Evaluation of Sampling Methods Required by Oil Grit Separator Testing Protocols

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ABSTRACT

Performance testing of oil grit separators requires determining how effectively they remove sediment from water. This requires sampling the effluent. This study looked at the effectiveness of two different sampling techniques: grab sampling and isokinetic sampling. A laboratory pilot plant was configured to allow for sampling under controlled conditions. A number of flow rates and sediment concentrations were tested. It was found that grab sampling is very effective at lower flow rates. At higher flow rates isokinetic sampling is required. For the sediment typically found in the effluent of an OGS truly isokinetic conditions are not required. Acceptable results are obtained as long as the ratio of tube velocity to pipe velocity is ≤ 1.3.

KEYWORDS isokinetic sampling, grab sampling, laboratory testing, oil grit separators

INTRODUCTION

Oil grit separators (OGS) are commonly used to remove sediment, measured as total suspended solids (TSS) from stormwater discharges. There are numerous OGS on the market and, while they all rely on gravity for separation, they all have slightly different internal geometry and thus different performance claims. Most performance claims are provided by the OGS manufacturer and there is a lack of standardization with respect to how the tests are conducted and how the results are reported. Thus it can be very difficult for an end user to compare claims. This leaves end users of the technology without good quality information to use in making a decision.

Efforts have been made to encourage standardized testing and numerous protocols have been developed. Examples include:

- Technology Acceptance Reciprocity Partnership (TARP)
- New Jersey Department of Environmental Protection (NJDEP)
- Washington State's Technology Assessment Protocol-Ecology (TAPE)
- Georgia Technology Assessment Program (GTAP)
- North Carolina Preliminary Evaluation Program (NCPEP)
- Virginia Technology Assessment Protocol (VTAP) program
- Massachusetts Stormwater Technology Evaluation Project (MASTEP)

More recently in the United Sates the Water Environment Federation (WEF) has been leading the Stormwater Testing and Evaluation for Products and Practices (STEPP) work group as it investigates the feasibility of a national program (WEF 2014). This effort is being watched by the Environmental Protection Agency (EPA). In Canada the Environmental Technology Verification (ETV) program published a nationally applicable OGS testing protocol in late 2013 (ETV 2013).

Unfortunately these protocols were not necessarily developed with ease of execution in mind, consequently the requirements can be very onerous in terms of labor and materials and this drives up the cost of testing. The extra cost may not result in significantly improved data. Higher costs will discourage companies from following the protocol and thus the end users may not get the standardized data they are looking for. The protocols end up defeating their own purpose. There needs to be a balance between the quality of data required and the cost to obtain that data.

Laboratory testing of OGS is relatively complex and there are numerous opportunities to balance testing cost and data quality. This study focuses on one aspect of OGS laboratory testing, sample collection. Proper sample collection is critical to getting good quality results and there is a labor component that impacts the testing cost. There are three generally approved methods: auto sampling, grab sampling, and isokinetic sampling. Each method has advantages and disadvantages.

Auto sampling has the advantage that it can be used in remote locations and can be automatically triggered by rain events but neither of these is important in a lab setting. Given that auto samplers are known to have problems providing quality data, especially with coarse particles (Gulliver, et. Al., 2010), this technique is not well suited to laboratory testing so it was dropped from consideration.

Grab sampling is the simplest and least expensive technique. It also tends to give very good results if the entire stream can be sampled. This can be difficult on the inlet side of a device but easy on the outlet side if the effluent is allowed to fall freely into a vessel. Even when whole stream sampling is possible, there is a limit to the flow rate that can be captured in standard sampling jars. The NJDEP protocol requires grab sampling for flow rates below 14.2 L/s (225 gpm). For higher flows it is not clear what method is preferred but grab sampling is allowed. Canadian ETV follows the NJDEP protocol but it is even less restrictive in that it allows any method to be used, as long as it is approved by the Canadian ETV program prior to testing.

Isokinetic sampling is recommended for higher flow rates. It is also relatively easy to use, though it can take a significant amount of effort to set up initially. An isokinetic sampler usually consists of multiple tubes at different heights from the invert of the pipe. The tubes are L shaped and arranged so that the opening faces into the flow, Figure 3. The flow rate in the sample tube is controlled by the vertical length of the tube extending below the pipe.

In order for the sampler to be isokinetic the flow rate in the tube must match the flow rate in the pipe. Once the sampler is installed the flow rate needs to be calibrated and the tube length adjusted as needed. Each new flow rate requires new tube lengths and thus recalibration. This requires shutting down, making changes and starting up again. This adds time and cost. It would be possible to use valves to adjust length but this still requires calibrations.

In the case of the Canadian ETV protocol section 4.3.1, Suspension Testing, requires that the flow rate changes must take less than 1 minute. This is not possible for samplers that do not use valves and it would be difficult to stabilize samplers that do use valves in that time. Since it is not practical to vary the flow rate in the sample tube that quickly, unless there is some kind of operating window for isokinetic sampling, the protocol cannot be strictly adhered to as written.

Previous work (1941) has shown that the error due to non-isokinetic conditions is small for small particles, < 60 µm. This study looked to explore that result in more detail and to put it in the context of the particle sizes and flow rates required by current protocols. It also updated the sediment analysis method from a buoyancy based calculation to the ASTM Method D3977-97 for SSC.

