Runoff Pollution Treatment Using an Up-Flow Equipment with Limestone and Geotextil Filtration Media

Daniel Castro-Fresno; Jorge Rodriguez-Hernandez; Andrés H. Fernández-Barrera; Miguel A. Calzada-Pérez.
D. Transportes y T. de P. y P. ETSICCP.
Universidad de Cantabria.
Av. de los Castros s/n, 39005 Santander.
Spain.
jorge.rodriguez@unican.es http://www.giteco.unican.es/

Abstract: - Runoff drags pollutant from different urban surfaces causing diffuse pollution in natural or artificial water bodies. To solve this problem, several solutions have been developed to purify the run-off water before the final spill, but still it is necessary to improve the applicability and efficiency of these systems. The project that is presented in this paper is focused on developing a System for Catchment, Pre-treatment and Treatment (SCPT) of contaminated runoff coming from impervious surfaces. The concept of SCPT is an on-line, up-flow filtration system, with the main elements of pervious pavements, which are being geotextiles and open grade gravel. The objectives of this research are to determine the influence of the main factors that affect SCPT efficiency and to evaluate the effects of SCPT long term use in its operational behavior.

Key-Words: - runoff, up-flow, filtration, non-point pollution, SUDS, BMP, water quality.

1 Introduction

The precipitation events and the consequent runoff generate flooding and pollution problems in urban areas. These problems are caused by the incapacity of drainage systems to handle the runoff of extreme events, and the capacity of the runoff to drag polluting agents to natural and artificial water bodies [1].

The kind and amount of the different pollutants dragged by runoff depend on a series of factors: size of the catchment, land use, precipitation intensity, storm magnitude, precipitation duration, dry period between events, average traffic in the catchment, seasonal period and wind direction [2-6]. As these factors change from one place to another, the amount of pollutants varies, too.

One type of contamination more difficult to control it is called non-point pollution or diffuse pollution, that is the pollution does not have a know origin point. In that way, the polluted runoff generates a strong service load to the wastewater treatment plant, or in the case of separated sewer system pollutes the receptors water bodies [7,8].

A way to minimise the impact of the non-point pollution is the use of on source water treatment. This kind of techniques have different names [9].

- Sustainable urban drainage system (SUDS) in U.K. and Spain.
- Stormwater Best Management Practice (BMPs) in U.S.A.
- Water Sensitive Urban Design (WSUD) in Australia.

Pervious pavement is the more commonly used system. It was developed in 1980s and since then has demonstrated great water purification efficiency. Their general structure consists in a porous surface, a bedding layer and a geotextil. The geotextil is the most important part of the structure because it is where the purification process takes place [10].

Pratt said that microbial communities or biofilm can be established in the geotextil layer. These microbes can degrade different pollutants, especially oils and grease (O&G) [11].

Pervious pavements are easy to install in new development areas, but in already developed areas with impervious pavements their installation is complex and expensive. In this situation, treatment systems integrated in the runoff sewer system can be used to lower pollutions.

The main pollutants loads in the case of urban impervious surfaces, for example in parking lot surfaces, are spills of oil, petrol, hydraulic and cooling fluids, incompletely combusted fuel, brakes and engine emissions, and particles from escapes, as well as different solid size, transported by wind or vehicles action [4, 5, 12-14].

The systems for treatment the polluted runoff from impervious surfaces can be grouped in on-line system and off-line systems [15]:

- On-line system. These systems are incorporated to the culvert system and follow the pipe directions.
- Off-line system: These systems are placed at one side of the pipes. Water is diverting to it and return to the pipes line after treatment.

There are many treatment systems in the market, but a published research by the California Department of Transportation Systems (CALTRANS) [15] concludes that the majority of the systems have no satisfactory behaviour and a low level of effective treatment confidence.

Some treatment methods and techniques are compared by Begun [16] and they are:

- Litter and basket pit.
- Trash/Litter racks.
- Catch basin.
- Sediment trap.
- Gross pollutant trap.
- Litter booms.
- Oil/Grit separators.
- Green Gully

The Oil/Grit separators are focused in remove the sediments and hydrocarbons, but one of its disadvantage is the resuspension of pollutants by the water turbulence inside them [16].

The hydrocarbons and it derivates (O&G) are one of the most important pollutant in the impervious surfaces, like it was said before, so if the specific methods to treat this kind of pollutant have not a satisfactory behaviour, it is necessary to improve the systems for ensure an effective treatment.

