Oil Retaining and Treating Geotextile for Pavement Applications

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SUMMARY

This paper reports the recent characterisation of a purpose designed geotextile focussing on enhanced hydrocarbon treatment. It describes initial testing designed to illustrate the capability of the system to maintain an oil degrading biofilm, it reports small scale and larger scale oil retention experiments. The findings were that pavement structures with geotextiles exposed to moderate oil contamination perform better than a typical system without a geotextile. Furthermore it could be demonstrated that a purposely engineered hydrocarbon retaining geotextile provides a worthwhile advantage over the traditional geotextiles based on heat bonded random mat polyolefin fibres. The results reported here demonstrate that this novel type of geotextile can retain hydrocarbons when applied at up to 600 ml/m^2.

KEYWORDS

oil retention; biodegradation; drainage; hydrocarbon pollution; water quality; permeable pavements; pavements; geotechnical fabric ; road construction

INTRODUCTION

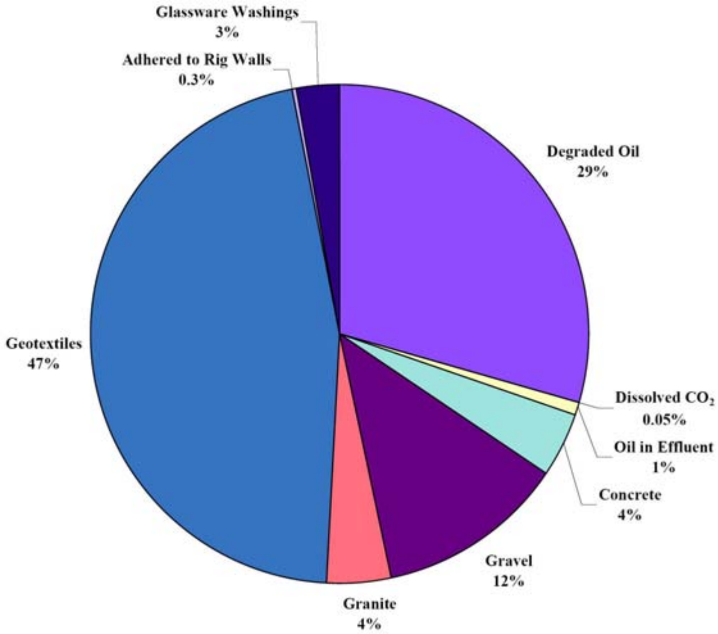
Geotextiles have been widely used in the domain of civil engineering Pervious pavements have been widely used as parts of sustainable urban drainage systems (SUDS) both alone and in conjunction with other types of SUDS devices (Woods-Ballard et al., 2007). They have been shown to provide significant improvements in effluent quality when compared to run-off from impervious surfaces. Much of the research effort has been on parking lots where one of the main pollutants of interest has been hydrocarbons (Pratt, 1999; Dierkes et al., 1999; Newman et al., 2004b). Since the work by Bond (1999) it has become widely established (Bond, 1999) that in those pervious pavement systems which utilise geotextiles in the upper layers of the pavement structure they play an important role in the hydrocarbon retaining capability of the system. Although the need for, or indeed the suitability (from an engineering point of view), of geotextiles is not universally accepted in (pervious) pavement installations (Knapton et al., 2002). However, the use of the geotextile in some designs of pavement is essential for separation purposes particularly when the void space is to be maximised by using large, single size aggregate or plastic void forming boxes to prevent of loss of bedding material into storage cavity. It is also widely understood that the role of the geotextile, when used for pollution control purposes, is to trap the hydrocarbon pollutants long enough for microbial activity to degrade it and to provide a suitable, high surface area, matrix for an oil degrading biofilm (Newman et al., 2004b) to develop at a level in the structure where aerobic conditions are adequately maintained. Additionally, the percentage performance treatment efficiency for pervious pavements designs without geotextiles seems unsubstantiated and this is supported by data reported here.

