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### Laboratory Analysis of the System for Catchment, Pre-treatment and Treatment (SCPT) of Runoff from Impervious Pavements.

A. H. Fernández-Barrera\*, J. Rodríguez-Hernandez\*, D. Castro-Fresno\*, A. Vega-Zamanillo\*

\*D. Transportes y T. de P. y P. ETSICCP de la Universidad de Cantabria, Av. de los Castros s/n, 39005 Santander, España.

(E-mail: [andreshumberto.fernandez@unican.es](mailto:andreshumberto.fernandez@unican.es); [jorge.rodriguez@unican.es](mailto:jorge.rodriguez@unican.es); [castrod@unican.es](mailto:castrod@unican.es); [angel.vega@unican.es](mailto:angel.vega@unican.es))

**Abstract** This article reports the development and construction of a 1:1 scale laboratory prototype of a System for Catchment, Pre-treatment and Treatment (SCPT) of runoff polluted by contaminants washed from impervious pavements. The concept of the SCPT is an online system with an up-flow filter. The filter is composed geotextile layers and limestone. Laboratory tests carried out were focused on determining the SCPT prototype behaviour under different working conditions. The variables studied were: inflow, pollutant loads and filtration system configuration. The results show that the designed system has a high capacity for total solids and oil treatment, with an average efficiency of 85% and 97% respectively. Moreover, the regression equations of the treatment efficiency have been determined for each of the studied pollutants, for different inflow conditions and pollution loads.

**Keywords** Non-point pollution, runoff, SUDS, up-flow filtration, water quality

## INTRODUCTION

The runoff pollution by water-borne elements present in impervious pavement surfaces is a serious problem that can negatively affect the environment and the population (Boving and Neary 2006).

Many methods and techniques have been developed to reduce the runoff pollution load (CALTRANS 2007). These methods can be grouped into two types according to the area of occupation and main application. On the one hand, the methods that require large areas and subsequently are more feasible in newly urbanized areas and on the other hand, the ones that require little space and can be easily located in urbanized areas.

In the first group, one of the most commonly used methods is pervious pavements (Newman et al. 2004). Their general structure consists of a permeable surface, a limestone bedding layer and a geotextile. Studies about pervious pavements have demonstrated a high treatment capacity, especially for hydrocarbons (Pratt 2003).

The second group can be divided according to the main function (Begum et al. 2008):

- ◆ Litter and basket pit: wire or plastic “basket” installed in a stormwater pit to collect litter from paved surface or within a piped stormwater system.
- ◆ Trash/Litter racks: series of metal bars located across a channel or pipe to trap litter and debris.
- ◆ Catch basin: stormwater pit with a depressed base that accumulates sediment.
- ◆ Sediment trap: trap for coarse sediment.
- ◆ Gross pollutant trap: sediment trap with a litter rack, usually located at the downstream end.
- ◆ Litter booms: floating booms with mesh skirts placed in channels or creeks to collect floating litter and debris.
- ◆ Oil/Grit separators: retention chambers designed to remove coarse sediment and hydrocarbons.
- ◆ Gully: road gully that collects water from stormwater or rain.

