VERIFICATION OF THE UP-FLO™ FILTER - AN UPFLOW FILTER FOR STORMWATER TREATMENT AT CRITICAL SOURCE AREAS

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ABSTRACT

Drainage areas such as parking lots, vehicle fueling and maintenance stations, and public works storage areas have been dubbed *critical source areas* due to the observation that runoff from these areas may contain high pollutant loadings of varying pollutant classifications, including trash and other debris, coarse and fine sediment, hydrocarbons, toxic trace metals, nutrients, pathogens, and/or other toxicants. Typically, various types of treatment are needed to target the different classifications of pollutants for effective stormwater treatment. The Up-Flo™ Filter, a new stormwater treatment technology developed under the EPA's SBIR program, has been designed to treat different classifications of stormwater pollutants by incorporating multiple elements of a treatment train into a single device. The Up-Flo™ Filter with CPZ Mix™ media has undergone a full-scale field evaluation at a site near the City Hall in Tuscaloosa, AL. This paper presents results of a comprehensive characterization and performance verification of a full-scale Up-Flo™ Filter unit tested under controlled laboratory conditions at Hydro International's facility in Portland, ME, and compares the results to the field data collected by the University of Alabama. Further verification work is currently underway at the Pennsylvania State Univeristy in Harrisburg, Pennsylvania.

The Up-Flo™ Filter with CPZ Mix™ media is shown to be a high-rate filtration device with a relatively high filtration rate per unit surface area of the filtration media. The Up-Flo™ Filter is also capable of TSS removal down to 0.45 – 3 μm range.

INTRODUCTION

The stormwater drainage from critical source areas has been shown to have higher-than-average loadings of pollutants such as trash, sediments, hydrocarbons, metals, nutrients, pathogens and other toxicants (Bannerman, *et al*. 1993; Pitt, *et al.* 1995; Claytor and Scheuler 1996). Multiple treatment processes are needed to address the highly variable composition and pollutant loadings of stormwater runoff from critical source areas (Pitt, *et al*. 1999).

The Up-Flo™ Filter is a new stormwater treatment device that was developed as a small-footprint, treatment train device to treat runoff from critical source areas upstream before it is piped downstream and mixed with less contaminated runoff from other drainage areas (Khambhammettu 2005). The Up-Flo™ Filter adopts a treatment train approach by incorporating sedimentation, screening, and high-rate filtration into a single device. The filtration media is housed within Filter Modules. The number of Filter Modules included in an installation may be designed according to site-specific runoff volume characteristics.

An Up-Flo™ Filter prototype was installed in a catch basin of the Tuscaloosa, Alabama City Hall in early 2005. Field work done at the site has shown that the Up-Flo™ Filter with CPZ Mix™ Media removed over 90% of suspended solids during controlled tests. For the controlled field studies, data showed suspended solids removal of over 95% of all particles greater than 30 μm, about 80% for particles in the 20 to 30 μm range, and at least 50% of particles in the 1 to 20 μm range. Statistical analysis of the field data showed that the percentage of suspended solids removed by the Up-Flo™ Filter was more dependent on influent sediment concentrations than the treatment flow rate (Khambhammettu 2005).

A commercial Up-Flo™ Filter consists of a concrete chamber with polypropylene internal components, stainless steel screens, and a stainless steel support frame. A grate or lid at ground level provides access for inspection and a direct route to the sump for cleanout. The internal components consist of wedge-shaped Filter Modules, an Outlet Module, and a siphonic Bypass/Floatables Baffle. The components of the Up-Flo™ Filter are shown in a basic 4-ft manhole configuration in Figure 1. The Filter Module components are shown in Figure 2.

