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A Novel Device for the Removal of Grits and Oils from Stormwater Run-off

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ABSTRACT

With increasing urbanisation, the problems of stormwater run-off from impermeable surfaces are becoming more apparent. Run-off from roads and parking areas often carries a high sediment load, and this, along with other associated pollutants, for example, polycyclic aromatic hydrocarbons (PAH's) and oils, can have a detrimental impact on receiving watercourses. The objectives of this work were to develop an effective, high rate, separator system for the treatment of stormwater run-off prior to discharge.

Data has been obtained from laboratory testing of a 1.2 m diameter prototype. This has indicated that removal efficiencies of up to 100 % are achievable when tested with sand, floatable particulate material (plastic beads) and oils. The head loss across the system prior to the operation of an integral emergency bypass was measured to be less than 125 mm.

The work has lead to the enhancement of the Downstream Defender™, a compact and economical stormwater treatment system. The improvements to the system have included both performance and operational enhancements, and modifications that have implications to a simplified installation procedure.

INTRODUCTION

The problems associated with increasing urbanisation in terms of increased stormwater run-off with reduced quality have become topical issues. Traditionally, stormwater has been perceived as a minor pollution source, and has frequently been discharged into the most convenient watercourse. However, as more significant sources of pollution have been either eliminated or alleviated, its significance has increased. Run-off from roads and parking areas can contain pollutants including sediments, heavy metals, asbestos, polycyclic aromatic hydrocarbons (PAH) and detergents as well as street litter. Many of these have been shown to have adverse effects on marine and aquatic environments, causing lasting damage to flora and fauna [(1)]. In recent years, environmental directives worldwide have moved towards addressing these issues.

The 'Mk2 Downstream Defender ™' has been developed as a compact, cost-effective device for the removal of both settleable and buoyant contaminants from stormwater prior to its discharge. The paper will describe the principles, development, test procedures and performance data for this new separator.

Initial work prior to 1999 was carried out on model scale units. Subsequently, a number of prototype units have been evaluated with the aim of meeting the requirements of the forthcoming European standard for 'light liquid separators' [(2)]. Testing has included evaluation of the removal efficiency of the system for graded sand, floatable plastic pellets, and vegetable oil. The results show that the total removal efficiency for the sand tested (of which 62 % was finer than 300 microns) was up to 100 %. Efficiency data obtained for the floatable material (density of 954 kg/m^3) has also shown up to 100 % recovery.

Work is currently ongoing at Coventry University's School of the Built Environment. This work involves testing the Mk2 Downstream Defender ™ in accordance with the procedure detailed within the standard. The test medias being used are oil, sand and peat.

THE MK2 DOWNSTREAM DEFENDER ™

The Mk2 Downstream Defender™ operates using the principle of hydrodynamic separation. Hydrodynamic separation occurs in rotary flow fields at energy levels much lower than those found in hydrocyclones. The principal of hydrodynamic separation was first observed by Bernard Smisson whilst working for Bristol City Council (UK), in the 1950's. Throughout the 1950's and 1960's he researched this effect in the UK to find a practical solution to the problem of combined sewer overflows [(3)]. In the 1970's he was contracted as a consultant to the American Public Works Association on a research project which culminated in the development of the US EPA "Swirl Concentrator" [(4)]. Subsequently, numerous hydrodynamic separation devices have been developed for the removal of specific fractions of the settleable material in fluid flows.

Conventional hydrodynamic separators, and indeed the Downstream Defender ™, use the primary rotation of flow in a cylindrical vessel to effect a long flow path, facilitating the separation of the settleable material. The primary flow patterns give rise to secondary flow effects, aided by the vessel's internal geometry, which cause material deposited on the base of the unit to be swept towards a central collection zone [(5)].