METHODOLOGY

The primary goal of this testing program was to generate data validating the effluent sampling methods for OGS testing. The effluent sampling methods includes the Effluent Grab Sampling Method and the Isokinetic Sampling Method. The Effluent Grab Sampling Method is used for flows less than 14.2 L/s (225 gpm) and the Isokinetic Sampling Method is used for flows greater than 14.2 L/s. Since these two sampling methods were applied for two different flows, they were validated separately.

Effluent Grab Sampling

The Effluent Grab Sampling test set-up was a water flow loop, consisting of water reservoirs, pumps, a stand pipe, a receiving tank, flow meters and a commercial 6’ diameter OGS. The OGS was not used as a settling device, sediment was injected at the outlet of the OGS. Injecting sediment at the inlet would introduce an uncontrollable variability in sediment concentration and PSD. The OGS was kept in the system because it was already installed.

A schematic of the test set-up is provided in Figure 1 below.

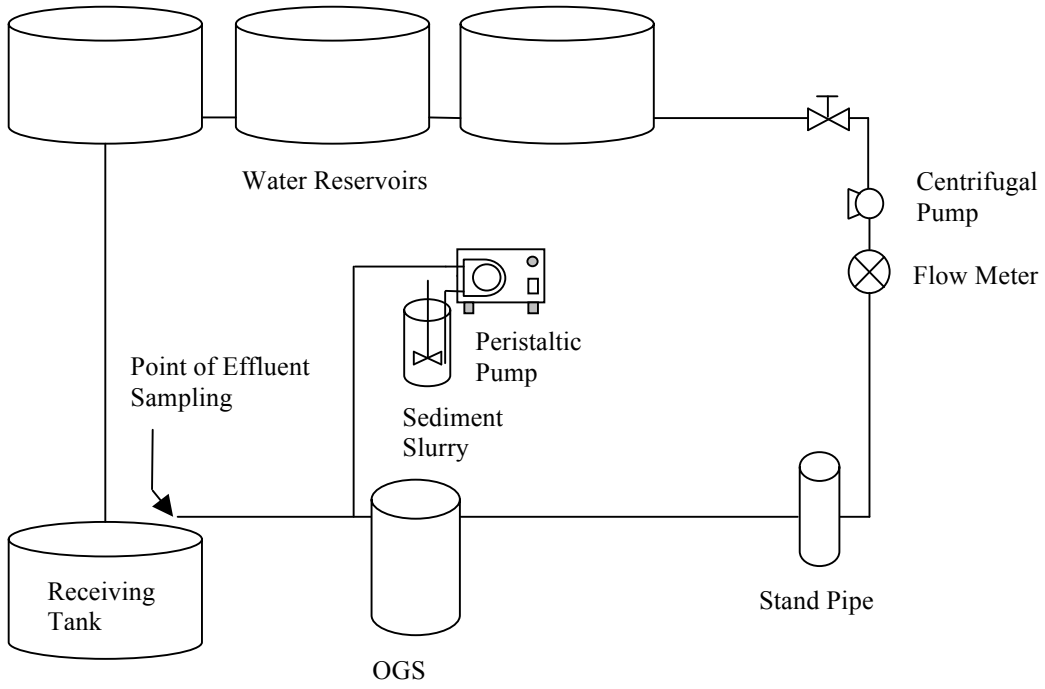

Figure 1 Effluent Grab Sampling Test Set-up

Fresh water was pumped from the inlet reservoir through a flow meter to the stand pipe, and from there it flowed by gravity through an inlet pipe to the OGS. Sediment slurry was pumped, to an injection point approximately 30 cm downstream of the inlet to the OGS effluent pipe. The length of the effluent pipe was approximately 249 cm.

An initial series of tests were run with the flow rates of 3.2, 6.4, 13.9 and 37.9 L/s (50,100, 220 and 600 gpm) and the sediment concentrations of 25, 50 and 100 mg/L. The data was highly variable. A number of causes were identified and changes were made to the methodology. One of the problems was, due to the injection location, that the sediment had very little time to mix and become uniformly distributed. This problem was overcome through trial and error by adding small V-shaped baffles to the bottom of the pipe, to simulate the mixing that would have occurred in the OGS.

Another problem was splashing while trying to collect a sample. Initially samples were taken using 500 mL plastic 5.7 cm (2.25 in) wide mouth jars. The sample jars were switched to 1000 ml plastic 8.3 cm (3.25 in) wide mouth jars and the larger jars gave more repeatable results. This solution did not work for the 37.9 L/s flow rate, no suitable sample jar was found so this flow rate was dropped from the testing.

Once the problems were addressed, the test was re-run. The flow rates tested were 3.2, 6.4, and 13.9 L/s. The sediment concentrations were 20, 50 and 100 mg/L. The initial 25 mg/L runs were replaced by 20 mg/L because this concentration is the maximum allowable background concentration so it is considered as a critical verification concentration. The sediment used for this study was Sil-Co-Sil® 106, from U.S. Silica, which has a particle size of approximately 1 – 106 µm and a d_{50} of 22 µm. It was chosen to be representative of the relatively fine particles that would remain in the effluent after sediment such as the NJDEP PSD passed through an OGS.

