Stormwater Total Suspended Solids Removal using a Coalescing Plate Separator

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Abstract

Particulate material, mobilized by stormwater, negatively affects receiving lakes, rivers and streams. Reducing quantities of stormwater particulate to receiving bodies improves water quality and is often necessary to meet regulatory requirements. A laboratory study of total suspended solids (TSS) removal efficiency was conducted on a coalescing plate separator, designed and provided by Mohr Separations Research (MSR), at varying flow rates and influent TSS concentrations. To simulate a typical runoff TSS particle size distribution (PSD) Sil-Co-Sil 106 (SCS), a commercially available ground silica product with a median particle size of 20 µm, was used. Approximately 30% of solids in SCS are smaller than 10 µm and 96% of particles are less than 100 µm. Flow rates tested were 5, 10 and 15 GPM; influent concentrations of 50, 100 and 200 mg/L were tested at each of the flow rates. Removal efficiencies tended to increase slightly at higher influent concentrations and decreased at higher flow rates. Median removals for combined influent concentrations were 67%, 59% and 50% at flow rates of 5, 10 and 15 GPM, respectively.

Background

Particles mobilized by stormwater have the potential to enter receiving bodies and can negatively affect a number of water quality parameters. In addition to the negative consequences associated with the physical presence of suspended solids in water, TSS correlates with chemical pollutants. Copper, chromium, lead, phosphorus and zinc have been shown to attach to urban particulate matter (Thompson et al. 1997). Of particular concern are fine particles, which require a longer time to settle, have a larger adsorptive specific surface area, and pose a potentially greater environmental risk than larger particles. Vaze and Chiew (2004) have shown that 30-60% of total nitrogen sorbs to particles with diameters less than 20 µm and 30-50% of total phosphorus sorb to particles less than 20 µm. Studies by Rodger et al. (1998) report that concentrations for many pollutants, besides nutrients, also are higher in fine particle sizes.

Given the association between runoff TSS and water quality, many types of best management practices (BMPs) have been used to mitigate solids loading to receiving waters. Numerous studies, both in the laboratory and in the field, have been performed to assess solids removal capabilities for many BMP types. Figure 1 shows box plots for influent and effluent total suspended solids (TSS) for a number of BMP categories taken from the International Stormwater BMP database, which has collaborated over 500 BMP studies for various water quality parameters and BMP types (Wright Water Engineers and Geosyntec 2012). As seen in the figure, a dozen different stormwater BMPs were assessed and exhibit a substantial range of removal efficiencies.

