was set constant to filtration velocity of 950m/day based on filtration cross-sectional area (289 cm^2) of experimental equipment by using standard pump and pouring inflow of $1.144 \text{ m}^3/\text{hr}$ constantly through flow rate control valve. The result of head loss measurement for each filter media by road runoff during procedure period up to 4 hours are as shown in Figure 4.26 and Table 4.12.

Table 4.12 Time to reach the limit head loss of each filter

Medias in maximum filtration velocity

Division	EPP	EPS	Perlite	Zeolite
Influent SS concentration range (mg/L)	261 ~ 1,886	261 ~ 1,886	533 ~ 2,020	463 ~ 1,546
Average influent SS concentration (mg/L)	722.6	718.7	901.3	833.2
Limit head loss reaching time (minutes)	unreached	200	120	90

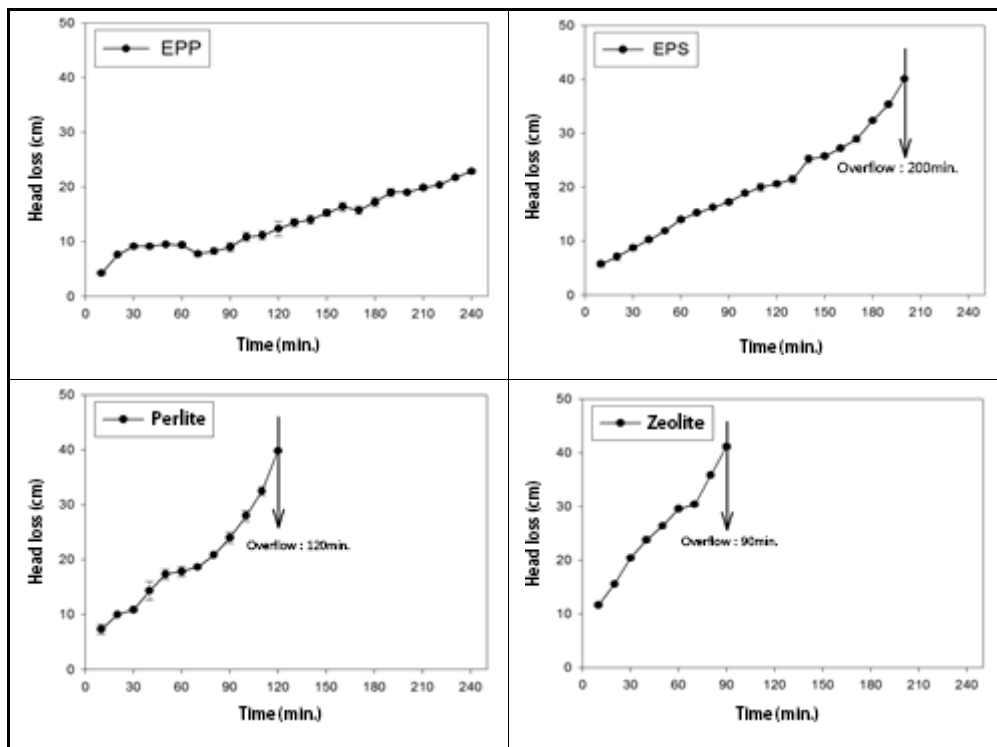


Figure 4.26 Change of head loss in road runoff during filtration time by each filter media

As shown in Figure 4.26, zeolite showed the shortest time to reach the head loss limit and be overflow which took only 90 minutes. Perlite and EPS respectively took 120 and 200 minutes. Also, it was confirmed that average head loss of EPP was 23, so overflow did not happen even after 240 minutes.

To standardize the head loss for each filter media, the head loss over time was expressed in log function and the result of log function according to head loss over time is as show in Figure 4.27 and Table 4.13.

For each filter media, the time taken to reach the maximum head loss 40cm was recorded and it took 215, 134, 104 minutes respectively for EPS, Perlite, and Zeolite, and the result was very similar to the calculation made by the experiment. EPP did not reach the head loss until 240 minutes in the experiment, but the calculation by log function showed that the time taken should be 357 minutes.

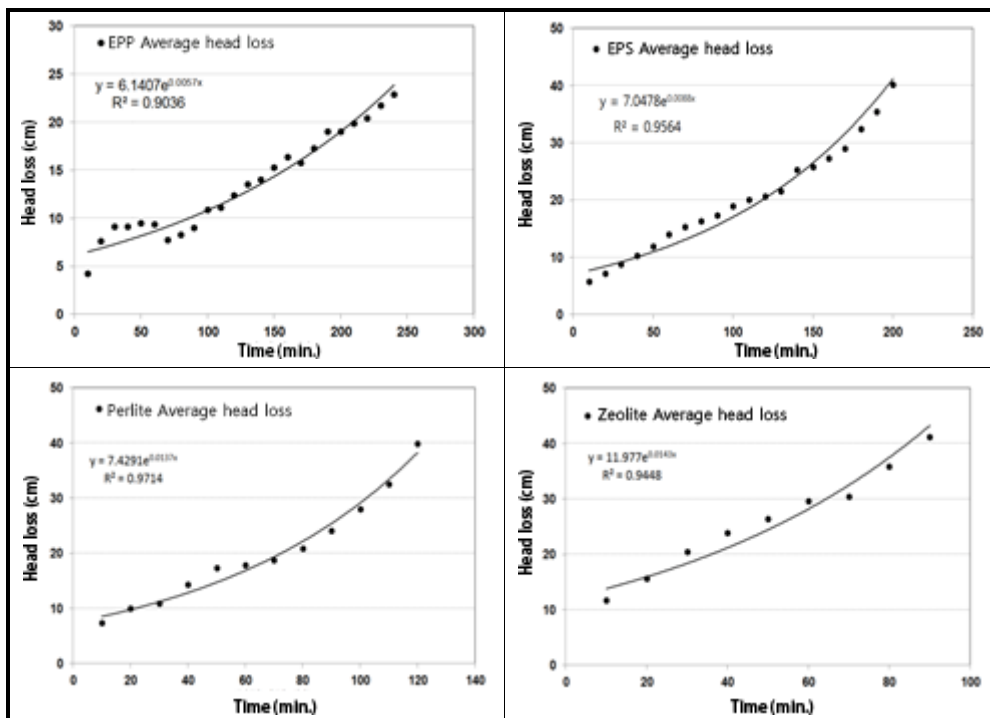


Figure 4.27 Exponential functions according to changing head loss in road runoff by media

Table 4.13 Calculated overflow time by regression equation of the head loss by media

Regression equation of the head loss: $Y = a \cdot e^{bx}$					
Y: head loss(cm), a, b: Coefficient, X: Elapsed time (minutes)					
Division		EPP	EPS	Perlite	Zeolite
a		6.1407	7.0478	7.4291	11.977
b		0.0057	0.0088	0.0137	0.0143
R ²		0.9036	0.9564	0.9714	0.9448
Elapsed time (minutes) (Overflow time, minutes)	Calculated values	357	215	134	104
	Experimental	-	200	120	90

Among the filter media used in experiment, Zeolite was the non-buoyant filter media that only has specific gravity greater than 1 and by operating with upward type, the concentrated filtration of particulate pollutants occurred at the bottom of filter layer which seemed to be causing the fast blockage of filter media. Among buoyant filter media, Perlite showed the fast reaching of limit head loss because the filter media is crushed operating in maximum linear velocity and generates fine particles. They are aggravated at the bottom of filter layer in which particulate pollutants are mixed and causes the faster reaching of limit head loss.

In case of EPP and EPS, the crushing of filter media by high filtration velocity as perlite was not observed, but it is judged that the physical differences coming from two filter media's porosity, the specific surface area and distribution of micro pore cause EPP to show the lower increase of head loss over time compared to EPS.

It was shown that impact of hydraulic loads about head loss over filtration time for four types of filter media was ordered as Zeolite > Perlite > EPS > EPP, which suggests that EPP gets the lowest impact from the hydraulic loads compared to other filter media. Therefore, the

EPP will be the most suitable media for the NPS reduction facilities for treatment of road runoff which operates in high filtration linear velocity

(2) Calculation of recurrence days classified by filter media over filtration duration time

For each filter media, with the result of head loss over time about the road runoff made with SS concentration range from 720mg/L to 901mg/L in Laboratory scale, the recurrence day was calculated.

The filtration duration time was calculated in recurrence days after the inflow loads about average SS concentration in study based on the Urban cumulative SS loads, 808kg/ha · yr proposed in ‘Study on basic research of Urban Combined Sewer Overflows and Separate Sewer Rainfall Discharge Pollution Loads’(Korea Environment Corporation, 2004).

The calculation procedure of recurrence days is taken by the average surface area 1.5 m² of filter media of NPS reduction facilities to treat the annually generated SS loads, 800kg, from drainage area of 1 was applied to this study’s surface area (0.0289 m²) of experimental apparatus, the annually generated SS loads are calculated to 15.67 kg.

During the experiment procedure, the SS outflow concentration measured in interval of 10 minutes and the proposed maximum filtration linear velocity by Ministry of Environment, 950m/day were maintained constantly and through the inflow rate 0.019 m³/min, the SS generation loads that are treated in interval of 10 minutes for each filter media were calculated.

For each filter media, the SS loads treated until head loss reached 40cm (or until limit head loss of 40cm was reached) were calculated and converted into the surface area of

experimental apparatus. With this value, recurrence days about annually generated SS loads were calculated.

The recurrence days calculation results are as shown in Figure 4.28. Until overflow time deduced by head loss regression equation, the cumulative recurrence days for each filter media was calculated and the result for EPP, EPS, Perlite, and Zeolite were respectively 163,100, 60, and 43 days.

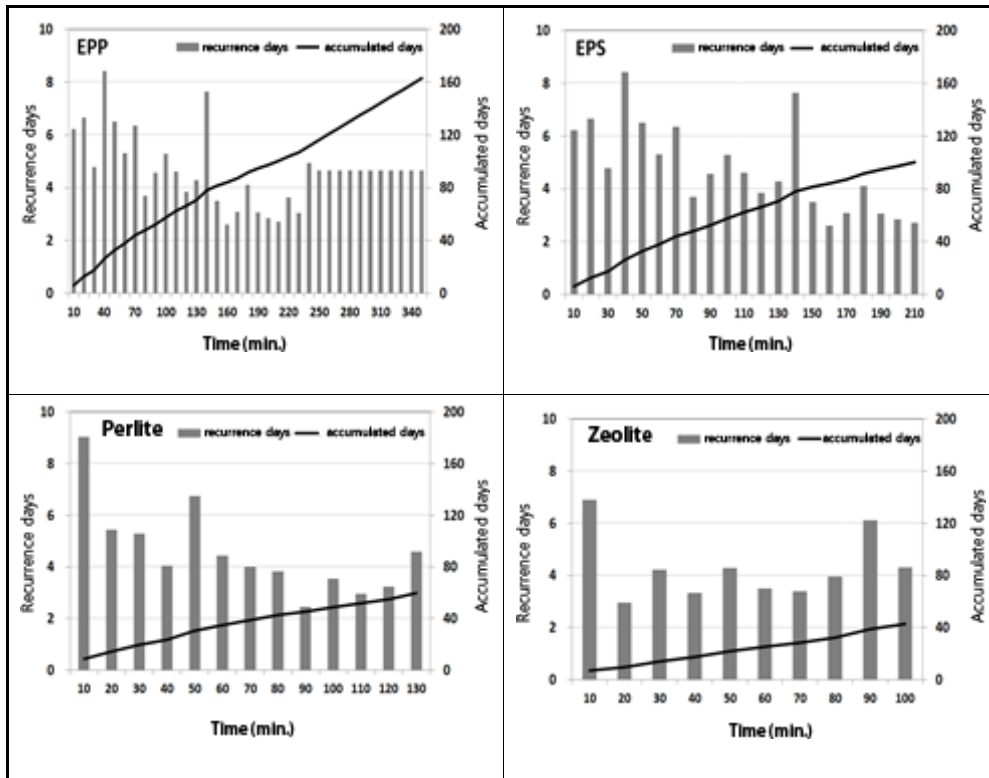


Figure 4.28 Recurrence days' calculation results of reaching time to limit head loss by each filter media

The recurrence day calculated in the figure above (Figure 4.28) might differ depending on the filtration linear velocity and the concentration of inflow raw water, but because EPP filter media has the least impact of hydraulic loads compared to other filter media and thus confirmed that EPP has the longest lifespan.

4.4.2 Changes of concentrations by layers in filter media

For each filter media, the treated water was collected in 10cm intervals from the floor of filtration refill chamber of 50cm height in up flow system, and the treatment efficient according to change in filter media's height was examined.

For the experiment, the filtration velocity was set constant to 950m/day and the collecting time was 1hour after the start of the experiment for all filter media. The SS analysis of treat water classified by filter layer about rod runoff based on the height of the filter media are as shown in Figure 4.29 and Table 4.14.

