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Long-Term Simulation of a System for Catchment, Pre-treatment and Treatment (SCPT) of Polluted Runoff Water.

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Abstract

The effects of pollutants in runoff on the environment have forced the development of several water treatment systems with the aim of reducing this kind of pollution before its final discharge. Nevertheless, many of these systems do not behave satisfactorily and, additionally, there is a low level of confidence in the treatment performance. This paper introduces the results of research on the long-term performance of a laboratory prototype of a System for Catchment, Pre-treatment and Treatment (SCPT) designed to deal with the polluted runoff water. Solid and oil treatment efficiency were the focus of the study. After fourteen consecutive simulated rain events, the treatment efficiency levels achieved by the prototype are higher than 80% of solids and 90% of oils.

Subject headings: Nonpoint pollution; Runoff; Best Management Practice; Water quality.

Introduction

Stormwater polluted by pollutants from impervious surfaces has become a serious problem that can negatively affect the environment and people (Boving and Neary 2006a). For this reason, several methods and techniques to reduce the stormwater runoff pollutant load have been developed (CALTRANS 2007).

Research on the performance of these methods and techniques concludes that the performance efficiency of the pollutant load treatment varies depending on the pollutant type. In some cases, the outflow pollutant load was shown to be even higher than the inflow (Boving and Neary 2006a; Lundberg et al. 1999; Hossain et al. 2005; Boving and Neary 2006b). In the same way, a specific study on the efficiency of devices designed for runoff treatment (Best Management Practices, BMPs), carried out by (CALTRANS 2007) concludes that most of the devices do not offer satisfactory performance and provide low confidence about the levels of quality treatment. In the case of Oil/Grit separators, the treatment efficiency could be negatively affected by the re-suspension of the retained pollutants. The re-suspension of retained pollutants due to water turbulence inside the devices can cause a higher concentration in the outflow (Begum et al. 2008).

This paper presents the research developed on a laboratory prototype of a System of Catchment, Pre-treatment and Treatment (SCPT) of the polluted runoff water. The aim is to assess the long-term treatment performance of solids and oils, under controlled conditions. The SCPT could be applied as a precast concrete element in a real car park just as substitution of the conventional manholes.

Methodology.

The research was carried out with a 1:1 scale laboratory prototype of the System of Catchment, Pre-treatment and Treatment (SCPT) of stormwater runoff developed by the University of Cantabria. This prototype of the SCPT is described in Castro-Fresno et al. (2009). In this paper, a brief summary of this description is presented.

The structure of the SCPT is made of methacrylate. It is 0.80 m wide, 1.30 m long and 1.00 m high. The inner space is split into two sections by a vertical screen, which allows the water to flow under it. The first section works as a hydraulic plug that retains the oils. The second section includes a decantation volume and a filter system.

The decantation volume is 0.80 m wide, 1.10 m long and 0.45 m high. The filter system is placed over the decantation volume with the same width and length. In this research, the filter system is made of two geotextile layers (Polyfelt TS20®), two PVC meshes and a metallic frame, giving strength to the filter system. In addition, a weight of 10 kg has been added to fix the filter in its position during the test.

The additional elements used in the test are an adduction ramp and a water recirculation system. The adduction ramp helps simulate the runoff and pollutant drag and its function is to discharge the runoff in the frontal part of the SCPT. Its surface is made of slurry like asphaltic impervious surface to simulate a car park (or a parking lot). The water recirculation system has an 1.0 m^3 capacity accumulation tank, two hydraulic pumps and a flow meter. The first pump sends the water from the accumulation tank to the head of the adduction ramp by a pipe line. When the water is discharged from the SCPT, it is pumped into the accumulation tank by the second pump. In this second pipe line, an additional filter was placed to remove the pollutants that still remain in the water. Figure 1 shows the SCPT components and the complementary elements.

The pollutants added to the water during the tests were solids and oils. The solids were particles fitted to the size distribution of a sample from urban streets in Cantabria, north of Spain (Zafra Mejía and Temprano González 2005). The oil pollution was simulated by controlled spills of waste engine oil over the adduction ramp, as done in previous research on pervious pavements (Rodríguez Bayón 2008; Pratt et al. 1999; Newman et al. 2002).

