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Evaluation of the Effectiveness of Wrapping Filter Drain Pipes in Geotextile for Pollution Prevention in Response to Relatively Large Oil Releases

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ABSTRACT

French drains or infiltrating filter drains are commonly fitted with slotted plastic pipe to act as an overflow mechanism when rainfall is too great to allow complete infiltration. The release of the effluent from such pipes is commonly to surface water courses. Whilst there is expected to be some slight degree of protection against hydrocarbon release because of interaction with the drain's stone infill material this will be severely limited. This paper reports an experiment in which model filter drains with or without geotextile sleeves around the slotted drain are challenged with lubricating oil. The textile was a surface-treated non-woven geotextile manufactured from polyester. The models were challenged with very high loadings of oil, as would be anticipated in a motor vehicle collision occurring close to the drain. A series of simulated 10-20mm rain events over 1 hour were applied and two sample types were collected which either included or excluded any free product. Additional aliquots of oil were added at each rain event. The un-sleeved models were found to release visible free product with the addition of as little as 100ml of oil per linear meter of drain. For the models with geotextile sleeves there was no such release with as much as 2000ml per linear metre. Analysis showed that under these conditions the geotextile sleeved pipes continued to produce effluent with hydrocarbon concentrations well below the 5000µg/l limit usually accepted in the UK.

INTRODUCTION

In the UK and Europe the name given to the types of drainage system which attempt to minimise flooding and maximise quality are called Sustainable Drainage Systems (SuDS)(EA, 2012, Bastien *et al.*, 2010) (or by some authors Sustainable Urban Drainage Systems (SUDS)(Abbot and Comino-Mateus 2003) The SuDS concept is broadly equivalent to the North American concept of Best Management Practices (BMPs) (EPA, 1993) or Low Impact Development (LID)(Dietz, 2007). The performance of SuDS elements in the retention of hydrocarbons is one of the most important characteristics of a SuDS treatment train (Heal *et al.*, 2004) and this is particularly the case at the upper end of the treatment train system since the loss of hydrocarbons from the first element of a treatment train can seriously affect the effectiveness, in terms of both quality and amenity of a downstream installation, such as a detention pond which may have ecological or amenity value.

Included amongst what are known as “in-ground SuDS” are devices that are variously identified as filter drains (Jefferies, 2001), french drains (Cooper, 2002.) or infiltration trenches. Although this latter term is usually restricted to linear systems which convey and infiltrate water, but lack a perforated pipe to carry the non-infiltrated water to a watercourse (Doyle *et al.*, 2003). Filter drains also feature regularly when required within restricted space such as along the margins of highways. The earliest study which looked at the pollution attenuation effectiveness of these installations appears to be the study by Perry and McIntyre (1986) on a filter drain on the M1 motorway near Luton. Notably, they measured oil and for example one storm event reported showed that, comparing the filter drain with untreated runoff, the oil concentrations were 3.7mg/l and 30mg/l, respectively.

The pollution reduction capabilities of filter drains depend on a number of mechanisms including sorption, precipitation, physical entrapment and biodegradation. In the latter case for the process to be effective the pollutant needs to be held in the system long enough for this relatively slow process to take place. The introduction of an overflow pipe to rapidly transport water during heavy storms would seem to encourage the rapid loss of pollutants. The primary aim of this research was to investigate the extent to which sleeves of geotextile wrapped around a slotted drainage pipe could prevent the loss of free product oil from a model filter drain system. The geotextile studied here (Permafilter, Permavoid Ltd, UK) is a needle punched textile and has been engineered to prevent the passage of oil by means of a high and uniform fibre density and a surface treatment to the polyester fibres. The use of geotextile in pervious pavements has been shown to be advantageous to the development of an oil degrading biofilm (Coupe *et al.*, 2006) but for typical heat bonded polyolefin geotextiles their oil retaining capability, in pervious pavement applications, when subjected to heavy oil loadings, has been shown to be limited (Newman *et al*., 2004). The enhanced barrier to oil transmission provided by Permafilter, relative to the performance of a standard heat bonded geotextile, has been previously reported (Puehmeier *et al.,* 2008). The passage of bulk free oil through this geotextile is prevented by the surface chemistry of the fibres which resists the passage of a bulk flow of the liquid oil until the pressure becomes very high. In addition the fact that the needle punched non-woven fabric is uniformly dense provides no areas where smaller droplets can pass through without being forced to impact on the fibre. Whilst held in the fabric, the previously suspended oil droplet will grow in size by interaction with subsequent drops until it becomes much bigger than the pore size of the textile and thus will either be retained or, if held close to the surface, will float off once the forces of buoyancy exceed the interaction with the fabric. To date, all tests on this textile have been related to its original design application, on horizontal surfaces as it would be used as a geotextile layer in a pervious pavement application but no attempt had previously been made to systematically study this material as a sleeve which is wrapped around outlet pipes in both PPS and filter drain applications.