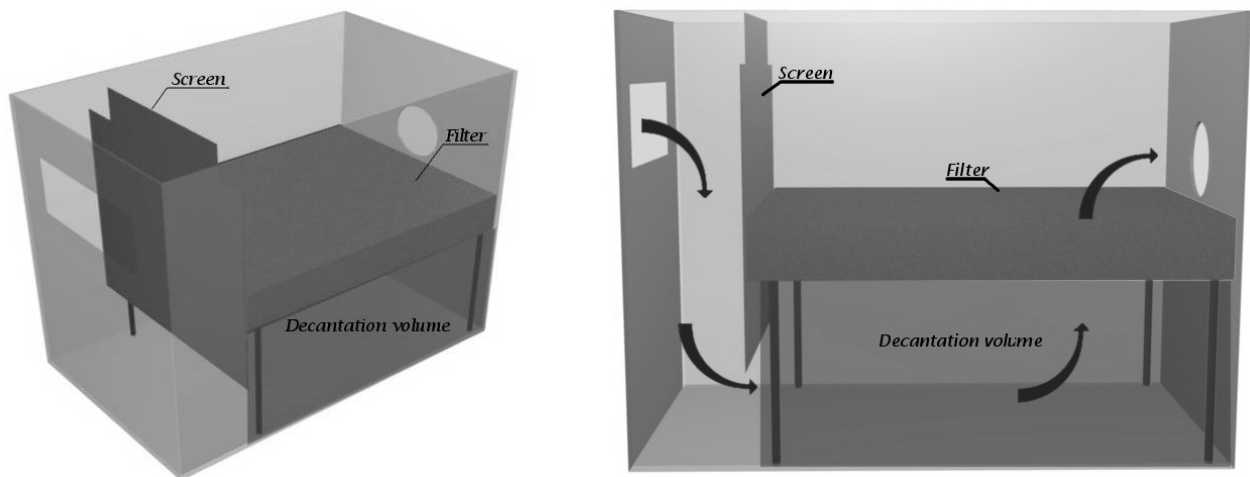
Published research about the performance efficiency of this kind of systems, carried out by CALTRANS (2007), concludes that the majority of these systems do not guarantee satisfactory behaviour and they have a low level of effective treatment confidence. Specifically, in the context of Oil/Grit separators, Begum et al. (2008) state that one of the disadvantages of these systems is the resuspension of pollutants by the water turbulence in them.

In this context, this study has developed a runoff treatment system attempting to solve these problems. This system integrates the main purification elements of pervious pavements, such as limestone and geotextiles, and focuses on already urbanized areas with impervious pavement and low surface disposition.

## **METHODS**

A 1:1 scale laboratory prototype of a System for Catchment, Pre-treatment and Treatment (SCPT) of runoff polluted by contaminants washed from impervious pavements (Figure 1) was built for this research.

The SCPT prototype is a methacrylate structure of 0.8m. width, 1.3m. length and 1.0m high. Its configuration consists of a screen, a decantation volume and a filter system, crossed by the ascending water flow. The filter system is a double layer system. One of the layers is made of geotextil and the other one of limestone aggregates. A detailed description of SCPT configuration is given in Castro-Fresno et al. (2009). Complementary elements are an affluent ramp, to simulate the runoff and pollutants drags, and a water recirculation system.



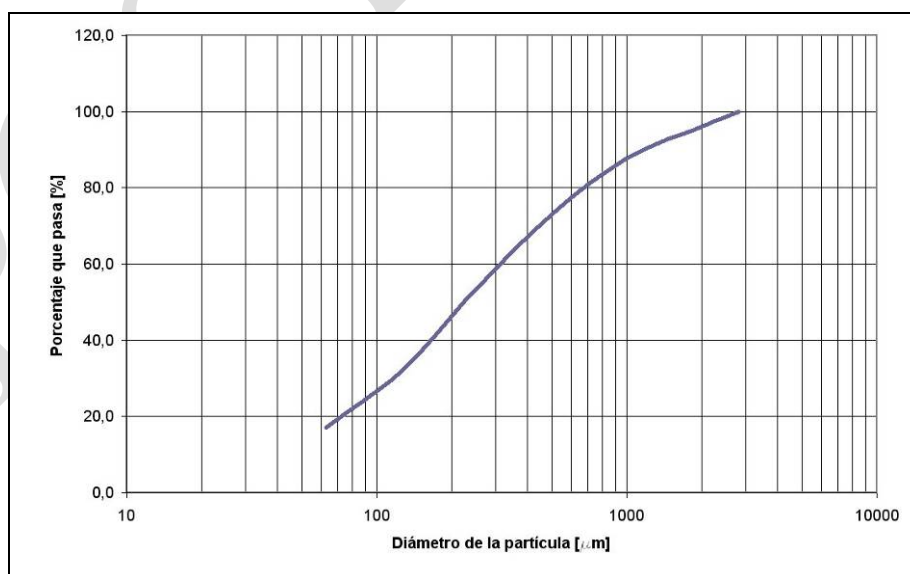
**Figure 1.** 1:1 scale laboratory prototype of the System for Collecting, Pre-treatment and Treatment (SCPT).