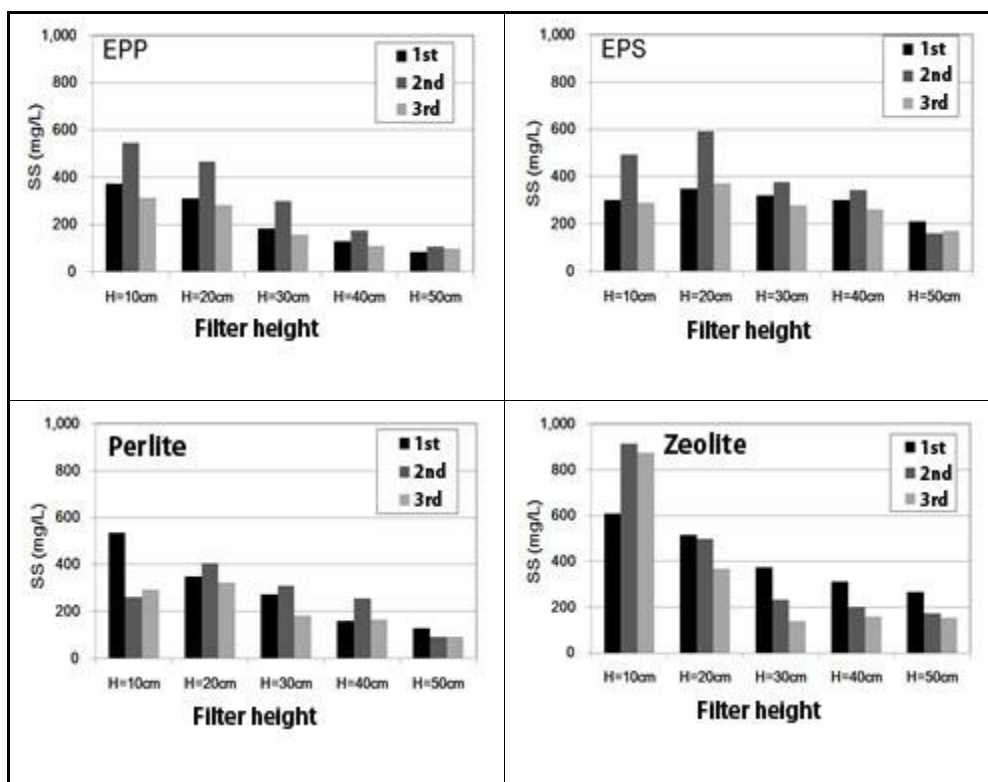


Figure 4.29 SS concentration variations by filter media's height

Table 4.14 Evaluation of SS removal efficiency by filter media's height

Division		SS (mg/L, average \pm standard deviation) removal efficiency (%)			
		EPP	EPS	Perlite	Zeolite
Influent		1,094.3 \pm 148.7	1,450.5 \pm 560.0	931.0 \pm 281.7	1,387.2 \pm 612.1
treated water	1 layer (H=10cm)	410.0 \pm 120.6 61.4 \pm 14.8	361.3 \pm 115.5 71.2 \pm 18.1	362.5 \pm 150.2 59.2 \pm 16.2	798.8 \pm 167.0 32.3 \pm 34.3
	2 layer (H=20cm)	353.2 \pm 99.1 66.9 \pm 12.2	438.3 \pm 134.0 64.9 \pm 21.6	359.7 \pm 41.2 59.4 \pm 10.3	461.2 \pm 79.7 64.0 \pm 9.8
	3 layer (H=30cm)	214.2 \pm 75.3 79.8 \pm 8.8	326.0 \pm 49.8 75.0 \pm 11.4	254.5 \pm 65.7 72.4 \pm 1.6	249.0 \pm 118.6 82.3 \pm 2.4
	4 layer (H=40cm)	137.7 \pm 34.3 87.1 \pm 4.4	301.7 \pm 41.0 77.0 \pm 10.0	193.0 \pm 55.1 78.6 \pm 5.5	200.5 \pm 96.3 83.4 \pm 1.4
	final treated water	96.7 \pm 11.1 91.1 \pm 1.5	179.5 \pm 26.4 86.9 \pm 2.9	102.7 \pm 21.9 88.3 \pm 3.5	157.5 \pm 94.8 85.2 \pm 1.9

The SS concentration of average influent for each filter media was the road runoff's SS concentration in range of 931.0mg/L~1450.5mg/L filtration after 1hour. The average SS treated water concentration was 96.7mg/L~179.5mg/L. The average SS treatment efficiency for EPP, EPS, Perlite, and Zeolite were 91.1%, 86.9%, 88.3% and 85.2% respectively which indicates that there is not much difference for each filter media.

In cases that zeolite was used as filter media, the finalized treated water's SS treatment efficiency was shown as 85.2% but at the bottom end of filter media layer(30cm before the floor) most of particulate materials were removed and thus the SS treatment efficiency was over 80%.

At filter layer higher than 30cm, the SS treatment efficiency over increment of filter layer height averagely 3.2% which was very slight.

Due to the property of filter media, Zeolite, which is buoyant media, the influence of hydraulic loads are great, so the blockage at the bottom of filter layer progresses in faster speed which causes the relatively higher SS concentration at the bottom compared to other media. It is determined the reason is that the function of filter media is not fully manifested by the collection of particulate substances at the top of filter layer above 30cm.

The filtration using Perlite which experiences the great impact of hydraulic loads shows the tendency that the SS concentration of treated water gradually decreases as the height becomes higher, but as the time goes by, runoff at 20 cm from filter layer showed the higher concentration than the runoff at 10cm from filter layer.

Perlite, different from Zeolite, is a buoyant filter media, which filter media itself is gradually crushed and generates fine particles rather than blockage is progressing from the bottom of filter later as Zeolite as times passes. It is determined that such phenomenon is due to the discharge of particulate substances with crushed filter media at the time of water sampling after certain period of time.

When EPS was used as the filter media, as the height of filter media increased, the water quality of treated water tended to decrease slightly. It was determined that this tendency was due to the difference in physical properties such as porosity and micro pore distribution which causes EPS to have lower collection ability compared to other filter media.

When EPP was used as filter media, as the height of filter media increase, the SS water quality of treated water tended to decrease clearly. This was because EPP showed the lowest

head loss by hydraulic loads compared to other media and even in the high speed condition of 950m/day, crushing of filter media did not occur, so that the particulate substances were evenly collected from top to bottom of the filter layer. Moreover, it was determined that the effect of reducing particulate substances was the greatest and the treatment efficiency was also the greatest.

The average concentration of treated water classified by height was expressed in the primary linear regression, and the results are as shown in Figure 4.30 and Table 4.15.

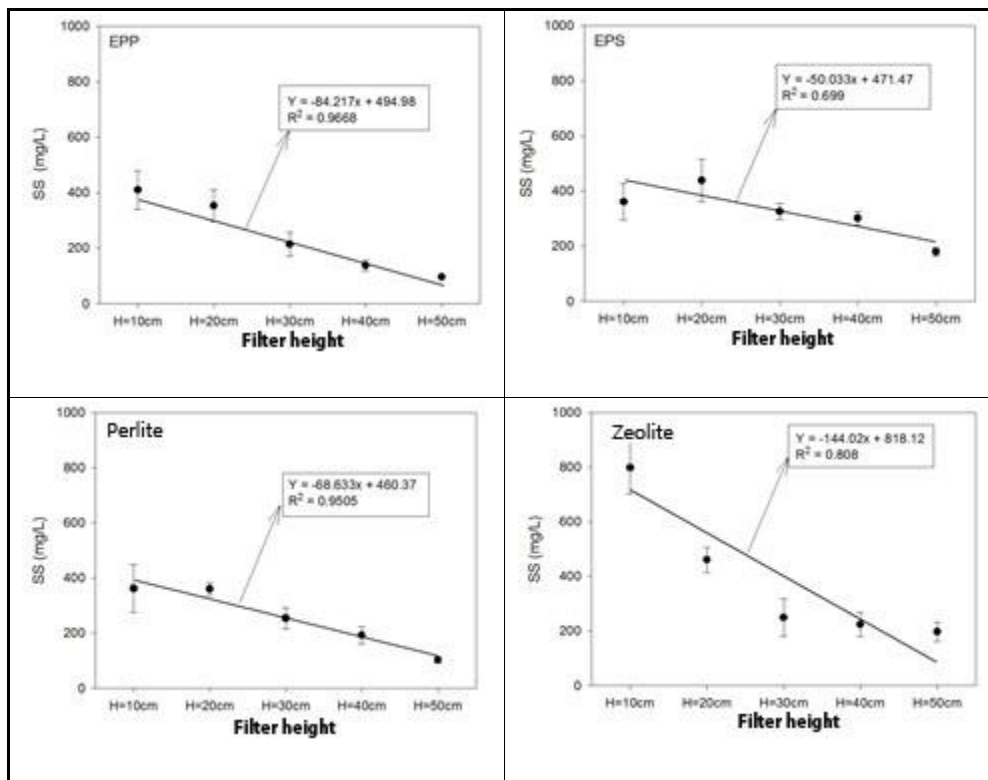


Figure 4.30 Primary linear regressions of the SS concentration variations by filter media's height

Table 4.15 Primary linear regression of the SS concentration variations by filter media's height

Regression equation of the head loss : $Y = -ax + b$ Y : SS Effluent concentration(mg/L), a, b : Coefficient, x : filter media's height (cm)				
Division	EPP	EPS	Perlite	Zeolite
a	84.22	50.03	88.63	144.02
b	494.98	471.47	460.37	818.12
R ²	0.967	0.670	0.951	0.808

As the negative slope, a, in primary linear regression of SS treated water by heights is greater, it means that the treated efficiency are great at upper part in contrast to bottom part. For each filter media, Zeolite was appeared to have the greatest slope and EPP has the lowest value. EPP and Perlite showed similar values. For zeolite, because the blockage phenomenon was progressed in great speed due to the collection of particulate substances only at the bottom, the SS outflow concentration at 10cm of filter layer was 798.8mg/L which was twice as high as the other filter media's concentration range at same height, 361.3mg/L~410.0mg/L. It is determined that difference in concentration caused the value to be the highest from the primary linear regression among other filter media.

The SS treated water's concentration at 10 height was expressed for EPP, EPS, and filter layer at similar range except zeolite, but for EPS, the negative slope "a" from the primary linear regression was 50.05 which was relatively small and thus it was determined that SS treatment efficiency was the lowest for EPS. In addition, the Relative constant R² of linear regression calculated from SS treated water's concentration was in order of EPP (0.967) > Perlite (0.951) > Zeolite (0.909) > EPS (0.670). Therefore it was expected that EPP had the most excellent mechanism to remove SS by collecting the particulate substances without blockage of some parts and EPS had the most inferior mechanism.

4.4.3 Treatment efficiency by media

(1) SS removal efficiency for each filter media

The average SS concentration of treated water and influent and treatment efficiency result by each filter media are as shown in Table 4.16 and Figure 4.31.

Table 4.16 SS removal efficiency by each filter media

Division		Number of samples	SS concentration (mg/L, average \pm standard deviation)
EPP	Influent	92	722.6 \pm 310.6
	Treated water	92	71.9 \pm 23.9
	Removal rate (%)		89.0 \pm 3.8
EPS	Influent	83	718.7 \pm 322.7
	Treated water	83	98.3 \pm 41.8
	Removal rate (%)		85.3 \pm 4.9
Perlite	Influent	48	901.3 \pm 337.3
	Treated water	48	95.4 \pm 20.8
	Removal rate (%)		88.5 \pm 3.6
Zeolite	Influent	36	833.2 \pm 266.6
	Treated water	36	116.7 \pm 24.6
	Removal rate (%)		84.9 \pm 5.0