The Mk2 Downstream Defender™ incorporates additional enhancements compared to conventional hydrodynamic separator systems, in that it has oil, as well as grit/sediment removal capabilities. A schematic of the system is shown in Figure 1, illustrating the secondary flow effects described. Rotating flows are inherently

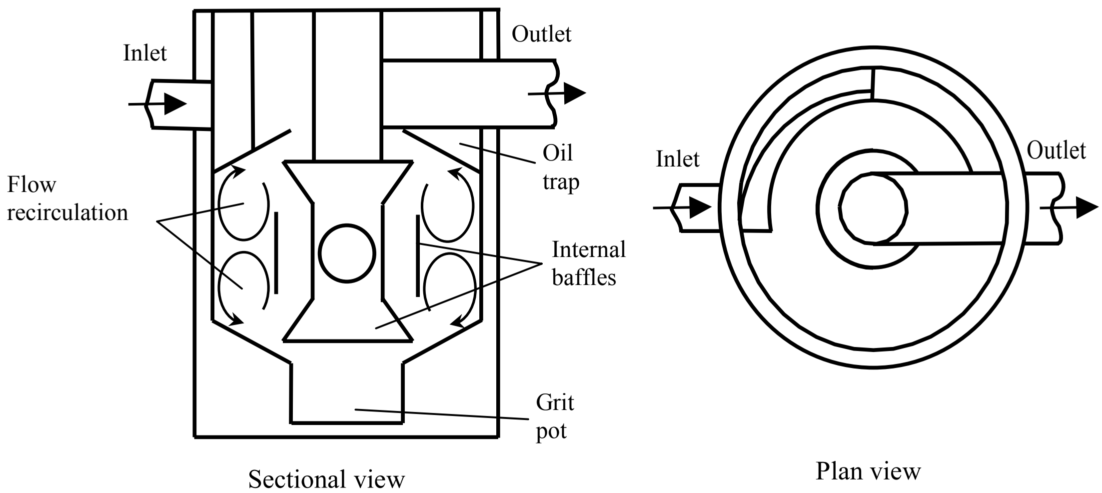

Figure 1 Schematic of Mk2 Downstream Defender ™

unstable, and this can lead to poor separation performance if not adequately controlled. The internal components of the Downstream Defender™, which have evolved over decades of development, provide both a controlling and performance enhancing effect. The cone shaped sections above the grit pot and below the floatables/oil trap provide stagnant zones which ensure that collected material cannot be re-entrained.

Flow passes into the unit through the inlet pipe into a flow splitting chamber. During periods of normal flows the stormwater is directed tangentially into the separation area of the vessel. The flow patterns in the separation area facilitate efficient removal of settleable and buoyant material to the grit pot and oil trap regions of the chamber. The cleaned flow then passes out of the vessel through the central outlet pipe. When the system is presented with flows greater than the design flow rate, excess flow is diverted from the flow splitting chamber, via a bypass, directly to the outlet pipe. This regulates the quantity of flow that is passed through the internal regions of the system, ensuring that material retained within the separator can not be washed out. Periodically, accumulated grits/sediments and oils can be removed using a vehicle mounted gully sucker.

The inclusion of the flow splitting (or bypass) chamber within the main vessel has implications to a simplified installation procedure, when compared to that required for systems incorporating a conventional tangential intake. The chamber allows the positions of the inlet and outlet connections to the vessel to be configured so that they are in line. This eliminates the need for an upstream flow diverting manhole, simplifying the installation procedure, as well as reducing costs, and alleviating the level of maintenance required.

LABORATORY INVESTIGATIONS

Prototype system configuration

A 1.2 m diameter prototype was fabricated from polypropylene for performance evaluation. The prototype was connected to a test rig in such a way that the flow passed in a continuous loop. A schematic of this is shown in Figure 2.

The unit was fed with water from sump tanks with a variable speed pump. An inlet box was connected directly to the inlet of the prototype unit to enable the introduction of test media into the flow, and to allow head measurements upstream of the unit to be made.