Whilst it has been shown by use of molecular biological techniques (Newman et al., 2004a) that the natural evolution of a complex oil degrading assemblage on the upper, aerobic, zone of a PPS is encouraged by the geotextile and, as Bond (1999) demonstrated, the geotextile is the predominant site of hydrocarbon entrapment (See Figure 1) those who have doubted the advantages of the geotextile have been vociferous in criticising the lack of comparative data between geotextile equipped and non-geotextile equipped paving systems with respect to hydrocarbon retention. One of the aims of this work was to start address this lack of comparative data (See Figure 9).

It has been shown that plastic box based systems behave comparably with stone systems in dealing with day to day drip losses (Puehmeier T. et al., 2004b). These systems rely greatly on the geotextile, for oil retention, and this indicates that the geotextile's oil retaining capability should be optimised.

Geotextiles that are currently in general use for pervious pavement design, providing a treatment capability, do not really differentiate from conventional commercial geosynthetics marketed since their introduction at all. Although they can be divided into two main groups: ones that have been academically investigated, describing their properties and other that have not. This paper addresses this issue, at least as far as moderately high oil spillages are concerned since in the comparison of the performance of model structures the new geotextile is tested in a situation where it is placed directly over such a plastic void forming structure.

Whilst the traditional materials used in geotextiles have been shown to be effective in many circumstances work previously reported by the authors has demonstrated that breakthrough of hydrocarbons before the onset of effective biodegradation was likely if the system was overloaded even moderately (Puehmeier T. et al., 2004b). Whilst designs capable of retaining almost 100% of spilled hydrocarbons in very high loading situations have been reported (Wilson S. et al., 2003) these are inevitably more difficult to construct and are thus best suited to high risk situations or for release of stormwater into highly sensitive receiving waters (and even to allow infiltration into sensitive groundwater zones).



5550 mg Oil Added to Structure, Along with 1.522g of Osmocote Plus Fertilizer. Rig Broken Down After 78 Days. Total of 1789 mg Oil Degraded (1747 mg if control subtracted). Recovery = 107.22 % of added oil.

Figure 1 Typical Results of Distribution of Oil Throughout Osmocote Plus Treated PPS (78 day experiment, Adapted from Bond, 1999)

With experiences of both stone based and geocellular based systems in high oil loading situations it became clear to the authors that a suitable compromise position may be to incorporate into the standard PPS design a geotextile which had been specifically manufactured for hydrocarbon retention rather than adopting a geotextile which is, at best, a slightly modified version of a one which had been originally manufactured for an entirely different purpose. The most commonly used geotextile is a heat bonded random mat geotextile which has fibres spun with a polypropylene core and a polyethylene sheath. Such geotextiles was used in the work used to derive results shown in Figure 1 and Figure 2 and indeed in most of the work that has been previously been carried out by the authors (Coupe et al., 2003; Puehmeier T. et al., 2004a; Newman et al., 2004b). Bond (Bond, 1999) provided an excellent set of data which showed impressive percentage retention data but if recalculated in absolute terms indicated that the output oil concentrations started to exceed over 200 mg/l after less than three years if oil was applied at rate which was ten times the typical oil loading on a car parking surface (see Figure 2). Whilst such a scenario is not necessarily to be expected it is not an impossible scenario, lending even more weight to the argument for the need for a purpose designed oil retaining geotextile.