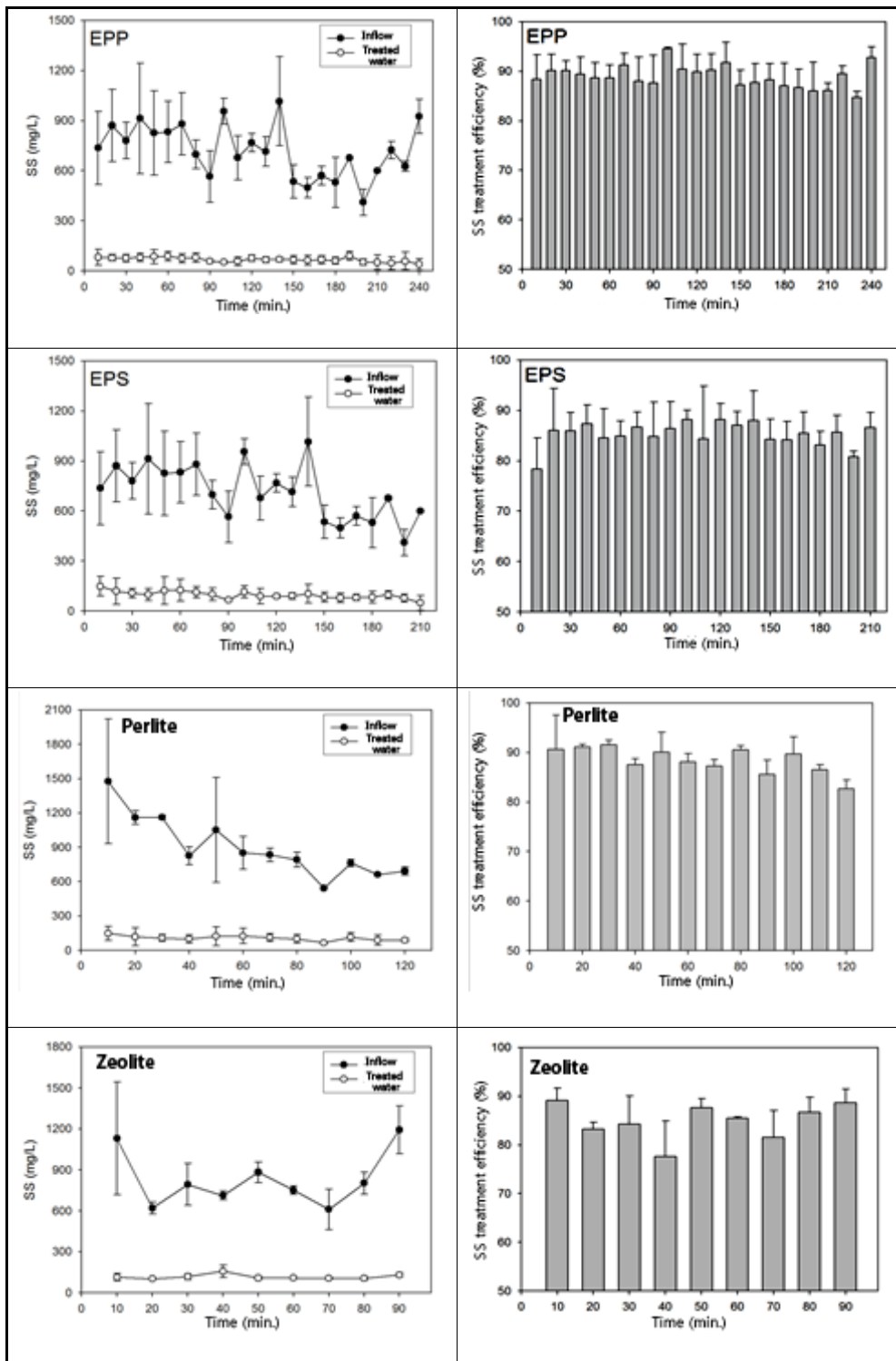


Figure 4.31 SS removal efficiency by each filter media

For each filter media, the average SS influent concentration for road runoff in range of average 718.7mg/L~901.3mg/L for EPP, EPS, Perlite and Zeolite were respectively, 71.9mg/L, 98.3mg/L, 95.4mg/L, 116.7mg/L, and the average treatment efficiency were 89.0%, 85.3%, 88.5% and 84.9% respectively, which Zeolite showed the lowest efficiency and EPP showed the highest. In the experiment procedure, there were quite a huge difference in the concentration of influent according to the inserting time and amount of the road surface dust mixed to influent, but regardless of type of filter media, the water quality of treated water showed quite constant concentration range and treatment efficiency was over 80%.

When we look at each filter media, Zeolite which showed the lowest SS treatment efficiency suddenly showed the treatment efficiency lower than 80%. It was determined that the reason is because of the temporary exposure of micro-particles collected at the filter layer 40 to 70 minutes after the experiment started at the high filtration linear velocity of 950m/day. For perlite, as the time goes by, the filter media was consistently crushed and from 80 minutes after the experiment when head loss drastically increased the treatment efficiency tended to decrease gradually.

In case of EPS, after 10 minutes from the beginning of experiment, the average SS treatment efficiency was the lowest as 78.4%. It was determined that the efficiency temporary decreased because the filter layer was not stabilized yet. EPP showed the stable treatment efficiency over time of over 85% without any increase or decrease in efficiency.

(2) COD treatment efficiency by filter media.

The result of treatment efficiency and COD average concentration of treated water and influent over time classified by filter media are as shown in Figure 4.32 and Table 4.17

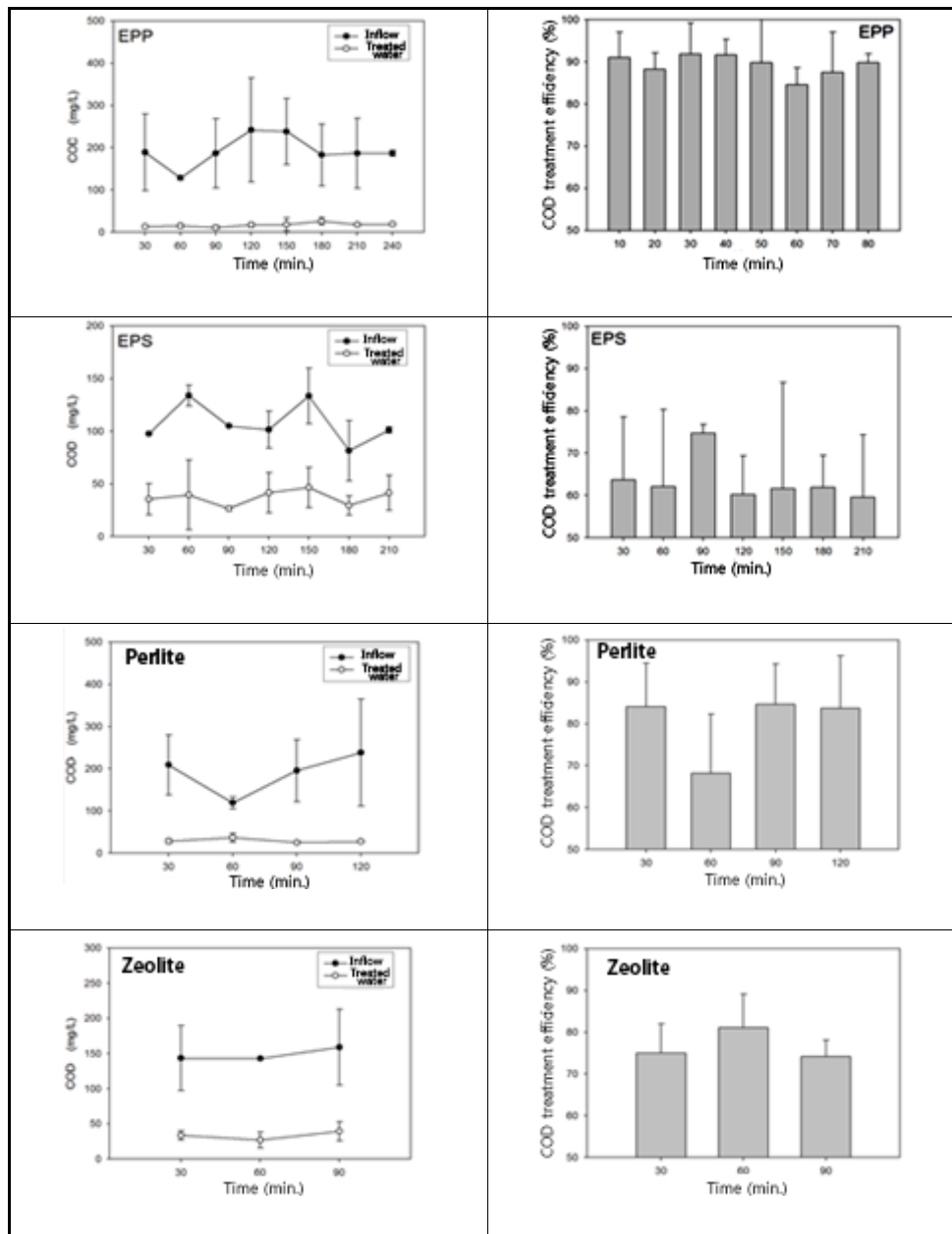


Figure 4.32 COD removal efficiency by each filter media

Table 4.17 COD removal efficiency by each filter media

Division		Number of samples	SS concentration (mg/L, average ± standard deviation)
EPP	Influent	16	193.6 ± 87.5
	Treated water	16	16.8 ± 6.8
	Removal rate (%)		89.3 ± 5.4
EPS	Influent	14	107.7 ± 25.3
	Treated water	14	37.2 ± 15.3
	Removal rate (%)		63.4 ± 12.0
Perlite	Influent	8	190.4 ± 99.3
	Treated water	8	29.3 ± 6.6
	Removal rate (%)		80.2 ± 11.6
Zeolite	Influent	6	148.5 ± 45.8
	Treated water	6	33.3 ± 10.1
	Removal rate (%)		76.8 ± 6.1

For each filter media, the average COD influent concentration for road runoff in range of average 107.7mg/L~193.6mg/L for EPP, EPS, Perlite and Zeolite were respectively, 16.8mg/L, 37.2mg/L, 29.3mg/L, 33.3mg/L, and average treatment efficiency of SS was over 80%, which was similar for all filter media, but for efficiency treatment of COD, Only EPP filter media showed the high treatment efficiency of 89%, and other filter medias showed lower treatment efficiency about 63.4%~80.2% compared to the SS category.

In the previous study case about removal property of contaminants in storm water runoff by filter media, Kim et al. (2009) reported that COD removal efficiency was 70~92% when studying about Perlite and synthetic filter media of polystyrene lines, and Lee et al. (2008) reported that removal efficiency of COD was over 90% for the treatment device that are combined with Zeolite filter media and eddy current.

Yoon et al. (1998) suggested the correlation between categories of each pollutant by the early-stage storm water runoff and reported that correlation of COD for SS were 0.756~0.962. Lee et al. (2008) reported that if total amount of elimination of SS through filter media was taken as 1, COD could remove 0.92 which was the highest.

This study also showed a similar COD removal efficiency but it is concluded that the removal efficiency was lower than the previous studies because the filtration line velocity was relatively high which cause filter media to contact with filter media for shorter time. In other words, it is deduced that the removal by collection of small particulate substance by filter media take most of removal and that EPP filter media shows the relatively high SS treatment efficiency. It is determined that the reason for high efficiency is EPP filter media has a high cross-sectional area and microspore distribution of 50~300 which is advantageous in removing micro-particles that has relatively high pollution loads.

(3) Heavy metals (Zn, Cu) treatment efficiency by filtration time for filter media

Among the heavy metals that are included in the storm water runoff of urban area, Zn and Cu are pollutants caused by the transportation of vehicles, and most heavy metals are attached to buoyant materials. Moreover, it has been reported that the concentration of heavy metals generally increases as the particles size decreases, the highest concentration are shown at size under 50 (Liebens,2001).Park et al. (2007) monitored the 5 categories(Zn, Cu, Pb, Cr, Cd) of heavy metals in road runoff for 2 years and reported reducing measures concentrated on Zn and Cu are necessary because the concentration of Zn and Cu categories were higher compared to other categories due to the usage of breaks and wearing of tire.

For each filter media, treatment efficiency and the average concentration of Zn and Cu in influent or treated water over time are as shown in Figure 4.33~4.34 and Table 4.18.