Unless there is a well established oil degrading biofilm no geotextile will have a significant impact on the release of aqueous phase dissolved hydrocarbons. Even with a biological element in place, the effect of biodegradation during the rain event, rather than between rain events, will be minimal. The rate of dissolved oil release is dictated by the kinetics of dissolution of the hydrocarbons. However at very high flow rates the dissolved fraction will be less significant but there will be an increase in the entrainment of small droplets. The trade off between increased entrainment and dilution is difficult to predict and will depend greatly on the structure of the system under study. During this investigation, an attempt was made to study both the release of free product oil and, in the earlier stages of the study, the dissolved and finely dispersed fraction of the released oil during repeated high rain events.

From the point of view of environmental harm, it is the release of a visible sheen of free product oil that is one of the most important characteristics of oil pollution. Whilst the average concentration of oil in a large water body may be very low, the concentrations of toxins in the layers of water close to the sheen will be extremely high and the harm caused to organisms that live on or near the surface will be great (including both chemical and physical effects). Furthermore, the appearance of a visible sheen is seriously detrimental to the amenity of a water body, whether this is the final receptor or an intermediate open water component of a SUDS treatment train.

The selection of a quality standard for the releases of dissolved and dispersed hydrocarbons is very difficult. The 5000 µg/l limit for gravity separators (British Standards Institution 2002) also includes any free product collected in the sample. This fraction was deliberately excluded in the first phase of this study. A number of commercial and regulatory bodies have adopted, for Tier 1 assessment of the water environment, the World Health Organisation drinking water standard for total hydrocarbons in this form which is 300µg/l. This screening value is also of the same order of magnitude as a number of groundwater limit values from various jurisdictions, particularly those aimed at protecting the surface water environment. Taking this limit as it stands, without allowing for dilution, is justified by the possibility that in a SUDS treatment train there may be open water bodies, of important ecological and recreational value, that are essentially receiving all of their water from the surface drainage system. With this in mind, a limit value of 300µg/l was adopted as the “failure point” for dissolved and dispersed hydrocarbons with a “failure” also being triggered by the release of visible free product or by a total oil concentration of over 5000µg/l.

MATERIALS AND METHODS

The apparatus used is shown in the schematic in figure 1. The plan size was 500mm x 500mm. The sleeves were stitched to form a cylinder matching the external diameter of the 178mm slotted pipe and held in place with tight fitting neoprene O-rings at either end. A tap to allow drainage and level control was provided in the supplementary box. During the simulated rain events this tap was used to maintain the level of water in the supplementary tank to approximately half the depth of the pipe. In the final design the sampling tap was replaced by a simple spigot attached to a flexible pipe. The purpose of the supplementary tank was to provide a clear flat surface so that the escape of free product could be easily detected. It also served to separate free product from the dissolved and dispersed oil so an integrated sample without free product could be obtained. Six (6) tanks (three replicates for each treatment) were mounted with sufficient height for them to drain into the shallow floor level tank. A drainage system was arranged to allow the excess water to be directed to this shallow tank before being pumped into the laboratory sink by a submersible pump arranged such that floating oil was not discharged. Water was applied via a spillway as shown in figure 2 and unused lubricating oil (Castrol GTX) was applied by means of a 50ml syringe directly along the line where the water spilling from the spillway impacted the layer of stone. This was to simulate a loss of oil which runs into the filter drain and then being immediately impacted by a large storm. Thus free product oil at the surface was impacted by high velocity water.

