INVESTIGATION INTO THE SEDIMENT REMOVAL AND RETENTION CAPABILITIES OF STORMWATER TREATMENT CHAMBERS

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ABSTRACT

With the objective of reducing the polluting impact of urban run-off on receiving watercourses, various proprietary treatment technologies have evolved, including ‘flow-through’ devices that are designed to intercept and store pollutants such as sediments and floatables for later removal and safe disposal.

Frequently, the performance of chambers is stated in terms of ‘ability to remove pollutants from the inflow’, often at discrete flowrates. However, a parameter that is often overlooked is chamber ‘retention efficiency’, the ability of chambers to retain stored pollutants once collected.

Based on the findings of a study that included theoretical as well as experimental analysis of different configurations of chamber, the significance of the parameter ‘retention efficiency’ is highlighted. It is concluded that chambers in which the pollutants storage regions are isolated from the main treatment area are likely to be most effective.

INTRODUCTION

With increasing urbanization, the problems of stormwater run-off from impermeable surfaces have become increasingly apparent. Run-off often carries a high sediment load, and this, along with other associated pollutants, can have a detrimental impact on receiving watercourses.

Recognizing urban run-off, and in particular, sediments, as one of the main sources of pollution in the USA (US EPA, 1998), Phases I and II of the US stormwater program, promulgated by the EPA in 1990 and 2000 under the 1972 Clean Water Act, are leading to significant improvements in the quality of US waters. The regulations largely target non-point source pollution in run-off from urbanized areas where land is often scarce and expensive.

In response to the technical need for compact and effective solutions, various configurations of proprietary ‘flow-through’ treatment device have evolved, designed to intercept and store pollutants such as sediments and floatables for later removal and safe disposal. The most popular of these, which are typically installed immediately downstream of stormwater intake points, utilize hydrodynamic principles to perform their function (US EPA, 1999). These can be categorized into the following three generic groupings;

- ***Gravity Sedimentation Devices*** - Rely on simple gravitational settlement to perform their function.

- ***Simple Vortex Separators*** - Rely on enhanced gravitational settlement to perform their function, through the use of a rotating flow field. Flow rotation results in extended particle residence times, and increased opportunity for settlement to take place.

- ***Advanced Vortex Separators*** - Operate in a similar manner to Simple Vortex Separators, but utilize specially designed internal components to control and enhance performance and provide isolated storage zones for captured pollutants.

Historically, simple catchbasins have been used as entry points (inlet chambers) to storm drainage systems, their objective being to remove debris from stormwater, preventing clogging in the receiving pipework. However, the studies of Lager *et al.* (1977) and also Butler & Karunaratne (1995) both identify re-suspension and subsequent loss of stored sediments as a potential problem. In this context, catchbasins can actually represent a source of pollution.

In the current study, a number of different configurations of 'flow-through' treatment chamber, including those described above, are analysed through both Computational Fluid Dynamics (CFD) simulation, and also experimental testing. The study focuses on the removal and retention of settleable particles.

THE SIGNIFICANCE OF 'RETENTION EFFICIENCY' AS A PERFORMANCE FACTOR

The effectiveness of a 'flow-through' treatment chamber can be denoted by two key variables;

- ***Pollutants Removal Efficiency.*** This represents the ability of a chamber to 'remove' pollutants from the influent. Typically, hydrodynamic separators (including gravity sedimentation and vortex separation devices) attain the highest removal efficiencies at the lower hydraulic loading ranges.

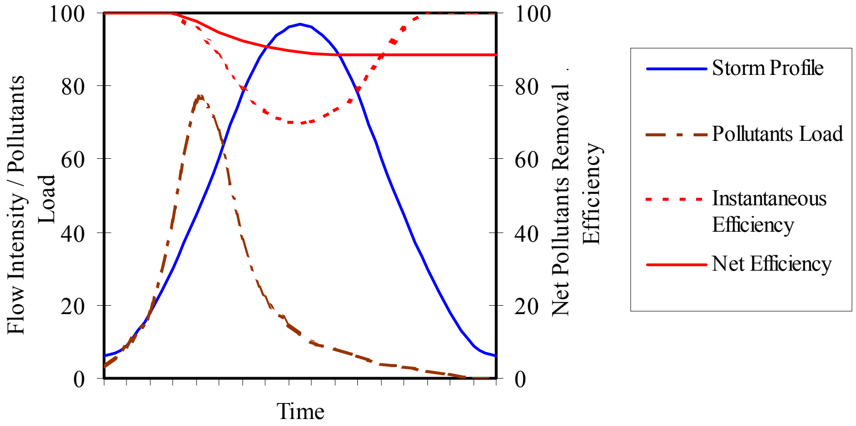
- ***Pollutants Retention Efficiency.*** This represents the ability of a chamber to 'retain' pollutants, once collected. While related to hydraulic loading rate in most practical cases, retention efficiency is also strongly dependent on chamber configuration.