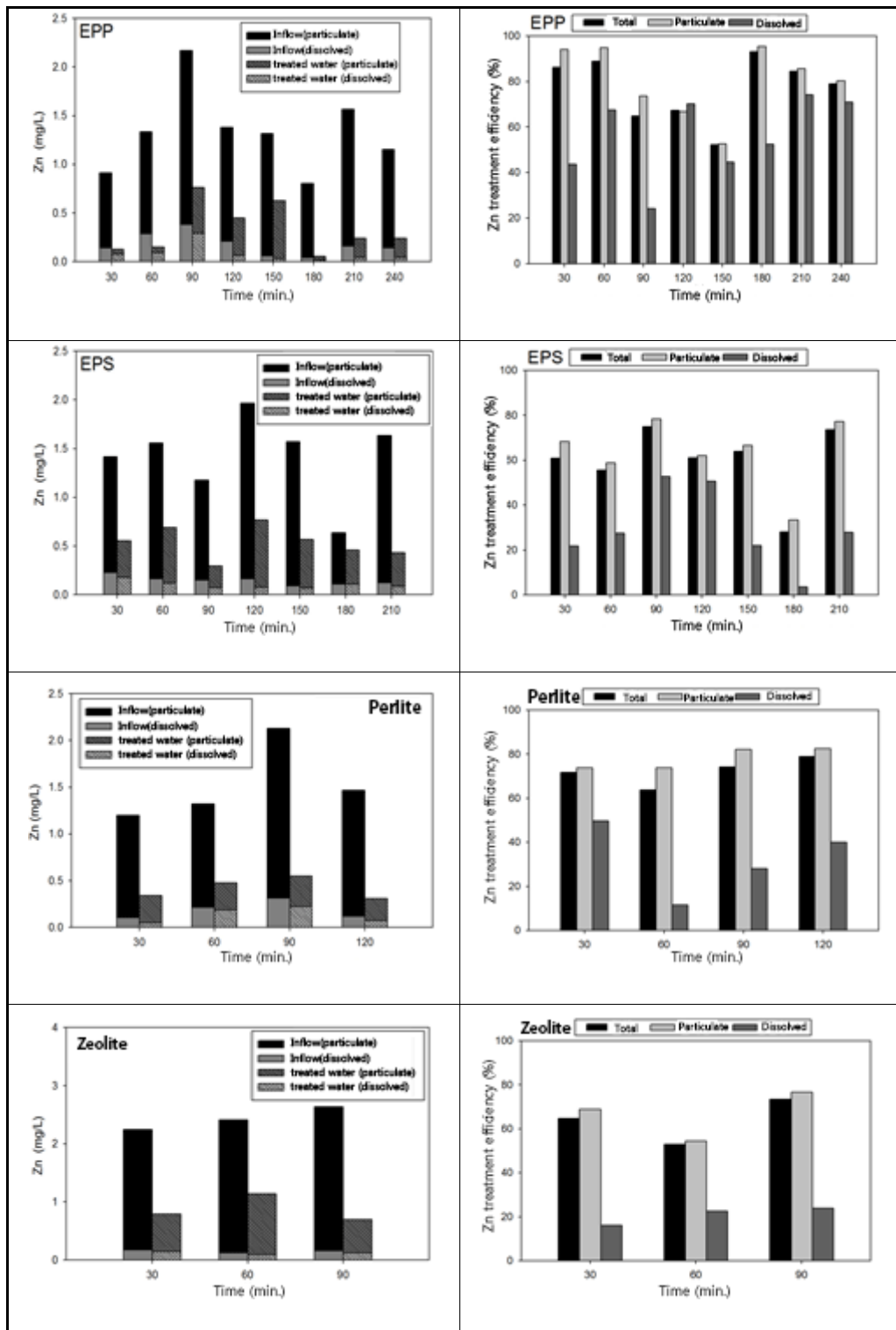


Figure 4.33 Zn removal efficiency by each filter media

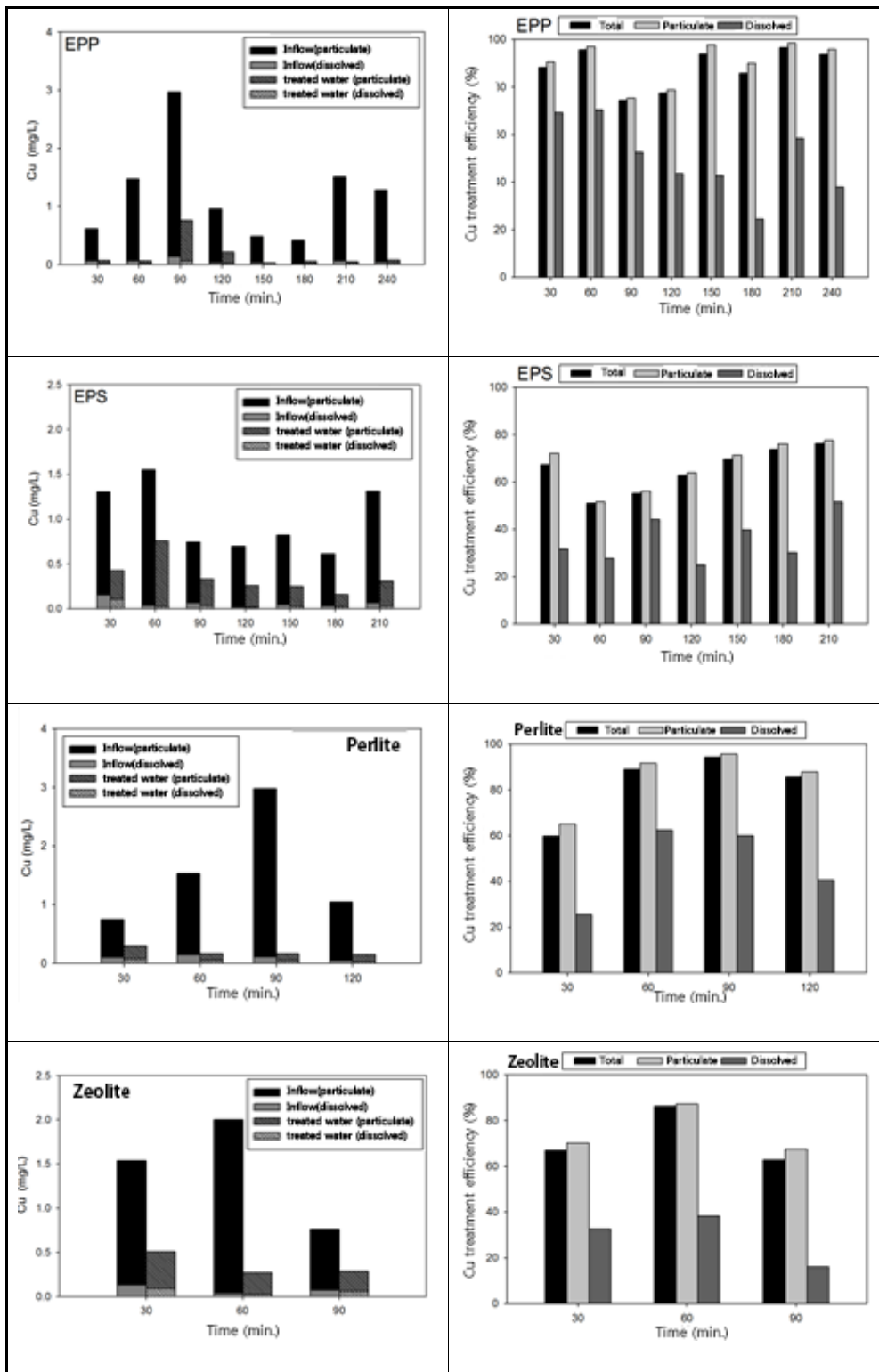


Figure 4.34 Cu removal efficiency by each filter media

Table 4.18 Zn, Cu removal efficiency by each filter media

Division			Numbers of Sample	Concentration (mg/L, average ± standard deviation)		
				Total	Particulate	Soluble
EPP	Zn	Influent	16	1.33 ± 0.42	1.15 ± 0.34	0.18 ± 0.11
		Treated water	16	0.33 ± 0.26	0.25 ± 0.21	0.08 ± 0.09
		Treatment efficiency (%)		77.1 ± 14.1	80.4 ± 15.3	56.0 ± 17.7
	Cu	Influent	16	1.21 ± 0.83	1.16 ± 0.80	0.06 ± 0.04
		Treated water	16	0.17 ± 0.25	0.14 ± 0.23	0.03 ± 0.02
		Treatment efficiency (%)		88.2 ± 8.5	90.4 ± 8.9	49.9 ± 15.8
EPS	Zn	Influent	14	1.42 ± 0.42	1.28 ± 0.41	0.15 ± 0.05
		Treated water	14	0.54 ± 0.16	0.44 ± 0.16	0.10 ± 0.04
		Treatment efficiency (%)		59.7 ± 15.6	63.5 ± 15.1	29.5 ± 17.2
	Cu	Influent	14	1.01 ± 0.37	0.95 ± 0.36	0.06 ± 0.05
		Treated water	14	0.36 ± 0.20	0.32 ± 0.19	0.04 ± 0.03
		Treatment efficiency (%)		65.1 ± 9.4	67.0 ± 10.0	35.7 ± 9.7
Perlite	Zn	Influent	8	1.53 ± 0.41	1.34 ± 0.34	0.19 ± 0.10
		Treated water	8	0.42 ± 0.11	0.28 ± 0.04	0.13 ± 0.09
		Treatment efficiency (%)		72.2 ± 6.3	78.1 ± 4.9	32.3 ± 16.4
	Cu	Influent	8	1.58 ± 0.99	1.47 ± 0.98	0.10 ± 0.04
		Treated water	8	0.20 ± 0.07	0.15 ± 0.05	0.05 ± 0.02
		Treatment efficiency (%)		82.1 ± 15.4	85.1 ± 13.7	47.1 ± 17.5
Zeolite	Zn	Influent	6	2.43 ± 0.20	2.27 ± 0.20	0.16 ± 0.03
		Treated water	6	0.88 ± 0.23	0.75 ± 0.25	0.12 ± 0.02
		Treatment efficiency (%)		63.6 ± 10.3	66.7 ± 11.2	20.9 ± 4.1
	Cu	Influent	6	1.43 ± 0.62	1.35 ± 0.64	0.08 ± 0.05
		Treated water	6	0.36 ± 0.13	0.30 ± 0.11	0.06 ± 0.03
		Treatment efficiency (%)		72.0 ± 12.6	75.0 ± 10.7	29.0 ± 11.5

As shown in Table 4.18 for each filter media, the average Zn influent concentration for road runoff in range of average 1.33mg/L~2.43mg/L for EPP, EPS, Perlite and Zeolite were respectively 0.33mg/L, 0.54mg/L, 0.42mg/L, 0.88mg/L, and the average Cu influent concentration for road runoff in range of average 1.01mg/L~1.58mg/L for EPP, EPS, Perlite and Zeolite were 0.17mg/L, 0.36mg/L, 0.20mg/L, 0.36mg/L respectively.

Looking at the average removal efficiency for each filter media, in case of Zn, treatment efficiency decrease in order of EPP (77.1%)> Perlite (72.2%)> zeolite (63.6%)> EPS (59.7%), and in case of Cu, the order was EPP (88.2%)> Perlite (82.1 %) > zeolite (72.0%)> EPS (65.1%) which indicates that for both cases, EPP shows the highest treatment efficiency while EPS shows the lowest.

The average dissolved concentration ratio of influent by each filter media of Zn and Cu were observed to be 6.6%~13.5% for Zn and 4.1%~7.0% for Cu. It was determined that the dissolved concentration ratio result was very low compared to preceding research cases where dissolved ratio of heavy metals in road runoff that are classified under size of 0.45 μ m take up more than 50% because the experiment was conducted by randomly manufactured influent.

Kim et al. (2009) reported that for dissolved materials and organic substances, absorption of dissolved organic substances through the chemical properties of filter media such as ion exchange within filter media or electrical force are very low (average 10%) through the research about removal characteristics of dissolved materials by filter media. Also, they reported that hours of contact time are needed in order to remove the pollutants according to chemical properties.

When treatment efficiency were calculated about Zn and Cu classifying into dissolved and particulate type, regardless of types of filter media, particulate substances showed the

63.5~90.4% of removal efficiency whereas dissolved substances showed low removal efficiency, 20.9% ~ 56.0%. It was determined that the chemical contact time which was 45 seconds were not enough for successful removal of dissolved substances and also treatment efficiency was lower for dissolved substances because they are not very influenced by physical properties that are removed by collecting on filter media's micro-pores.

When the change in treatment efficiency of Zn and Cu are examined, regardless of type of filter media, the treatment efficiency was maintained constantly. For Zn, there was a point where the treatment efficiency rapidly decreased and it was determined that sudden decrease was due to exposure of micro-particles collected in the filter media by the influence of hydraulic loads caused by the high filtration linear velocity as for cases in EPP and EPS filter media at time elapse.

To sum up, it is supposed that removal mechanism of heavy metals present in road runoffs is mostly depending on the physical collection by the filter media according to characteristics of filter media, and among the four filter media used in the experiment, EPP filter media's micro-pores are mostly developed, such that EPP filter media are most advantageous in removing heavy metals that contains a lot of particulate substances and EPS filter media are mostly at disadvantage.

4.4.4 SS removal rate of media by various particle sizes

(1) Change in particle size distribution of outflow by filtration time for filter media

In order to figure out the removal mechanism for micro-particles that has relatively greater pollutants loads in sample collected over time in road runoff for each filter media, the particle size analysis were conducted in 30 minutes interval, and the result are shown in Figure 4.35 and Table 4.19.

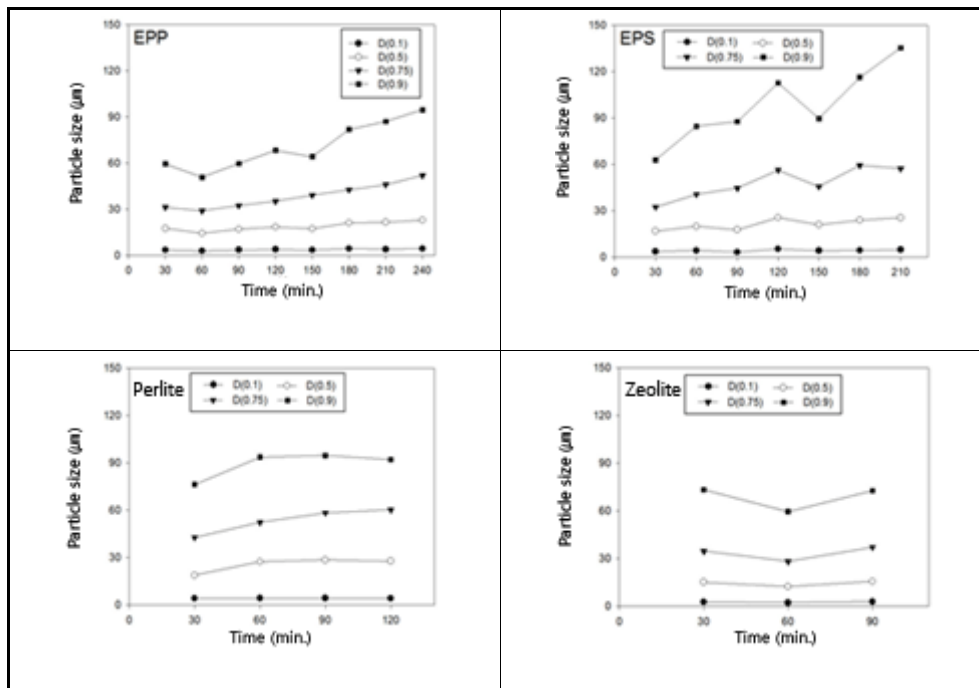


Figure 4.35 Particle size distribution of treated water by filtration time for each filter media

Table 4.19 Particle size distribution of influent and treated water for each filter media

Division	Number of samples	Particle size(µm, average ± standard deviation)				
		D(0.1)	D(0.5)	D(0.75)	D(0.9)	
Influent	22	10.8 ± 3.3	78.1 ± 16.6	152.1 ± 41.6	317.3 ± 52.5	
Treated water	EPP	8	3.9 ± 0.5	18.9 ± 2.8	38.6 ± 8.0	70.9 ± 15.4
	EPS	7	4.4 ± 0.7	21.6 ± 3.6	48.1 ± 10.0	98.5 ± 24.3
	Perlite	4	4.3 ± 0.1	25.7 ± 4.6	53.5 ± 7.9	89.3 ± 8.6
	Zeolite	3	2.6 ± 0.3	14.4 ± 1.8	33.4 ± 4.6	68.6 ± 7.8

As particle size of treated water treated by filter media compared to influent gets smaller, removal of micro-particles are at advantage and it can be determined indirectly that the treatment efficiency decrease for the particle size lower than that. The particle size was analyzed for the road runoff with size 78.1 μm and 317.3 μm that fall under the volume ratio according to average particle size distribution, 50% and 90% and the result showed that the D (0.1) was in range of 2.6 μm ~4.4 μm , D (0.5) was in range of 14.4 μm ~25.7 μm , and D (0.9) was in range of 68.6 μm ~98.5 μm

For each filter media, excluding D(0.1) which the size are similar, D(0.5) of treated water was in decreasing order of Perlite(25.7 μm) > EPS(21.6 μm) > EPP(18.9 μm) > Zeolite(14.4 μm), D(0.75) of treated water was in decreasing order of perlite (53.5 μm) > EPS(48.1 μm) > EPP(38.6 μm) > zeolite (33.4 μm), D(0.9 μm) of treated water was in order of EPS(98.5 μm) > Perlite (89.3 μm) > EPP(70.9 μm) > zeolite (68.6 μm). Therefore, Zeolite showed the smallest particles size for all of them and Perlite and EPS showed larger particle size compared to other filter media.