To achieve the proper sediment concentration in the effluent stream, a concentrated sediment slurry was used. The sediment slurry was prepared in a 20 L bucket and continually agitated using a mechanical mixer. For flow rates above 3.2 L/s a second bucket was added in order to maintain the required slurry flow rate without running out. The slurry was pumped using a positive displacement peristaltic pump from the bucket to the injection point, approximately 30 cm downstream from the inlet of the OGS effluent pipe.

Each test run was 3 minutes in duration, with effluent sampling occurring every 30 seconds for a total of six samples. In addition to the effluent samples, three background samples were taken at 1 minute intervals.

Effluent samples were taken at the exit of the effluent pipe. The samples were taken in a single pass by passing a sample jar across the effluent stream. The jar was held on the side of the pipe, opposite the analyst, and pulled towards the analyst in a smooth, constant motion. The speed of movement was such that at the end of the pass, the sample jar was full of water.

The background samples were taken from the outlet pool of the OGS, at the inlet of the outlet pipe, 30 cm upstream of the sediment injection point. Samples were taken by submerging the sample jar below the surface of the water until it was full.

All samples were analysed for suspended sediment concentration (SSC) using ASTM Method D3977-97, Determining Sediment Concentration in Water Samples. The performance of the sampling method was evaluated in terms of the recovery of sediment in the sample versus the calculated concentration of sediment added to the stream.

Isokinetic Sampling

The isokinetic sampling test set-up included water reservoirs, a pump, a flow meter, a 3 m long pipe with an isokinetic sampler in it and a receiving tank. In order to obtain grab samples as a reference to compare to the isokinetic samples it was necessary to scale down the flow rate compared to the grab sampling test set up. A smaller diameter pipe was used so that the sampler remained submerged at the lower flows. A schematic of the test set-up is provided in Figure 2 below.

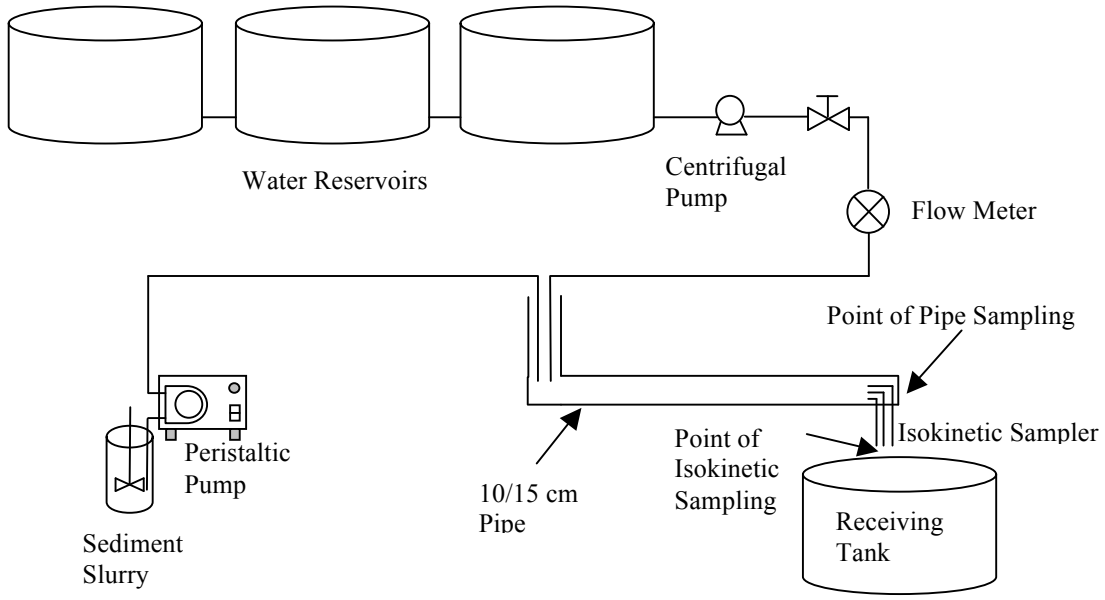

Figure 2 Isokinetic Sampling Test Set-up

In this study, two pipe flow velocities were tested, 1.0 and 1.4 m/s. A 10.2 cm (4 in) diameter pipe was used for the 1.0 m/s flow velocity and a 15.2 cm (6 in) diameter pipe was used for the 1.4 m/s flow velocity. The start of the pipe was constructed in an "L" shape and as water entered the "L" shape it created enough turbulence, to provide mixing of the test sediment slurry.

The isokinetic sampler was installed at the end of the pipe. The sampler included three evenly spaced, vertically and centrally aligned sampling tubes. The tubes were made from commercially available off-the-shelf stainless steel or copper tubes. The diameter of the tubes and the horizontal and vertical length of the tubes were altered in order to get isokinetic and non-isokinetic conditions. Non-isokinetic conditions occur when the flow velocity in the sampler tubes are higher or lower than the velocity in the pipe. A schematic of the isokinetic sampler is presented in Figure 3 below.