Frequently, the performance of chambers is stated only in terms of 'ability to remove pollutants from the inflow', often at discrete flowrates. Retention efficiency, however, is rarely given consideration. This is thought to stem from the difficulties associated with measuring and quantifying this parameter, combined with a lack of appreciation of its significance. Difficulties arise due to the fact that retention efficiency is time-dependent, in addition to being dependent upon hydraulic loading rates and stored pollutants characteristics and quantities.

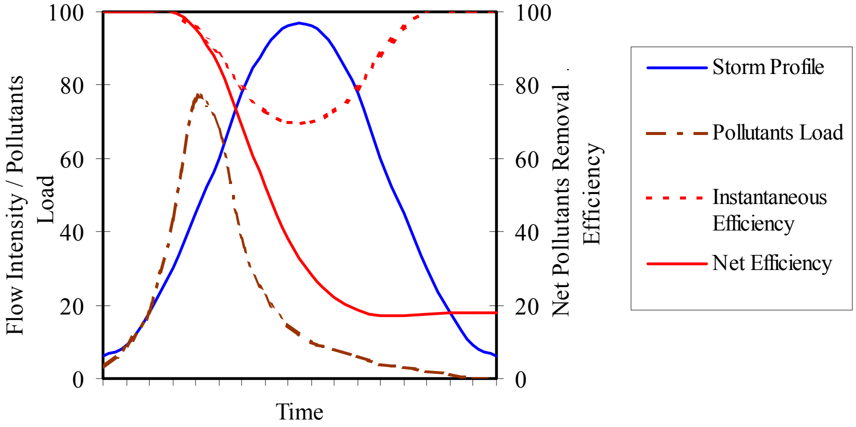
The importance of 'retention efficiency' as a device parameter can be demonstrated through considering the operation of a treatment chamber during a storm event. Hydrodynamic treatment chamber removal efficiencies tend to be at their highest when flowrates are low (i.e. during the early or latter stages of a storm). Conversely, when flowrates are high (i.e. at a storm peak), efficiencies tend to be at their lowest. Assuming that most of the polluting load in a storm flow occurs at the beginning (i.e. in the form of a 'first flush'), it might be deduced that net pollutants removals will be high. However, this is dependent upon the pollutants retention efficiency of the device being high.

Figure 1(a) provides an illustration of the general trends that instantaneous and net removal efficiency might follow during a storm event. With a retention efficiency of 100 % assumed, the net efficiency for the event is shown at around 90 %, where net efficiency is defined as;

$$\frac{\left(\left(\text{removal efficiency}\right)_{t(n)} \times \left(\text{pollutants influx}\right)_{t(n)}\right) + \left(\left(\text{retention efficiency}\right)_{t(n)} \times \left(\text{stored pollutants}\right)_{t(n-1)}\right)}{\sum_{t(n)}^{t(0)} \text{pollutants influx}} \qquad \text{(Equation 1)}$$



(a) Device with Excellent Retention Efficiencies



(b) Device with Poor Retention Efficiencies (Retention No Better Than Removal)

Figure 1 – Trends of 'Flow-Through Treatment Chamber' Instantaneous and Net Pollutants Removal Efficiency During a Storm Event with a 'First Flush' (Extracted from a Simple Spreadsheet Based Model)

Figure 1(b), however, provides a similar illustration, in which all conditions remain the same, except that the chamber retention efficiency is assumed to be no better than the removal efficiency (within the period of a time step). The result is catastrophic, showing a final net removal efficiency of less than 20 %.

While this simple example assumes extreme circumstances (including that stored pollutants erosion occurs almost instantaneously), it does demonstrate how critical the pollutants retention efficiency of a chamber can be. In practice, bypass facilities are often employed to prevent overloading. However, the importance of retention efficiency remains in that it governs at what point bypass (and hence the limit of treatment) should commence. Clearly, it is preferable to treat as much of the storm flow as possible.