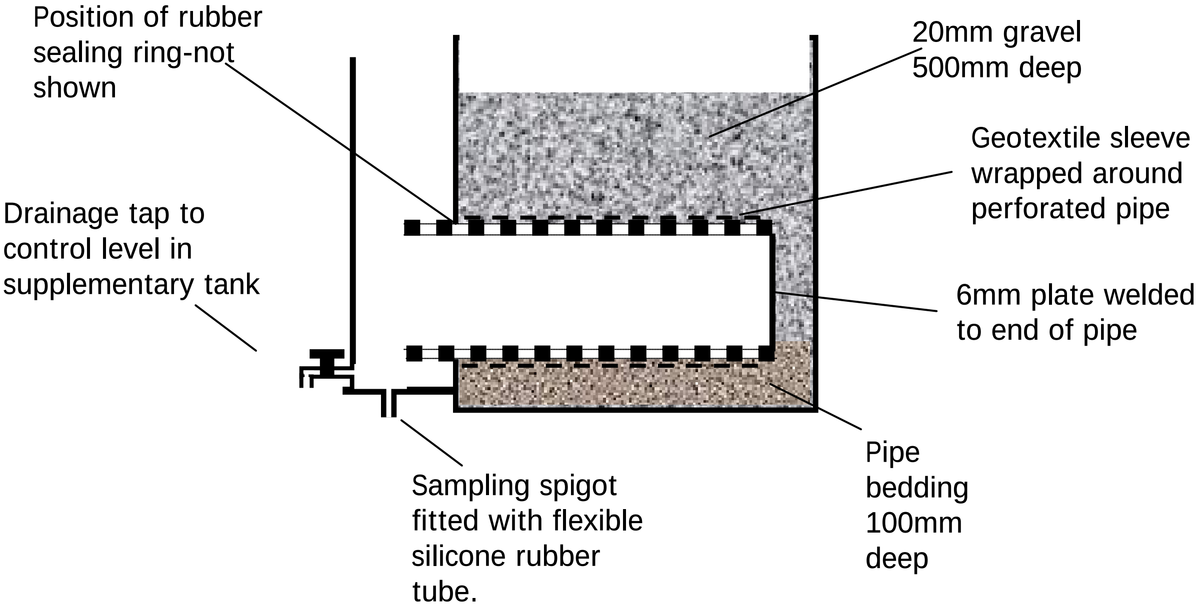

Figure 1 Schematic of Test Models Used

The two different model types were:

1) Models with the pipe only with no sleeve
2) Models with a sleeve made of Permafilter.

Before starting the experiments a 20mm simulated rain event was applied (over 1 hour) to each of the models and integrated samples were collected as indicated below. All results were below the 10µg/l limit of detection for total petroleum hydrocarbons**.**

Sampling Regime 1

This sampling regime was intended to investigate the release of dissolved oil and finely divided droplets, excluding any free product. Five rain events were applied in this initial phase. The first one was a 10mm event and the remainder were 20mm events. All rain events took place over 1 hour. The flow rate was based on a catchment area of $20m^2$ per linear metre of drain. No deliberate provision was made to simulate direct rainfall onto the aggregate but there was sufficient splashing to ensure that the aggregate surfaces were wet by the end of the rain event.

On the first 2 rain events 50ml of oil was added just before the rain event. For the next event, the volume added was 100ml and for the next 2 events it was 200ml.

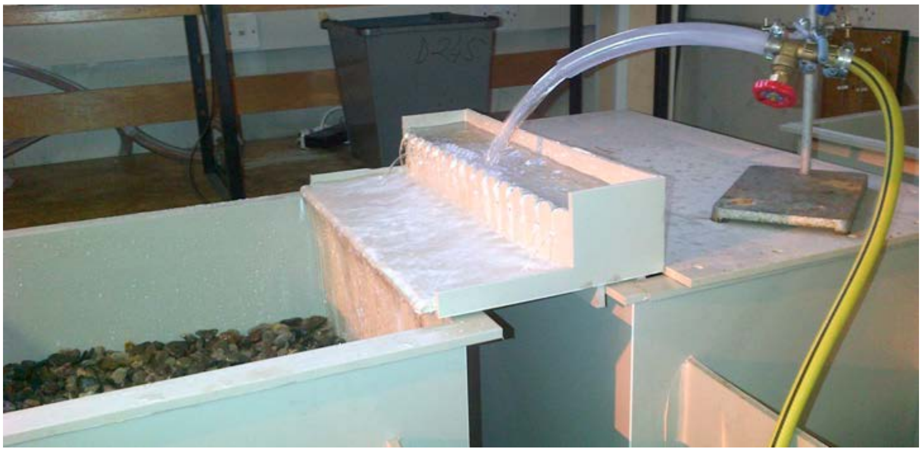

Figure 2 - Spillway in operation

Continuous observation for free product was made during all rain events. Ten 25ml sub samples were collected from the supplementary tank at regular intervals throughout the events and were pooled to form composite samples. Samples were analysed at a laboratory accredited for the determination of Total Petroleum Hydrocarbons by solvent extraction followed by GC-FID. Rain events were such that for any particular model the time between events was at least 1 week.