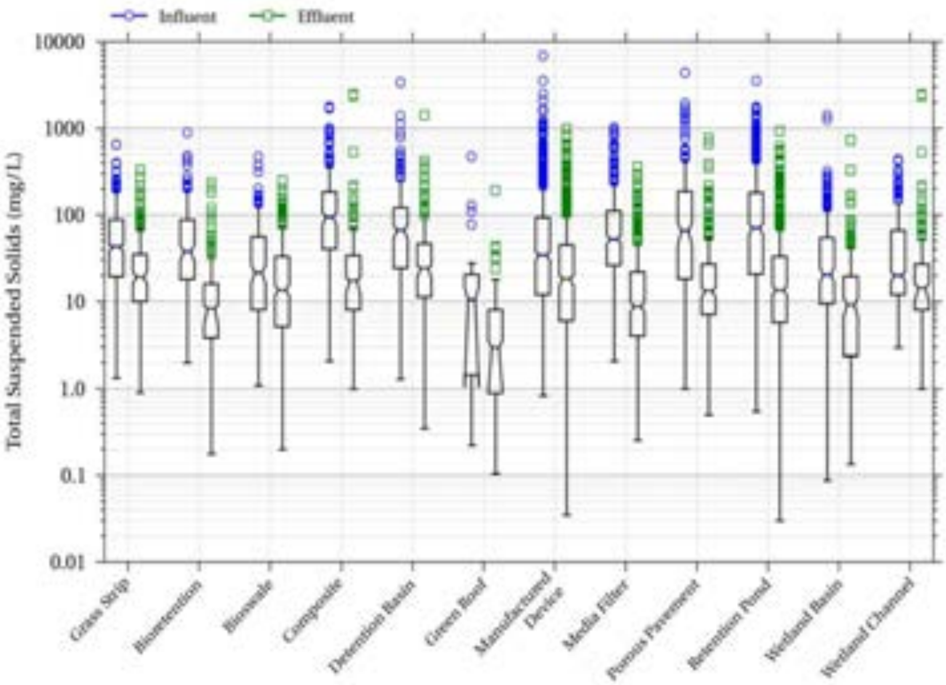

Figure 1: Box plots for influent/effluent TSS concentrations (Wright Water Engineers and Geosyntec 2012)

As new BMP technologies emerge, experimental testing is required to assess performance. To assist with evaluating new technologies, regulatory agencies, such as the Portland Bureau of Environmental Services (PBES), the New Jersey Department of Environmental Protection (NJDEP) and Washington's Department of Ecology (Ecology), have developed device testing protocols. It should be noted that the solids removal testing protocol specified by these agencies is similar, but not uniform. In addition to specifications provided by regulatory agencies, full scale laboratory tests conducted at universities, such as studies performed by Schwartz and Wells (1999), provide guidance for experimentally assessing BMP technologies.

Problem Statement and Objectives

Mohr Separations Research produces an enhanced gravity separator that utilizes a system of multiple angle plates to slow the flow of water, minimize turbulence, reduce rise/settling distance, provide solid/oil removal paths and enhance the coalescing of oil droplets.

Influent to the MSR unit first enters a disengaging chamber, where larger solids can settle and bulk oil rises to the surface. From the disengaging chamber, water enters the inlet chamber, where the flow is distributed by a baffle before entering the coalescing plate system, where liquid solid separation is increased. Within the coalescing system, light non aqueous phase liquids (LNAPL) merge and rise along paths through perforations in the plates. LNAPLs are subsequently collected in a chamber while solids are directed along paths to the bottom of the unit. After flowing through the coalescing plates, water passes over an adjustable weir and exits the system.

The MSR unit was designed primarily as an oil-water separator, but in operation, it was observed to also remove suspended solids. The objective of this study was to quantify the efficiency with which the MSR unit removes TSS using a standardized source of particles with known PSD. The TSS removal efficiency was measured for three flow rates and with three TSS influent concentrations. It remains unknown how well the MSR unit will remove TSS if influent contains oil and grease.

Experimental Testing Procedure

The MSR separator unit was installed in the Hydraulics Laboratory in the Portland State University Engineering Building. The setup is shown in the schematic drawing in figure 3 and a photograph of the setup is seen in figure 2. To supply required flow rates, a water supply tank was connected to a centrifugal pump (Dayton model #5k476C). The pump feeds into the system via a gate valve and inline flow meter, which allowed for variable influent flow rates. Solids were introduced at the crown of the influent pipe in the form of a well-mixed slurry using a peristaltic pump (Pulsafeeder model # VSP-20) to provide a consistent delivery rate. The desired influent concentrations of solids were achieved by adjusting the solids/water ratio of the slurry. The slurry was mixed and maintained as a uniform suspension using a mounted electric drill with mixer attachment. Influent with a specified solids concentration was introduced to the MSR unit using a 1.5" PVC pipe and exited the unit under free fall conditions into a trough located below the unit. Preliminary tests were conducted to ensure accurate and consistent flow rates and solids influent rates.