The flow velocity of the sampler was calculated by dividing the water flow rate through the sampler by the total cross-section inside surface area of the tubes. The flow rate of the sampler was measured by collecting the water in a pre-weighed beaker for 1-2 minutes. The diameters of the tubes were measured by a caliper.

According to Bernoulli's principal, for an inviscid, incompressible fluid in steady flow, the sum of all energies including kinetic, potential and pressure energy is constant at any point. The principle can be expressed in the follow equation:

$$\frac{v^2}{2} + gh + \frac{p}{\rho} = Constant \qquad (1)$$

where:

v is the fluid flow speed

h is the height of the point or the elevation of the point to a reference point

g is the acceleration of gravity

P is the pressure

ρ is the density of the fluid

Based on Bernoulli's principal, the flow velocity inside the pipe at the inlet of the tubes (V_1 in Figure 3) should be lower than the flow velocity at the end of the tubes (V_2 in Figure 3), as the potential energy at the point of V_1 is higher than the potential energy at the point of V_2. In terms of the equation, h is larger at V_1 than at V_2 so v must be higher in order to keep the right hand side of the equation constant.

The implication of this is that the pipe velocity should always be less than the tube velocity so an isokinetic condition is not possible. However, the Bernoulli equation does not consider friction losses in the tubes. Particularly in small tubes, the friction losses will be significant and the flow velocityV_2 can be greater, equal or even less than the flow velocity V_1 when the horizontal and vertical length of the tubes and the diameter of the tubes are properly selected.

In any case, the flow velocity inside the pipe at the point of the start of the tubes (V_1 in Figure 3) should be equal to the flow velocity at the end of the pipe (V_3 in Figure 3), as the sampler is very close to the end of the pipe and the friction loss of the pipe is negligible.

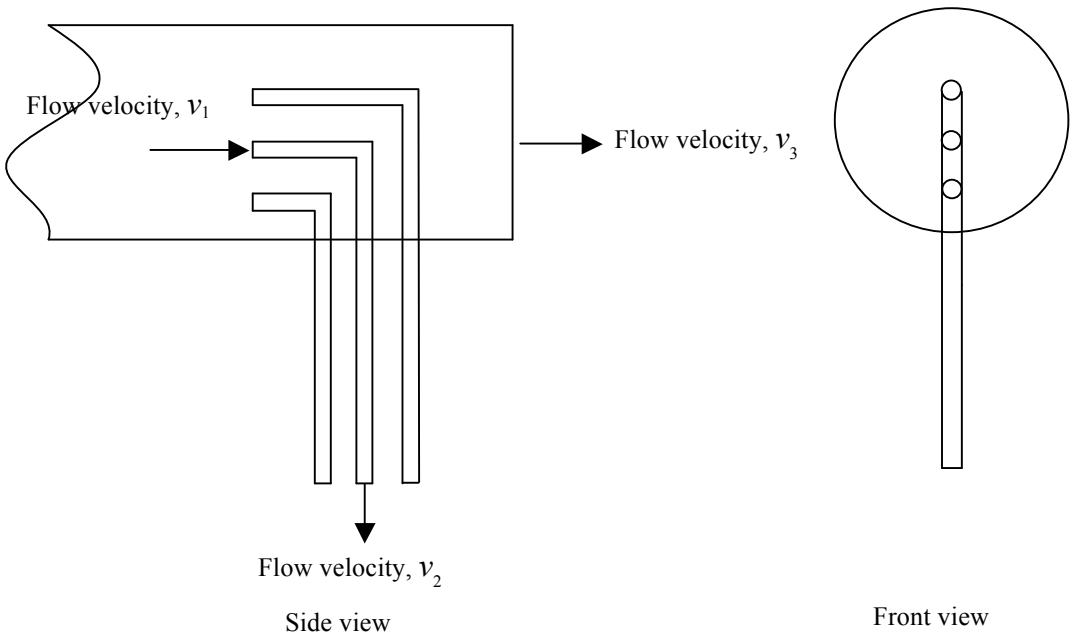

Figure 3 **An Isokinetic Sampler**

In this study, three different diameters of tube were used: 0.64 cm (¼ in), 0.96 cm (⅜ in) and 1.27 cm (½ in). The horizontal and vertical length of the tubes was altered in order to get the conditions where V_2 was greater, equal or less than V_1. No valves were used in the isokinetic sampling tubes in order to eliminate any variability they might cause. V_3 and V_2 were measured directly and $V_1 = V_3$ so all the required velocities were known. The range of $\frac{v_2}{v_1}$ was 0.7 to 1.9 in this study.

Two kinds of sediment were tested in the Isokinetic Sampling study. One was Sil-Co-Sil® 106, with a particle size of approximately 1 – 106 µm and a d_{50} of 22 µm. The other one was sediment with a particle size of 53 – 125 µm. This sediment was wet sieved from the test sediment specified by NJDEP (2013).

The sediment was injected using the same slurry system as the Effluent Grab Sampling testing. The test sediment concentrations were also the same as the Effluent Grab Sampling: 20, 50 and 100 mg/L. Samples were taken from both the isokinetic sampler and the end of the 10.2 or 15.2 cm diameter pipes. The corresponding SSC results were compared to evaluate the sediment recovery in the sampler at both isokinetic and non-isokinetic conditions.