2 Objectives

This study aims to develop an on line treatment system and its specific objectives are:

- Design the System for the Catchment, Pre treatment and Treatment (SCPT) of the polluted runoff coming from impervious parking surfaces.
- Analyse with a laboratory SCPT prototype the physical aspects of the system, such as dimensions and characteristics of the main components, behaviour against clogging and durability for different quality and quantity affluent conditions.
- Analyse the purification performance and behaviour of the hydrocarbons' degradation by microbial communities that colonize in the SCPT prototype for different conditions of affluent volume, filter materials and pollutant loads.

3 Laboratory Prototype

The constructed and studied system in this research will be a real scale SCPT prototype with the complements that allow the simulation of the pollutant wash off process.

The SCPT prototype is a methacrylate structure of 0.8m. width, 1.3m. length and 1.0m high. In its frontal wall has a rectangular opening of 0,20m.x 0,50m. for the inflow, and in its rear wall has a circular orifice of 0.20m.diameter for the outflow (figure 1).

The height of orifice center is aligned with the lowest part of the inner rectangular opening which gives a hydraulic slope towards the exit. At the bottom of the SCPT there is an orifice with a plug, which allows the water-drainage and the sediment withdrawn during the cleaning operations.

Inside of the methacrylate structure the other parts of the SCPT are placed. These parts are a screen, a decantation volume and a filter system, crossed by the ascending water flow (figure 2)

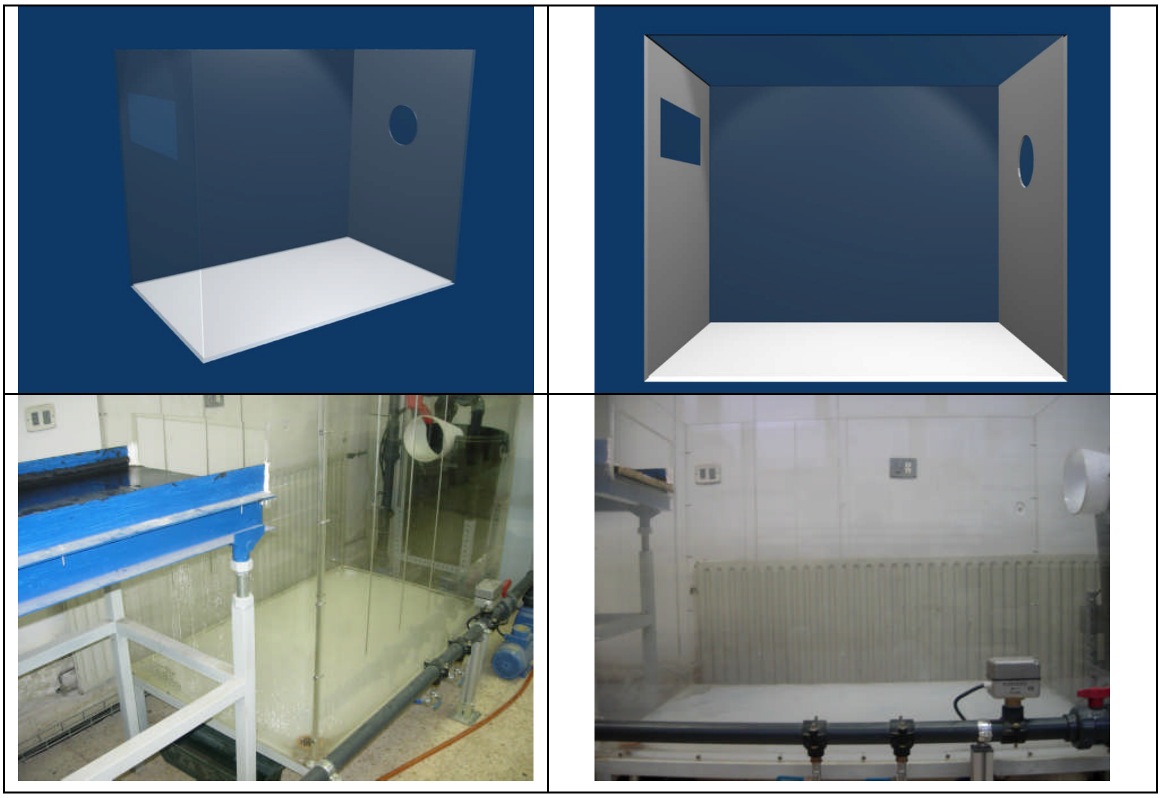

Figure 1. The methacrylate structure of System for the Catchment, Pre treatment and Treatment (SCPT) prototype