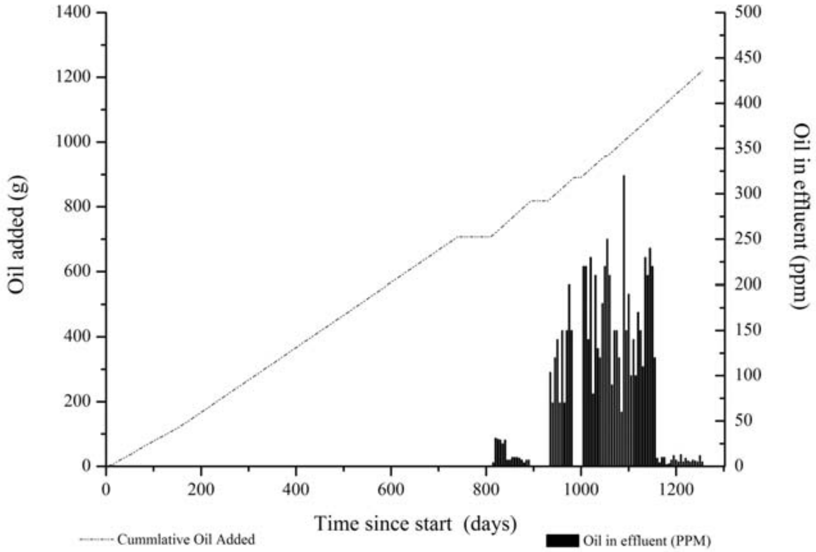


Figure 2 Re-interpretation of Bond's Long Term Experiment

This paper outlines the work done to date in characterising the purpose designed geotextile which resulted from the arguments introduced above. Whilst the work to date has focussed on enhanced hydrocarbon treatment in the short term the physical and biological properties have not been ignored. Experiments are reported which simulate moderate intensity oil spill scenarios in comparing pervious pavements models equipped with the new geotextile with those which have been traditionally used and, up to the point where they seemed to have failed catastrophically, with the a popular design of pavement which has no geotextile.

Most geotextiles serve applications depending on design such as, separation, reinforcement, filtration, drainage and containment functions etc. (Ingold and Miller, 1988; Koerner, 1994). The newly developed geotextile utilised in these experiments places equal emphasis on the pollutant trapping mechanisms as on physical and structural performance, resulting in a greatly enhanced hydrocarbon treatment geotextile that is unique in the civil engineering sector. The new geotextile comprises a non-woven, needle punched textile made from a proprietary blend of modified polyester fibres. The working principle of the new geotextile relies on the blend of fibres exhibiting modified surface properties (hydrophilic and hydrophobic). These modified fibres form multiple layers with inherent oil retention properties. The hydrophobic material receives and retains the hydrocarbon pollutants in the long term, whilst the hydrophilic elements simultaneously facilitate water retention, maintaining the biofilm, which subsequently degrades the entrapped pollutants. Furthermore the hydrophilic elements promote water retention supporting the hydraulic functions of the geotextile and aids dramatically in forming the initial barrier to hydrocarbon penetration. This novel geotextile has been subjected to rigorous tests in model systems which, in addition to model pavement tests included tests made excluding the pavement cross section. These were undertaken using the textile in isolation to avoid any influences by the aggregate materials.

Development of the Geotextile

The concept of this new geotextile could be formulated as a concept from experience of previous research using the heat bonded random mat polyolefin textiles as originally used by Pratt (Pratt et al., 1999). The authors' research group had previously compared two types of random mat geotextiles (Newman et al., 2004b) with woven geotextile and illustrated that at the start of the geotextile's working life the random mat geotextile gave significantly better oil retaining performance than the woven geotextile but that when subject to silting the difference in performance was reduced as both textile types showed improved performance. This group have proposed that the mechanism of initial hydrocarbon retention in the early life of the geotextile has relied upon the formation of a temporary gravity separator above the geotextile during rain events. It was envisaged that with the siltation and biofilm formation parts of the structure would be modified to improve the oil retaining characteristics of the textile cross section and in addition create a water retaining mat in the aerobic region of the pavement cross section which would encourage the maintenance of the oil degrading biofilm in times of stress.

Whilst the desirable properties of the proposed geotextile were established (Newman et al., 2005) the method of achieving the desired performance was rather more difficult. An extensive series of combinations between base polymer and additive were investigated using in the first instance the contact angle of oil droplets applied to the surface as the initial measure of performance (Puehmeier, 2008). The combination selected for further testing was polyester based random mat system using a proprietary fluorocarbon additive.