RESULTS

Effluent Grab Sampling - Initial tests

The conditions for the initial tests for grab sampling consisted of a sediment level of 25, 50 and 100 mg/L, an effluent flow of 3.2, 6.4, 13.9 and 37.9 L/s, a sediment slurry concentration of 2500 and 5000 mg/L, and sediment slurry flows which ranged from 0.95 to 9.08 L/min.

The initial results showed high variability in the data. The data was discarded and new tests were run after some changes were made to the methodology. The 37.9 L/s condition was not re-tested because at that flow rate, useable samples could not be obtained. The 1 L jar filled much too quickly and there was significant splashing. A larger jar was not used because the resulting sample would be impractical to properly analyze for SSC.

Effluent Grab Sampling - Final Tests

The conditions for the final study for grab sampling consisted of sediment levels of 20, 50 and 100 mg/L and effluent flows of 3.2, 6.4, and 13.9 L/s. To get the required sediment levels the sediment slurry concentrations were 1250, 2500 and 5000 mg/L, and the sediment slurry flow rate ranged from 3.79 to 4.16 L/min. The results of the final study for grab sampling are summarized in Table 1.

Table 1: %Recovery from Final Trial

Replicate	Sediment Concentration: 20 mg/L			Sediment Concentration: 50 mg/L			Sediment Concentration: 100 mg/L		
	3.2 L/s	6.4 L/s	13.9 L/s	3.2 L/s	6.4 L/s	13.9 L/s	3.2 L/s	6.4 L/s	13.9 L/s
1	96.4	114.5	105.9	92.2	106	99.5	92.7	99.3	97.3
2	99.5	106.4	97.9	94.5	102	88.5	92.2	104	83.7
3	97.8	89.8	101.4	98.6	98.6	77.5	93.1	99.8	69.8
4	87.2	123.4	87.2	92.2	94.7	86.0	90.9	95.6	105
5	99.2	102.1	105.7	99.4	104	100	91.6	101	105
6	100.1	73.6	94.7	84.6	88.9	107	89.9	89.6	94.0

Isokinetic Sampling

Table 2 contains the raw data for the isokinetic sampling runs under all the conditions described in the Methodology section. The % recovery in the pipe was determined by grab sampling. Effluent grab sampling method was used to confirm the isokinetic test results.

Table 2: Summary of Isokinetic Sampling Testing Results

Velocity		Ratio	Test Sediment		% Recovery		Normalized Recovery
Pipe (m/s)	Tubing (m/s)	Tubing velocity /pipe velocity	Type	Concentration (mg/L)	Tubing	Pipe	
1.4	1.4	1.0	Sil-co-sil 106	50	96.0	99.8	0.96
1.4	1.4	1.0	Sil-co-sil 106	50	97.4	96.2	1.01
1.4	1.9	1.4	Sil-co-sil 106	50	95.9	91.4	1.05
1.5	2.1	1.4	Sil-co-sil 106	20	96.7	100.8	0.96
1.5	2.1	1.4	Sil-co-sil 106	50	96.1	97.6	0.99
1.5	2.1	1.4	Sil-co-sil 106	100	94.9	98.5	0.96
1.4	1.0	0.7	Sil-co-sil 106	20	97.3	90.2	1.08
1.4	1.0	0.7	Sil-co-sil 106	50	93.0	92.2	1.01
1.4	1.0	0.7	Sil-co-sil 106	50	108.3	101.5	1.07
1.4	1.1	0.8	Sil-co-sil 106	50	98.1	96.1	1.02
1.4	1.1	0.8	Sil-co-sil 106	50	94.1	94.8	0.99
1.4	1.0	0.7	Sil-co-sil 106	100	94.7	96.3	0.98
1.4	1.4	1.0	Sil-co-sil 106	20	96.6	91.2	1.06
1.4	1.4	1.0	Sil-co-sil 106	20	97.6	98.9	0.99
1.4	1.4	1.0	Sil-co-sil 106	100	97.6	98.5	0.99
1.4	1.4	1.0	Sil-co-sil 106	100	97.5	98.1	0.99
1.5	2.1	1.4	NJDEP 53-125 um	50	86.5	111.8	0.77
1.5	2.1	1.4	NJDEP 53-125 um	50	87.5	101.1	0.87
1.4	1.0	0.7	NJDEP 53-125 um	50	102.5	95.2	1.08
1.4	1.0	0.7	NJDEP 125-250 um	50	86.9	79.9	1.09
1.4	1.0	0.7	NJDEP 125-250 um	50	112.9	113.0	1.00