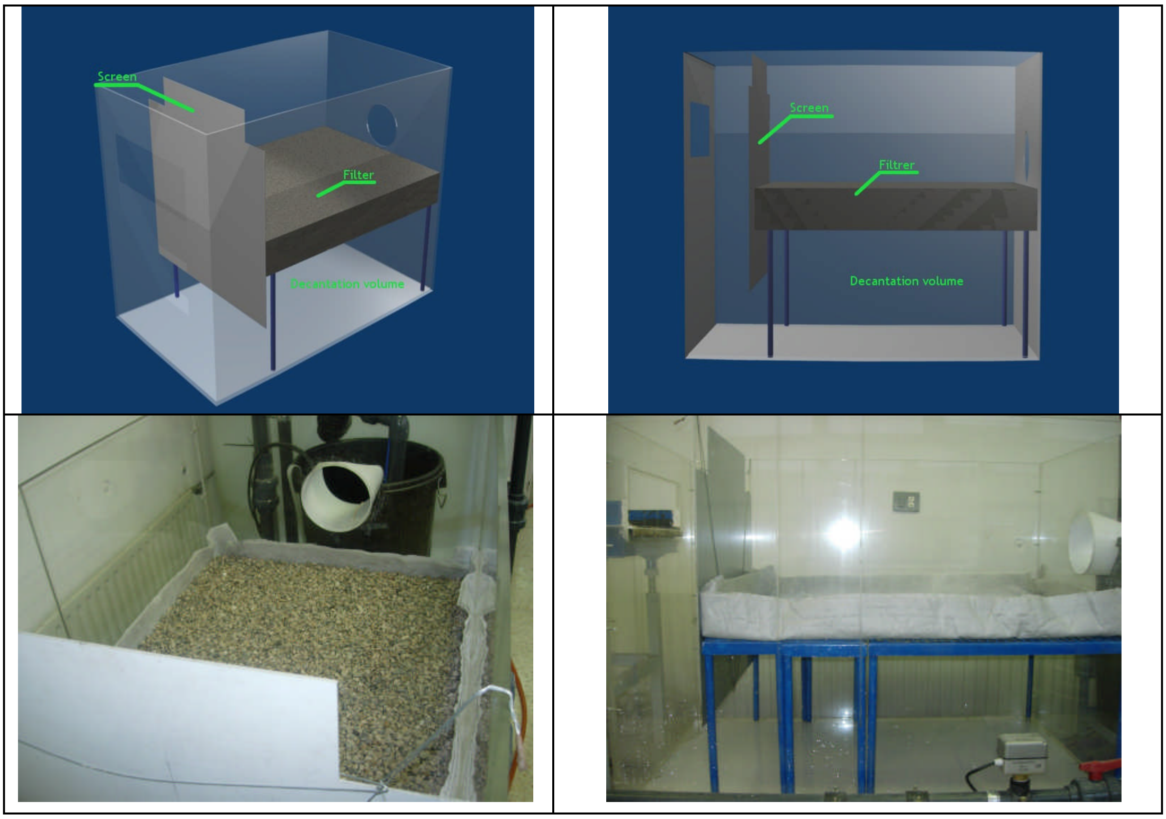

Figure 2. Configuration of the System for the Catchment, Pre-treatment and Treatment (SCPT)

- The screen has a double function; the first one is to dissipate runoff energy, and the second one to split the inner space of the SCPT in two parts. The first part works as a hydraulic plug retaining mainly oils dragged by runoff, the second is the zone called decantation volume.

  The screen has 0.80m. width, 0.75m. high and 0.04m. thickness. In its two superior vertex are rectangular openings of 0.12m. width and 0.13m. high, designed to work as by pass when an excessive flow exists.

  The screen goes inserts in grooves guides placed in the sidewalls of the SCPT structure. Those grooves are at 0.24m., 0,42m. and 0,61m. from the frontal wall where is the water entrance to the SCPT.

- The decantation volume is the part of the SCPT where a quiet water zone is generated and where up flow is done. In this zone most of the solid carried by runoff is retained.