Whilst time has not yet permitted replication of the excellent long term experiments by Bond (1999) and later by Coupe (2004) on systems using the random mat polyolefin type geotextiles there is no reason to doubt that long term performance will be at last as good as those previously demonstrated. Work is currently underway to confirm this. Similarly time has not yet permitted the completion of experiments on the new geotextile such as the long term biological studies previously carried out (Newman et al., 2004b; Puehmeier T. et al., 2004b). However some preliminary biofilm establishment experiments have been carried out.

INITIAL BIOFILM EXPERIMENTS

A small model system was established to mimic the use of the new geotextile on a situation in which it was not resting on a bed of stone in the subbase. This was achieved by trapping a 300mm x 300mm sample between two lengths of PVC pipe (dimensions 88mm and 90 mm diameter). The system was seeded with a small amount of soil to provide a complex microbial assemblage and 4 ml of oil (Castrol GTX, Castrol Ltd., Swindon, UK) was added directly to the geotextile. Before covering with a layer of gravel to reduce water evaporation the system was dampened with distilled water and nominally 1.3 g of "Osmocote Plus" (Scotts Miracle-Gro Company, Surrey, UK) slow release fertiliser was added to speed up the development of the biofilm. Following this exposure of the geotextile to oil, water and inorganic nutrients in for a period of two weeks microscopic examination demonstrated that biofilm was capable of establishing on the fibre surfaces,

The material is certainly capable of supporting a biofilm. Work is ongoing to investigate to investigate the use of previously developed molecular biology tools to compare the microbial diversity achieved on this geotextile compared to that on the heat bonded polyolefin previously investigated (Newman et al., 2004b) by the Coventry University research group.

HYDROCARBON RETENTION EXPERIMENTS

Two main series of oil retention experiments were conducted using small and larger scale test facilities.

Retention Experiment 1

The first experiments to investigate the oil retaining capabilities of this geotextile were carried out using a small scale experimental rig described above for the biofilm studies except that in this case no gravel layer was installed. Oil was applied at a rate equivalent to 6 litres of oil (Castrol GTX) per 10 m^2 parking bay. This was a very short term experiment over 200 minutes under rainfall conditions equivalent to 50mm/hour. The effluent was analysed using a oil and grease analyser (OCMA 310; Horiba Ltd., UK) as described previously (Newman et al., 2004b). Effluent monitoring results are presented in Figure 3 showing a maximum discharge of 4.5ppm during the beginning of the experiment and during consecutive rain events a mean concentration of 1.5ppm was measured.

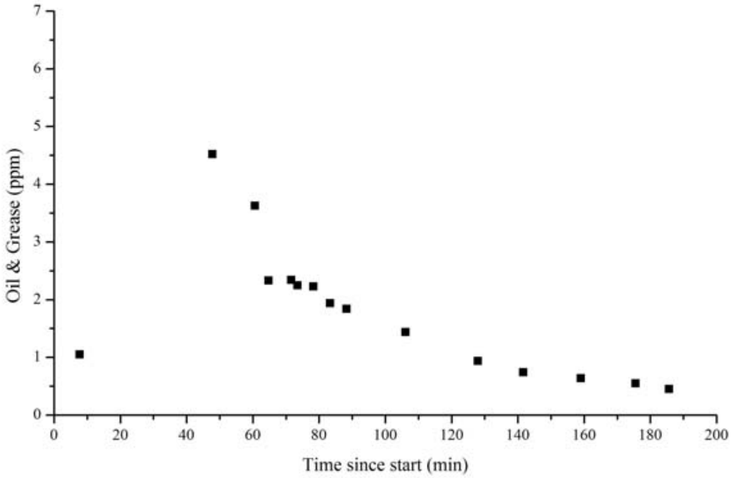


Figure 3 Initial Dynamic Retention Trial

Retention Experiment 2

The next experiment followed on from the small scale tests reported above and were carried out in 710 mm x 360 mm x 350 mm deep silicone rubber-bonded fish tanks each of which had a 50 mm hole cut into the base to accommodate a borosilicate glass funnel to collect the effluents. Each tank was extended in height with a 150 mm high HDPE insert. 5 separate experiments were carried out each based on a nominal oil application of 6 litres per 10 m^2. The geotextile samples were folded using “hospital corners” to form a pan and thus prevent escape of hydrocarbons at the edges.