The laboratory work was aimed at determining SCPT prototype behaviour under different working conditions, analysing what variables had significant influence on treatment efficiency and establishing the magnitude of this influence.

The studied variables were:

- ◆ Inflow in litres per hour.
- ◆ Pollutant loads: total solids (TS) and hydrocarbons (O&G) in milligrams per litre.
- ◆ Filtration system configuration (area and number of geotextile layers).

The TS were simulated with solids prepared in laboratory from gravel pit. The particle size was adjusted to the size found in the sampling of urban streets in Cantabria, north of Spain (Figure 2) (Zafra Mejía and Temprano González 2005). The hydrocarbon pollution was simulated by controlled spills of waste engine oil.



**Figure 2.** Particle size of the silts used in the study

The test series was fitted to a  $2^{5-1}_{IV}$  factorial design with two central points, which in total needed eighteen tests under different conditions.

The duration of the test was limited to 20 minutes as a car-park with an assumed longest flow path of 120m. or less was assumed, which means a time of concentration about 10 minutes. The additional 10 minutes simulated the time for the total drainage of the catchment.

The testing procedure was:

1. Wash the SCPT.
2. Set the SCPT configuration.
3. Calibrate and fix the inflow.
4. Empty the SCPT.
5. Spread the TS on the adduction ramp.
6. Spill the oil on the adduction ramp.
7. Start the inflow again maintaining it for 20 minutes, taking water samples at the outlet every four minutes (5 samples in total).
8. Empty the SCPT.

### Sample analysis

The outflow TS analysis was carried out like total suspended solids (TSS), because the particle size was less than  $80\mu\text{m}$ . The methodology used was that proposed by the American Public Health Association et al. (2005). In the case of O&G, the sample analysis was performed by infrared, according to U.S. EPA 600/4-79-020, complemented with the HORIBA OCMA-310 instruction manual (Coupe et al. 2006).

## RESULTS AND DISCUSSION.

The average pollution treatment efficiency of the SCPT was 85% for the TS and 97% for the O&G. All the results obtained and used to calculate this average are shown in Table 1.

**Table 1.** Pollutant concentration and treatment efficiency results obtained with the SCPT.

Q (m <sup>3</sup> /hr)	C.Fil	L.Fil (cm)	C. Sed (mg/l)	C.O&G (mg/l)	EMC <sub>TSS</sub>	EMC <sub>O&amp;G</sub>	Ef <sub>TS</sub>	Ef <sub>O&amp;G</sub>
3,6	1	70	100	30	17,2	0,7	83,6	97,7
8,5	1	70	100	10	18,5	0,4	83,9	96,3
3,6	3	70	100	10	6,3	0,5	94,0	94,9
8,5	3	70	100	30	19,4	0,5	83,2	98,3
3,6	1	110	100	10	18,1	0,4	82,5	96,4
8,5	1	110	100	30	23,2	0,2	80,7	99,4
3,6	3	110	100	30	16,7	0,5	84,4	98,3
8,5	3	110	100	10	11,8	0,3	89,1	96,7
3,6	1	70	300	10	35,6	0,4	89,0	96,0
8,5	1	70	300	30	70,2	0,3	80,1	98,9
3,6	3	70	300	30	33,3	0,7	90,3	97,8
8,5	3	70	300	10	42,5	0,0	87,2	99,9
3,6	1	110	300	30	42,3	0,7	86,6	97,7
8,5	1	110	300	10	66,2	0,3	81,2	96,8
3,6	3	110	300	10	39,2	0,6	87,7	94,1
8,5	3	110	300	30	40,6	0,5	87,6	98,2
6,05	2	90	200	20	32,3	0,2	85,3	99,2
6,05	2	90	200	20	30,0	0,5	86,2	97,4
Average							85,7	97,4