  Its width is 0.80m. and has a variable length, given by the screen position. Under the screen the decantation volume is connected with the space of the hydraulic plug by a 0.25m. high opening and covers all the inner section with the SCPT. At this way the screen covers a height of 0.35m. of the decantation volume were the up-flow is predominant.

- Over the decantation volume, the filter system is placed. The filter system is a double layer system. One of layers is made of geotextil and the other one of clean limestone aggregates; elements usually used in pervious pavements.

  The filter covers all the inner width of the SCPT and could have a length between 0.70m. and 1.10m. following the configuration of the test. It rests on grids that allow the free water passage and separate it 0.45m. of the SCPT base.

  The aim of this configuration is to generate a biofilm which biodegrades oil and grease retained in the filter system. The generation of this biofilm occurs especially in the geotextil layer, helping depuration and self-maintenance of the system.

To complete the laboratory prototype it was necessary to construct, an adduction ramp and a recirculation water system, to simulate the runoff and the pollution drag (figure 3)

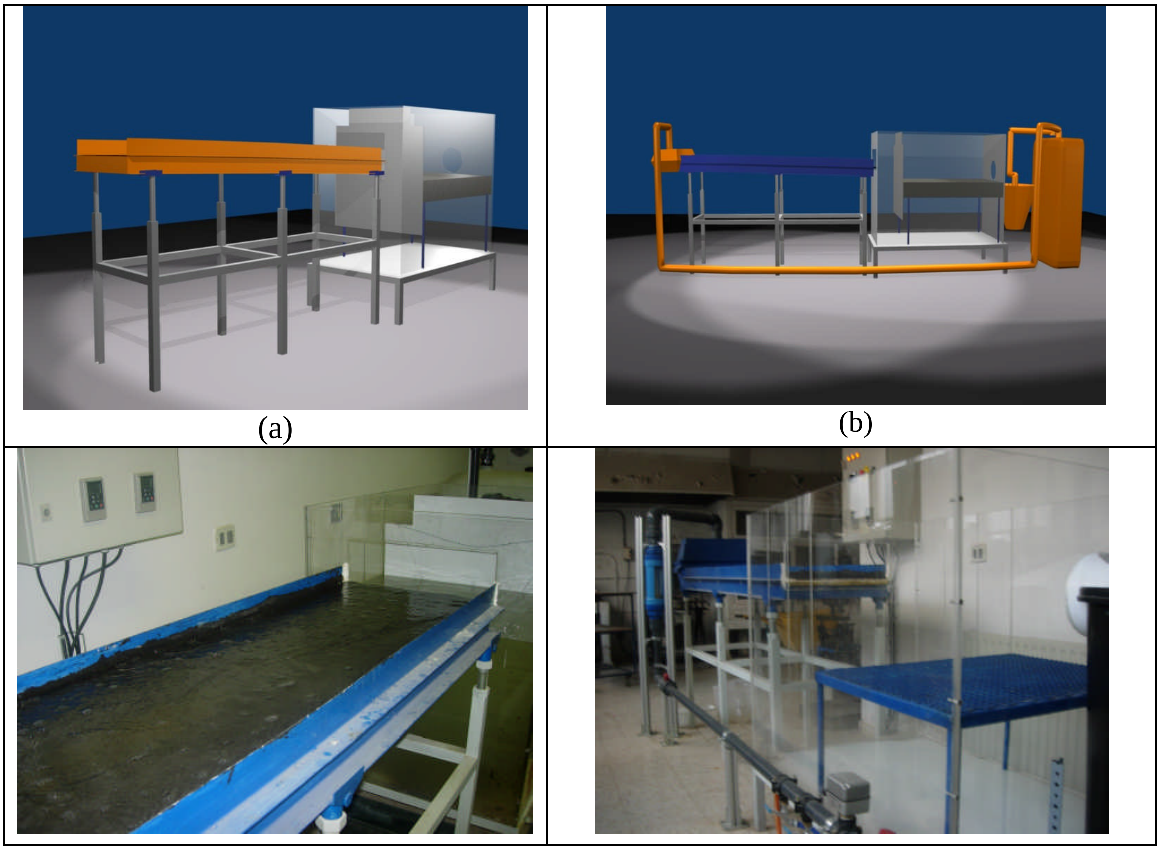

Figure 3. (a) Adduction ramp and (b) recirculation water system.

The adduction ramp is 2.0m. long and 0.5m. width and its longitudinal slope is adaptable. The ramp has a supporting mesh which is covered with asphalt as impervious surface.

