The PPL filtration treatment for highway runoff

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Abstract The purpose of this research is to design a device which can treat highway runoff, especially runoff during initial rainfall with high pollution intensity, by connecting it with the draining grid sink of a drainage ditch on a highway, through which runoff flows. Porous polypropylene (PPL) particles were used as a treatment agent. The device treated highway runoff during initial rainfall by filtration and adsorption. It had a capacity to treat highway runoff in an area of 7.0 m × 20.0 m when rainfall intensity was up to10 mm/hr. Two cases of rainfall intensity were set for the experiment: 5 and 10 mm/hr. The relationships between the efficiency of SS and COD removals and the rainfall intensity were investigated. Using artificial highway runoff with constant flow and SS concentration, results of 70% or more of SS removal with 5 mm/hr and 50% or more with 10 mm/hr were obtained. COD removal efficiency was about 90% of SS removal efficiency. This device was effective to remove non-point source pollutants in runoff on highways.

Keywords COD; highway runoff; initial rainfall; polypropylene (PPL); rainfall intensity; SS

Introduction

The efforts of improving water quality have been introduced in the area of so called point sources namely sewage works and industrial wastewaters by specifying the plant effluent criteria and environment criteria. However, water quality has not been improved in closed waters such as lakes, marshes, or gulfs (The Environment Agency, 2000). This is because pollution loads from non-point sources are larger than those that many scientists estimated (Wada, 1990). Among them, the pollution load from highways is increasing along with increasing urbanization. Suspended particulate matter in air, dust fall, automobile discharge gas, suspended particulate matters from industrial plants and refuse incineration facilities, all accumulate on highways, and they flow out to public water areas when it rains. Yamane *et al*. (1993) reported that most PAHs carried to Nogawa River in Tokyo on rainy days accumulate at the bottom of the river while adsorbed to SS in water in side ditches of highways. Asada and Ohgaki (1996) pointed out that cancer-potential benzo(a)pyrene is included in runoff in side ditches during initial rainfall while adsorbed to SS. In addition, Ono *et al*. (1997) pointed out those ingredients of runoff on highways during rainfall, especially those molten from solid matter contained nitro-aromatic carbons that had potential for genetic toxicity induction. Although the pollution of runoff on highways has been reported and clarified, almost no measures have been taken yet.

In this research, a device to treat highway runoff, especially during initial rainfall when pollution intensity is high, was designed by connecting it with the draining grid sink part on highways through which runoff flows, and the effects were investigated in experiments. Difficulties in operation of the device as a highway runoff measure were clarified.

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Design of the treatment method

Designed rainfall intensity

According to the data of 80 major weather observation stations in Japan for 30 years from 1961 to 1990, the average number of days in a year with daily rainfall of 1 mm or more is 124.7 days (National Astronomical Observatory, 2000). When it is converted to a percentage in a year (365 days), it is 34.2%. The average number of days with daily rainfall of 10 mm or more is 49.2 days/year, and it corresponds to 13.5% of the days in a year. Approximately 40% of the days with daily rainfall of 1 mm or more have daily rainfall of 10 mm or more. Approximately 60% have daily rainfall of 1 mm or more and less than 10 mm. The data was taken only when the daily rainfall was 1 mm or more. Therefore, if the daily rainfall of less than 1 mm is included, it can be said that the most rainfall is less than 10 mm/day.

The above results were converted to rainfall per hour. This is because the initial rainfall with high pollution intensity of highway storm water runoff is limited to 2 or 3 hours from the start of rainfall. The pattern of rainfall varies a lot. For example, when the daily rainfall is 10 mm, it means that rainfall with rainfall intensity of 1 mm/hr continues for 10 hours, or rainfall with rainfall intensity of 5 mm/hr continues for 2 hours. However, excluding the special cases such as typhoons, the amount of rainfall per hour during initial rainfall or at the beginning of rainfall is regarded to be small.

According to the above analysis, the designed capacity of the treatment device was specified to meet the condition of rainfall of 10 mm for 1 hour.

Designed treatment amount

A draining grid sink was installed at certain intervals, about 20 m in general, on both sides of highways for drainage in Japan (*J. Japan Soc. of Road*, 1987). Because the treatment device is installed on site to take measures for pollutants in runoff on highways, it must be compact and be connected with a draining grid sink, or alternative equipment. The runoff amount passing through the draining grid sink, in other words, the water collection area is set at a designed value.

The structure of the highway depends on the highway type, traffic conditions, and regions. The maximum lane width is 3.5 m except in a certain case. The number of lanes depends on traffic conditions. Here, four lanes (two lanes on each side) were in use. Therefore, the area from which the treatment device collects runoff on the highways is: $A = 20\ \text{m} \times 3.5\ \text{m} \times 2\ \text{lanes} = 140.0\ \text{m}^2$.