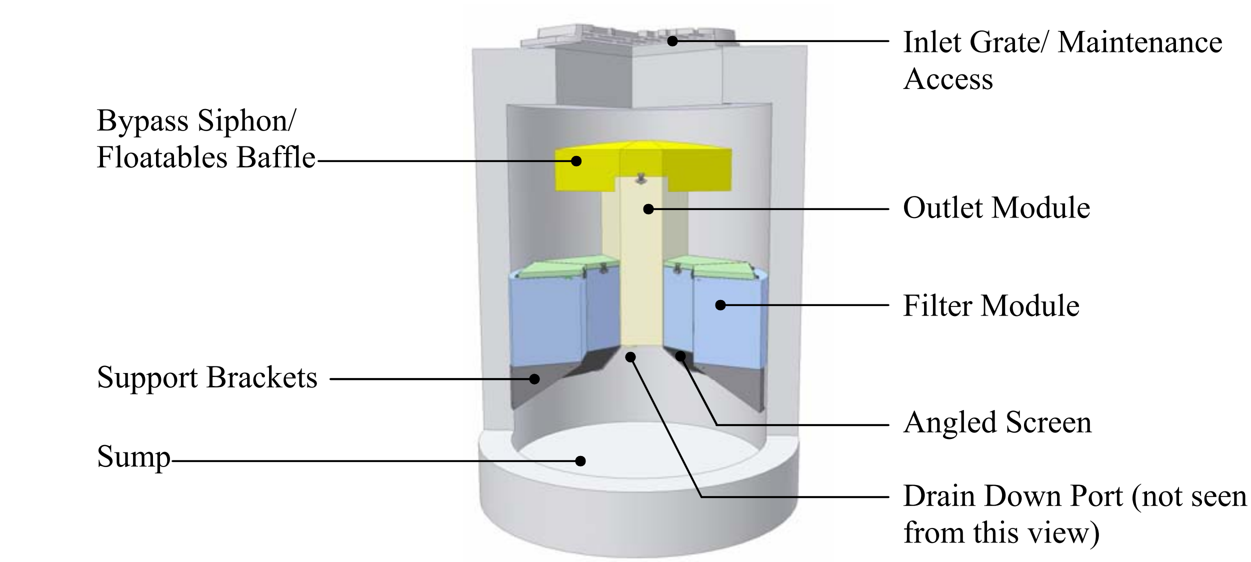

Figure 1 – Up-Flo™ Filter Components

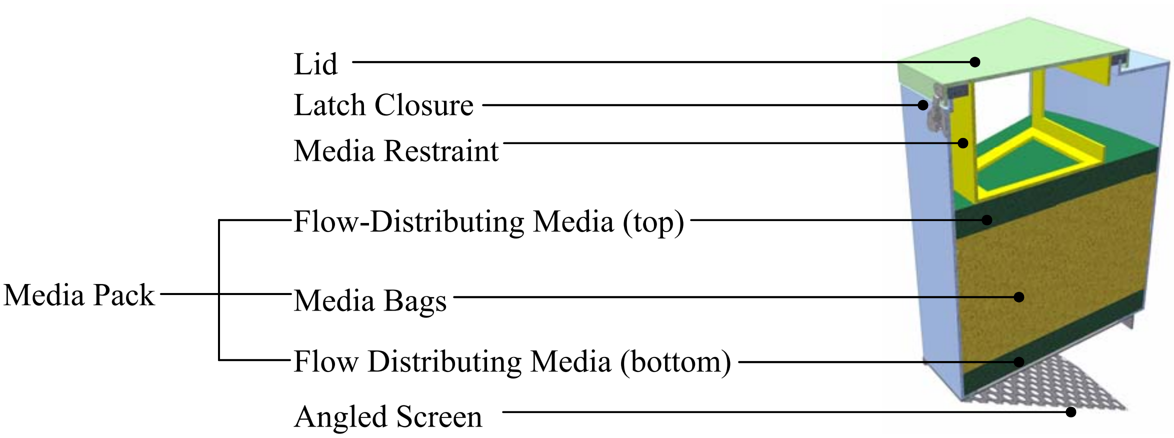

Figure 2 – Up-Flo™ Filter Module

A full-scale, commercial Up-Flo™ Filter was installed at the Hydro International hydraulics testing facility in Portland, Maine in June 2005. The study described in this paper sought to benchmark the hydraulic characteristic and sediment removal performance of the in-field Up-Flo™ Filter prototype with the laboratory unit.

METHODOLOGY

A 4-ft x 4-ft catch basin configuration, polypropylene test chamber equipped with one full-scale Up-Flo™ Filter Module was used for the studies. A submersible 3-inch Flygt pump delivered water from a 23,000-gallon clean water reservoir through an 8-inch PVC pipe network to a free discharge point located above the open top of the Up-Flo™ Filter test chamber. The 8-inch PVC delivery line was equipped with clear standpipes and a Hershey VP-820 butterfly valve that redirected flows in excess of the desired influent flow rate of 25 gpm back into the clean water reservoir. A flanged 12-inch outlet pipe delivered effluent from the test chamber to a large underflow sedimentation basin. Water from the underflow sedimentation basin was redirected back to the clean water reservoir by two submersible 2-inch Flygt pumps.

Hydraulic performance tests and TSS removal efficiency tests were conducted as part of this study. For TSS tests, a slurry mixture was continuously agitated by a stirring motor. A Watson Marlow 704 S/R peristaltic pump conveyed slurry from the slurry tank into the delivery line via a standpipe about 3-feet upstream from the Up-Flo™ Filter. A schematic of the lab setup is shown in Figure 3.