The recirculation system is made of two regulated pumps with flows between 1 and 2.5 l/s, one accumulation tank of $1m^3$, one water container at the outflow and one chamber in the head of the adduction ramp.

One pump takes water from the accumulation tank and pumps it into the chamber. The chamber function is to ensure that the water flow has an uniform height in all of the ramp width until entering the SCPT.

Once the water passes through the SCPT, it is spilled into a container. From here it is pumped to the accumulation tank by the second pump, closing the recirculation circuit. In this reload line there is an additional external filter to capture the pollutants remaining in the flow.

The prototype and complements for this study are placed in the Laboratory of Roads of the University of Cantabria in Santander, Spain.

4 Laboratory Testing Procedures

The laboratory work is focused on the study of two aspects of the SCPT operation, the first one is the purification efficiency under high intensity precipitation events and the second one is its long time performance.

The SCPT efficiency will be determined by the analysis of suspended solids (SS) and oils and grease (O&G), because these pollutants are related to the presence of other pollutants [17].

The silt particle size used in laboratory for the test corresponds to the one collected in Cantabria in the north of Spain [18] and it is shown in Figure 4.

To simulate the O&G leakages, wasted engine oil is used, following the criteria set out in previous research about pervious pavements [19, 20].

The wasted engine oil use in this testing procedures is the same used for Rodríguez B. [19] and its characteristics are in table 1.

Table 1. Characteristics of the wasted engine oil [19].

Band	Percentage
C5-C6	0.71
C6-C8	0.82
C8-C10	1.76
C10-C12	0.50
C12-C16	0.60
C16-C21	3.55
C21-C35	17.26
>C35	74.80
Total	100.00

For this investigation it will used the event mean concentration (EMC) to determinate the affluent and effluent pollution load. The EMC corresponds to the total mass of pollutant divide for the total volume of water, according to the equation 1 [21].

Figure 4. Granulometry of sediments will use in the study [18].

$$EMC = \frac{\sum_{i=1}^{N} \Delta M_i}{\sum_{i=1}^{N} \Delta \forall_i} = \frac{\sum_{i=1}^{N} C_i Q_i \Delta t_i}{\sum_{i=1}^{N} Q_i \Delta t_i} \qquad \textbf{Equation 1}$$

Where

N : Number of samples.
ΔM_i : Pollutant total mass.
$\Delta \forall_i$: Runoff volume for Δt_i.
C_i : Average concentration of pollutant.
Q_i : Average runoff flow.
Δt : Discreet time interval.

4.1. Assessment of the purification efficiency on high intensity precipitation events.

The first stage aims to obtain information about the prototype model behaviour in different working conditions in order to assess which of the variables has significant influence in the SCPT purification efficiency and to quantify the importance of that influence.

The variables that are being studied are:

- Water inflow quantity.
- Pollutant load of suspended solids (SS) and oils (O&G).
- Configuration of filter system.

The tests follow a sequential approach design to the optimal conditions. The analysis of the first test series will help to improve SCPT efficiency-making adjustments in its elements. With this new configuration, a second test series will be carried out. It will produce new improvements as well, and so on until a level of at least 80% depuration with SCPT is reached under the worst simulated conditions.

The first tests series is fit to a 2_{IV}^{5-1} factorial experiment design with two central points, which in total are eighteen tests. The specific variables and its rank are shown in table 2.

The testing procedure for this stage is:

- Wash the SCPT.
- Arm the SCPT configuration.
- Calibrate of the inflow.
- Drain the SCPT.
- Spread thesediment on the adduction ramp.
- Spill the oil on the adduction ramp.
- Circulate water through the system for 20 minutes, taking water samples at the outlet every four minutes.
- Drain of SCPT.

Table 2. Variables for SCPT laboratory test.

Variable	Rank		
	Unit	min.	Max.
Water inflow	l/s	1	2.5
Silt	mg/l	100	300
O&G	mg/l	10	30
Filter lenght	cm	70	110
Filter layers	Nº	1	3

4.2 Long time SCPT performance.

The second stage of this research is divided in two sub-stages. The first one aims to determinate how the continuous operation affects SCPT efficiency and what is the maximum work time without cleaning or changing the filter. The second sub-stage aims to determine the existence and performance of the oil biodegradation biofilm in the filter element.

The methodology of the first sub-stage, consists in simulating cycles of precipitation events and dry periods during four months. The dry period will be represented for two days between precipitation events.