Looking at the change in particle size distribution over time, the particle size of outflow tended to increase gradually for all media except Zeolite. It is determined that the reason comes from the gradual blockage of pores caused by collection of micro-particles on pores and the greatest increase of size was shown for EPS filter media and D(0.9) which corresponds to 90% volume ratio.

(2) Calculation of SS treatment efficiency classified by particle size distribution

With the size distribution and SS result about influent and treated water over time for each filter media, SS treatment efficiency classified by size distribution was calculated. When calculating the SS treatment efficiency, all parties were assumed spherical and the range of

particle size was classified into nine steps (less than 100: step 6, over 100: step 3). The specific gravity for each particle size was refer to the specific gravity classified by road surface dust particle size proposed by USEPA and classified into 3 steps (less than 30, 2.14, 30 μm ~ 60 μm : 2.15, over 60 μm : 2.6)

The calculation process of SS removal efficiency classified by particle size distribution was first volume ratio deducted from the particle size distribution result was converted to weight ratio by applying the specific gravity corresponding to range of particle size and SS loads (g) classified by particle size distribution and treatment efficiency were calculated by applying the SS concentration to the converted weight ratio.

The calculation result of SS treatment efficiency classified by particles size distribution calculated for each filter media is shown in Figure 4.36 and Table 4.20.

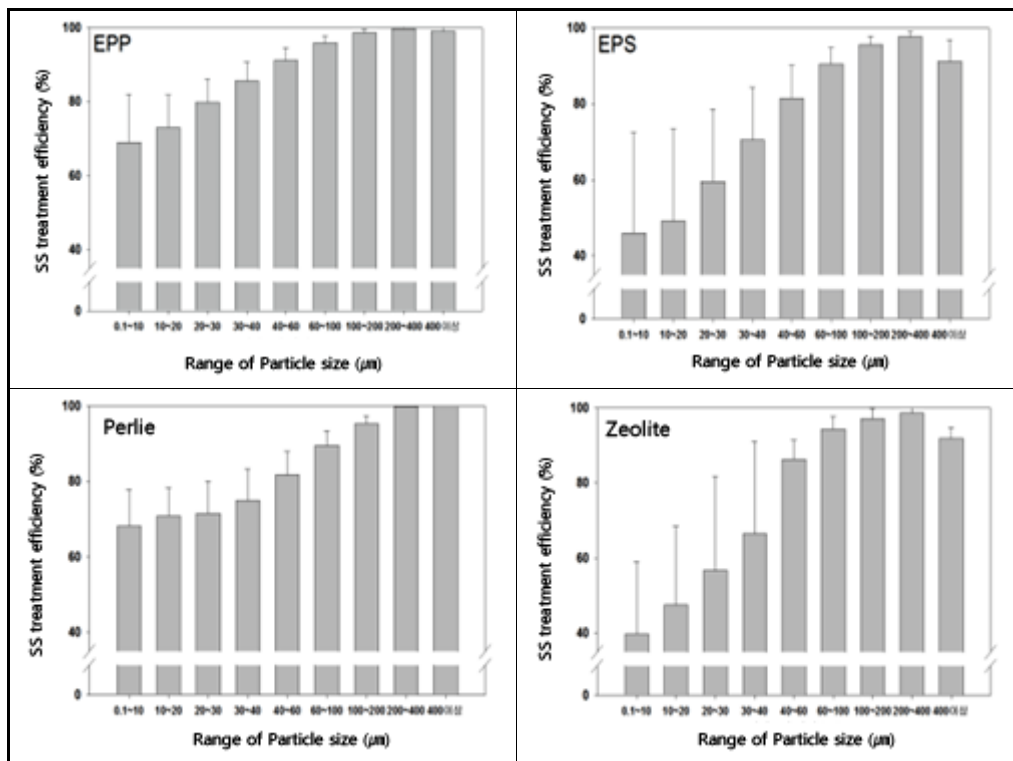


Figure 4.36 SS treatment efficiency classified by particles size distribution for each filter media

Table 4.20 SS average treatment efficiency classified by particles size distribution for each filter media

Particle size range (μm)		SS treatment efficiency (%, average \pm standard deviation)			
		EPP	EPS	Pelite	Zeolite
Less than 100 μm	0.1 ~ 10	69.0 \pm 13.0	46.0 \pm 26.4	68.1 \pm 9.7	39.8 \pm 19.2
	10 ~ 20	73.1 \pm 8.7	49.2 \pm 24.3	70.8 \pm 7.6	47.5 \pm 20.9
	20 ~ 30	79.8 \pm 6.4	59.6 \pm 19.1	71.6 \pm 8.6	56.7 \pm 25.0
	30 ~ 40	85.6 \pm 5.1	70.5 \pm 13.9	74.9 \pm 8.4	66.5 \pm 24.4
	40 ~ 60	91.2 \pm 3.5	81.4 \pm 8.7	81.7 \pm 6.3	86.3 \pm 5.2
	60 ~ 100	95.8 \pm 1.8	90.4 \pm 4.3	89.5 \pm 3.8	94.4 \pm 3.3
100 μm or more	100 ~ 200	98.7 \pm 0.8	95.6 \pm 2.3	95.3 \pm 2.0	97.1 \pm 2.8
	200 ~ 400	99.7 \pm 0.4	97.6 \pm 1.4	99.9 \pm 0.2	98.6 \pm 1.6
	400 or more	99.1 \pm 1.1	91.1 \pm 5.7	100.0 \pm 0.0	91.8 \pm 2.8

As shown in Figure 4.36, regardless of types of filter media, the range of particle size greater than 100 μm over 95% of high treatment efficiency whereas in range of particle size under 100 μm , the treatment efficiency tended to decrease as the particle size decreases. Classifying by filter media, Zeolite and EPS showed the greater decrease in treatment efficiency according to the decrease in particle size compared to EPP and Perlite.

For particles with size greater than 100 μm , the treatment efficiency was high and it is determined that the reason is that they precipitate at the bottom before they are exposed passing through the filter media at upward system. For particles with size less than 100 μm which are

treated by collecting while passing through the filter media, treatment efficiency varied according to the properties of filter media.

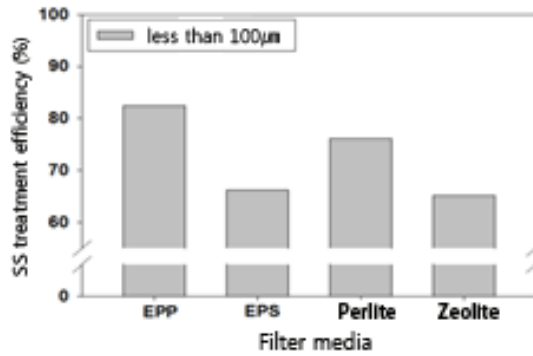


Figure 4.37 SS average treatment efficiency of particles (less than 100µm for each filter media)

Figure 4.37 shows the average SS removal efficiency by each filter media for micro-particles with size less than 100µm. The efficiency was in decreasing order of EPP(82.4%) > Perlite(76.1%) > EPS(66.2%) > Zeolite (65.2%) which confirmed the fact that EPP filter media are more favorable compared to other filter media for treatment of micro-particles that have high pollutants loads. For EPP filter media, the treatment efficiency according to particle size distribution is more than 80% for small particles under 30µm. Therefore, EPP can manage the broad size range of pollutant particles.

For EPS, Perlite, and Zeolite filter media, their treatment efficiency is more than 80% for particles over 40µm, which is quite small treatment range.

4.4.5 SEM analysis.

The examples of mechanism that reduces pollutants through filtration are sedimentation, collision, obstruction, adhesion, physical collection, chemical absorption, and biological proliferation, and in case of using NPS reduction facilities combined with upward system

filtration that operates with high linear velocity as in this study, it is hard to expect removal through biological mechanism and chemical absorption due to the short retention time of pollutants with filter media and it is known that pollutants are removed through collision, obstruction, adhesion and physical collection.

Therefore, most of the device-type non-point reduction facilities adapt macro pore filter media that are advantageous for removal of pollution due to the large cross-sectional area and large porosity. The micro-pores' extent of contribution to collection of particles were figured out by SEM analysis before and after treatment for each filter media and the result are shown in Figure 4.38.

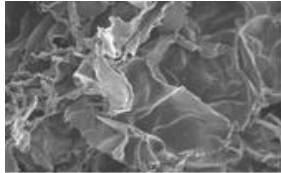
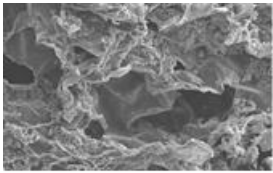
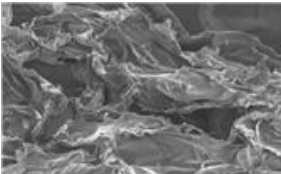
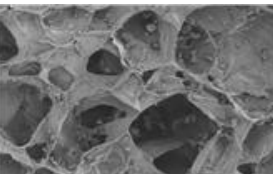
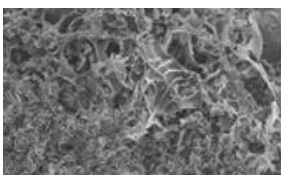
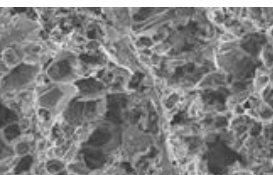
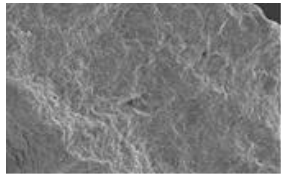
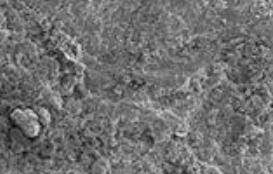
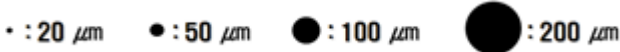
Division	Before filtration	After filtration
EPP		
EPS		
Pelite		
Zeolite		
Reference		

Figure 4.38 SEM analyses after · before treatment for each filter media

As shown in Figure 4.38, the result of SEM analysis of before and after then treatment about the road runoff for each filter media showed that EPP filter media has adequate structure for treatment of road runoff for its size of micro-pores ranging from dozens to hundreds. The thickness of cell wall seems too thin, but the media is polypropylene which tensile strength is strong, so that it has a property that at the time of pressure, it does not break but compresses.

The particles of pollutant collected inside of micro-particles can be observed from picture of EPP filter media after filtration. EPS has very similar micro-pore size as EPP, but the porosity rate and cross-sectional area are relatively small, and it was observed that pollutants particles are not much collected in micro pores at SEM after filtration.

In case of Perlite, it can be observed that lots of filter media debris are contained in micro pores of filter media before the filtration, and cell wall is very thin and made of mineral materials and thus showed a tendency that it can be easily break by pressure. It is determined that discharge phenomenon of SS temporary occurred with the crushed filter media by the hydraulic loads and increase of head loss over time.

Zeolite has the micro-particles with size under 1 which cannot be seen through eyes in SEM picture, and the cross-sectional area of zeolite is the greatest among all 4 filter media, but it is determined that the micro pore does not contribute much in treatment of road runoff, and that the increase of head loss was observed to be the highest due to distribution of this small micro pores compared to other filter media

CHAPTER 5 EVALUATION OF FILTRATION EFFICIENCY FROM CSOs

In this section, in order to analyze the filtration treatment effectiveness for CSOs, the generation characteristics from the generation source and filtration effectiveness of CSOs were reviewed.

The blockage period is the important factor that determines the lifespan of the filtration device. Therefore to test this, the change in head loss over time was analyzed and to fit the property of CSOs, the treatment efficiency was evaluated by analyzing influent and treated water for 5 water quality categories: SS, BOD, COD, T-N, T-P

5.1 Characteristics of CSOs in the study area

In the previous study case about particle distribution of CSOs and sewer sediments, Yoon (1999) reported that the at the diverging tanks with size of 170ha of combined region, the analysis result of particles size distribution of CSOs corresponding to First flush period showed that the median of superficial frequency analysis of particle was 85 which was similar to that of ground runoff. Lee et al. (2005) reported that according to the result of heavy metal analysis classified by particle size distribution of sewer sediments for each sewer basins according to land-use of seven different places such as residential, industrial areas, bridges, forests, agriculture and industry complex, the highest concentration was shown in the range of 250 μm which was classified into the smallest size group.