The aim of the long-term test is to assess the SCPT performance after repetitive runoff events, without removing the pollutants accumulated inside it. The possible re-suspension of pollutants is a problem with oil/grit separators (Begum et al. 2008). The SCPT avoids this problem even with a low water level inside, which is the worst case condition to test for the re-suspension of solids. So, in the long-term test, at the end of every single runoff event a thin layer of water was left to simulate the aforementioned condition.

The inflow is 1.7 L/s for 20 minutes and it corresponds to the stormwater runoff generated in an impervious car park with a driveway and eight car parking bays for a typical 2 year rain event in Santander (a city in the north of Spain).

The pollutant concentration of the inflow is assessed by the event mean concentration (EMC) (Taebi and Droste 2004). Two levels of EMC were used in this research: "High Load" and "Medium Load". High Load is 200 mg/L of solids and 20 mg/L of oil, and Medium Load had 100 mg/L of solids and 10 mg/L of oil, half of the High Load.

The test procedure was performed as follows. Firstly, the pollutants were poured onto the adduction ramp (solids and oil). The second step was the stormwater runoff simulation for 20 minutes, taking samples every 4 minutes. Afterwards, there was a decantation period of 10 minutes to let the solids settle inside the SCPT. Finally, the SCPT was emptied, leaving a water layer of 0.08 m to cover the sediments.

Supplementary water samples were taken in the hydraulic plug zone and in the zone over the filter system, after the 20 minutes of the runoff simulation.

The total number of consecutive simulated events was 14. This was shown to be the filter limit for the methacrylate SCPT. More than 14 consecutive simulated events caused filter system displacement (Figure 2).

After filter system displacement, the geotextile was replaced by a clean one without removing the pollutants inside the SCPT. The aim of doing this was to assess the changes on the SCPT treatment efficiency when the geotextile was replaced and when re-suspension was still possible.

Results and Discussion.

<u>*Solids*</u>

There is a statistically significant difference (p-value< 0.05) between the two pollutant load conditions (high load and medium load), applying the T-test (Milton and Arnold 2003) to the solid treatment efficiency data. Consequently the data treatment is carried out separately for each of the levels of polluting load.

The curve fitting for the solid treatment efficiency data (Ef_S) indicates that the quadratic curve provides the best fit for both pollutant load cases. The regression coefficient R^2 is 0.999 for the high load case (the standard error is 0.069) and 0.996 for the medium load case (the standard error is 0.107). The treatment efficiency behaviour in each case is described by Equations 1 and 2, and displayed in Figure 3.

$$Ef_{SH} = 86.956 + 1.960n - 0.112n^2$$ **Equation 1**

$$Ef_{SM} = 97.205 + 0.412n - 0.029n^2$$ **Equation 2**

Figure 3 shows that the solid treatment efficiency for medium load (Ef_{SM}) is greater than high load (Ef_{SH}), for all the repetitive events. The Ef_{SM} is consistently greater that 97%, which shows that the repetitive events have a reduced effect on the SCPT solid treatment efficiency.

With both pollutant loads, the treatment efficiency increases for about 7 consecutive events and reduces after that. This trend is more drastic with the high pollutant load condition. The increase in the efficiency could be due to the pore obstruction of the geotextile in the filter system. This obstruction promotes the solid particle retention when the effective pore size of the geotextile is reduced. Nevertheless, after several consecutive events the pore occlusion generates an increase in the pressure exerted by the water on the geotextile, causing the retained particles to break through and, therefore, the effective pore size increases diminishing the treatment efficiency.

After the geotextile of the filter system was replaced, the solid treatment efficiency of the SCPT returned to the highest values obtained before. Nevertheless, the number of consecutive events after which the displacement of the filter system took place was 6 not 14. This could be due to re-suspension since the first event.

Oils

When applying the T-test (Milton and Arnold 2003) to the oil treatment efficiency of the SCPT data (Ef_A), a significant statistical difference was not observed between the response of the high and medium load conditions. As for a curve fitting analysis, it was determined that it was not possible to fit a curve with an acceptable level of confidence (95%) and a high regression coefficient for all the data.