At the beginning of this sub-stage the SCPT is washed carefully and the configuration is armed. This configuration corresponds with the one to have the best performance in the first stage.

The testing procedure of simulate the cycles for precipitation is:

- Spread of sediment on the adduction ramp.
- Spill of oil on the adduction ramp.
- Circulation of water through recirculation

system for 20 minutes.

- Drain of SCPT.

This water drain will be done whilst trying not to drag the sediments. The water in the SCPT will be drain because the interval time that dry periods represent will not be extensive enough to allow the natural evaporation of the water.

Once a week, samples of the water will be taken during one of the precipitation simulation from the outlet of the SCPT. The samples are taken every 4 minutes at the outlet of the SCPT, at the same way of the first stage.

The pollutant concentration will be 200 mg/l for sediments and 20 mg/l for oil, these concentrations correspond to the highest concentration found in literature review for field researches.

The second sub-stage methodology is like follows:

- Divide the filter into slices as is show in figure 3.

- Wash the SCPT carefully.

- Arm the SCPT configuration.

- Repeat the first sub-stage testing procedure for simulating of the cycles of precipitation.

- After two weeks of simulated cycles in the SCPT, one slice will stay and the rest of the filter is changed.

- Repeat the last point until there is no slice to change.

Like in the previous sub-stage the pollutant concentration will be 200 mg/l for sediments and 20 mg/l for oil.

After two weeks of the last filter change, it will be takes from the SCPT.

All slices of the geotextil will be carefully examined looking for biological activity by mass difference and by direct observation.

4.3 Analysis of the biofilm behaviour in geotextiles.

At same time of the long time SCPT performance stage, it will be realised an analysis of the biofilm behavior in the geotextiles. This analysis will be done outside the SCPT, in special designed devices prepared to simulate the same conditions of polluting oil load during 6 months (figure 4).

The test will be done on samples of the same geotextiles used in the filter of the SCPT. The samples will be put in special supports and under similar work conditions to the one in the SCPT.

To estimate the mass of the oil retained in the geotextiles during the study period control samples of geotextil will be used. These samples will be testing with distilled water and the same condition of oil load of the other geotextil samples but withour nutrients. In these control samples is expect that the biofilm not growth.

The test series of this stage its fit to a 2^3 factorial experiment design with 2 central points and six control samples (CS), which in total are eighteen tests (table 3).

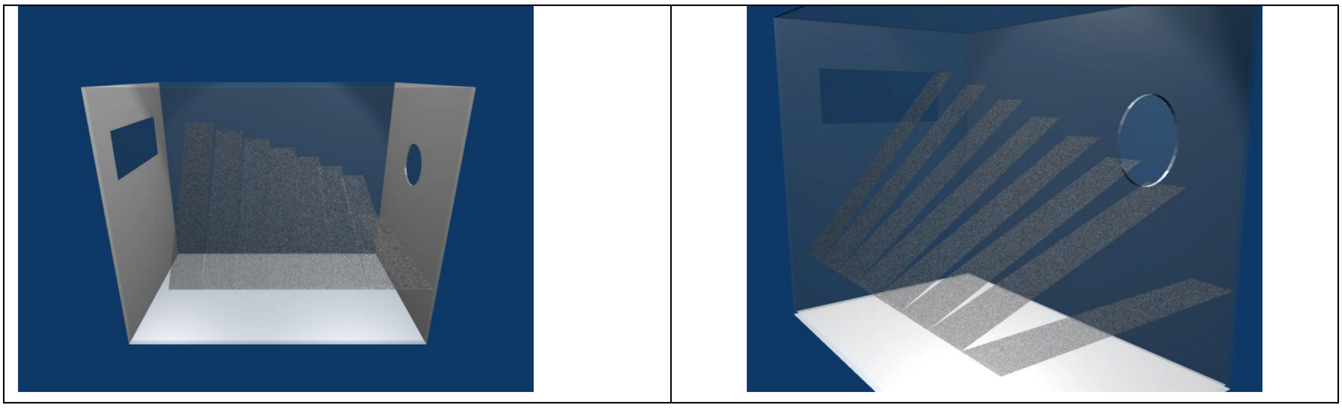

Figure 3. Geotextail slices for second sub-stage of long time SCPT performance tests.

Table 3. Design for the bofilme behaviours analysis.