Likewise, it is determined that the characteristics of particle distribution and concentration of heavy metal are similar to those of road runoff because the sewage mixed with road runoff is discharged with sediments in sewer and also the assumption is supported by

the preceding research . Therefore, the analysis of particle size distribution and concentration of heavy metals for CSOs were not executed

5.1.1 Study site

In order to figure out the discharge characteristics of combined sewer overflows (CSOs), the flow and water quality monitoring during dry season were conducted. The current conditions of each storm overflow diverging tanks are as shown in Table 5.1

Table 5.1 Summary of CSOs investigation points

Point	Watershed Area (ha)	Land-use (%)					Combined sewer (m)
		Housing	Green fields	Commercial	Road	Etc.	
C Point	33.26	28	12	10	17	33	1.2 × 1.5
D Point	540.11	17	20	8	14	41	3.0 × 2.0
Photos		C storm overflow diverging tank		D storm overflow diverging tank			
							

The chosen storm overflow diverging tanks in Seoul to be CSOs monitoring area are C storm overflow diverging tank of small scale with drainage area of 33ha and D storm overflow diverging tank of large scale with drainage area of 540ha, and two area both shows various form of land-use such as housing, industrial, green field, commercial, and roads as shown in Table 5.1

5.1.2 Flow and water quality analysis during dry season

The flow and water quality analysis for each point during dry season are shown in Figure 5.1.

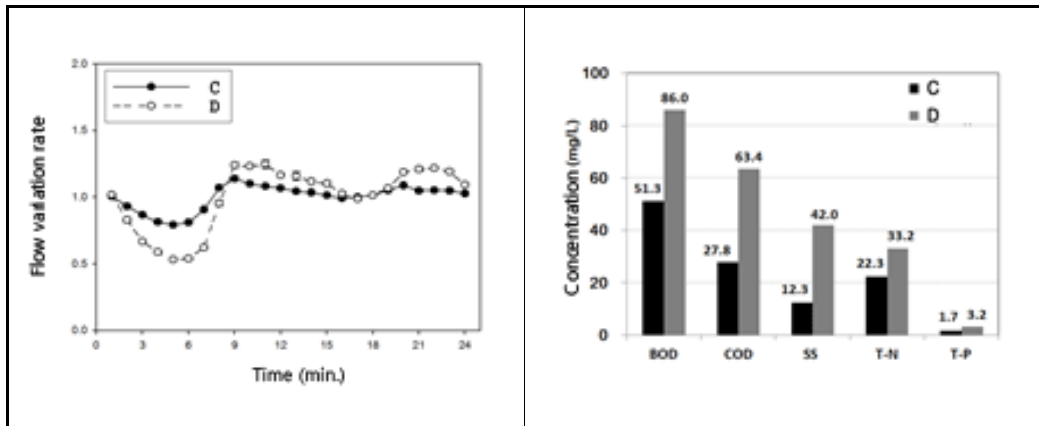


Figure 5.1 Flow and water quality during dry season for each storm water diverging tanks

For each place, the average flow (C: $101.7 \text{ m}^3/\text{hr}$, D: $136.1 \text{ m}^3/\text{hr}$) during dry season, daily contrast to hourly flow variation rate was 0.7~1.14 for place C and was 0.54~1.25 for place D.

Both areas showed the decrease in flow at dawn and typical flow rate patten in residential area was observed at 8am ~10am and 7pm~10pm when water usage is relatively high. For storm water diverging tank at point D, due to the influence of unidentified-water, the hourly flow variation rate was small compared to point B and the sudden decrease in flow rate was not observed at dawn.

The storm overflow diverging tanks of Point D, which impact of unknown source sewages are relatively low, marked higher for all categories in water quality during dry season than point C. It is determined that both spots marked lower than other research cases.

5.1.3 Flow and water quality analysis during rainy season

For each point of storm overflow diverging tanks, Field monitoring of CSOs during rainfall was conducted and the rainfall and water quality analysis result about monitoring are as shown in Table 5.2~5.3 and Figure 5.2~5.3.

Table 5.2 Analysis rainfall of CSOs monitoring for each places

Point	Total rainfall	Average rainfall intensity	Preceding dry days	Duration of rainfall
C	3.5 mm	7.0 mm/hr	11 days	30 minutes
D	33.5 mm	10.6 mm/hr	4 days	190 minutes

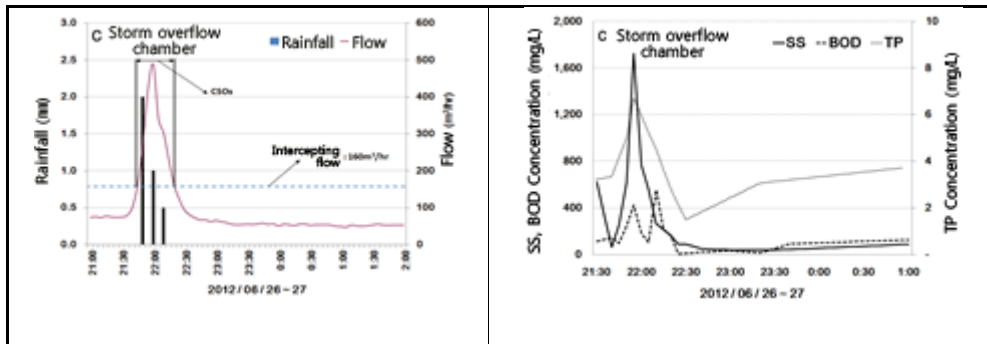


Figure 5.2 Flow and water quality during rainfall in storm overflows diverging tanks (C Point)

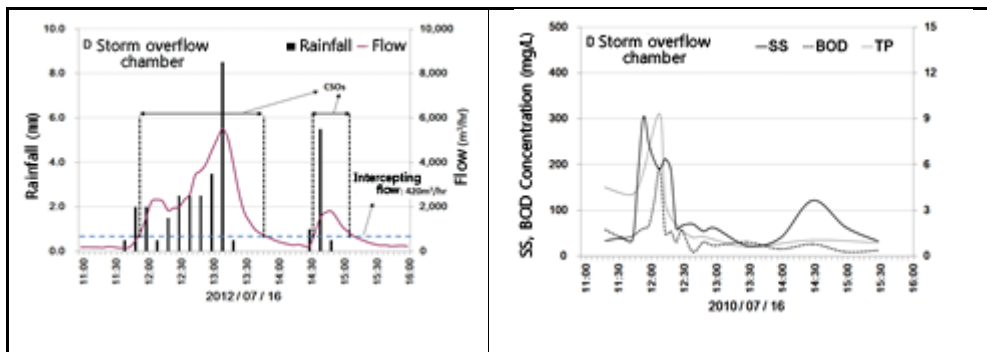


Figure 5.3 Flow and water quality during rainfall in storm overflows diverging tanks (D Point)

Table 5.3 Water quality analysis during rainfall in storm overflow diverging tanks

Division			BOD	SS	T-P
C	Measured value (mg/L)	Average	107.6	173.3	3.3
		Range	7.6~554.9	37.3~1,723.3	1.5~6.7
	EMC(mg/L)		192.6	523.0	4.3
D	Measured value (mg/L)	Average	48.7	111.1	3.1
		Range	8.6~191.3	22.5~304.4	0.6~9.3
	EMC(mg/L)		44.0	91.7	2.7

From the monitoring result of CSOs at combined sewer storm water diverging tanks, the average concentration for each water quality categories for BOD, SS, T-P at spot C were respectively 107.6mg/L, 173.3mg/L, 3.3mg/L and for those at spot D were 48.7mg/L, 111.1mg/L, 3.1mg/L respectively.

The flow weight mean concentration or Event mean concentration (EMC) which was converted considering the measured flow rate were 192.6mg/L for BOD, 523.0mg/L for SS, and 4.3mg/L for T-P which was in similar range as the research result conducted by Environmental Management Corporation for urban area CSOs. For spot D, EMC was 44.0mg/L for BOD, 91.7mg/L for SS, and 2.7mg/L for T-P which was generally lower than those of spot C. It is determined that the EMC concentration was calculated lower for spot D because spot D had the shorter preceding dry period at the time of monitoring and had more rainfall which causes lower first flush and more discharge.

The maximum concentration of CSOs generated by rainfall categorized by water quality was observed to be 2.9 times, 3.3 times, 1.6 times higher than EMC for BOD, SS, and T-P respectively for spot C and 4.3 times, 3.3 times, 3.4 times higher respectively.

First flush is defined as phenomenon that highly concentrated pollutants are discharged in the early stage of storm water, and in the CSOs manual of EPA in United States defined the range of early stage storm water as “within 30 minutes after the beginning of rainfall discharge or until the time when concentration at early stage generation decreases to mean sewer concentration during dry season” (USEPA, 1993). Sansalone et al. (1997) defined it to be early stage storm water if the standard cumulative pollutant loads exceed the standard cumulative runoff curve.

Other than this, Deletic (1998), and Taebi et al. (2004) conducted research about early stage storm water and reported that early stage storm water phenomenon are complicated and vary much according to the regional characteristics.

The dimensionless L (V) curve to evaluate the first flush categorized in water qualities for each spot was shown by a diagram and the result are shown in Figure 5.4.

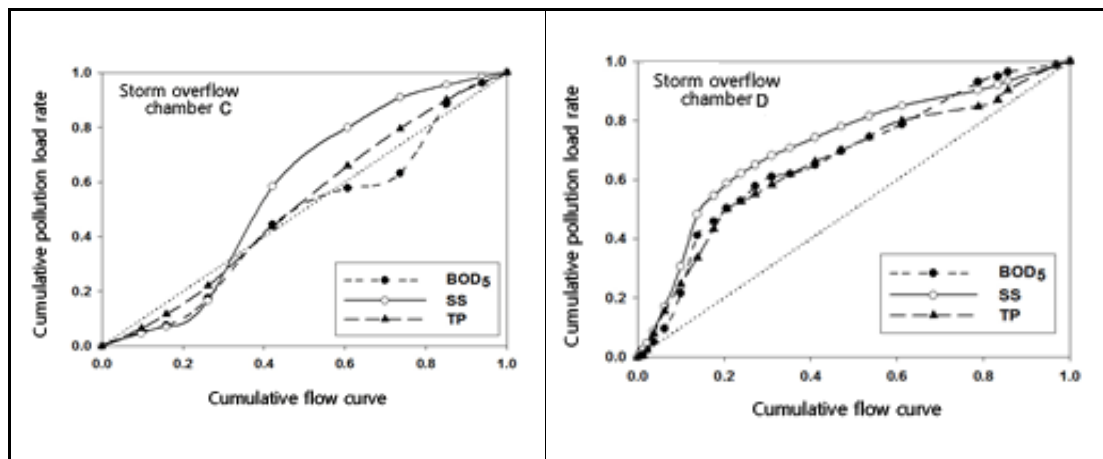


Figure 5.4 Cumulative pollution load curve by C and D points (BOD, SS, T-P)

In Figure 5.4, the slope of mass loads curve classified by water quality categories is greater than 1, it can be determined that first flush occurred. For both spots, it was confirmed that the first flush phenomenon of SS was greater compared to that of BOD and T-P.

According to Taebi et al. (2004), it was reported that as the urbanized area and impervious area ratio were higher, the first flush effect were greater. It is expected that in case CSOs are reduced by filtration facilities, treating overflows of early stage rainfall that pollutants loads are relatively higher are the method to maximize the reduction effect of pollutant loads.

5.2 Evaluation of filtration efficiency

The influent for evaluation of filtration efficiency about CSOs were manufacture by mixing the road surface dust to domestic sewage during dry period generated from storm overflow diverging tank with size of 40ha drainage area, and for each media the experiment for inflow flow conditions was conducted by maintaining the 950 of filtration linear velocity which is the maximum linear velocity allowed for device-type NPS reduction facilities proposed by Environment Management Corporation and Ministry of Environment.

5.2.1 Change in head loss by media

When selecting the filtration type to treat the NPS source, the blockage period of filter media are very important factor for construction and operation of filtration device because the function of reduction facilities are deteriorated if the filter media are easily blocked. The laboratory scale experiment about filter media for CSOs was conducted and the recurrence days were calculated based on this. The head loss for each filter media by CSOs in laboratory scale are shown in Figure 5.5.