ASSESSMENT OF CHAMBERS USING COMPUTATIONAL FLUID DYNAMICS (CFD)

In recent years, Computational Fluid Dynamics (CFD) fluid flow simulation codes have become increasingly applied for the study of sewer and drainage systems and processes (Faram & Harwood, 2000). They can be used particularly efficiently where the objective of the study is to examine 'qualitative' outputs, for example, the relative effects of design change on a performance parameter.

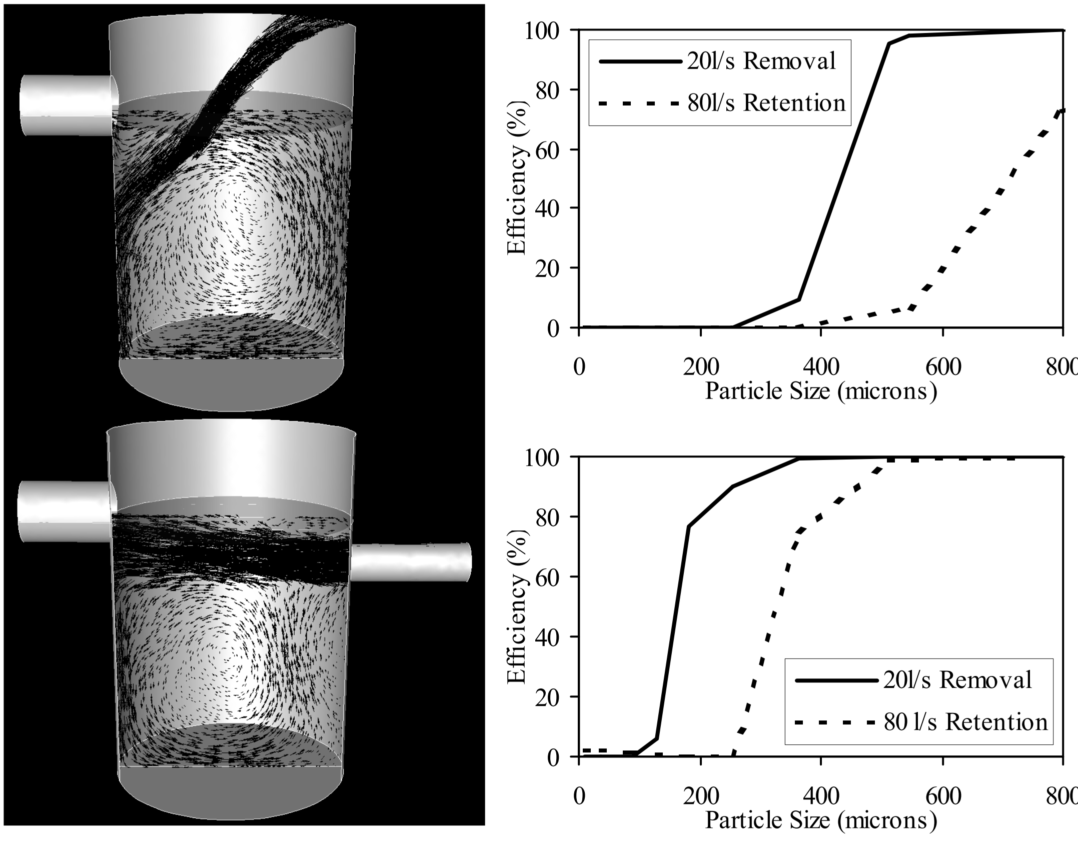
In the current study, the Fluent CFD software was applid for the comparative assessment of different configurations of 'flow-through' treatment chamber, including a simple catchbasin **(SCB)**, a gravity sedimentation device **(GSD)**, a simple vortex separator **(SVS)** and an advanced vortex separator **(AVS)**. Performance was quantified in terms of both the sediment particle removal and retention efficiency of 1.2 m diameter chambers.