1.4	1.4	1.0	NJDEP	50	40.9	51.5	0.79
1.0	0.7	0.7	Sil-co-sil 106	50	89.7	95.1	0.94
1.0	0.7	0.7	Sil-co-sil 106	50	96.1	103.6	0.93
1.0	0.7	0.7	NJDEP 53-125 um	50	99.3	104.6	0.95
1.0	0.7	0.7	NJDEP 53-125 um	50	109.6	98.6	1.11
1.0	1.0	1.0	Sil-co-sil 106	50	94.4	95.9	0.98
1.0	1.0	1.0	Sil-co-sil 106	50	92.4	96.1	0.96
1.0	1.0	1.0	NJDEP 53-125 um	50	90.3	93.2	0.97
1.0	1.0	1.0	NJDEP 53-125 um	50	101.0	107.0	0.94
1.0	1.9	1.9	Sil-co-sil 106	50	95.1	92.2	1.03
1.0	1.9	1.9	Sil-co-sil 106	50	93.6	97.5	0.96
1.0	1.9	1.9	NJDEP 53-125 um	50	83.4	103.4	0.81
1.0	1.9	1.9	NJDEP 53-125 um	50	80.1	104.3	0.77

DISCUSSION

Effluent Grab Sampling

The suitability of a sampling method has a basic success criterion: the sampling method must obtain a representative sample of the effluent. Though this sounds like a simple process, completing this task successfully relies on many factors, one of the most critical being flow rate. At very low flow rates, a sample jar can be simply held at the exit of the effluent pipe to capture the entire flow stream.

As the flow increases this becomes impossible. Since the sediment concentration is unlikely to be uniform along the cross section of flow, the sample jar must be swept across the full flow stream in an attempt to approximate the true sediment concentration. This technique was used and Table 3 summarizes the recovery results for the ranges of flow and sediment concentrations tested.

Table 3: Summary of Recovery Results in %, Mean (Relative Standard Deviation)

Flow (L/s)	Sediment Concentration (mg/L)		
	20	**50**	**100**
3.2	96.7 (5.0)	93.6 (5.8)	91.7 (1.3)
6.4	102 (17.5)	98.9 (6.4)	98.2 (5.2)
13.9	98.8 (7.3)	93.2 (11.9)	92.4 (14.7)

The overall average recovery was 96.1% and the average standard deviation was 8.3%. It should be noted that as the flow rate increases, the precision of the results also decreases. Given the intended application of modeling TSS removal from a stormwater treatment device, grab sampling over the flow rates and sediment concentrations tested provided acceptable results. Attempts were also made to take samples at flows above 37 L/s however both the accuracy and the precision of the results were found to be unacceptable.

In the case of grab sampling, having the correct size sample jar and jar geometry were critical parameters. For low sediment concentrations, a larger sample size increases the accuracy and the precision of the results. Initial testing for this study used a 500 mL jar with a 5.7 cm opening to sample a water stream with a 20 mg/L sediment concentration over a flow range of 3.2-13.9 L/s. The test was repeated a second time, using a 1000 mL jar with an 8.3 cm opening. The difference in sampling container resulted in an increase in the average sediment recovery from 63% to 99%. Additionally, the average relative standard deviation (RSD) of the results was reduced from 34% to 10%.

Isokinetic Sampling

By definition, for an isokinetic sampler, the water flow rate in the sampler should be equal to that of the flow rate in the surrounding pipe. It is then assumed that the sediment concentration in both the pipe and sample are equivalent. The degree to which a system is isokinetic is determined by the ratio $\frac{V_t}{V_p}$, where V_t is the linear velocity of fluid through the sampler tube and V_p is the velocity in the surrounding pipe. Experiments were grouped into three categories, isokinetic, where $\frac{V_t}{V_p} = 1$ and non-isokinetic, where $\frac{V_t}{V_p} > 1$, or $\frac{V_t}{V_p} < 1$. The recovery of sediment was determined for both the end-of-pipe samples and the isokinetic tube samples. Each run was then evaluated based on the Normalized Recovery, R

$$R = \frac{\%Recovery\ from\ isokinetic\ sampler}{\%Recovery\ from\ end-of-pipe} \qquad (2)$$

Tests were run with two different types of sediment, a fine and course particle size. For the fine particle size, Sil-Co-Sil ® 106 (1-106 µm, d_{50} = 22 µm) was used and the wet-sieved NJDEP test sediment (53-125 µm) was used for the coarse sediment. Table 4 presents a summary of the results and a comparison of the mean recovery at the non-isokinetic levels vs. isokinetic at a 95% confidence interval.

Table 4: 2-Sided t-Test Assuming Equal Variance

V_t/V_p	Fine Particle Size				Coarse Particle Size			
	mean R	*t*-stat	*df*	*p*-value	mean R	*t*-stat	*df*	*p*-value
0.7	0.988	-0.272	22	0.788	1.03	-1.11	10	0.293
1.4	1.02	-1.43	16	0.171	0.825	2.29	10	0.0451
1.9	0.982	-0.672	16	0.511	0.789	3.470	10	6.03E-3

For the fine particle size, the average recovery of the sediment using the isokinetic sampler was ± 2% of the average recovery from the end-of -pipe manual sample, over the velocity ratio of 0.7 – 1.9. This demonstrates that if an isokinetic sampler is used to sample effluent from a stormwater filtration device, the sampler does not need to be truly isokinetic, if the sediment particle size is less than 100 µm.

For sediment with a larger diameter, the velocity of water in the sampling tube was more of a critical factor in obtaining an accurate sample. The mean recoveries for V_t/V_p of 1.4 and 1.9 were found to be statistically different from isokinetic conditions with a *p*-value < 0.05 at a 95%

confidence interval. The recovery accuracy was found to decrease as the velocity ratio, $\frac{V_t}{V_P}$, increased. This relationship is illustrated in Figure 4 by the linear regression of the data.