Figure 2: Photograph of setup

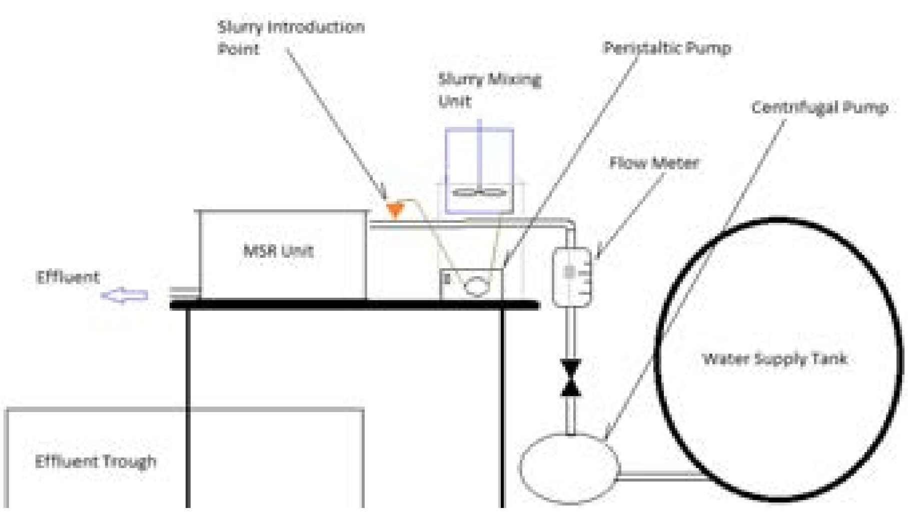

Figure 3: Schematic drawing of setup

TSS removal of the MSR unit was tested at three influent TSS concentrations (50, 100 and 200 mg/L) and three different flow rates (5, 10 and 15 GPM) for a total of nine operational conditions. Table 1 shows Reynolds numbers for each flow rate assuming a characteristic length of 2 times the plate separation distance. Additionally, table 1 shows surface loading rates at each flow. Flow rates were specified by the product manufacturer and TSS concentrations represent typical influent concentrations required by regulatory agencies for assessing removal. Ecology states that tests be run at influent TSS concentrations of 100 and 200 mg/L, but strongly encourages tests be run at lower influent concentrations as well (2008).

Table 1: Surface loading rates and Reynolds numbers at tested flow rates

Flow (GPM)	Surface Loading Rate (ft/min)	Reynolds Number
5	0.0111	41.1
10	0.0223	80.1
15	0.0334	123.4

To achieve consistent and reproducible results, we used SCS, a commercially available ground silica product, as the source of influent solids. SCS is manufactured by U.S. Silica and has a median particle size of 20 µm, with a particle size distribution (PSD) shown in figure 4. SCS is 99.8% pure silica and has a specific gravity of 2.65. Regulatory agencies, such as the Washington State Dept. of Ecology (2008), require SCS to be used as the testing solids for assessing TSS removal of a stormwater treatment device in the laboratory. Use of this commercially available testing media, facilitates performance comparisons of different technologies and ensures the experiment can be reproduced. It also has a consistent and known proportion of the very fine particles that are often of greatest concern in stormwater management.

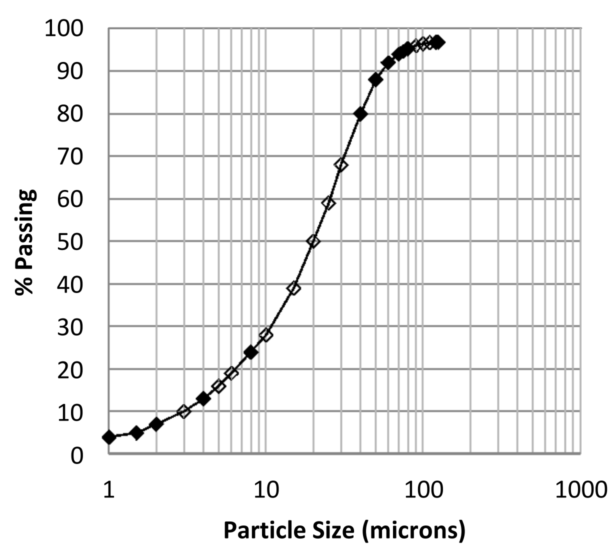

Figure 4: Particle size distribution for U.S Silica SCS 106 ground silica product

Four effluent grab samples were taken at different times for each one of the specified influent and flow rate conditions, a total of 36 grab samples were analyzed. The unit was allowed to cycle a minimum of three volumes (100 gallons) before samples were collected. On average, samples were collected every 25 gallons for the 50 mg/L run, every 31 gallons for the 100 mg/L run, and every 32 gallons for the 200 mg/L run .