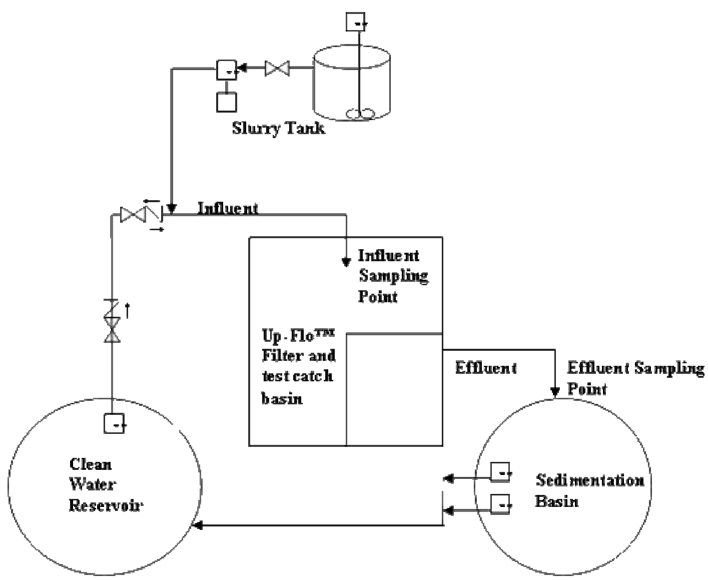

Figure 3 – Schematic of Laboratory Set Up

Hydraulic Testing Methodology

The filtration rate through an upflow filter is dependent upon the surface area and depth of the filtration bed, as well as the particle size, density, porosity and expansion velocity of the filtration media. The flow rate through the media will be proportional to the driving head of water acting on the filtration media. The objective of the hydraulic testing program was to determine the filtration rate of the Up-Flo™ Filter at varying levels of driving head for a range of media.

The Up-Flo™ Filter Module was filled with two media bags and flows were piped into the Up-Flo™ test tank until the water level was at a driving head of 20 inches above the top of the filtration media. The Hershey VP-820 valve was then used to throttle influent flows down until a steady-state water level at 20 inches of driving head was reached in the test chamber. The filtration rate of the Filter Module was determined using the Volumetric Time-To-Fill method. For a given steady-state height of driving head in the Up-Flo™ test tank, the amount of time required for the Up-Flo™ Filter effluent to fill two cubic foot increments of the underflow sedimentation basin was recorded. The influent was then throttled down further to allow the driving head to drop one inch. Once the water level once again reached steady state level in the test tank, the time-to-fill was recorded. This process was repeated until zero inches of driving head remained in the test tank.

TSS Testing Methodology

The slurry tank was filled with a mixture of Sil-Co-Sil 250 and clean water. The slurry mixture was continuously agitated with a stirring motor and fed into the delivery line with the Watson Marlow 704/SR peristaltic pump operating at 80 rpm. The delivery line freely discharged the synthetic stormwater with a TSS concentration of 200 – 300 mg/L into the open top of the Up-Flo™ test chamber at a rate of 25 gpm. Results of hydraulic testing set the target filtration rate of 25 gpm for a steady state level of 20 inches of driving head. Throughout testing, water levels in the Up-Flo™ test chamber were continuously monitored to confirm that the water level was not rising or falling, indicating that the filtration rate was operating as desired at 25 gpm. After synthetic stormwater had been fed to the test chamber for 15 minutes, five (5) influent grab samples were taken at one-minute intervals from the free discharge point of the delivery network. Five (5) effluent grab samples were taken, also at one-minute intervals, from the Up-Flo™ Filter outlet pipe, two feet downstream of the Up-Flo™ test chamber.

RESULTS

Hydraulic Testing Results

The flow rate Q, for a given operating head was determined using Equation 1:

$$\mathbf{Q_{(gpm)} = Volume\ of\ bin_{(gal)} / time\text{-}to\text{-}fill_{(min)}} \qquad \textbf{Equation 1}$$

An example of the filtration rate versus operational net driving head characteristic for the CPZ Mix™ media is shown in Figure 4. The CPZ Mix™ is Hydro International’s custom blend of granular activated Carbon, Peat, and manganese-coated Zeolite. This mix is designed to remove fine sediments, metals, nutrients and organics from stormwater runoff with a high hydraulic throughput.

The flow rate through the CPZ Mix™ was determined to be 20.9 gpm/ft^2 of filtration surface area at an operating head of 20 inches. The flow rate per unit surface area (gpm/ft^2) characteristic of the CPZ Mix™ is shown below in Figure 4.