Test Chamber	Water type	Filter layers	Oil Concentration
1	+ +	+ -	+ +
2	- -	+ -	+ +
3	+ +	+ -	- -
4	- -	+ -	- -
5	+ +	0 0	0 0
6	- -	0 0	0 0
7	CS CS	+ -	+ +
8	CS CS	+ -	- -
9	CS CS	0 0	0 0

The testing procedure is:

- Wash the test chamber.
- Mix water and oil in proportion to reach the concentration indicated for the test, in the test chamber.
- Place the geotextiles in the test chamber.
- Increase the water level until the geotextiles is under 5 cm of water.
- Keep the geotextiles submerged by 20 minutes.
- Retire the geotextiles of the test chamber

After 6 months, the growth of biofilm will be determined by mass difference between the geotextiles at the end and the geotextiles at the beginning.

5. Expected Results.

The expected results from the different stages of the research are the following:

- Assessment of the most efficient configuration.
  - Determine the factors that influence the SCPT efficiency performance for solids and oils pollution.
  - Determine how the variation of the pollutant loads affects the SCPT efficiency.
  - Determine the most efficient configuration base on the previous information
  - Develop a mathematical expression that describes the SCPT efficiency performance.
- Long time SCPT performance.
  - Find out the effects of continued operation in the SCPT efficiency.
  - Determine if the biodegradation takes place in the filter, specifically in the geotextil.
  - Define a mathematical expression that describes the effects of the number of precipitation events and the dry periods between them on the SCPT efficiency.
  - Determine the conditions under which it becomes necessary to clean the SCPT or change the filter.

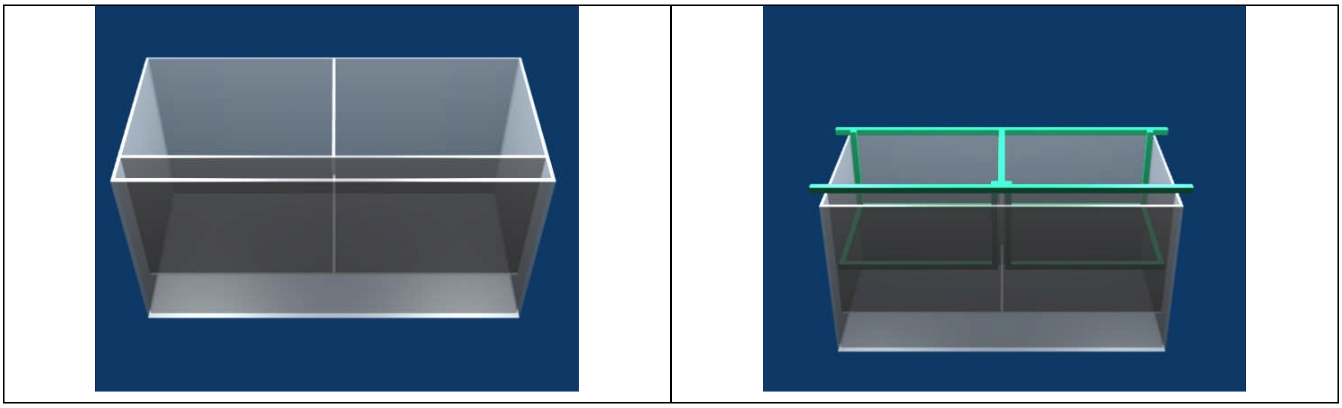

Figure 4. Structures for analysis of biofilme behaviours of in the geotextiles. (a) Test chamber, (b) geotextiles support in test chamber.

- Analysis of the biofilm behaviour in the geotextiles.
  - Determine the condition of the geotextil to develop the biofilm.
  - Define the microbial community behaviour against different pollutant concentrations.
  - Determine the microbial community behaviour against water conditions.

Additionally, related with it is expected that the conclusions of this research could be compare with a field operation research of the SCPT.

6. Acknowledgment

This study is part of a mayor project entitle “Development of New Systems of In Situ Reception, Pre-Treatment and Treatment of Water Contaminated by Hydrocarbons from Urban Runoff in Car Parks with Impermeable Pavements (TRAPI)” developed by the Construction Technology Research Group (GITECO) of the University of Cantabria, with the support of the Ministry of Science and Technology of Spain, as a part of the “Projects of Scientific Research and Technological Development” program

References:

1. Castro Fresno D, Rodríguez Hernández J, Rodríguez Bayón J. “Sistemas urbanos de drenaje sostenible”. 2006.

2. Crabtree B, Moy F, Whitehead M, et al. Monitoring pollutants in highway runoff. Water and Environment Journal. 2006;20:287-94.