With the exception of the AVS, which was based on a Hydro International Downstream Defender®, proprietary designs were not simulated. Rather, generic 'types' were considered, in each case retaining identical overall dimensions to ensure the meaningfulness of the comparisons. The main physical parameter differences between the chambers included the inlet orientation, and the presence or absence of internal components. The AVS and SVS each had a 200 mm diameter tangential inlet, while the GSD had a 200 mm perpendicular inlet. The inlet to the SCB was based on a calculated approximation of a falling fluid stream, defined based on the assumption of a lateral kerb, rather than overhead grating style intake. Each chamber had a 300 mm diameter outlet, the invert of which was located approximately 1.2 m above the base of the sediment storage region. Differentiating itself from the other chambers considered, the AVS contained a number of flow modifying members.

Flowfield characteristics were initially predicted for each chamber, at flowrates ranging from 20 to 80 l/s. Following this, particles ranging from 10 to 1000 microns in size, and with a density of 2650 kg/m^3 were injected into the inlet of each chamber for ‘removal efficiency’ predictions, and into a plane 100 mm above the base for ‘retention efficiency’ predictions. Recognising efficiency as a ‘time dependent’ parameter, a particle monitoring time of 20 minutes was used. Further details relating to the modelling procedures used and parameter selections made are presented elsewhere, along with validation against experimental data (Faram & Harwood, 2003).

The most significant outputs of the study are presented in Figure 2 and 3. A more detailed account of the findings can be found elsewhere (Faram & Harwood, 2002). The Figures show the configurations of each of the chambers considered, including typical vertical plane flowfield vector predictions (scaled by vector length), sediment particle removal efficiency predictions at 20 l/s and retention efficiency predictions at 80 l/s.

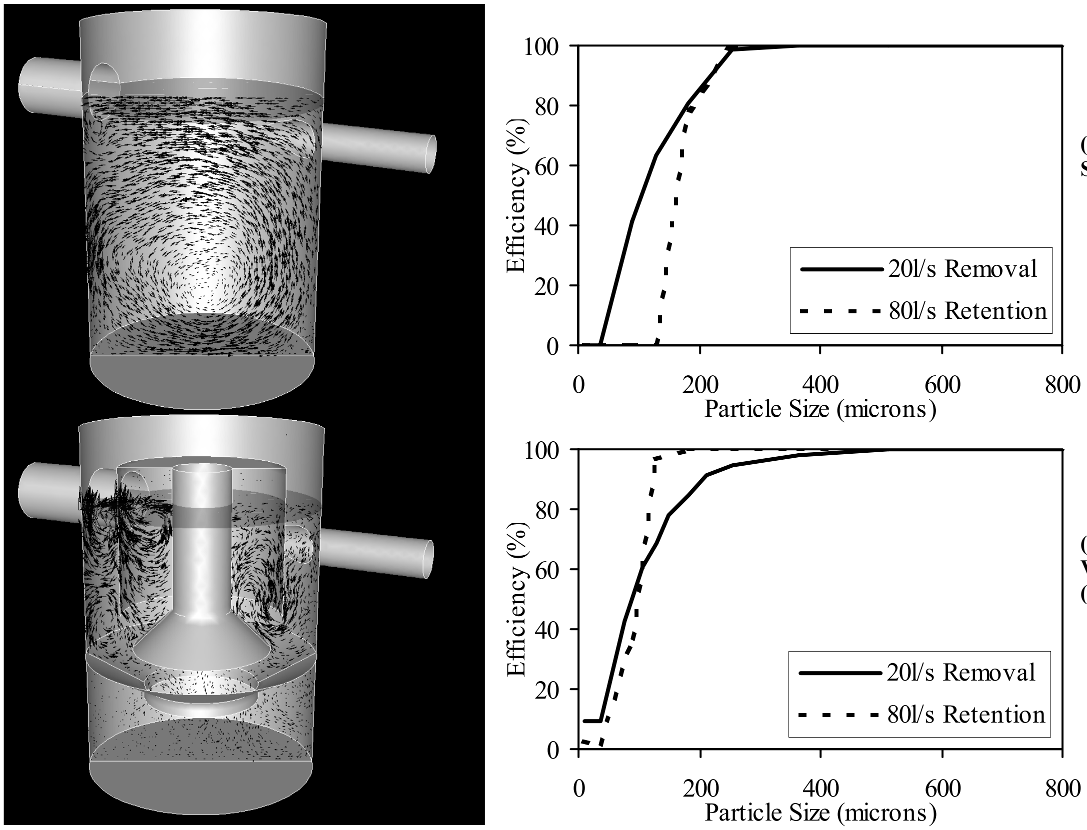
It is clear from the predictions that chamber configuration has a major impact on both particle removal and particle retention efficiencies. The SCB is predicted to have the poorest performance capabilities overall (Figure 2(a)), which is explained by the relatively high levels of flowfield activity predicted in the base region, corresponding to the area where sediments would be expected to collect. The best performance characteristics overall are predicted for the AVS (Figure 3(b)), for which a relatively quiescent flowfield region is predicted in the base. In particular, for this chamber, particle retention efficiencies at 80 l/s are predicted to be similar to or better than particle removal efficiencies at 20 l/s, implying that net efficiencies during a storm event could be expected to be good.