### Regression analysis

Assuming linear behaviour that corresponds to the results of the SCPT test, the different response variables can be described by Equation 1.

$$y_i = \beta_0 + \beta_1 Q + \beta_2 C.Fil + \beta_3 L.Fil + \beta_4 C.Sed + \beta_5 C.O \& G$$

**Equation 1**

Where:

- $y_i$ : response variable<sub>1...i</sub>  
 $\beta_i$ : regression coefficient<sub>1...i</sub>  
 $Q$ : inflow (m<sup>3</sup>/hr).  
 $C.Fil$ : number of geotextile layer (unit/filter).  
 $L.Fil$ : filter length (cm).  
 $C.Sed$ : inflow TS concentration (mg/l).  
 $C.O\&G$ : inflow O&G concentration (mg/l).

The response variables studied were:

- $EMC_{TS}$ : outflow TS concentration (mg/l).  
 $EMC_{O\&G}$ : outflow O&G concentration (mg/l).  
 $Ef_{TS}$ : TS treatment efficiency (%).  
 $Ef_{O\&G}$ : O&G treatment efficiency (%).

Shapiro-Wilk (1965) and Durbin-Watson (Navidi, 2006) tests were applied to all the response variables. It was found that all of them have normal distribution, and  $EMC_{TS}$ ,  $Ef_{TS}$  and  $Ef_{O\&G}$  satisfy the conditions for regression analysis. The values of regression coefficients obtained for these variables are shown in Table 2. The  $EMC_{O\&G}$  was not homocedastic, so it was not possible to determine its corresponding regression equation (Navidi, 2006).

For the  $EMC_{TS}$ , the regression equation is highly representative of the retention capacity of the SCPT with a  $R^2 = 0.863$ . It can be observed that the  $EMC_{TS}$  has a direct relationship with the inflow and with the TS concentration in this, and an inverse relationship with the number of geotextile layers.

**Table 2.** Values of regression coefficients, standardised regression coefficients and 95% confidence intervals

				$EMC_{TS}$	$Ef_{TS}$	$Ef_{O\&G}$
$\beta_0$	Coef			-1.278	85.089	93.801
	95% confidence interval	min		-15.694	80.390	91.803
		Max		13.407	89.756	95.799
$\beta_1$	Coef			2.138	-0.640	0.284
	Stand Coef			0.293	-0.417	0.428
	95% confidence interval	min		0.587	-1.219	0.038
Max			3.683	-0.062	0.530	
$\beta_2$	Coef			-5.094	2.244	-
	Stand Coef			-0.285	0.597	-
	95% confidence interval	min		-8.886	0.827	-
Max			-1.302	3.661	-	
$\beta_3$	Coef			-	-	-
	Stand Coef			-	-	-

	95%	confidence	min	-	-	-
	interval		Max	-	-	-
	Coef			0.149	-	-
	Stand Coef			0.834	-	-
$\beta_4$	95%	confidence	min	0.111	-	-
	interval		Max	0.187	-	-
	Coef			-	-	0.098
	Stand Coef			-	-	0.603
$\beta_5$	95%	confidence	min	-	-	0.038
	interval		Max	-	-	0.158

The analysis of the standardised regression coefficients shows that the most influencing factor is TS concentration in the inflow (0.834) and its importance is about 3 times higher than the inflow (0.293) and the number of geotextile layers (-0.285).

This strong influence means that small increases in the inflow TS concentration require important increases in the number of geotextile layers to maintain the same TS concentration in the outflow. In contrast, an increase in the inflow needs a similar increase in the number of geotextile layers to ensure the treatment level. So for the design and application of any SCPT it is very important to ensure a known TS concentration in the inflow. One way to do this is to complement the SCPT installation with periodic street sweeping.

For the  $EMC_{TS}$ , the factors that were excluded from the model by the regression analysis were the filter length and the O&G concentration in the inflow.

