# 도로유출수 내에 존재하는 부유입자의 입도분포 및 침전속도에 대한 연구

## Size Distributions and Settling Velocities of Suspended Particles from Road Runoff

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## 1. Introduction

Nonpoint sources (NPSs), unlike pollution from industrial and sewage treatment plants, come from many diffuse sources, occurring at any time in any type of land use (EPA, 1994). Among NPSs, the paved areas such as roads or highways are stormwater intensive land uses since they are highly impervious, and have high pollutant mass emission from vehicular activities. A storm event usually brings the highly polluted runoff washed-off from a road. It is directly affecting to the water quality near the site (Kim et al., 2004). Road runoffs have various pollutants such as heavy metals, oil and grease and polycyclic aromatic hydrocarbons from sources such as fuels, brake pad wear and tire wear. These pollutants are strongly associated with road or highway surface particulates. Some recent field studies showed that fine to medium particles accounted for most of the total suspended solid (TSS) load and solid pollutant load in highway runoff. Removal of small particles is an important issue in the design of runoff treatment facilities and thus particle size distributions (PSDs) of particulates from road or highway runoff need to be evaluated.

The runoff behavior of particle-bound pollutants is thought to depend on particle size distribution. The objective of this study is to characterize PSD in road and highway runoff and settling characteristics of particles. Relationship between particle concentration and other parameters such as turbidity, event mean concentration (EMC) of pollutants was also evaluated. Particulate removal efficiency with different size fraction determined by the PSD can be estimated and used for a better sedimentation pond or basin design.

## 2. Materials and Methods

### 2.1 Site Description and Sampling

Urban road and highway was selected as the monitoring and sampling sites which are located in Yongin city, Gyunggi province of South Korea. The types of surfaces found in this area and the study sampling dates are summarized in Table 1. During storm event, flow rate was continuously monitored and grab samples with 5 L were collected. Generally, 5 samples were collected in the first hour with an

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interval of 5, 10, 15, 30, and 60min at the very beginning of runoff. After one hour, additional samples were continuously collected each hour until the end of the runoff according to the guideline from Korean Ministry of Environment. The samples were immediately transported to a laboratory for analysis.

Table 1. Site description summary

| Site Number | Type | Pavement | Area ($m^2$) | Imperviousness (%) |
|---|---|---|---|---|
| Site 1 | Road | Asphalt | 3,000 | 100 |
| Site 2 | Road | Asphalt | 7,700 | 100 |
| Site 3 | Highway | Asphalt | 1,000 | 100 |
| Site 4 | Highway | Asphalt | 9,522 | 100 |

### 2.2 Particle Size Analysis and EMC determination

All grab samples collected at the predetermined schedule were analyzed for PSD at the end of storm event in the laboratory. A Marvern Size Mastersizer-S (Model: 300RF) equipped with a light scattering sensor was used for the particle size range of 2~880 ㎛. The volume fraction of particles in specific size range was obtained from analyzer and then converted to number fraction. A large range of water quality parameters including turbidity, TSS, oxygen demand parameters, metals, and nutrients was also measured according to the Standard Methods. EMCs were calculated by integrating the product of runoff rate and concentration and dividing it by total runoff volume (Lee et al., 2004).

### 2.3 Particle Settling Velocity

Empirically derived settling velocity curves for the particulates from runoff are required to provide adequate information for the design of settling pond or basin. It is well known that UFT-type settling column developed by Umwelt- und Fluid- Technik produces results that are reproducible and comparable with other methods (Wong and Piedrahita, 2000). Therefore, in this study, UFT-type device and test method was used. For comparison, sediment samples were also collected from roadside gully pot located downstream of stromwater drainage.

## 3. Results and Discussion

### 3.1 Event Mean Concentration (EMC)

Table 2 summarizes the characteristics of the events and sites such as event date, antecedent dry days (ADD), total rainfall, storm duration, average rainfall intensity and runoff coefficient. EMC results for all parameters are described in Table 3.