When these lager scale repetitive tests were performed on the new geotextile it was intended that it should again be tested without any additional hydrocarbon adsorbing surface area of a

pavement cross section (subbase, bedding layer and blocks). They were thus supported on a single polypropylene Permavoid void forming box, assuming that, compared to the sorbing potential of a stone subbase, such a support structure would provide minimal oil retention on its own, relying almost exclusively on the geotextile for such performance. Figure 4 is a schematic cross section of the model system used. Figure 8 below illustrates the results obtained in this experiment.
Having been satisfied that the results obtained indicated that the retention of hydrocarbons by the new geotextile were reproducibly good a series of comparative experiments were performed comparing a number of model pavement cross sections.

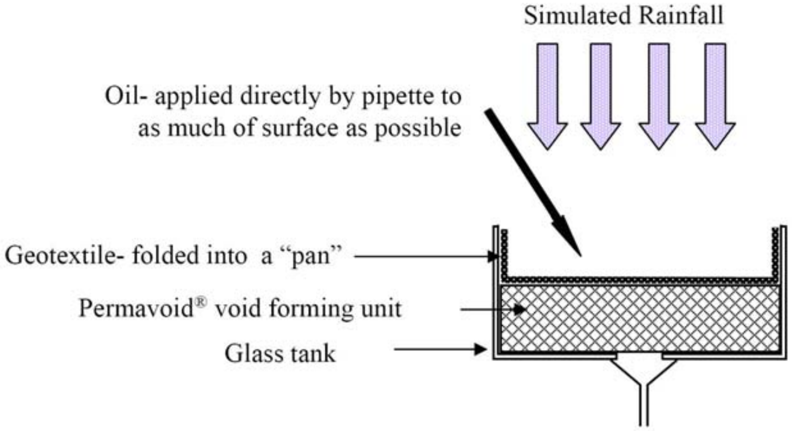


Figure 4 Cross section of larger textile-only rig

These comparative experiments again used the fish tanks described above but for the deeper stone based cross sections the glass fish tanks were vertically extended using welded-to-fit rectangular plastic sleeves so as to accommodate both the additional depth of stone subbase.

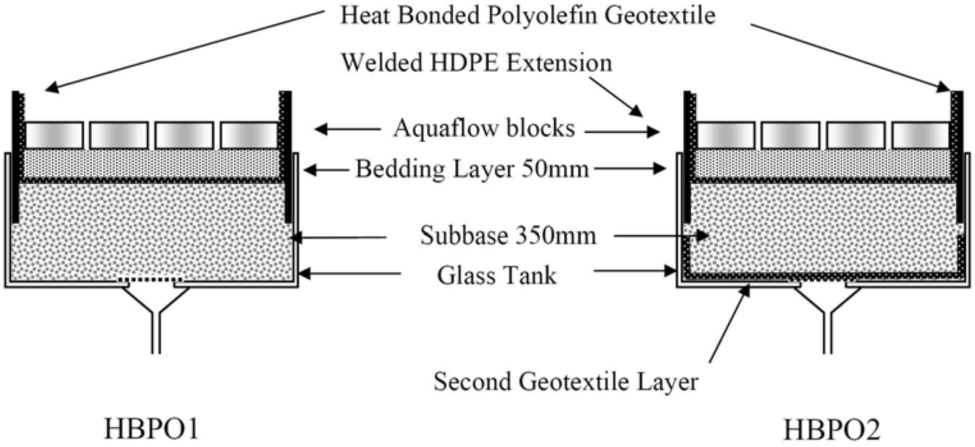


Figure 5 Schematic Experimental Systems Using Heat Bonded Polyolefin Geotextile HBPO1- single upper layer, HDPO2 Upper and Lower Layers