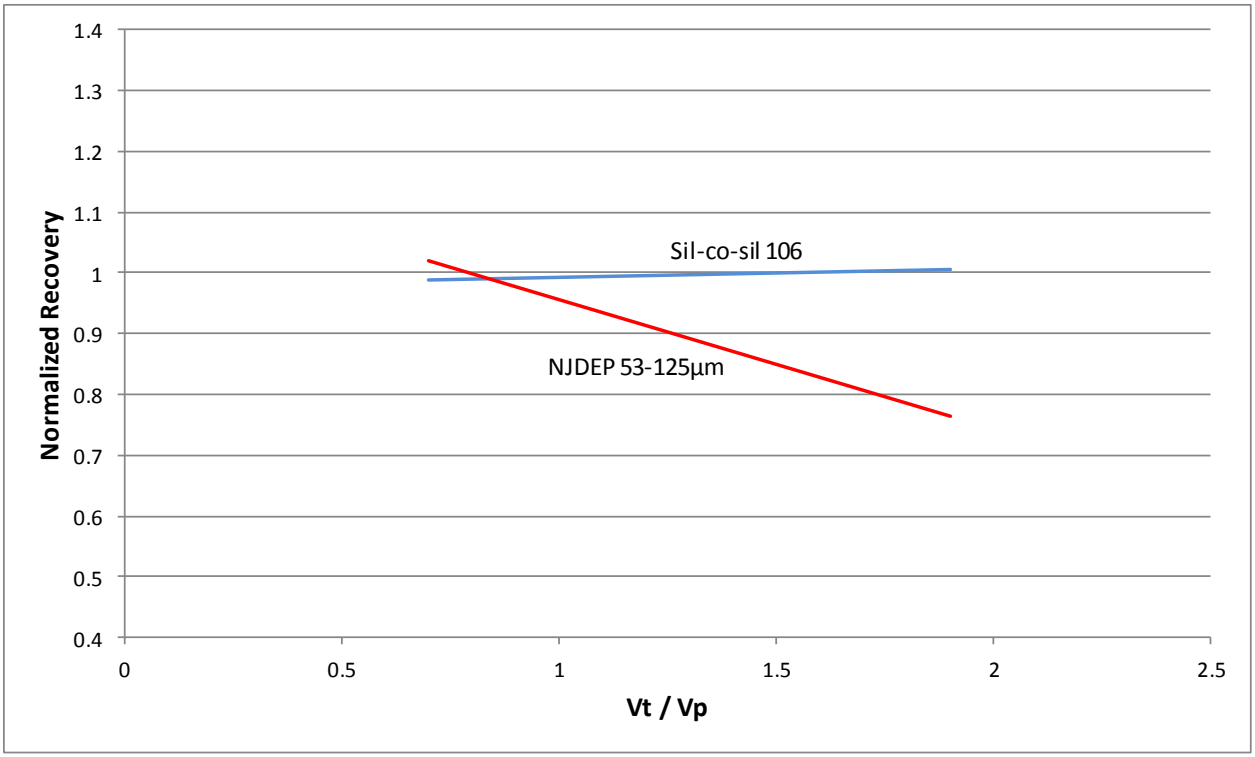

Figure 4: Effect of particle size and tube velocity on average normalized sediment recovery

The reason that sample recovery is influenced by particle size can be explained by flow patterns and inertia. Any curvature in the flow patterns or streamlines, caused by changes in velocities or by disturbances due to the sampler itself, will tend to segregate the sediment from the water. This, in turn, will change the concentration of the sample collected (University of Iowa, 1941).

This phenomenon is illustrated in Figure 5. In the case of an isokinetic system, Figure 5(a), the velocities are the same in both the tubing and the pipe; it is expected that the sediment concentration in the tubing will be equivalent to the concentration in the pipe.

When $V_t > V_P$, Figure 5(b), the tendency is for the sampler to be super-isokinetic. The water streamlines converge towards the sampling tube, however, larger sediment particles, having greater inertia than the water, will continue on their path and lead to a sample that is too low in sediment concentration. Conversely, smaller particles, having a lower inertia, are able to follow the change in direction of the altered streamlines and are sampled at a more accurate level. The reverse situation exists when $V_t < V_P$, the system is sub-isokinetic, as illustrated in

Figure 5(c). The streamlines move away from the sample tube while large particles continue on a relatively straight path. In this case, the larger particles are oversampled, resulting in a sediment concentration that is too high.