(a) Simple Catchbasin (SCB)

(b) Gravity Sedimentation Device (GSD)

Figure 2 – Flowfield and Particle Removal/Retention Efficiency Predictions from CFD for Gravity Sedimentation Chambers



(a) Simple Vortex Separator (SVS)

(b) Advanced Vortex Separator (AVS)

Figure 3 – Flowfield and Particle Removal/Retention Efficiency Predictions from CFD for Simple and Advanced Vortex Separation Chambers

EXPERIMENTAL ASSESSMENT OF CHAMBERS

To support the outputs of the CFD studies, a series of tests were undertaken on half-scale versions of the GSD, SVS and AVS, as described previously. Each chamber was initially filled with water, and a layer of 'Styrocell' grade R743 (Shell Chemicals unexpanded polystyrene beads) allowed to settle evenly on the base. The beads had a mean density of around 1035 kg/m^3, and a D_{50} of 560 microns (equivalent in settling velocity to 75 micron sediment particles with a density of 2650 kg/m^3 settling in water at 10 ˚C).

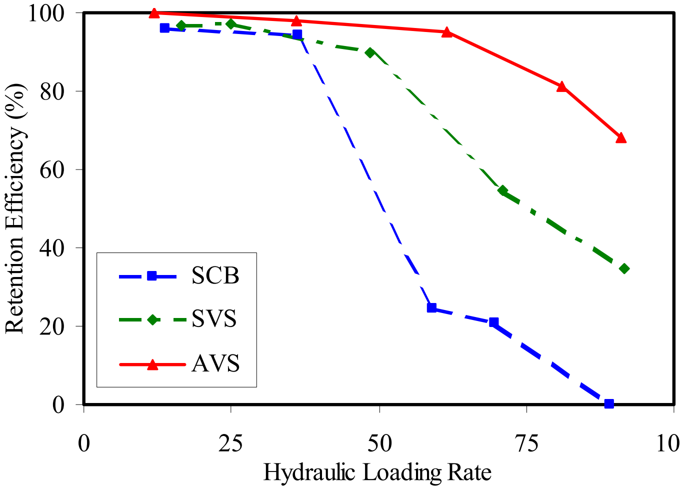


Figure 4 – Retention Efficiency Measurements for Three Chamber Configurations Using Unexpanded Polystyrene Beads (Equivalent in Settling Velocity to 75 micron Sediment Particles)

Retention efficiency testing was subsequently undertaken for a range of hydraulic loading rates, with a test duration of 20 minutes. The results of the study are presented in Figure 4.

Agreeing with the general findings of the CFD studies, the SCB is shown to have the poorest retention efficiency capabilities, while the AVS is shown to be the best performing system overall.

CONCLUSIONS

Stormwater treatment chamber performance is often presented in terms of the ability of a chamber to remove pollutants from a contaminated influent. However, the ability of a chamber to subsequently retain stored pollutants, particularly during extreme hydraulic conditions, is also important.

Focusing on the sediment removal and retention capabilities of various configurations of 'flow - through' treatment chamber, the following conclusions can be drawn from the study;

- The performance of treatment chambers is highly dependent upon the inlet and outlet orientations, and the design of internal components.

- Rotary flowfield devices are likely to be more effective than linear flow devices, on the basis that particle residence times are likely to be longer, and therefore the opportunity for particles to settle is greater.

- Particle retention efficiencies are likely to be better in chambers where collected pollutants are isolated and protected from the main regions of flow activity.

In particular, the study found that an 'advanced vortex separator' (AVS) (based on the Hydro International Downstream Defender®), exhibited far superior ability to retain settleable material compared to other configurations of chamber considered, highlighting it as being the most effective system overall.

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