Complementarily, the oil treatment efficiency was analyzed comparing the oil concentration remaining in the first section of the SCPT (hydraulic plug) and in the second section (over the filter system), represented by the equation 3.

$$Ef_{A2} = 100 * \left[1 - \frac{CA_{ZTH}}{CA_{ZSF}} \right] \qquad \textbf{Equation 3}$$

The homogeneity of the values of Ef_{A2} is in agreement with what was previously said in relation to the lack of statistically significant differences between Ef_A with high and medium load conditions. The curvilinear analysis of Ef_{A2} data reveals that the quadratic curve has the best fit (Equation 4). Figure 4 shows the measured values and the fitted curve.

$$EfA_{ENDE} = 99.218 - 0.072n + 0.006n^2 \qquad \textbf{Equation 4}$$

Once the geotextile in the filter system is replaced, the treatment efficiency returns to the maximum values near 98%. An explanation of the high SCPT oil treatment efficiency and its smooth variability can be deduced from the fact that the inner walls of the structure retain an important amount of oils. Indeed, even while the retained oil slips down the walls and the water level within the SCPT is low, the inflow water circulation path in the SCPT leads to the oils being retained by the walls of SCPT structure, as it is observed in Figure 5.

This characteristic will not necessarily continue if another material is used to manufacture the structure of the SCPT. The variations due to the change of SCPT materials cannot be measured *a priori*, since the adhesion of the oil will be conditioned by the oleophylic characteristics and the porosity of the new material.

Conclusions.

The main conclusions of this study are:

- The amount of polluting load influences the SCPT solid treatment efficiency in the long term. The change in solid treatment efficiency is smaller with higher loads in the influent as studied.

- The solid treatment efficiency in the long term for a specific polluting load was shown to increase during the first events, but then decreased constantly.

- The oil treatment efficiency is constant throughout the period studied. This may be because the oil adheres to the inner faces of the methacrylate structure of the SCPT.

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Notation

Ef_{SH}	:	Solid treatment efficiency under high load conditions (%).
Ef_{SM}	:	Solid treatment efficiency under medium load conditions (%)
n	:	Repetitive event number.
Ef_{A2}	:	Oil treatment efficiency comparing the concentrations between the zone of the hydraulic plug and the zone over the SCPT filter system (%).
CAZ_{TH}	:	Oil treatment concentration in the zone of the hydraulic plug (mg/L).
CAZ_{SF}	:	Oil treatment concentrations in the zone over the SCPT filter system (mg/L).
EfA_{ENDE}	:	Oil treatment efficiency measured between the zone of the hydraulic plug and the zone over the SCPT filter system (%).

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Figure Caption List:

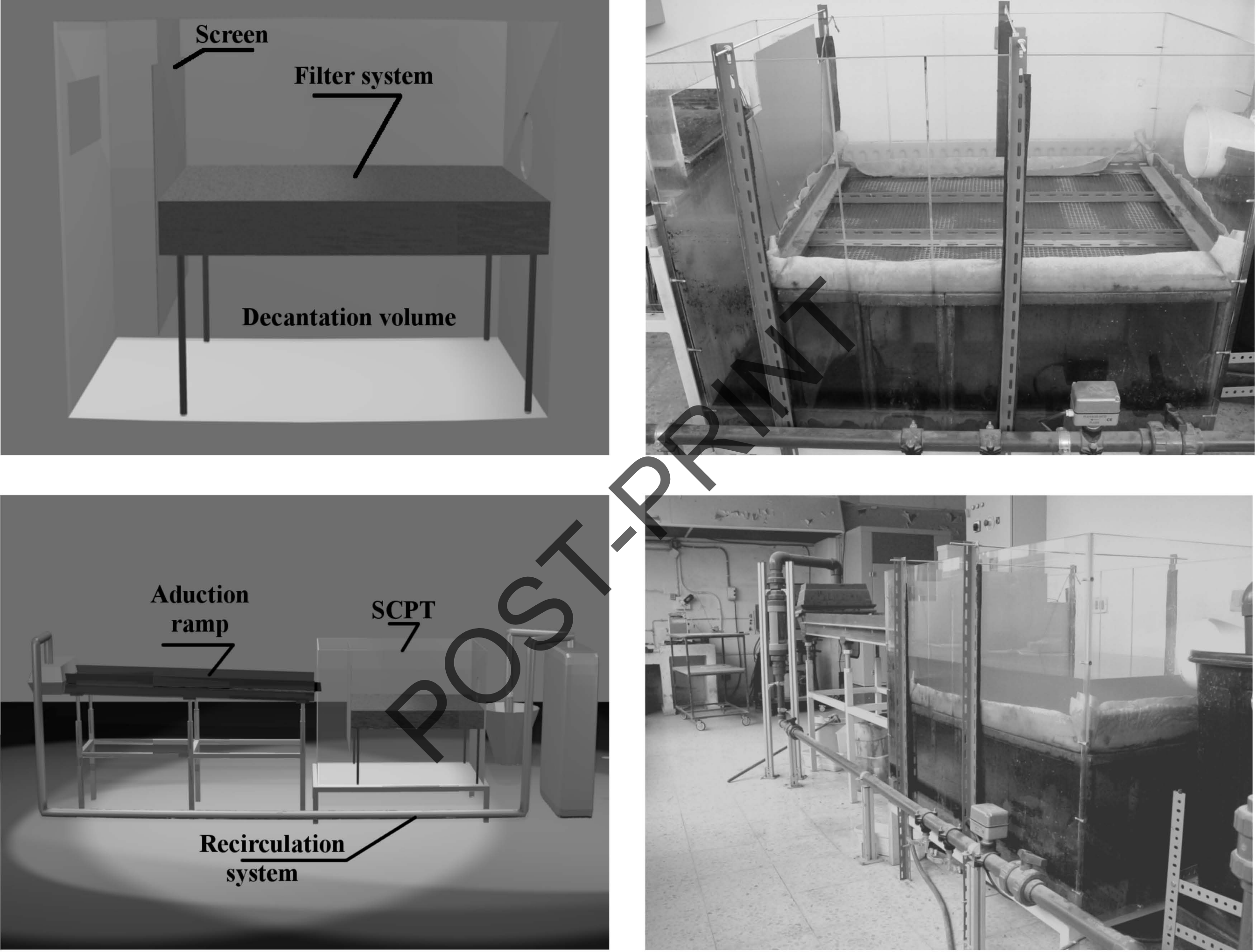
Figure 1. Components and additional elements of the System for Catchment, Pre-treatment and Treatment (SCPT).