The lack of influence of the filter length was not expected. This could be due to the use of “brand new” SCPTs for each test (absolutely clean). The filter length is associated with the filter area and it is hypothesised that it acquires importance when the geotextile starts to clog with contaminants over time, that is, under the transition from clean to clogged conditions.

The lack of influence of the O&G concentration in the inflow was expectable and means that the presence of oils in the runoff does not facilitate the retention of TS in the SCPT, in the concentrations studied.

In the case of the efficiency of SCPT in capturing the TS ( $Ef_{TS}$ ), the fit with the regression line is rather low ( $R^2=0.531$ ). However, the analysis of the regression coefficients shows how the inflow factor has an inverse relationship with the  $Ef_{TS}$ , while the number of geotextile layers has a direct relationship. This is just the opposite of what happens in the case of the  $EMC_{TS}$  due to the inverse relationship between  $Ef_{TS}$  and  $EMC_{TS}$ .

For the  $Ef_{TS}$ , the factors that were excluded from the model by the regression analysis were filter length, TS concentration in the inflow and O&G concentration in the inflow.

The absence of influence on the  $Ef_{TS}$  for the first and the third factor is explained in the same way as it was for the  $EMC_{TS}$ . It is remarkable that the TS concentration in the inflow is not considered in the model of  $Ef_{TS}$  because the efficiency is the ratio of outflow pollutant concentration and inflow

pollutant concentration. So it is already included in the variable response  $Ef_{TS}$ .

As in the previous point, the amount of sediment that the SCPT can retain depends on the flow, so by increasing the flow rate the amount of sediment held increases as well. This is because the ratio of TS concentration between outflow and inflow is kept within a range, being independent of the TS concentration in inflow.

The standardised coefficients of inflow (-0.417) and number of geotextile layers (0.597) have a similar importance but in the opposite sense. This contributes to emphasize the statement that an increase in the inflow can be counteracted by a variation of similar importance in the number of geotextile layers.

The number of geotextile layers and the inflow O&G concentration have been excluded from the model. This may be for the same reasons that they were excluded from the model of  $EMC_{TS}$ , that is, that the filter length should acquire importance when the process of clogging the filter up is greater, and that the inflow O&G concentration does not facilitate the TS retention or precipitation in the SCPT.

Even considering that the fit of the regression line is rather low, a diagram has been compiled that shows the capacity of TS treatment of SCPT (Figure 3). In the calculation of inflow ( $Q$ ) the rational method (Equation 3) was used, assuming a runoff ratio equal to 1.0.

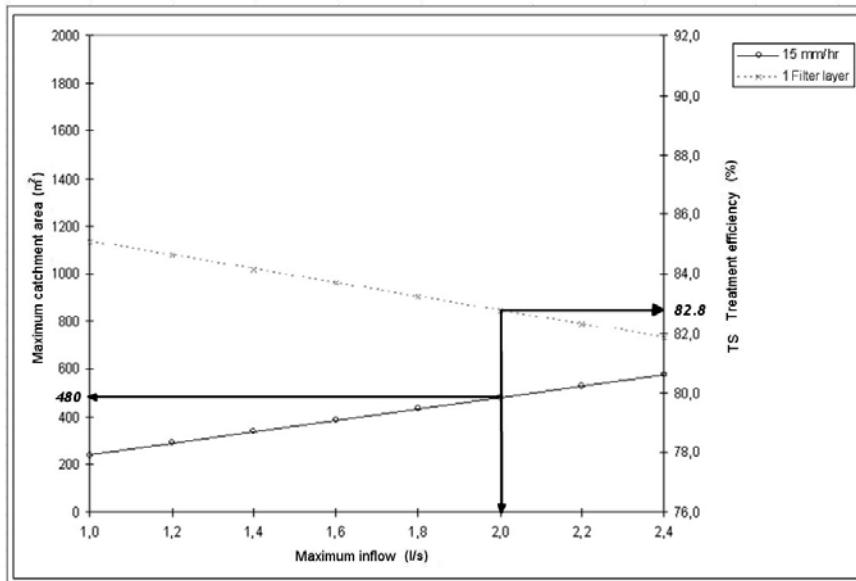
$$Q = \frac{C * i * A}{3600}$$

**Equation 3**

Where:

- $Q$ : Inflow (l/s)
- $C$ : runoff ratio (non dimensional).
- $i$ : Precipitation intensity (mm/hr).
- $A$ : Catchment area (m<sup>2</sup>).