Table 2. Summary of storm events

| Site | Event date | | Area ($m^2$) | ADD* (days) | Precipitation (mm) | Duration (hr) | Intensity (mm/hr) | Runoff Coefficient |
|---|---|---|---|---|---|---|---|---|
| Site 1 | E-1 | 06/21 | 3,000 | 6 | 28.5 | 13.7 | 2.19 | 0.71 |
| | E-2 | 07/29 | 3,000 | 2 | 3.1 | 1.1 | 3.00 | 0.76 |
| Site 2 | E-1 | 06/21 | 7,700 | 6 | 28.5 | 13.7 | 2.19 | 0.38 |
| | E-2 | 07/29 | 7,700 | 2 | 3.1 | 1.1 | 3.00 | 1.00 |
| Site 3 | E-1 | 09/14 | 1,000 | 4 | 76.3 | 11 | 6.91 | 0.49 |
| | E-2 | 10/19 | 1,000 | 15 | 6.5 | 2.5 | 3.25 | 0.66 |
| Site 4 | E-1 | 09/14 | 9522 | 4 | 76.3 | 11 | 6.91 | 1.00 |
| | E-2 | 10/19 | 9522 | 15 | 6.5 | 2.5 | 2.60 | 0.81 |

*antecedent dry days

Table 3. EMC of various pollutants from road and highway

| Site | Event | TSS (mg/L) | BOD (mg/L) | $COD_{Mn}$ (mg/L) | DOC (mg/L) | T-N (mg/L) | T-P (mg/L) |
|---|---|---|---|---|---|---|---|
| Site 1 | E-1 | 60.2 | 13.5 | 23.4 | 15.2 | 8.3 | 0.04 |
| | E-2 | 64.8 | 26.9 | 52.0 | 28.7 | 21.9 | 0.19 |
| Site 2 | E-1 | 58.0 | 12.2 | 27.2 | 12.5 | 12.1 | 0.03 |
| | E-2 | 57.1 | 15.6 | 14.5 | 12.2 | 23.3 | 0.20 |
| Site 3 | E-1 | 68.2 | 4.25 | 58.07* | 5.2 | 3.6 | 0.02 |
| | E-2 | 142.0 | 16.19 | 130.8* | 20.5 | 7.3 | 0.05 |
| Site 4 | E-1 | 61.7 | 4.11 | 49.8* | 3.2 | 1.8 | 0.02 |
| | E-2 | 168.5 | 16.84 | 71.3* | 19.4 | 8.9 | 0.06 |

* $COD_{Cr}$

Table 4. Number and mass fraction of particles with each size range

| Size range (㎛) | #/mL | Number Fraction | Accumulated Number Fraction | Mass | Mass Fraction | Accumulated Mass Fraction |
|---|---|---|---|---|---|---|
| 2-5 | 5.63E+09 | 0.8048106 | 0.8051 | 0.394 | 0.119 | 0.119 |
| 5-7 | 8.24E+08 | 0.1177163 | 0.9225 | 0.236 | 0.072 | 0.191 |
| 7-10 | 3.30E+08 | 0.0471313 | 0.9696 | 0.233 | 0.071 | 0.262 |
| 10-20 | 1.93E+08 | 0.0275850 | 0.9972 | 0.545 | 0.165 | 0.427 |
| 20-30 | 1.21E+07 | 0.0017326 | 0.9989 | 0.197 | 0.060 | 0.487 |
| 30-50 | 6.14E+06 | 0.0008765 | 0.9998 | 0.340 | 0.103 | 0.590 |
| 50-100 | 8.26E+05 | 0.0001180 | 0.9999 | 0.287 | 0.087 | 0.677 |
| 100-200 | 1.85E+05 | 0.0000264 | 0.99999 | 0.514 | 0.156 | 0.833 |
| 200-400 | 2.25E+04 | 0.0000032 | 0.999999 | 0.449 | 0.136 | 0.970 |
| 400-880 | 9.40E+02 | 0.0000001 | 1.0 | 0.100 | 0.030 | 1.000 |