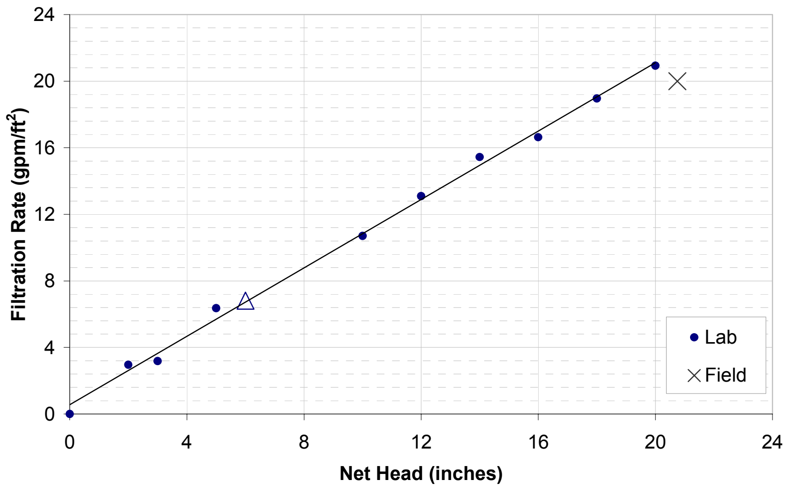

Figure 4 – Flow rate versus net driving head for the CPZ Mix™

TSS Testing Results

Influent and effluent samples were analyzed using TSS Test Method 2 Filtration in ASTM, 1999, D 3977-97 – the Standard Methods 19th Ed 1995 for the Examination of Water and Wastewater prepared and published by the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF) Chapter 2-2540 D Total Suspended Solids Dried at 103 – 105 deg.

The average TSS removal efficiency was determined using Equation 2:

$$\textbf{Average \% Removal} = 100 \times ([TSS]_{\text{Mean inflow}} - [TSS]_{\text{Mean outflow}}) / [TSS]_{\text{Mean inflow}} \qquad \textbf{Equation 2}$$

The average removal efficiency for one Filter Module with CPZ Mix™ operating at a filtration rate of 25 gpm was determined to be 94%.

DISCUSSIONS

Hydraulic Performance

The data shows that the flow rate through the filtration media is linearly dependent on the height of driving head in the Up-Flo™ chamber. During testing, a *critical driving head*, defined to be the driving head required to initiate flow through the media when water is first filling the filter chamber, was observed. For two media bags filled with CPZ Mix™, this critical driving head was determined to be six (6) inches. The critical driving head is denoted by the triangular data point in Figure 4. When influent flows were stopped and the water level in the chamber dropped, the water would continue to flow up through the Up-Flo™ Filter until the height of driving head in the chamber fell to zero inches.

Results from field work done by Khambhammettu in Alabama are superimposed on Figure 4. This shows that the Up-Flo™ Filter would filter 20 gpm/ft^2 at a net driving head of 20.75 inches. Figure 5 shows further work that benchmarked the laboratory and in-field filtration rates of manganese-coated zeolite (Mn-Z) and bone char in addition to the CPZ Mix™.

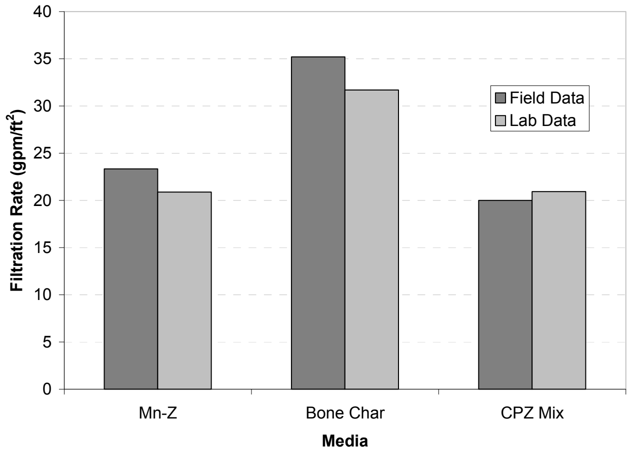

Figure 5 – Filtration rates of various media operating with equivalent heights of driving head

Suspended Solids Removal Performance

Based on laboratory testing, the Up-Flo™ Filter CPZ Mix™ will remove over 94% of Sil-Co-Sil 250 at 25 gpm per Filter Module, as the concentrations of influent and effluent samples illustrate in Figure 6.