As an example, an area of 480m<sup>2</sup> that receives a precipitation of 15mm/hr is shown. The TS treatment efficiency of SCPT is almost 83% if a filter with one geotextile layer is used.



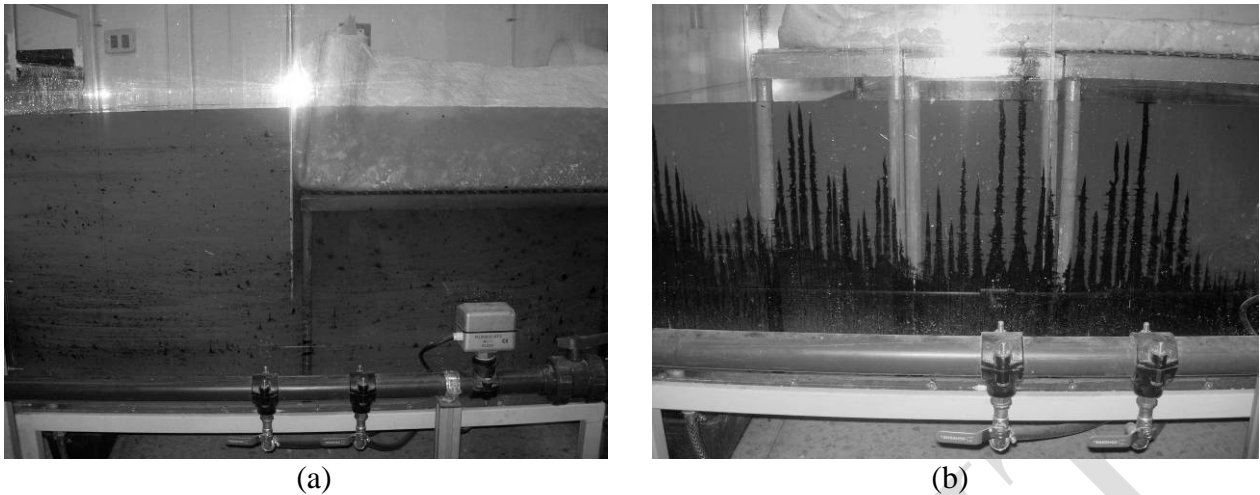
**Figure 3.** Diagram of TS treatment efficiency of SCPT performance.

Finally, for the efficiency O&G retention with the SCPT ( $Ef_{O\&G}$ ), the fit of the results with the calculated regression line is rather low ( $R^2=0.547$ ). The factors that influence this efficiency are inflow ( $Q$ ) and O&G concentration in the inflow ( $C.O\&G$ ). In both cases the relationship is direct and the standardised coefficients shows that  $C.O\&G$  (0,603) is more important than  $Q$  (0,428). However, the coefficient  $\beta_0$  (93.801) has greater importance in the calculated value of  $Ef_{O\&G}$ . For this reason the values  $C.O\&G$  and  $Q$  only mean a little correction, and their importance is very low for the SCPT design, which is itself able to ensure the high treatment action.

In fact, none of the factors associated with the filters are present in this model, which indicates that the filter would not have influence in the O&G treatment, at least in the initial phase of SCPT use, starting with it brand new (totally clean).

The explanation for this unexpected result is that the O&G remained trapped on the inner faces of the SCPT walls (Figure 4), perfectly clean at the beginning of each test, simulating the operation of the apparatus newly placed. Therefore, these faces are the main elements producing the retention, the filter not helping to produce significant differences in these conditions.