Samples were analyzed according to EPA method 106.2 (USEPA 1999). Each Whatman Glass Microfiber Grade GF/C Filter was placed in a 47mm Pall Magnetic Filter Funnel and suction flask with vacuum attachment, then washed with three successive 20 mL aliquots of distilled water while vacuum was applied. After washing, filters were placed in a drying oven at 105˚C for one hour. After drying, filters were placed in a desiccator. After cooling, the weight of each filter was taken to ensure a constant mass was obtained. Filters were stored in a desiccator at room temperature until immediately before use. Immediately before being placed in the suction apparatus for analysis, masses were taken of each filter. Each filter was then placed in the 47mm Pall Magnetic Filter Funnel with suction flask and vacuum attachment. An aliquot of 200 ml for each well mixed effluent sample was measured using a graduated cylinder and run through the filter while vacuum was applied. The filter funnel and graduated cylinder were then rinsed with a small amount of distilled water to ensure all effluent solids had been captured by the filter. The vacuum was then turned off and the filter was removed and placed into a drying oven for one hour at 105˚C, after drying filters were cooled in a desiccator and weighed. Effluent concentrations were calculated as follows:

Where:

A=Weight of filter and captured solids (mg)
B=Weight of filter (mg)
D=Sample volume (mL)

Results

The TSS percent removal efficiency was calculated for each test condition as the difference of effluent and influent solids concentrations times 100. Box plots are used to represent variability in observations as four grab samples were taken for each of the influent conditions.

Figure 5 shows that TSS removal by the MSR unit, with an influent concentration of 50 mg/L, was generally between 50% and 66% and declined with increasing flow. Influent temperatures during sample collection ranged between 12.1 and 11.4˚C. Variability of measured effluent concentrations for this run do not correlate with volume cycled at the time of collection or flow rate.

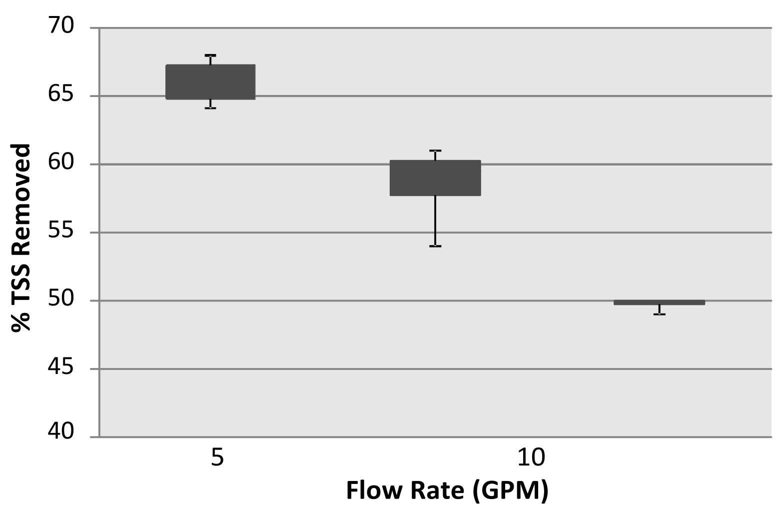

Figure 5: Box plots for %TSS removal. Influent TSS=50 mg/L

Figure 6 shows a very similar pattern of TSS removal by the MSR unit with an influent concentration of 100 mg/L. Once again, removals ranged from about 66% at 5 GPM to about 50% at 15 GPM. Influent temperatures during sample collection ranged between 15.0 and 11.7°C. Two-tailed, paired T-tests were performed to compare influent concentrations of 50 mg/L and 100 mg/L at each flow rate. P values seen in table 2 indicate that differences in removal efficiencies, measured at different influent concentrations, are not statistically significant.