3. Soller J, Stephenson J, Olivieri K, et al. Evaluation of seasonal scale first flush pollutant loading and implications for urban runoff management. Journal of Environmental Management. 2005;76:309-18.

4. Brown JN, Peake BM. Sources of heavy metals and polycyclic aromatic hydrocarbons in urban stormwater runoff. Science of the Total Environment. 2006;359:145-55.

5. Göbel P, Dierkes C, Coldewey WG. Storm water runoff concentration matrix for urban areas. Journal of Contaminant Hydrology. 2006;doi:10.1016/j.jconhyd.2006.08.008.

6. Kayahanian M, Suverkropp C, Ruby A, et al. Characterization and prediction of highway runoff constituent event mean concentration. Journal of Environmental Management. 2007;doi:10.1016/j.jenvman.2006.09.024.

7. Hamidov A, Beltrao J, Costa C, Khaydarova V, Sharipova S. Environmentally useful technique - portulaca oleracea golden purslane as a salt removal species. WSEAS Trans.Environ.Dev. 2007;3(7):117-22.

8. Yang TC, Kao CM, Yeh TY, Lai YC, Lin CE. Evaluation of NPS pollution in drinking water protection area of kaoping river watershed. WSEAS Trans.Math. 2006;5(10):1131-7.

9. Castro Fresno D, Bayón JR, Rodríguez J, Ballester F. Sistemas urbanos de drenaje sostenible (SUDS). 2005;Vol. 30(No. 5):pp. 255-260.

10. Newman AP, Puehmeier T, Kwok V, et al. Protecting groundwater with oil-retaining pervious pavements: Historical perspectives, limitations and recent developments. Q J Eng Geol Hydrogeol. 2004;37(4):283-91.

11. Pratt CJ. An application of geosynthetics in sustainable drainage system. Loughborough, UK: Thomas Telford; 2003:121-35.

12. Huang L, Boving TB, Xing B. Sorption of PAHs by aspen wood fibers as affected by chemical alterations. ENVIRONMENTAL SCIENCE & TECHNOLOGY. 2006;40(10):3279-84.

13. Mahler BJ, Van Metre PC, Bashara TJ, et al. Parking lot sealcoat: An unrecognized source of urban polycyclic aromatic hydrocarbons. Enviro Sci Technol. 2005;39(15):5560-6.

14. Boving TB, Neary K. Attenuation of polycyclic aromatic hydrocarbons from urban stormwater runoff by wood filters. Journal of Contaminant Hydrology.2006;doi:10.1016/j.jconhyd.2006.08.009.

15. City of Knoxville, Tennessee, Storm Water Engineering Division. Knox County Tennessee Stormwater

Management Manual. Available at: http://www.knoxcounty.org/stormwater/pdfs/vol2/4-2-6%20Off-Line%20Versus%20On-Line%20Structural%20BMPs.pdf. Accessed June, 2008.

16. Begum S, Rasul MG, Brown RJ. A comparative review of stormwater treatment and reuse techniques with a new approach: Green gully. WSEAS Trans.Environ.Dev. 2008;4(11):1002-13.

17. Huang J, Du P, Ao C, et al. Multivariate analysis for stormwater quality characteristics identification from different urban surface types in macau. Bull Environ Contam Toxicol. 2007;79(6):650-4.

18. Zafra Mejía CA, Temprano González J. Análisis granulométrico y contenido de metales pesados en los sedimentos acumulados sobre una vía urbana. ESPAÑA: Universidad de Cantabria; 2005.

19. Rodríguez Bayón J. Análisis de los aspectos de depuración y degradación de los hidrocarburos presentes en las aguas prodecentes de la escorrentía urbana, en los firmes permeables. Santander: Universidad de Cantabria; 2008.

20. Rodríguez Hernández J. Estudio, análisis y diseño de secciones permeables de firmes para vías urbanas con un comportamiento adecuado frente a la colmatación y con la capacidad portante necesaria para soportar tráficos ligeros. Santander: Universidad de Cantabria; 2008.

21. Taebi A, Droste RL. Pollution loads in urban runoff and sanitary wastewater. Science of the Total Environment. 2004;327:175-84.