In the case of the new geotextile a "worst case" scenario for a pavement cross section was adopted in that the system was based on a Permavoid box subbase replacement with the geotextile placed directly on the box to support the 5-10 mm gravel bedding layer (50 mm deep) and a layer of paving blocks, as was used on all the cross sections tested.

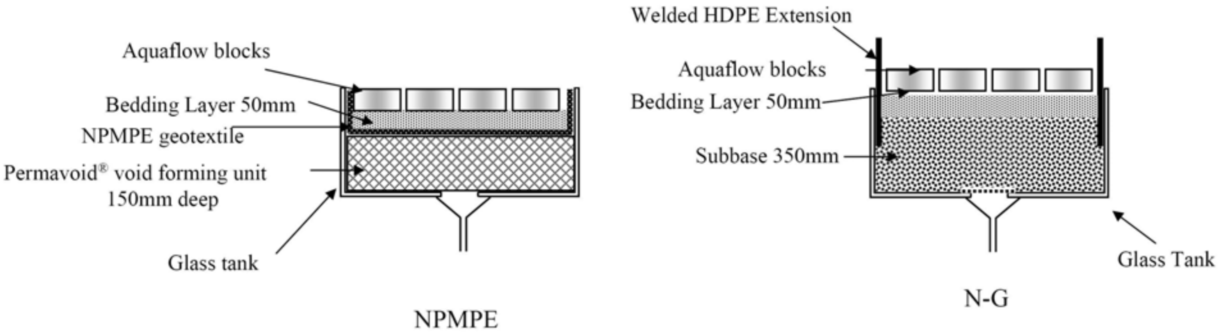


Figure 6 Experimental systems for the new geotextile (NPMPE) and Non-Geotextile (N-G) pavement sections

Four different subbase arrangements were tested, One was based on the non-geotextile design proposed by Interpave (Interpave, 2005) using the subbase specified. The other three arrangements included geotextiles, one included the new geotextile fitted between subbase and bedding layer, one was constructed with Inbitex® (Formpave, UK) between subbase and bedding layer and another had two layers of geotextile, one between subbase and bedding layer and one below the geotextile. In these cases the subbase was as specified by Formpave (Formpave, 2007).

RESULTS AND DISCUSSION

In terms of biological studies the novel geotextile still requires further work before firm conclusions on the biological capabilities of the system can be drawn. However in the brief colonisation studies carried out there seems to be no problem in establishing a biofilm which can grow with hydrocarbon as the prime carbon source. Ongoing long term durability tests carried out according to British/European standards (BS EN 13249:2001) have indicated that the structure of the geotextile is not broken down by the action of micro organisms and can serve more than 25 years. What remains to be shown is whether the polarity characteristics of the textile will enable water retention such that microbial activity is retained in drought conditions but it must be understood that the ability of a PPS system to break down hydrocarbons is a product of both biological factors and the ability of the system to retain the pollutant until activity becomes established (or re-established). Given the retention results presented below and the initial results from microscopic studies (see Figure 7) the author's have every confidence that long term biodegradation capability will be shown to be at least as effective as found with geotextiles of lesser oil retaining capability.