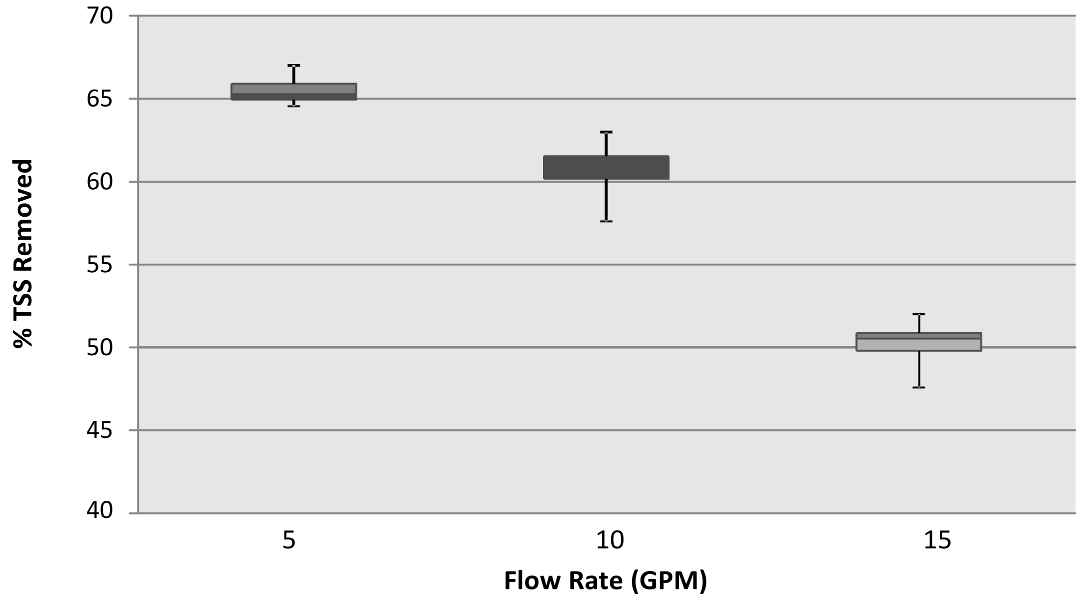

Figure 6: Box plots for % TSS removal. Influent TSS=100 mg/L

Table 2: P values for two-tailed, paired T-tests comparing 50 mg/L and 100 mg/L influent concentrations

Flow Rate (GPM)	P Value
5	0.654
10	0.398
15	0.735

Figure 7 shows TSS removal of the MSR unit with an influent concentration of 200 mg/L. Influent temperatures during sample collection ranged between 18.3 and 10.8°C. Table 3 shows P values from two tailed T-tests comparing removal efficiencies, observed at previous influent concentrations, to removal efficiencies observed at the 200 mg/L influent concentration. F-tests were performed on each data set to determine if equal variance or unequal variance T-tests would be used. As seen in table 3, the 200 mg/L influent concentration at 10 GPM does display a statistically significant difference. Other flow rates at the 200mg/L influent concentration do not display a statistically significant difference, most likely due to the small number of samples taken. As mentioned, samples were collected on average every 32 gallons at this influent concentration; effluent solids concentration tended to increase at each successive grab for both the 10 GPM and 15 GPM flow rates. Variability in removal efficiency was not observed to correlate with volume cycled for other influent concentrations, suggesting that some degree of re-suspension or scouring occurs in coalescing plate separators at higher flow rates and influent solids concentrations. It is also possible that the slurry with higher solids content behaved differently and short circuiting of the flow path occurred. To confirm observations, the 200 mg/L test was rerun at 15 GPM and results were the same.