After passing through the unit the flow was discharged into a collection tank. The water then returned to the sump tanks via a flow diverter. The flow diverter allowed the flow to be discharged into a calibrated off-line tank for a timed period in order to measure the flow rate. The size of the off-line tank was such that feedback effects on the rest of the system were negligible, and of sufficient size such that the time to fill the tank was at least 20 seconds. The flow rate through the test rig was allowed to stabilise before any measurements were taken.

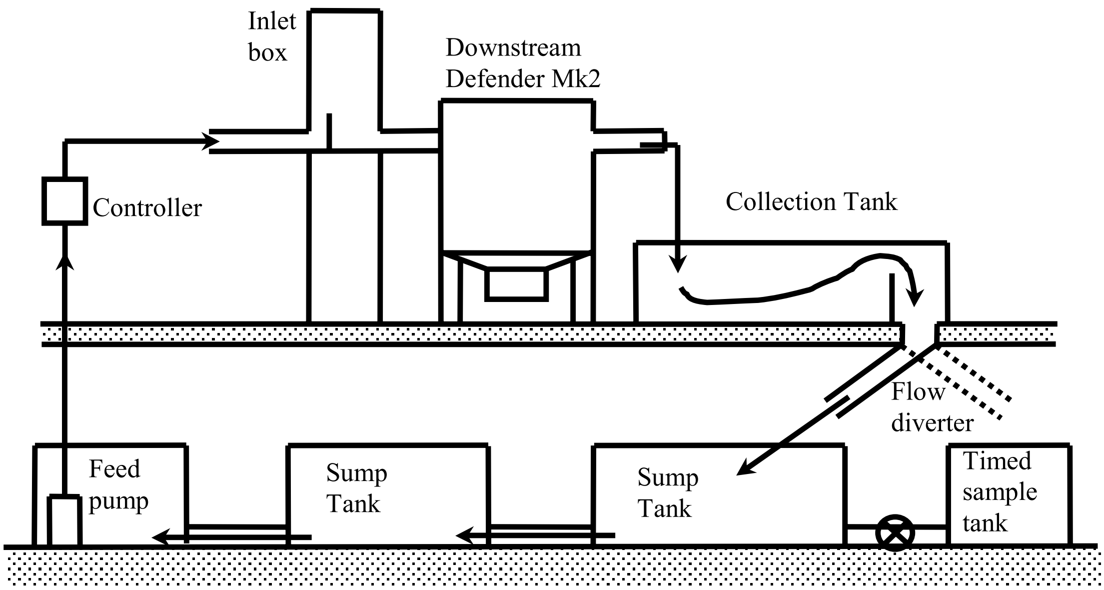

Figure 2 Schematic of the test facility

Hydraulic testing

Hydraulic testing was carried out to determine the head loss across the system and the performance of the flow bypass arrangement.

Head measurements were taken for a range of flow rates between 0 and 45 l/s. The measurements were taken from the inlet box, flow splitting chamber, oil trap, and the outlet. The heads were measured relative to the invert of the outlet.

After each set of measurements had been taken the flow rate through the system was adjusted, and was allowed to stabilise for around 20 minutes before moving on to the next test. The flow rate through the system was measured volumetrically prior to the head measurements being taken.

The head loss measured across the Mk2 Downstream Defender ™ immediately prior to the internal bypass coming into operation was less than 125 mm at 25 l/s. This is shown in Figure 3.

Figure 4 highlights the operation of the bypass system. In the case of the prototype separator the bypass was designed to operate at flow rates exceeding 25 l/s. Plotted in the Figure is the rate of flow into the main separation region against the overall flow rate pumped to the system. This clearly shows that, as intended, the flow rate into the main separation region remains around 25 l/s for total system inlet flows of up to 40 l/s, ensuring that captured material cannot be re-entrained.