Sampling Regime 2

Once the models had been significantly loaded with hydrocarbon and the loss of dispersed hydrocarbons from the un-sleeved models had become significant it was decided to investigate the potential effect of the loss of free product in terms of the total hydrocarbon concentrations released. By the end of the initial tests, a total of 600 ml of oil had been added to each model. A further 2 test runs were carried out with an application of an additional 200ml of oil at each test. This resulted in a final loading of 1000ml, equivalent to 2 litres per linear metre of drain. In these two tests two 250ml samples were collected in each rain event. The first sample was taken at the first sign of free product and the water continued to be applied until a 20 mm rain event had been simulated so as to allow the flushing out, where possible, of the most mobile of the hydrocarbons. The water flow was then discontinued and the water was allowed to drain out of the system until the flow rate from the outlet pipe had been reduced to a steady trickle with the aim being to collect as closely as possible the last 250ml of effluent (labelled “slow discharge”). If no free product was observed only a “slow discharge” sample was collected after the 20 ml rain event application had been stopped. In this sampling regime, water samples were collected directly from the effluent outlet with no attempt to exclude the free product and were deliberately aimed at obtaining worst case samples. At the first attempt to do this procedure, all “first flush” samples from the un-sleeved models were over the range of the analytical method and the amount of oil caused damage to the GC capillary column. Because of this the results from the 6th sampling event is not reported. Following a consultation with the laboratory the analytical method was modified to safely allow a greater range in all samples presented to the lab with visible free product. However, this was outside the scope of the formal validation of the method and, whilst there is no doubt that the concentrations from the un-sleeved models were extremely high, the values reported must be viewed as indicative only. One must also acknowledge the great uncertainty when sampling a flowing stream containing two phases, the relative contributions of which vary greatly with time, and this probably contributed to the high variability between models with the same treatment.

RESULTS AND DISCUSSION

Performance with Respect to Dissolved and Dispersed Oil

The results obtained with respect to the release of dissolved and dispersed hydrocarbons are shown in figure 3. We can see a steady increase in the concentrations in the effluent from the un-sleeved models but a relatively constant and lower value in the sleeved models. The increase in measured TPH from samples which excluded the free product is probably due to the release of verysmall disperseddroplets that are being effectively excluded by the geotextile sleeves. In the final rain event shown in figure 3 the maximum value measured from the three un-sleeved models was 21400µg/l some 25 times the value of the median. This has been removed from the plot as a probable outlier which possibly occurred as an artefact of the sampling regime but readers should bear this in mind when interpreting the data and that the difference in performance could be even greater than shown in figure 3.

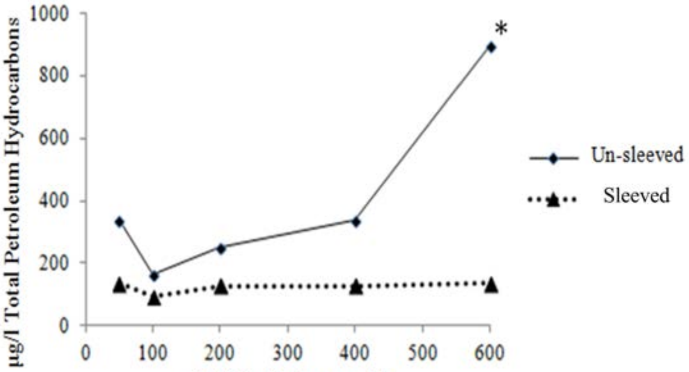

Figure 3: Mean concentration of oil released against total volume of oil added to each model. n=3 except for * where n=2 (massive outlier removed)

Without removing the outlier the mean value of that point would be 7500µg/l which is in excess of the UK limit for a class 1 gravity separator. In this experiment, the overall mean for the un-sleeved models exceeds the adopted 300 µg/l standard by the final rain event (whether the outlier is removed or not) and they exceeded that value in at least 1 model for all but 1 of the rain events. For the sleeved models no single sample exceeded that standard with the overall mean at less than 48% of that very conservative value. Clearly from the point of view of the most dispersed fraction of oil the value of this geotextile sleeve is significant.