Table 3: P values for two-tailed T tests comparing 50 and 100 mg/L influent concentrations to the 200 mg/L influent concentration

Flow Rate (GPM)	T-test type	P value
5	Equal variance	0.058
10	Equal variance	0.018
15	Unequal variance	0.424

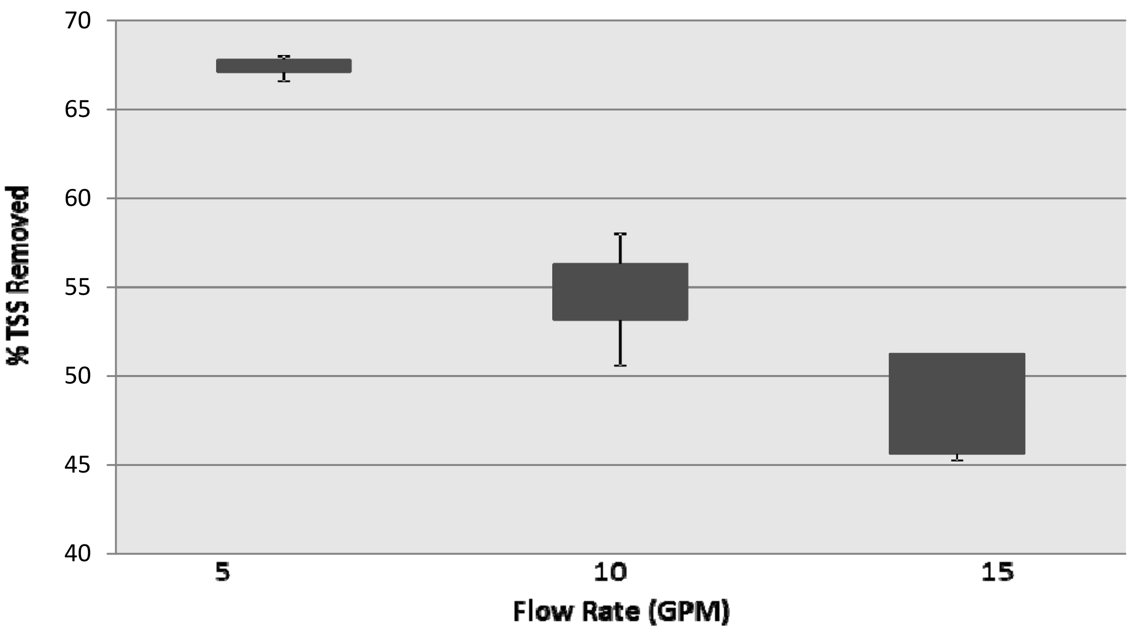

Figure 7: Box plots for % TSS removal. Influent TSS=200 mg/L

Figure 8 shows a photograph of the coalescing plate system after a test had been run. Plates function as designed and direct solids down paths to the bottom of the unit. Upon removing the plate system, solids appear to be uniformly distributed along the bottom of the unit in a flat layer. Solids with a fine PSD, such as those used in this experiment, appeared to slightly accumulate within the plates and some buildup of solids was noted along the edges of the plates, as seen the figure. The unit could possibly benefit from a solids collection sump to reduce solids removal frequency and handles to remove the plate system for inspection and cleaning.

Figure 8: Photograph of coalescing plates after a test

Five number summaries and mean values for removal efficiencies at all influent concentrations and flow rates can be seen in table 4. Variance in removal efficiencies is relatively small at all flow rates and influent concentrations.