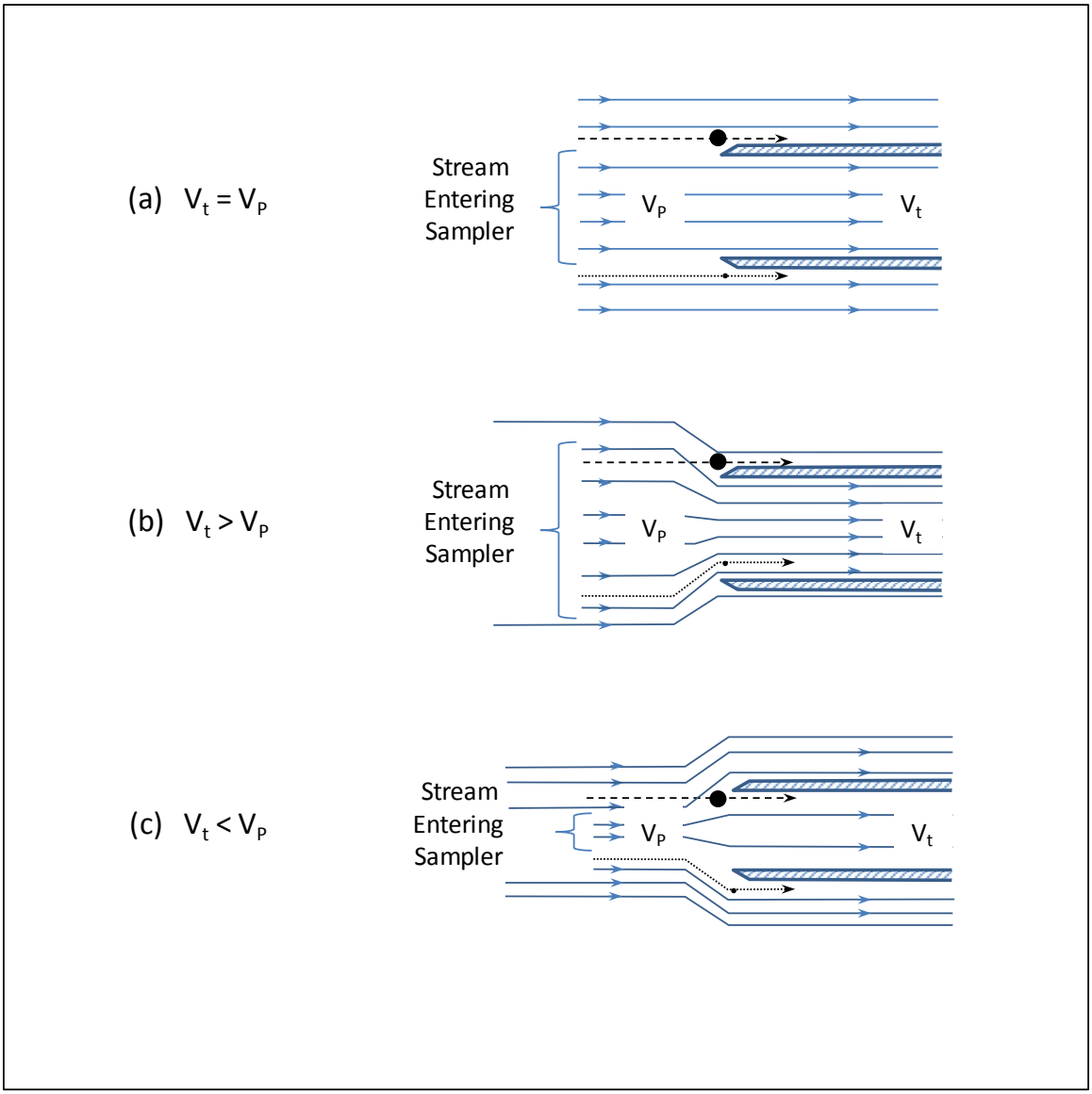

Figure 5: Flow patterns at isokinetic and non-isokinetic velocities

An earlier study (Wilson et. al., 2009) evaluated the performance of six hydrodynamic separators; two devices were tested in the laboratory and four devices were tested in the field. The six devices effectively removed sand, particles with diameter >250 µm, and removed 30–70% of very fine sand (89–125 µm). Using this data as a benchmark, it is expected that the

typical effluent from a hydrodynamic separator will contain sediment that will not be accurately sampled if the sampling conditions are not isokinetic

However, if an accuracy of 90-110% is acceptable then isokinetic conditions are not required. This is illustrated by the results for the sieved NJDEP sediment in Figure 4. If we assume that a sediment recovery greater than 90% is sufficiently accurate for the purposes of evaluating hydrodynamic separators, then interpolation of the data from Figure 4 shows that maintaining a $\frac{V_s}{V_p}$ ratio of ≤ 1.3 will provide acceptable recovery for an isokinetic sampler.

CONCLUSIONS

Grab sampling is the simplest and most cost effective method for collecting TSS samples. Over the flow range recommended in typical OGS protocols, 0-13.9 L/s (0-225 gpm), it can yield very good results. In this study the overall average recovery was 96.1% with a standard deviation of 8.3%. It is important to use the proper size container to get the best results. A test run at higher flow rates did not give acceptable results.

Since grab sampling is not effective flow rates above 13.9 L/s, isokinetic sampling is recommended for these conditions. This is a more complicated process because it requires adjusting the equipment every time the flow rate changes in order to maintain true isokinetic conditions. For protocols requiring continuously varying flow rate this means isokinetic sampling is not possible. However, this study discovered that over the ranges tested, a true isokinetic condition is not required for sediment with particle size < 100µm. Recoveries of 100 ±10% could be obtained for a sampling tube velocity to pipe velocity ratio of less than 1.3.

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