The designed rainfall intensity is 10 mm/hr. The designed treatment amount according to highway engineering and drainage guidelines is as follows:

$$Q = C \times 10\ \text{mm/hr} \times 140.0\ \text{m}^2/\gamma/3{,}600 = 0.389\ \text{L/sec}.$$

where:
Q: Designed treatment amount
C: Coefficient of runoff (= 1.0)
γ: Drop coefficient to drainage equipment (= 1.0).

Structure of the treatment device

After the designed initial rainfall was collected, highway runoff was discharged into the drainage equipment such as the side ditch in Figure 1. The structure of the treatment device is shown in Figure 2. The inlet of the treatment device is small enough only to receive the amount equal to or less than the designed treatment amount. The runoff exceeding the designed amount is not treated but directly discharged to the discharging equipment such as the side ditches as overflow. The highway runoff that is collected in the device

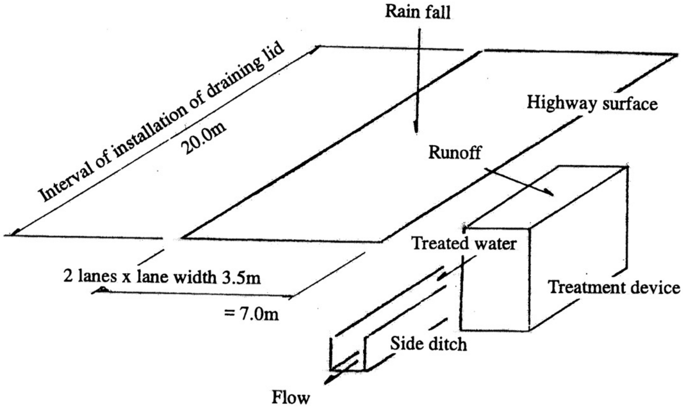


Figure 1 Highway runoff flow

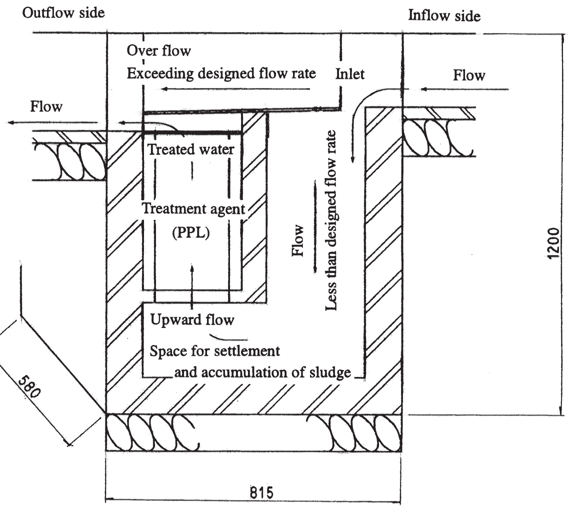


Figure 2 Structure of treatment device

flows down under the device. Large particles of dust and coarse particulates settle down and separate. The runoff passes upwards through the filtration section of the treatment agent, which is porous polypropylene (PPL) particles, while polluting materials are removed by filtration and adsorption. The treated runoff is discharged to runoff equipment such as a side ditch. Polluting materials separated from runoff by settlement, filtration, and adsorption accumulate in the deposition space installed at the bottom of the device until the sludge collection by maintenance services are carried out.

Materials and methods

The bench scale experiment set up the filtration section, which was designed in a way in which the dimensions were a vinyl chloride cylinder of 6 cm diameter and 30 cm high, and polyethylene mesh of a hole diameter of 250 μm as a divider. Porous polypropylene particles of 1–3 mm diameter were filled as a treatment agent. The artificial highway runoff was made using road dust collected by highway cleaning services. Wood pieces, metal dust, large or medium-sized rocks and stones were removed from the road dust. Four kg of the dust was weighed and mixed with 80 litres of tap water to generate artificial runoff on highways. Two types of flow velocity, 440 mL/min (equivalent to rainfall intensity 5 mm/hr, flow velocity 9 m/h) and 880 mL/min (equivalent to rainfall intensity 10 mm/hr, flow velocity 19 m/h) were used in the experiment so that the flow velocity in the filtration section could be the same as in actual cases. The experiment was executed three or four times for each case without replacing the treatment agent. The raw water samples before passing through the device and the treated water were taken, and SS and COD were analyzed. SS was analyzed using a glass fiber filter of hole diameter 1.0 μm. COD was analyzed according to Standard Methods of $K_2Cr_2O_7$ COD. In the experiment using the full-size model indicated in Figure 2, the artificial highway runoff (dust 50 kg mixed with water from Lake Biwa 1,000 L) was used, and two cases of the designed maximum treatment amount 0.389 L/sec (corresponding to rainfall intensity 10 mm/hr) and 0.194 L/sec (corresponding to rainfall intensity 5 mm/hr) were investigated. The bench scale and full-size model experiments were executed three times for each case without replacing the treatment agent. After that, the treatment agent filtration section was cleaned in countercurrent water, and the experiment was executed once again. Sample waters were taken at the inlet and outlet every 30 minutes from the start in total four times in each experiment, and the treatment efficiency was measured by analyzing SS.