Concentrations of dissolved and dispersed hydrocarbons, which were initially relatively low in both treatments, grew rapidly in the un-sleeved pipes as the amount of added oil was increased (whilst the concentration from the sleeved models remained low). The initial low concentrations are because the release rate of dissolved and dispersed oil is dependent on the kinetics of release rather than an equilibrium concentration. With the water passing through the system at a high rate we expect to see significant dilution whilst the amount of finely dispersed oil leaving the system will depend on the rate at which such small droplets are generated. In turn this may be expected to be dependent on the degree of contamination of the stone fill and the barrier posed by the geotextile. It is clear that the un-sleeved pipe offers little barrier to their escape. It should be remembered that this experiment was carried out in such a way that little biological oil degradation could have contributed to the performance observed.

Visual Observation Of Free Product

Table 1 shows the performance in respect of visual observation of free product released throughout all of the 7 experimental rain events. It is clear that the un-sleeved models failed immediately in respect to free product release. The response was virtually immediate with free product observed as soon as a level plane of water had been established in the supplementary tank. Since the models were 500mm sided squares in plan, we can see that the geotextile used is capable of preventing the release of oil when accumulating in the filter drain at a rate of at least 2 litres per linear metre of drain.

Table 1 Performance of the models with respect to free product release.

	Un-sleeved	Sleeved
Volume of oil added before first release of free product from **all** of the 3 models in a single rain event	50ml	No Free Product
Number of rain events when free product was released.(including both sampling regimes) max=7	7	0

Quantitative Measurements of Free Product

In the final 2 rain events the sampling regime deliberately targeted the free product and table 2 shows the large differences which were observed between the treatments indicating disturbingly high concentrations released when free product is included in the sample. The very low concentrations in the “slow discharge” samples from the sleeved models may indicate that the rain event had flushed what little dissolved oil was present prior to the sample being taken, with the geotextile acting as a barrier to the dispersed oil.

Table 2 performance during 7th rain event and after 1000 ml oil of added

	Un-sleeved	**Sleeved**
Mean concentration total hydrocarbons µg/l (3 models) collected during initial free product discharge	125467	No Free Product
Mean concentration total hydrocarbons µg/l (3 models) collected in final 250ml of discharge	42577	<10
Maximum concentration of total hydrocarbons µg/l collected during initial free product discharge	301000	No Free Product
Maximum concentration of total hydrocarbons µg/l collected in final 250ml of discharge	105000	<10

CONCLUSIONS AND FURTHER WORK

Whilst the filter drain without the sleeve releases free product oil immediately under the test conditions used, the wrapping of the pipe in the geotextile used provided advantages both in terms of free product release and the concentration of dissolved and dispersed hydrocarbons. The concentrations of dissolved and dispersed oil from the un-sleeved models exceeded the environmental quality standard adopted but the sleeved models provided excellent performance, with the maximum value not exceeding the standard and typical values not even approaching it. The low concentrations of dissolved and dispersed oil during the early parts of the experiment were perhaps to be expected as the volume of water passing the system was high leading to dilution of the oil which is largely controlled by the kinetics of release.

The large surface area of stone and the tendency of the rising and falling water level to smear much of the oil onto parts of the system less strongly scoured during storm events would be expected to result in a relatively low release rate until sufficient oil was present throughout the system to expose a large mass of oil to the rapidly moving water. Another factor to consider is that these models only contain a short length of pipe. Where free product enters the pipe, the turbulence encountered during passage to the discharge point in intense rain events would tend to increase significantly the emulsified fraction. Experiments involving a range of different water flow rates would be worthwhile. An ongoing study on these models in terms of the degradation of the oil trapped in the system would also be of tremendous value and will form the next phase of this study. After significant oil had been added and when free product was not excluded from the samples the difference in performance between the two types of models used was large and in particular the geotextile used was found to be capable of totally preventing visible free product release under the conditions of the experiment. Further planned experiments include the combination of a sacrificial, horizontally laid geotextile layer laid near the surface of the filter drain. This should provide an even better performance with respect to oil retention and an easily accessible upper trap which could be easily removed following either a major oil release event or one which might lead to blockage.

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