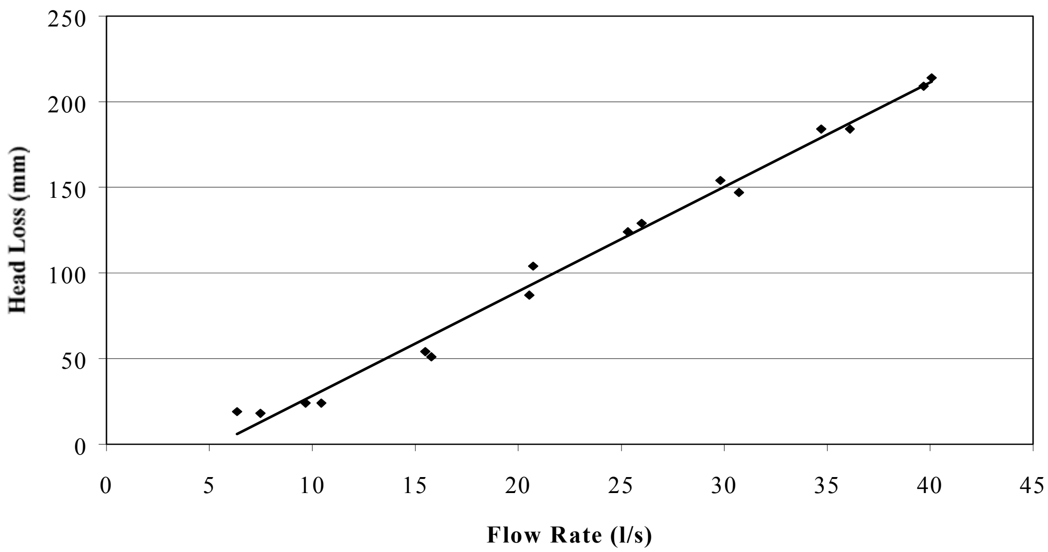

Figure 3 Head loss across Mk2 Downstream Defender ™

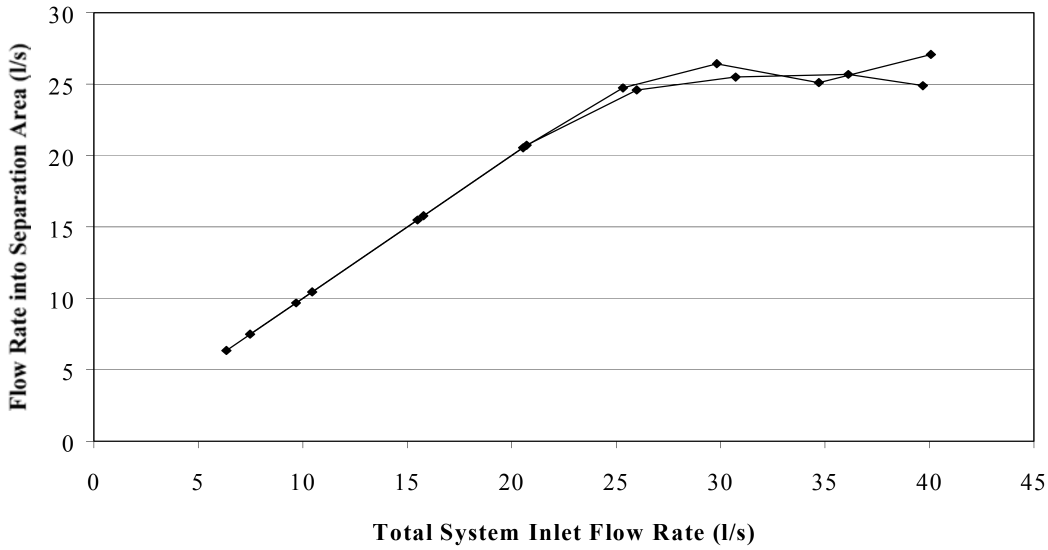

Figure 4 Flow rates showing operation of bypass

Testing using grit media

Efficiency testing was carried out on the Mk2 Downstream Defender ™ using sand. An approach suggested by Gardner and Deamer was used [(6)]. These tests were carried out for a series of flow rates between 5 and 25 l/s. For each test a known mass (1 kg) of graded sand was added to the influent through the inlet box.