Results and discussion

The results of the bench scale experiment are shown in Figures 3, 4, and 5. Figure 3 shows the analysis results of SS. Suspended substance concentration of raw water depends on the used dust collected by highway cleaning services. But the graph shows that the concentration of the treated water is kept almost constant. When the removal ratios at rainfall intensity 5 mm/hr and 10 mm/hr were compared, the difference was about 10%. The reason could be explained that some amount of SS was not held nor adsorbed in the filtration section, but passed through because the treated water amount (i.e. flow velocity) was large. According to the results of the removal ratio, it is shown that the removal ratio increases when the experiments are repeated regardless of the rainfall intensity. The reason might be that the SS is held and adsorbed by the treatment agent, the held particles were enlarged, and the gaps among the filtration agents were decreased.

In Figure 4, the analysis results of COD are shown. Different from the case of SS, the COD concentration of treated water is influenced by the change in raw water concentration.

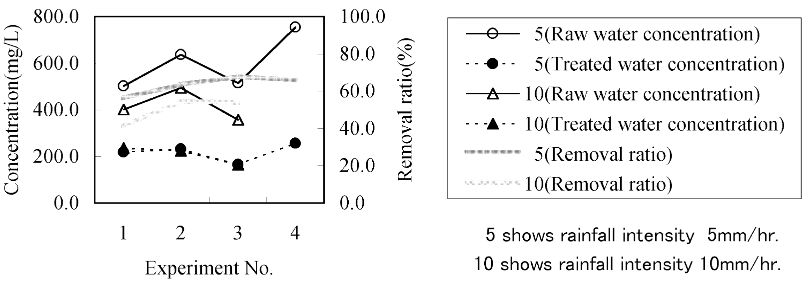


Figure 3 SS analysis results

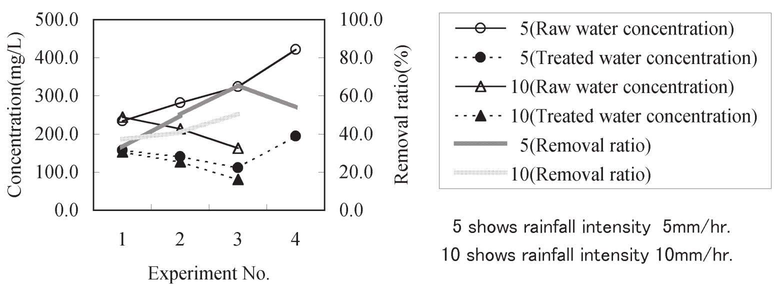


Figure 4 COD analysis results

This could be explained by some portions of COD adhering to SS, but other portions not adhering to it. According to the results of the removal ratio, it was found that, in the same way as SS, the removal ratio was influenced by the rainfall intensity (i.e. flow velocity) and increased when the treatment was repeated.

In Figure 5, the analysis results of the relationship between SS removal ratio and COD removal ratio are shown. As shown in Figures 3 and 4, the removal ratio increased in inverse proportion to rainfall intensity, and the removal ratio increased in proportion to the repeated number of treatments. The COD removal ratio is nearly 90% of SS removal ratio, and in proportion to SS removal ratio.

The results in the experiment using a full-size model are shown in Figures 6 and 7. Figure 6 shows the results in the experiment (SS analysis results) when the rainfall intensity is 5 mm/hr. The treated water SS concentration is kept below 40 mg/L, and 70% or more of SS removal ratio was obtained. Compared to the large fluctuation of SS with the artificial highway runoff, it is shown that the treated water SS concentration is almost constant. The treated water concentration and SS removal ratio are improved when the experiment is repeated. Experiment No. 4 is the result after the treatment agent is cleaned by countercurrent water. It is similar to the result of experiment No. 1 when the treatment agent is cleaned by countercurrent water after it is used for a certain period. The filtration condition can be recovered to the original level by simple washing. In other words, if the filtration section is clogged, the previous function can be recovered by cleaning with countercurrent water.