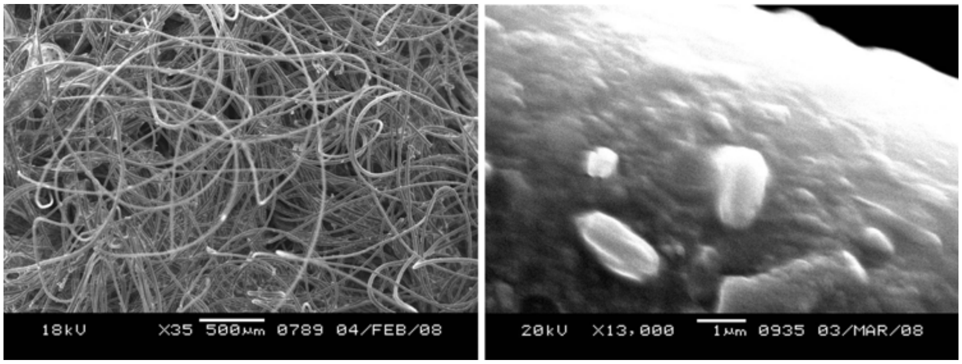


Figure 7 SEM micrographs of NPMPE textile showing general structure of the textile (left) and initial biofilm formation after incubation for two weeks (right).

The tests on the geotextile-only models were carried out using a rainfall intensity of 50.0 mm/h over a period of three hours using an oil (Castrol GTX) application of 600 ml/m^2 (equivalent to a loss of 6 around litres of on a single car parking bay). Six replicate tests were carried out on the new geotextile, over a period of 189 minutes using application of water equivalent to a rainfall intensity of 50 mm/h. Figure 8 illustrates that during this period the peak concentrations measured were all below 5 mg/l except for a single excursion to 5.1 mg/l during replicate 2. In retention experiment 2 on the pavement cross-section models measurements were carried out over 18 rain events following an oil application of 600 ml/m^2 except for the design without the geotextile which from rain event 1 produced concentrations greater than 200 mg/L thus exceeding the upper range of our analytical method. Since free product was also clearly evident a reasonable dilution could not be made. The experiment on this design was thus discontinued after a series of four rain events exhibited the same result.

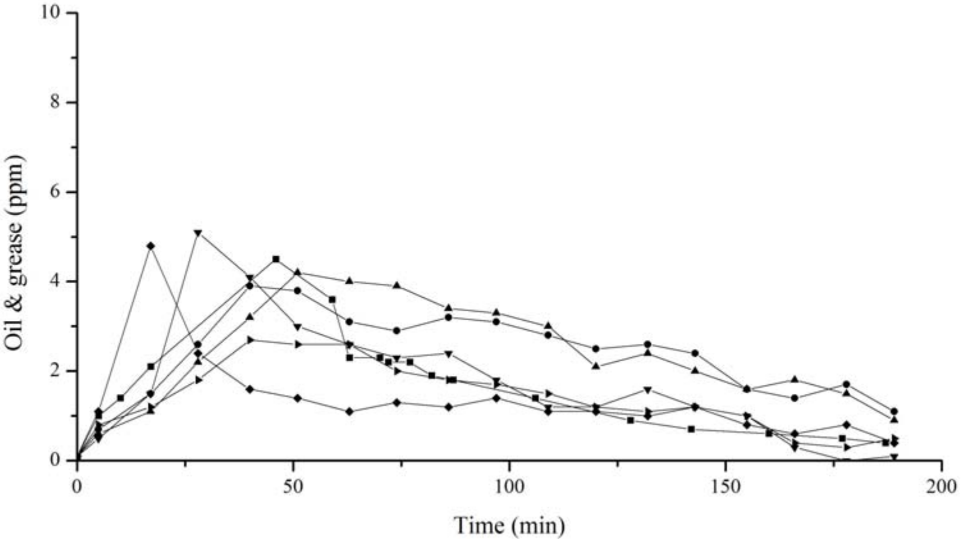


Figure 8 Oil and Grease concentration during a 50mm/h rain event for 6 replicate experiments using the geotextile-only rig. Oil applied 600ml/m^3

Figure 9 illustrates the results obtained for experiment 2. Clearly there is a great improvement with the model equipped with the heat bonded polyolefin geotextile (HBPO1) over the non-