Sand retained within the grit pot was removed by draining down the unit through a fine aperture porous bag. Sand lost to the outlet was captured using another large porous bag. The contents of these bags were then dried in an oven over night at 105 Celsius before being weighed and graded.

Efficiencies for each test were calculated by comparison of the masses and particle size distributions of the feed sand and the recovered sand. The grading analysis performed on the feed sand showed that 91 % by mass was between 75 and 425 μm. The minimum total particle removal efficiency measured was 73 % just prior to the bypass operating, which increased to 100 % at around 7 l/s. Figure 5 illustrates this. In order to verify the reliability of the results the efficiency was calculated on the basis of both grit removed from the flow and grit lost to the outlet. However on no occasion did these figures have a discrepancy of more than 4 %; the data presented represents that calculated on the basis of material removed.

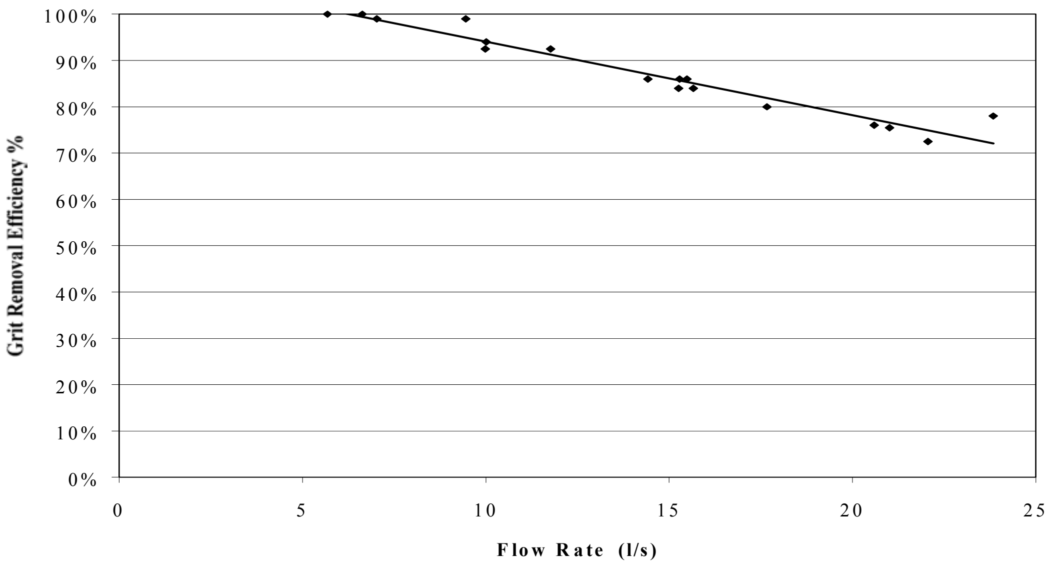

Figure 5 Grit removal efficiency

Testing using buoyant particles

Tests were carried out over a range of flow rates from 5 to 25 l/s using buoyant particles as the tracer material. The tracer material used was BP Chemicals' Rigidex HD5502XA, which has a density of 954 kg/m^3 . Given that many fuel oils have a lower density than this (~ 850 kg/m^3), and thus would have a higher rise velocity, one would expect that the use of these buoyant plastic beads should result in lower efficiencies than for a similarly sized droplet of oil. The particles were cylindrical in shape, approximately 3 mm in diameter and 2 mm long, and were measured to have a rise velocity between 3.7 and 6.9 cm/s, the average being 4.9 cm/s.

The method for these tests was similar to that used for the grit testing. One notable difference was that the temperature used for drying the particles prior to weighing was reduced to 50 Celsius.

Figure 6 presents the results of this testing. As with the testing using grit, the expected decrease in efficiency with increasing flow rate was observed, with efficiency values falling from around 100 % at 7 l/s down to around 75 % at 24 l/s.