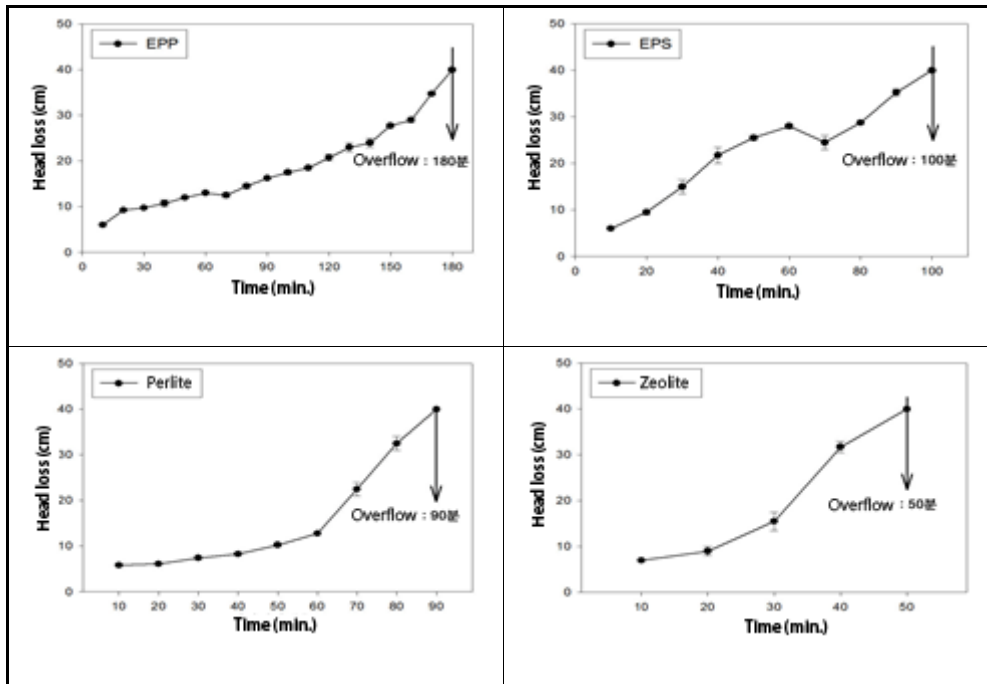


Figure 5.5 Change of head loss CSOs during filtration time by each filter media

The overflow time when reaching 40cm limit head loss was in decreasing order of EPP(180min)> EPS (100min) > Perlite (90min) > Zeolite (50min) where zeolite had the fastest overflow time and EPP had the slowest.

The result shown above showed the faster overflow time for each filter media compared to that of overflow time for road runoff and it is inferred that the overflow time was faster than road runoff due to the blockage of filter media which is caused by abundance of particulate particles, organic substances and dissolved substances in influent in case of CSOs.

The cumulative SS loads in urban combined sewer area proposed by basic analysis research downtown of combined sewer overflow pollutant loads (Environmental Management Corporation, 2004) was used as criteria for calculating recurrence days by CSOs and the result are shown in Figure 5.6.

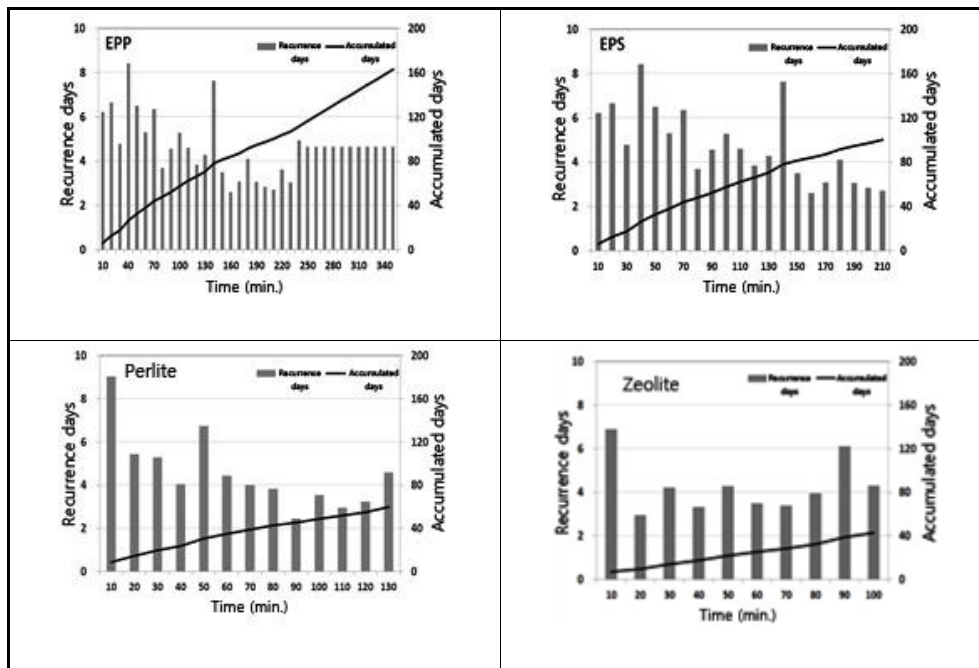


Figure 5.6 Result of calculating recurrence days by CSOs for each filter media

When recurrence days of CSOs for each filter media derived from the measurement result of limit head loss are calculated, EPP, ESP, Perlite and Zeolite was respectively calculated to 40, 22, 21, 11 days.

Compared to cases of road runoffs, CSOs' recurrence days ranged from 11 to 40 days which showed the gradual decrease in recurrence days and it is determined that the decrease is caused because annually generated SS loads are 3.2 times higher due to re-emergence of sewer sediments at the time of rainfall and also due to effects of hydraulic loads caused by property of influent.

In order to reduce the pollutant loads of CSOs with facilities combined with filtration equipment, the method to minimize the hydraulic loads acting on filter media by installing baffle plate and baffle wall inside the device would be necessary

5.2.2 SS removal rate of media

The SS average concentration and treatment efficiency of treated water and influent for each filter media are shown in Figure 5.7 and table 5.4.

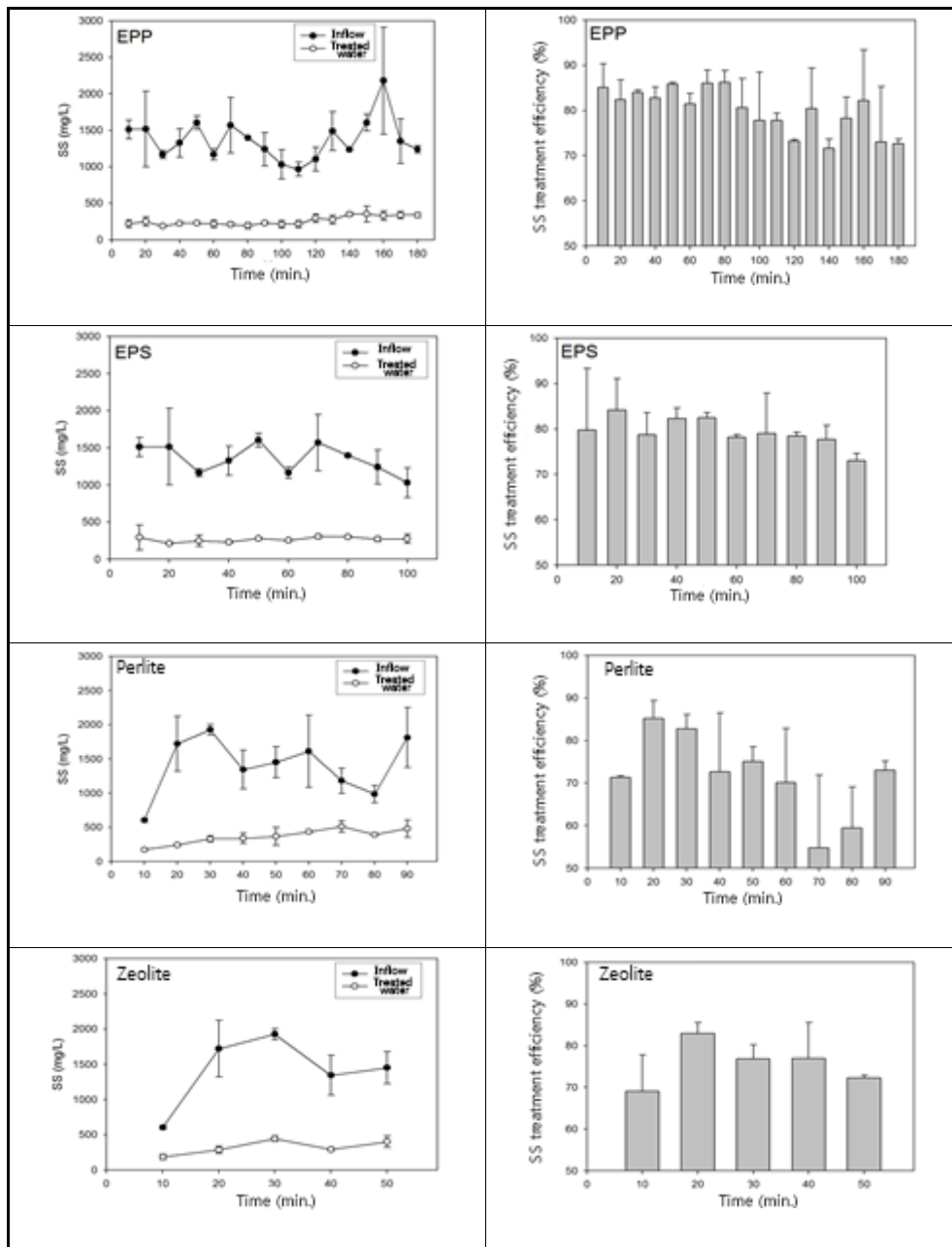


Figure 5.7 SS removal efficiency by each filter media

Table 5.4 SS removal efficiency by each filter media

Division		Number of samples	SS concentration (mg/L, average \pm standard deviation)
EPP	Influent	36	1,372.9 \pm 391.5
	Treated water	36	259.2 \pm 67.6
	Treatment efficiency (%)		80.1 \pm 6.4
EPS	Influent	20	1,353.9 \pm 312.9
	Treated water	20	267.5 \pm 54.4
	Treatment efficiency (%)		79.4 \pm 5.3
Perlite	Influent	18	1,404.8 \pm 517.9
	Treated water	18	363.4 \pm 118.5
	Treatment efficiency (%)		71.6 \pm 11.7
Zeolite	Influent	10	1,409.8 \pm 542.3
	Treated water	10	321.6 \pm 103.8
	Treatment efficiency (%)		75.6 \pm 6.6

For each filter media, the average SS runoff concentration for CSOs in range of average 1,353.9mg/L~1,409.8mg/L for EPP, EPS, Perlite and Zeolite were respectively 259.2mg/L, 267.5mg/L, 363.4mg/L, and 321.6mg/L, and the average treatment efficiency were respectively 80.1%, 79.4%, 71.6% and 75.6% that Perlite showed the lowest treatment efficiency and the others showed similar efficiency that falls under range of 75%~80%.

In case of CSOs, the SS average treatment efficiency for each filter media was observed to be low as 6%~17%, and it is determined that the reason is that CSOs are greatly influenced by hydraulic loads by filter media due to highly concentrated influent and the difference in water quality nature containing lots of dissolved organic substances.

In case of Perlite, at the time after 70 minutes, the collected particles inside the filter media were temporary discharged with crushed filter media and thus lowered the SS average treatment efficiency compared to other filter media.

Examining the treatment efficiency over time, except for early 10 minutes before the stabilization of filter layers, as times passes, the treatment efficiency tended to decrease gradually and from this it is determined that in case of CSOs the collection ability of particles by micro pores in filter media decreases faster than that of road runoff due to the blockage of filter media by hydraulic loads.

5.2.3 BOD/COD removal rate of media

The BOD and COD concentration and treatment efficiency of influent and treated water over time for each filter media are as shown in Figure 5.8 and Table 5.5.