Figure 7 shows the result of the experiment (i.e. SS analysis result) with the rainfall intensity 10 mm/hr. When it is compared with the experimental result of rainfall intensity 5 mm/hr, the tendency is the same, but the treatment efficiency is not good. The treated water concentration is approximately 60 mg/L or less and SS removal ratio is about 50% or more, which are about 70% of the treatment efficiency with rainfall intensity 5 mm/hr. In

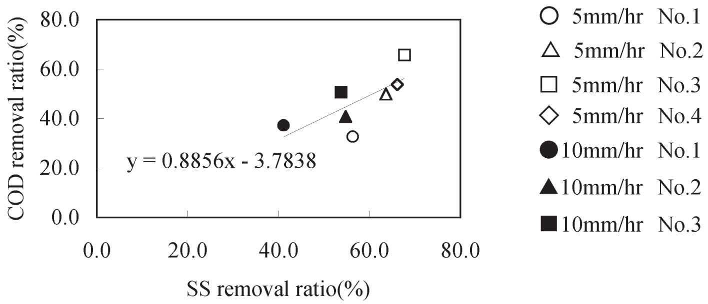
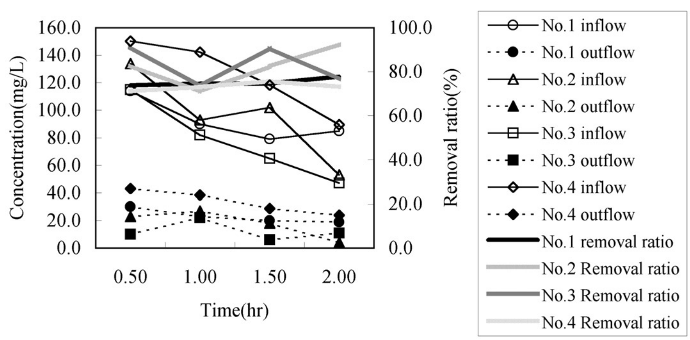


Figure 5 Correlation between SS and COD removal ratios



No.4 shows data after cleaning of treatment agent after countercurrent

Figure 6 Rainfall intensity 5 mm/hr

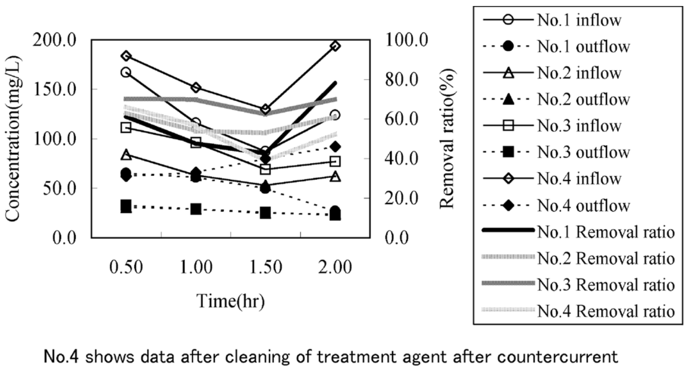


Figure 7 Rainfall intensity 10 mm/hr

addition, when comparing experiments No. 1 and No. 4, it is seen that SS concentration of treated outflow is affected by the change in inflow runoff concentration. The reason might be that, because the inflow rate is larger than the case of rainfall intensity 5 mm/hr and the flow velocity is large, the treatment agent can not be completely held and adsorb SS, resulting in unstable treatment efficiency. In fact, the outflow concentration is almost constant in experiments No. 2 and No. 3.

Conclusions

According to the bench-scale and full-size model experiments, the following conclusions could be drawn.

1. The treatment efficiency of SS and COD was improved in inverse proportion to rainfall intensity (i.e. treated water amount or flow velocity).
2. The treatment efficiency of SS and COD was improved on repeat of the experiment.
3. SS concentration of the treated water was almost constant without any influence from change in inflow SS concentration.
4. It was difficult to remove dissolving COD using the treatment agent of polypropylene. COD concentration of treated water tended to be affected by the change in dissolved COD concentration of inflow water.
5. COD removal ratio was nearly 90% of SS removal ratio, and improved in proportion to SS removal ratio.
6. Concerning the treatment efficiency of the device, SS removal ratio was 70% or more when rainfall intensity was 5 mm/hr, and SS removal ratio was 50% or more when rainfall intensity was 10 mm/hr.
7. If the treatment agent was clogged, the situation could be improved by cleaning it with countercurrent washing water, and the treatment efficiency could be recovered.

According to the above results, the treatment device designed in this research can contribute to treatment and improvement of SS and COD in highway runoff during initial rainfall. In the future, it will be necessary to confirm the treatment efficiency on actual highways, and also improve the treatment efficiency of dissolved polluting materials such as polynuclear aromatic carbons, nitrogen, phosphorus, heavy metals and other hazardous substances.

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