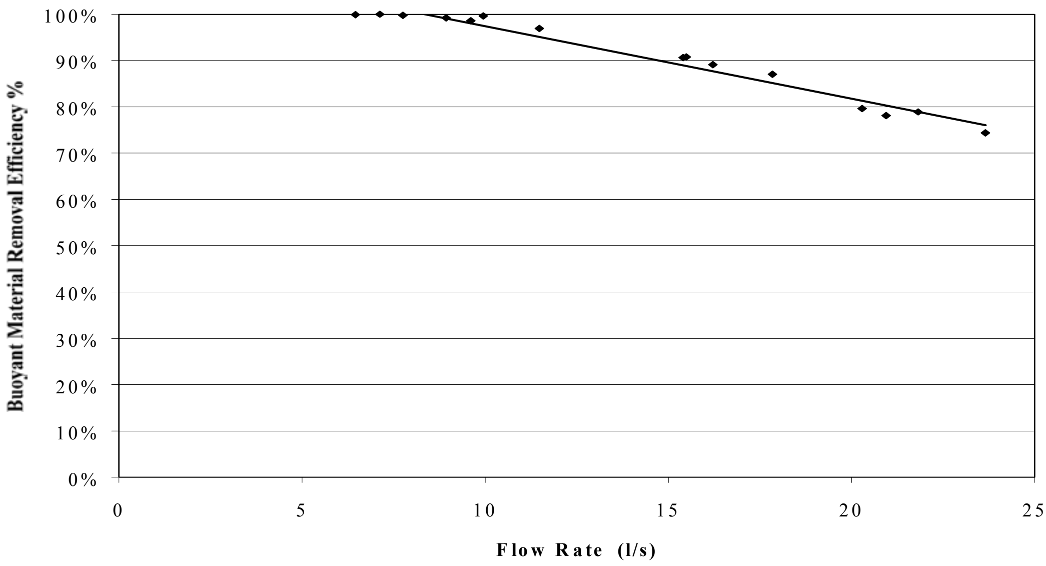

Figure 6 Buoyant particle removal efficiency

Testing using vegetable oil

A series of tests were performed on the Mk2 Downstream Defender ™ using vegetable oil as the tracer material. Vegetable oil was chosen largely to avoid the hazard issues that would be associated with using fuel oil, as recommended by the draft European Standard for oil interceptors [(2)]. Vegetable oil, with a density of 910 kg/m^3, is less buoyant than fuel oil, and therefore for equally sized droplets, is more difficult to separate. A disadvantage of its use is that it is more soluble than fuel oil in water.

The oil was added to the inflow by means of chemical dosing pumps at a rate of approximately 500 ppm. The delivery pipe from the dosing pump was positioned such that all of the oil entered the separator system. As with the previous tests the system was allowed to stabilise before taking samples or measuring flow rates. In order to measure the efficiency of the unit, grab samples were taken from the inlet (upstream of the oil addition point) and the outlet at one minute intervals for a period of five minutes. Efficiency calculations were based on the arithmetic mean of the oil concentrations in the five samples. Samples were taken from the inlet in order to enable the elimination of the effects of oil re-circulation. The samples were analysed using a specially calibrated 'Hach DR2000' spectrophotometer. A number of the samples collected were also sent to an external laboratory for analysis, the comparison between internal and external analysis is shown in Table 1.

Table 1 Comparison of analysis results

Sample analysed	Internal analysis results ppm	External analysis results ppm
Overflow 2 run 12	22	15
Overflow 3 run 12	20	15
Overflow 4 run 12	17	9

Given the extremely low levels that were experienced, the correlation shown is considered acceptable, thus validating the spectrophotometer technique.

Figure 7 presents the results of this phase of testing. The efficiency of the system was measured to be greater than 97 % when tested at a flow rate of 20 l/s, increasing to over 99 % as the flow rate was reduced.