Figure 2. Filter system displacement of the SCPT after 14 rain events.

Figure 3. Solid treatment efficiency of the SCPT in conditions of high and medium pollutant load (Ef_{SH} and Ef_{SM}).

Figure 4. Oil treatment efficiency of the SCPT in conditions of high and medium pollutant load (EfA_{ENDE}).

Figure 5. Oil adhesion to the SCPT inner walls.



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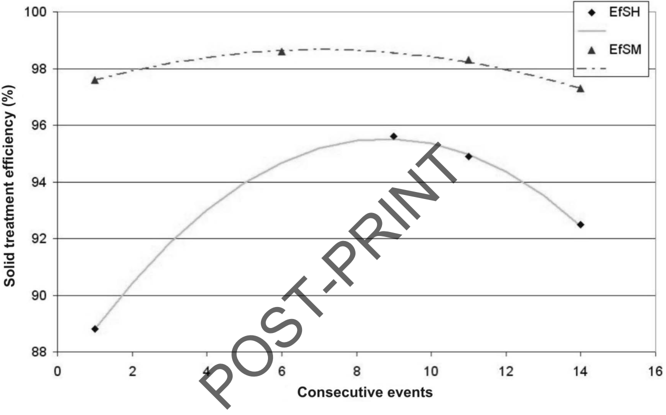

Figure 3. Solid treatment efficiency of the SCPT in conditions of high and medium pollutant load (EfSH and EfSM).

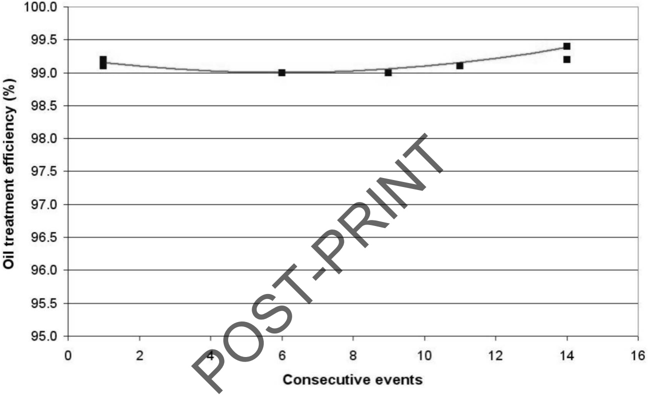

Figure 4. Oil treatment efficiency of the SCPT in conditions of high and medium pollutant load (EfAENDE).

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