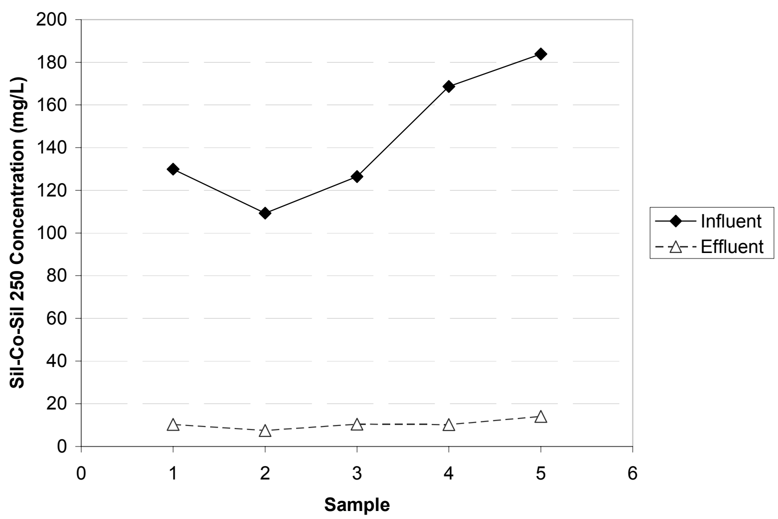

Figure 6 – Up-Flo™ Filter TSS Removal Test Using Sil-Co-Sil 250

The particle size distribution of Sil-Co-Sil 250, as determined by ASTM D422 (AASHTO T88) is shown in Figure 7. Sil-Co-Sil 250 has over 90% of material less than 150 µm and a mean particle size of 45 µm.

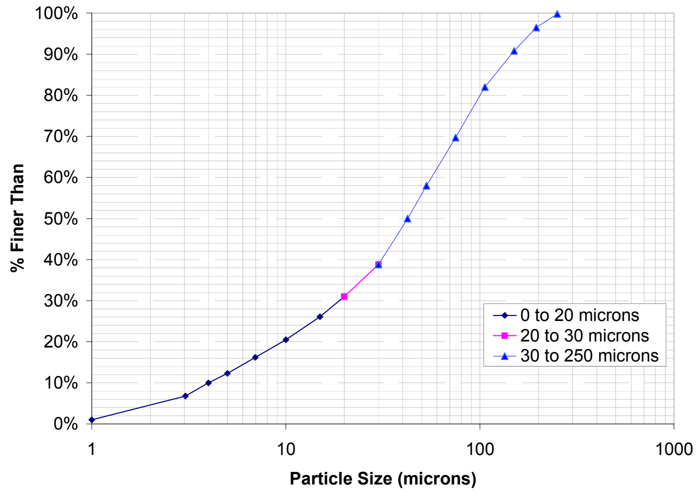

Figure 7 - Sil-Co-Sil 250 particle size distribution verified according to ASTM D422 (AASHTO T88)

Field work done by Khambhammettu in Alabama showed that the Up-Flo™ Filter would remove over 95% of particles greater than 30 µm, 80% of particles from 20 to 30 µm, and at least 50% of particles from 1 to 10 µm. The percentage of material removed for the given particle size bands from the field work suggests that the Up-Flo™ Filter can be expected to remove greater than 80% of Sil-Co-Sil 250 (see Table 1).

Micron Range	Up-Flo™ % Removal Observed in Field Work	Mass in range for Sil-Co-Sil 250	Removal of Total Sil-Co-Sil 250 Mass Expected based on Field Work Observations
1 to 20	>50%	30%	>15%
20 to 30	80%	10%	8%
30 to 250	>95%	60%	>57%
Expected % Sil-co-Sil 250 Removed based on Field Work			**>80%**

Table 1 – Expected Up-Flo™ Filter removal of Sil-Co-Sil 250 based on field work

The laboratory test results showing 94% removal of Sil-Co-Sil 250 are consistent with what would be expected based on projections from the field testing results for the different particle size bands and suggests that these projections should result in a conservative approach to the design of the Up-Flo™ Filter.

CONCLUSIONS

Laboratory performance verification data corroborates the field data and confirms that the Up-Flo™ Filter is a relatively high-rate filtration device. Due to varying data collection methods between field and lab-based testing programs, slight differences between the field data and lab data observed are to be expected. However, both the laboratory and in-field data sets show that the Up-Flo™ Filter has a relatively high filtration rate and will remove a significant proportion of suspended sediment with a particle size distribution similar to Sil-Co-Sil 250. Additional performance verification work is being conducted under the protocols of the EPA Environmental Technology Verification Program and will be available for further benchmarking.

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