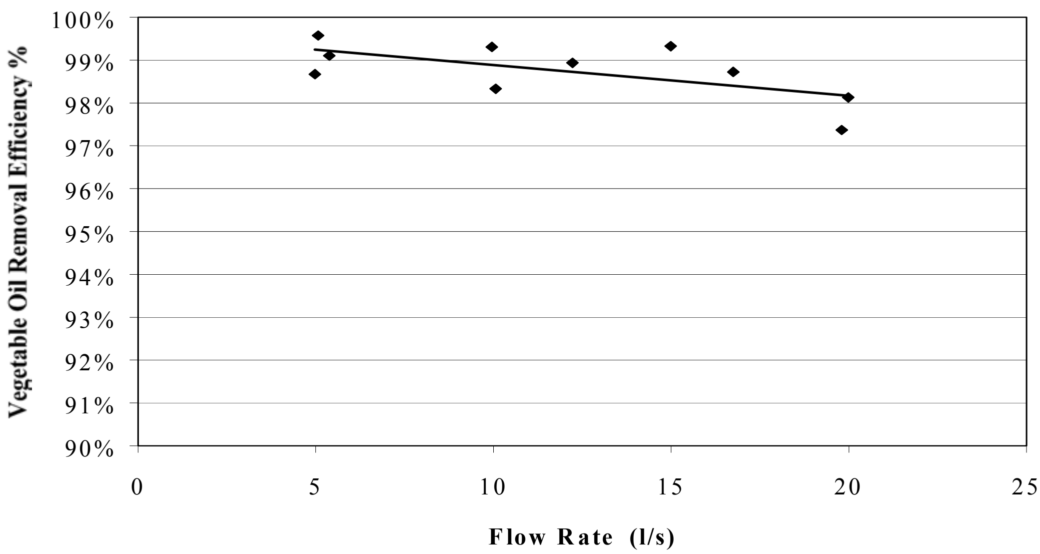

Figure 7 Vegetable oil removal efficiency

EXTERNAL VALIDATION

Independent verification work is currently ongoing at Coventry University's School of the Built Environment. The tests are using gas oil (density 850 kg/m^3), sand (density 2650 kg/m^3), and peat (density 450 kg/m^3) as the test media. The procedures given by the draft European standard for oil interceptors are being applied.

It is anticipated that the results of this work will form the basis of a future publication.

SYSTEM APPLICATIONS

The Downstream Defender™ would most commonly be applied as an interceptor immediately prior to a final discharge point, for example, at a coastal, stream or riverside location. In some instances, depending on the sensitivity of local waters, it may be used to intercept contaminants prior to discharge to a foul sewer. A common application, particularly in the UK, is that in which the system is used as a debris/floatables trap immediately upstream of stormwater attenuation facilities. When stormwater enters a large chamber such as a storage vessel the settleable material accumulates on the base. This builds up, potentially interfering with the operation of discharge flow controls and reducing the storage volume available, dictating a maintenance commitment. In this instance, the Downstream Defender™ serves to collect and concentrate debris to a central location. Although this also requires maintenance, in the form of collection of accumulated material, it can be performed more quickly and effectively.

CONCLUSIONS

The paper describes development work that has lead to the enhancement of the Downstream Defender™, a compact and economical stormwater treatment system. The improvements to the system include performance, operational, and installation procedure enhancements. The principle of hydrodynamic separation has been applied extensively around the world for the removal of settleable material in both municipal and industrial wastewater treatment applications. In this respect, it can be regarded as 'known technology'

The results of the work show that this system has the potential to be a very effective method for removal of stormwater related contaminants. Removal efficiencies have been found to be up to 100 %, for both settleable and buoyant tracer material, and greater than 97 % for all flows when tested with vegetable oil. The buoyant tracer materials were chosen because of higher densities, hence lower rise velocities and consequently lower removal efficiencies, than the mineral oil contaminants found in stormwater run-off.

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