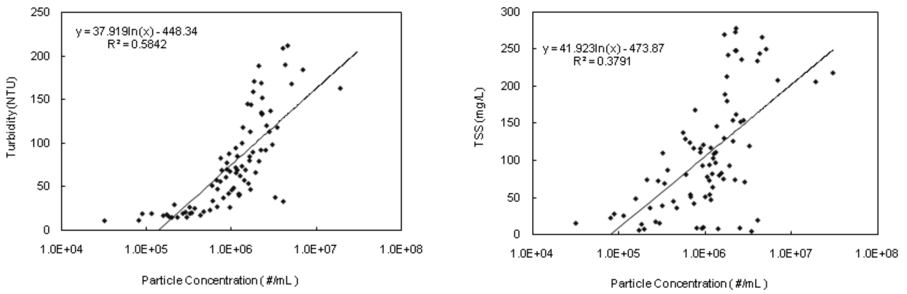


Fig. 1. Relationship between particle concentration and turbidity or TSS.

### 3.2 Particle Size Distribution (PSD)

A total of 89 samples from four sites were analyzed for PSD. Total number of particles in the range of 2~880 ㎛ was described in Table 4. The washed-off particulates generally decreased with time as rainfall progresses. Sharp decrease in the particle concentration was observed at the very beginning of the storm, because storm on highway has fast and high runoff characteristics. This phenomenon was explained by the first flush effect and can therefore be used to determine the treatment criteria. The particle PEMC (partial event mean concentration) reached a maximum within 10 minute after the beginning of runoff and then decreased to the EMC of particles. The particle PEMC was not affected by variations in runoff flow rate. Among many pollutants, TSS and turbidity that has close relationship with particle concentration showed good correlation with PEMC, as shown in Fig. 1. These results imply that control of the initial fraction of runoff could contribute to the removal of large fraction of pollutant mass and thus must be taken into account for the design of BMP.

### 3.3 Particle Settling Velocity

The averaged particle settling velocity obtained from all settling tests was shown in Fig. 2. The mass fraction of particles slowly increased as the settling velocity increased. Then, sharp increase in mass fraction was observed when settling velocity reached a certain value.

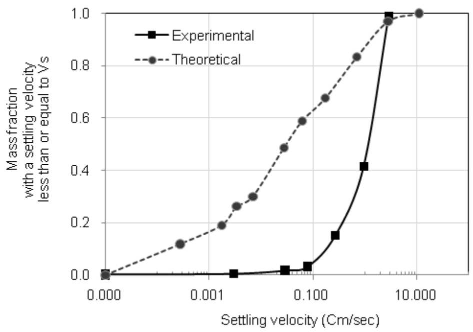


Fig. 2. Settling velocity curves of runoff particles with the column tests and theoretical calculation.

## 4. Conclusions

It is well known that many pollutants including heavy metals, polynuclear aromatic hydrocarbons and fuel additives are strongly bound to fine particles that have the large surface area-to-volume ratios. Therefore, effective removal of particles from road or highway runoff can contribute to the additional removal of various pollutants associated with particles. In this study, a total of 89 grab samples during two rainfall events at four sites in Gyunggio-Do were collected and particle size distributions (PSD) in the size range of 2～880 ㎛ were determined. It was found that particles with less than 5 ㎛ size accounted more than 80% of number fraction while their mass fraction was about 12%. Particles larger than 50 ㎛ contributed more than 40% of mass fraction. Partial event mean concentration (PEMC) of particle showed inverse relationship with accumulated rainfall and sharply decreased at the early stage of rainfall, implying the first flush phenomena in particle runoff. Other pollution parameters such as turbidity, TSS, BOD, TN, and TP also have similar temporal runoff trend with the PEMC. Settling velocities of runoff samples were determined by column tests and their values were compared with theoretical velocities. Slightly greater settling velocities were observed for experimental values. Based on the particle settling velocity of each size range, removal efficiency by sedimentation was evaluated.

## References


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