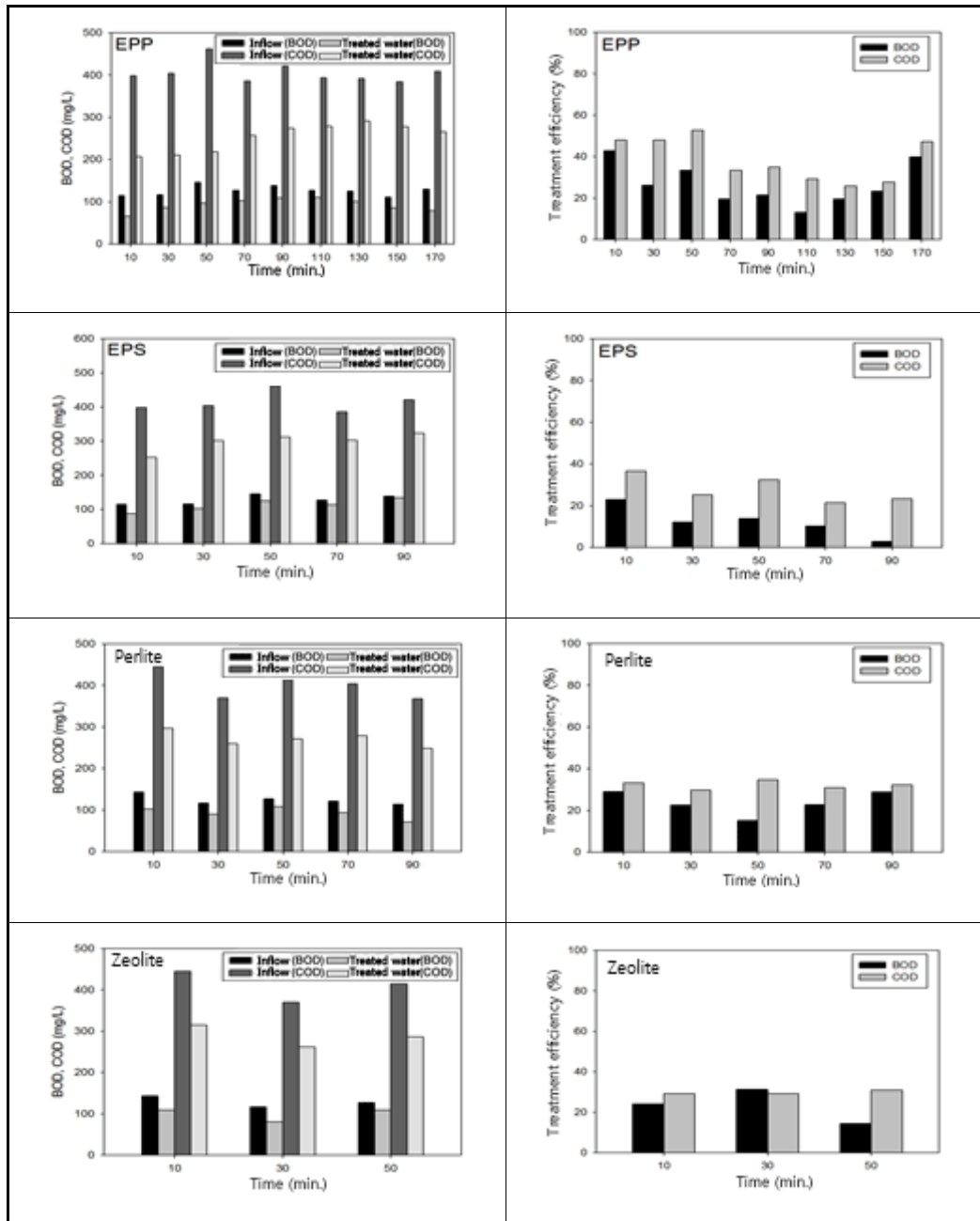


Figure 5.8 COD and BOD removal efficiency by each filter media

Table 5.5 COD and BOD removal efficiency by each filter media

Division		Number of samples	Concentration (mg/L, average \pm standard deviation)	
EPP	BOD	Influent	9	126.1 \pm 11.2
		Treated water	9	92.6 \pm 15.0
		Removal rate (%)		26.6 \pm 10.0
	COD	Influent	9	405.6 \pm 24.1
Treated water		9	247.8 \pm 34.5	
Removal rate (%)			38.5 \pm 10.4	
EPS	BOD	Influent	5	128.4 \pm 13.5
		Treated water	5	112.9 \pm 18.4
		Removal rate (%)		12.4 \pm 7.2
	COD	Influent	5	414.2 \pm 29.5
Treated water		5	298.4 \pm 27.3	
Removal rate (%)			27.8 \pm 6.5	
Perlite	BOD	Influent	5	124.6 \pm 11.8
		Treated water	5	95.0 \pm 10.4
		Removal rate (%)		23.7 \pm 5.7
	COD	Influent	5	400.4 \pm 32.4
Treated water		5	271.2 \pm 18.3	
Removal rate (%)			32.2 \pm 1.9	
Zeolite	BOD	Influent	3	129.1 \pm 13.6
		Treated water	3	99.4 \pm 16.6
		Removal rate (%)		23.2 \pm 8.5
	COD	Influent	3	410.0 \pm 37.7
Treated water		3	288.0 \pm 26.5	
Removal rate (%)			29.7 \pm 0.9	

For each filter media, the average BOD treatment efficiency for influents in range of average 124.6mg/L~129.1mg/L for EPP, EPS, Perlite and Zeolite were shown to be respectively 26.6%, 12.4%, 23.7% and 23,2 % and average COD treatment efficiency for influents in range of 400.4mg/L~414.2mg/L for EPP, EPS, Perlite and Zeolite were shown to be respectively 38.5%, 27.8%, 32.2% and 29.7%.

In case of BOD, the treatment efficiency was observed to be generally 12.4%~26.6% regardless of types of filter media and time elapse and it is determined that the removal effect by physical treatment by adhesion and collection through filter media was only minimal because pollutants loads were mostly existed in forms of dissolved organic substances on characteristics of water quality of CSOs.

The average treatment efficiency for each filter media for COD of CSOs were 29.7%~38.5 5% which was very low compared to average treatment efficiency for each filter media for COD of road runoff (63.4%~89.3%). It is determined that general treatment efficiency was appeared low because as the pollutants loads of dissolved substances are higher the pollutants removal efficiency by physical treatment using filtration operating at high linear speed is insignificant regardless of concentration difference considering the characteristics of water quality of influents.

5.2.4 TN/TP removal rate of media

The T-N, T-P average concentration and treatment efficiency of influent and treated water over time for each filter media are shown in Figure 5.9 and Table 5.6.

Table 5.6 T-N and T-P removal efficiency by each filter media.

Division			Number of samples	Concentration (mg/L, average \pm standard deviation)
EPP	T-N	Influent	9	26.4 \pm 6.0
		Treated water	9	24.7 \pm 5.6
		Removal rate (%)		6.3 \pm 2.3
	T-P	Influent	9	2.7 \pm 0.4
		Treated water	9	2.5 \pm 0.4
		Removal rate (%)		8.6 \pm 7.4
EPS	T-N	Influent	5	23.3 \pm 1.0
		Treated water	5	22.4 \pm 0.5
		Removal rate (%)		3.6 \pm 2.3
	T-P	Influent	5	2.6 \pm 0.2
		Treated water	5	2.3 \pm 0.1
		Removal rate (%)		9.4 \pm 2.8
Perlite	T-N	Influent	5	32.7 \pm 9.3
		Treated water	5	32.2 \pm 8.9
		Removal rate (%)		1.6 \pm 1.0
	T-P	Influent	5	3.5 \pm 0.9
		Treated water	5	3.4 \pm 0.9
		Removal rate (%)		3.8 \pm 4.8
Zeolite	T-N	Influent	3	37.9 \pm 8.4
		Treated water	3	33.5 \pm 8.1
		Removal rate (%)		11.9 \pm 2.8
	T-P	Influent	3	4.0 \pm 0.8
		Treated water	3	4.0 \pm 0.8
		Removal rate (%)		1.3 \pm 0.7

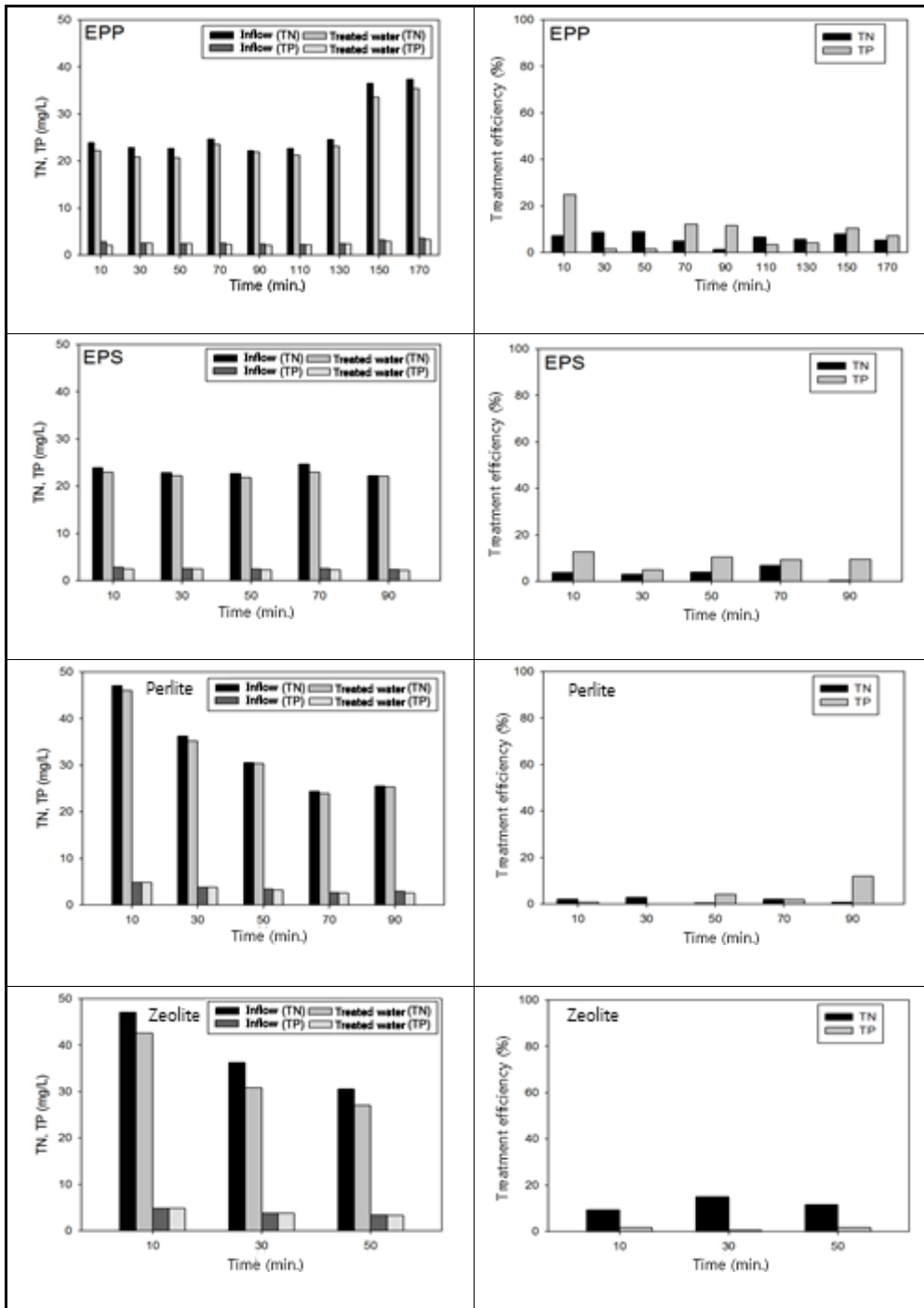


Figure 5.9 T-N and T-P removal efficiency by each filter media

As suggested in Table 5.6, the average T-N treatment efficiency for influents in range of average 23.3mg/L~37.9mg/L was 1.6%~11.9% and average T-P treatment efficiency for influents in range of average 2.6mg/L ~ 4.0mg/L were shown to be 1.3%~9.4%.

It was confirmed that the filtration treatment efficiency for T-N, T-P of CSOs were less than 10%, meaning that the treatment effect are very slight or almost none. This is because the pollutant loads of nutrients exist in form or dissolved substances in case of CSOs as the case of BOD.

When examining the domestic research cases about CSOs using filtration equipment, Lee et al. (2010) reported that after they treated CSOs using fibrous filter media and eddy current type separator, the treatment efficiency of T-N and T-P were observed to be 8~18% and that in cases the pollutants removal mechanism only consisted of physical process such as sedimentation and filtration, the dissolved organic substances were hard to remove.

Therefore, for T-N and T-P, only parts of N and P in particulate forms were removed through filtration treatment and removal of dissolved nutrients thorough filtration process are hard to expect.

CHAPTER 6 CONCLUSION

This study is about the filtration treatment of Combined Sewer Overflows and Road runoff according to the particle size distribution of pollutants. The particle size and generation characteristic of non-point pollutants were understood and head loss of filter media, treatment efficiency, characteristics before and after treatment according to particle size distribution were analyzed.

As target pollutants, road runoff and combined sewer overflows were used and the road runoff were those discharged from roads, bridges, and parking lots.

In order to conduct comparison analysis about treatment efficiency classified by filter media within filtration process according to particle size distribution of pollutants, the four filter media utilized typically, Expanded Polypropylene(EPP), Expanded Polystyrene(EPS), Perlite, and Zeolites were used and analyzed and for analysis, lab-scale upward device-type filtration reactor were constructed for experiment. Also, to deduce various design factors through brief numerical simulation were practiced side by side, and the following results were deduced from the study.

First, through lab-scale experiment, filtration process for road runoff sample were conducted and the result was shown that expanded polypropylene among four filter media showed the 89% of removal efficiency of non-point pollutants (SS, COD). Also, removal efficiency of heavy metals such as Zn and Cu by EPP was approximately 80% which was 7~40% higher removal efficiency compared to that of other filter media.

Second, the recurrence days of filter media among filtration process of non-point pollutants were studied and the result showed that Zeolite, Perlite, Expanded polystyrene, and Expanded polypropylene showed blockage of filter media after respectively 43, 60, 100, and 163 days which supported that EPP was the most favorable in aspects of recurrence days.

Third, in order to analyze the particle distribution characteristics of particles with size less than 100 μm which require filtration process classified by NPS generation source, the runoff of road, bridges, and parking lots were analyzed and the result was that micro-particle ration was highest for road runoff and the order was road > bridges > parking lots.

Fourth, numerical analysis about treatment of particulate pollutants with size greater than 100 μm for which gravitational sedimentation is possible showed that by controlling the inflow velocity the sedimentation efficiency could be improved and it is determined that maintenance will become facilitated through the installment of facilities such as baffles at grit chamber.

Fifth, the filtration duration time of combined sewer overflows through change in head loss of filtration treatment process were examined and the result showed that the filtration duration time was noticeable shorter than that of road runoff due to hydraulic loads and high concentration of buoyant substances.

Moreover, the removal efficiency of dissolved organic substances, total nitrogen (T-N), and total phosphorus (T-P) included in combined sewer overflows during filtration process was low. Thus it is appeared that high efficiency cannot be expected by non-point pollutants filtration process which has short retention time.

This study suggests the proper filter media when applying the filtration technology as treatment process for NPS pollution such as road runoff and CSOs, and the study result of removal characteristics of pollutants in sedimentation and filtration process can be applied to proper design and operation variable of filtration treatment devices for non-point pollutants.

For study from now on, the review of cleaning method of filter media and understanding of relation between filtration duration time and filter media are necessary for improvement of non-point pollutants inflow function for the improved the performance of filtration treatment equipment. It is expected that more efficient treatment process can be suggested by conducting various studies on forms of structure for filtration.

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