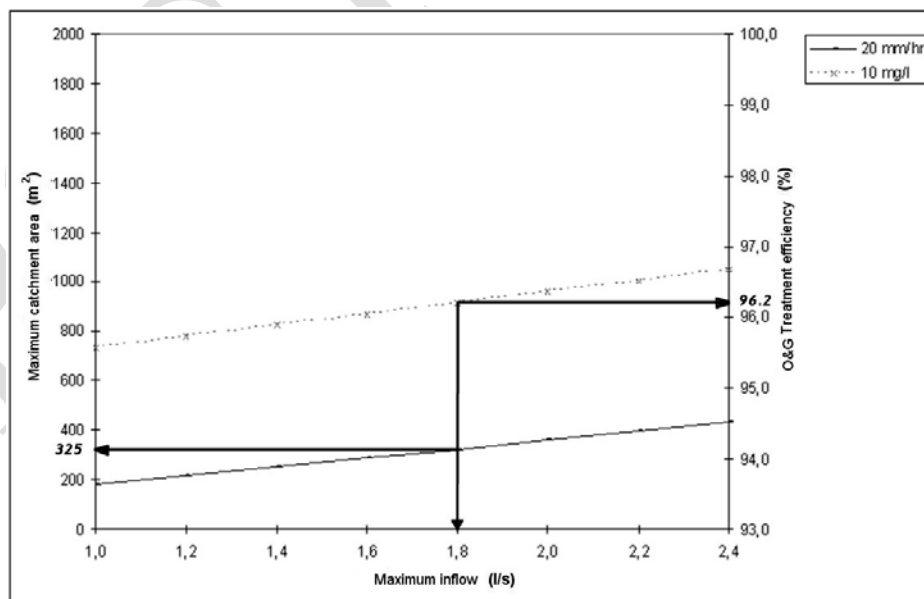


**Figure 4.** Oil retention by the SCPT inner walls in conditions of (a) low inflow O&G concentration and (b) of high inflow O&G concentration.

Moreover, the fact that the factor inflow TS concentration is not considered in the regression implies that the content of oils in sediments that are retained in the SCPT is not significant when compared to those retained by the walls, proving the independence between these two contaminants.

Figure 5 presents the diagram corresponding to the O&G treatment efficiency of SCPT ( $E_{fo\&g}$ ), following the same method used in Figure 2 to extract the results.

The example used to show the operation of the diagram in Figure 5 corresponds to a drainage area of  $325\text{m}^2$  in which a precipitation of  $20\text{ mm/hr}$  falls and O&G Event Mean Concentration (Taebi and Droste 2004) is  $10\text{ mg/l}$ . Under these circumstances, the efficiency of purification of the SCPT is over  $96\%$ .



**Figure 5.** Diagram of the O&G purification treatment efficiency of SCPT.

## CONCLUSIONS

The SCPT prototype is capable of reaching high levels of purification of runoff polluted with TS

and O&G. The average treatment purification efficiency for the test series was 85% for TS and 97% for O&G. These high efficiencies of the TS are mainly associated with the up-flow in the second part of the SCPT, and the O&G are associated with the inner walls surface.

Although the regression coefficients are not high, the analysis of the main variables shows their influence on efficiencies. The factors that influence the TS treatment efficiency are the inflow and the number of geotextile layers in the filter, both factors having a similar importance. In the case of the O&G treatment efficiency, the factors that have most influence are the inflow and inflow O&G concentration, but not the number of geotextile layers of the filter because the main retention of oils takes place in the walls of the SCPT prototype.

All these results correspond to a laboratory SCPT prototype, made of methacrylate brand new and clean, confronting a first flush with high pollutant concentration. Certainly, the deputation efficiency will change in a field SCPT because of the different interaction of the O&G with the concrete walls. The importance of this variation will depend on the final roughness and oleophilic properties of the SCPT inner walls. This is a future research issue.

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