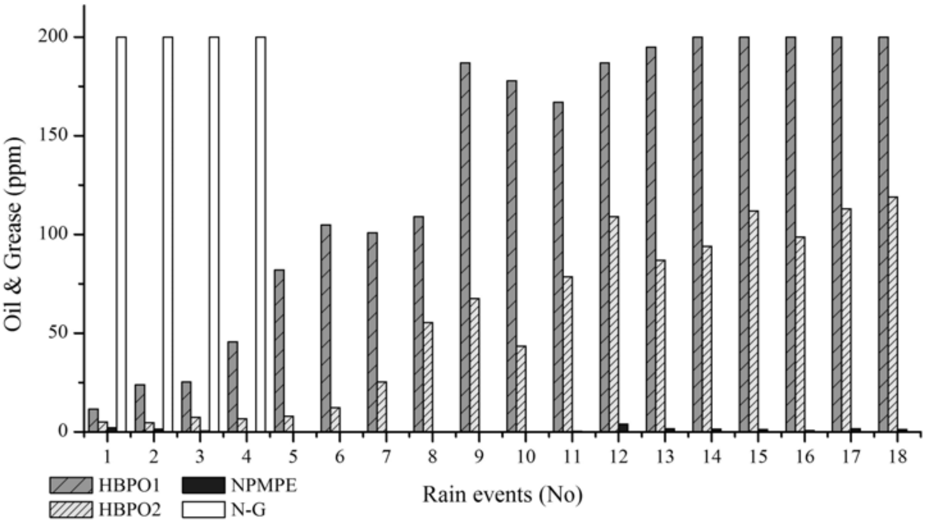


Figure 9 Experiments on Pavement Cross Section Models

geotextile design (N-G) and if an additional geotextile is applied below the subbase (HBPO2) a further dramatic improvement in performance is observed. However the needle punched modified polyester (NPMPE) rig showed a better performance than all of the other designs tested. In the case of HBPO1 the concentrations reached the 200 mg/l upper limit of the analytical system after 14 rain events. Whilst these experiments represent only the initial short term response of the systems under test it is clear that if such performances were to be replicated following real spillages the new geotextile would offer considerable improvements over the standard polyolefin geotextile and also that both geotextile-equipped systems offer an advantage over a non geotextile system with respect to short tem oil retention. The mechanism for the oil retention of the no geotextile system (N-G) entirely relies on physical interaction with the stone/concrete materials. Once the critical mass of oil is reached these forces are overcome resulting in the release of oil from the N-G system. The HBPO1 and HBPO2 systems do not rely on these effects alone. The interaction with the geotextile benefits from a temporary separation layer with oil distributed on the water film above the textile. With sufficient build-up of hydrocarbons the oil will start penetrating the textile due its own weight. This effect can take place during the same rain event or consecutive events or after periods of drying with a following rain event. These effects are strongly related to the amounts of oil and their resulting layer thickness. However with thermally bonded textiles it needs to be mentioned that the finished product quality of those can show huge variations in mass per surface area resulting in very thin/weak areas neither filtering particulates nor interacting with hydrocarbons pollutants. This is particularly the case with lighter-weight thermally bonded geotextiles of below 200g/m^2. For the new textile (NPME) an eventual oil loading limit would similarly apply but because of the interaction between the oil and the modified fibres the required mass is much greater, thus explaining the greatly increased performance.

CONCLUSION

This work demonstrates that in moderate oil spillage scenarios the use of geotextiles in pervious pavement structures will significantly reduce hydrocarbon pollutants in run off from pavement structures compared to structures without geotextiles and that the NPMPE geotextile can do so to very low levels compared to polyolefin geotextiles.

Furthermore it renders effluent suitable for discharge into controlled waters even when subjected to larger hydrocarbon loadings. This novel geotextile provides an additional treatment stage within drainage applications using geotextiles without compromising common geotextile properties. The experiments presented here were based on permeable pavement structures. However the authors believe that utilisation of the novel geotextiles should provide oil retaining benefits for most infiltration practices.

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