Table 4: Means and variances of removal efficiencies at all testing conditions

		Flow Rate (GPM)		
		5	**10**	**15**
Influent TSS =50 (mg/L)	Max	68.0	61.0	50.0
	3rd Quartile	67.3	60.3	50.0
	Median	66.0	59.5	50.0
	Mean	66.0	58.5	49.8
	1st Quartile	64.8	57.8	49.8
	Min	64.0	54.0	49.0
Influent TSS=100 (mg/L)	Max	67.0	63.0	52.0
	3rd Quartile	65.9	61.5	50.9
	Median	65.3	61.0	50.5
	Mean	65.5	60.6	50.1
	1st Quartile	64.9	60.1	49.8
	Min	64.5	57.5	47.5
Influent TSS =200 (mg/L)	Max	68.0	58.0	51.3
	3rd Quartile	67.8	56.3	51.3
	Median	67.5	54.9	48.5
	Mean	67.4	54.6	48.4
	1st Quartile	67.1	53.1	45.6
	Min	66.5	50.5	45.3

Conclusion

Laboratory testing was conducted to assess the TSS removal efficiency of the MSR coalescing plate separator at flow rates of 5, 10 and 15 GPM. To simulate PSD typical of TSS in runoff, a ground silica powder with median particle size of 20 µm was used. EPA method 106.2 was followed to assess effluent TSS concentrations and multiple samples were analyzed at each of the specified influent conditions. Three TSS influent concentrations of 50, 100 and 200 mg/L were run at each of the flow rates. Median removals for combined influent concentrations were 67%, 59% and 50% for flow rates of 5, 10 and 15 GPM respectively.

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Appendix

Date:	12/16/2012	Date:	12/16/2012	Date:	12/16/2012
Run Start Time	7:46	Run Start Time	5:01	Run Start Time	1:50
Flow Rate (GPM)	5	Flow Rate (GPM)	10	Flow Rate (GPM)	15
Target Influent Concentration (mg/L)	50	Target Influent Concentration (mg/L)	50	Target Influent Concentration (mg/L)	50
Slurry Details		**Slurry Details**		**Slurry Details**	
Mass of solids added (g)	66	Mass of solids added (g)	135	Mass of solids added (g)	204
Volume of water used (L)	1.8	Volume of water used (L)	1.8	Volume of water used (L)	1.8
Temperature at grab (C)	11.4	Temperature at grab (C)	11.6	Temperature at grab (C)	12.3
Time at grab	8:12	Time at grab	5:11	Time at grab	1:55
Effluent Grab Sample ID	16.1	Effluent Grab Sample ID	14.1	Effluent Grab Sample ID	12.1
Initial Weight of Filter (mg)	130.9	Initial Weight of Filter (mg)	131.5	Initial Weight of Filter (mg)	133.7
Weight of filter and residue (mg)	134.4	Weight of filter and residue (mg)	135.5	Weight of filter and residue (mg)	138.7
Effluent Concentration (mg/L)	17.5	Effluent Concentration (mg/L)	20.0	Effluent Concentration (mg/L)	25.0
Temperature at grab (C)	11.4	Temperature at grab (C)	11.5	Temperature at grab (C)	12.1
Time at grab	8:17	Time at grab	5:16	Time at grab	2:00
Effluent Grab Sample ID	16.2	Effluent Grab Sample ID	14.2	Effluent Grab Sample ID	12.2
Initial Weight of Filter (mg)	132.4	Initial Weight of Filter (mg)	131.3	Initial Weight of Filter (mg)	132.2
Weight of filter and residue (mg)	135.7	Weight of filter and residue (mg)	135.9	Weight of filter and residue (mg)	137.2
Effluent Concentration (mg/L)	16.5	Effluent Concentration (mg/L)	23.0	Effluent Concentration (mg/L)	25.0
Temperature at grab (C)	11.4	Temperature at grab (C)	11.4	Temperature at grab (C)	12.1
Time at grab	8:18	Time at grab	5:21	Time at grab	2:00
Effluent Grab Sample ID	16.3	Effluent Grab Sample ID	14.3	Effluent Grab Sample ID	12.3
Initial Weight of Filter (mg)	132.6	Initial Weight of Filter (mg)	133.3	Initial Weight of Filter (mg)	133.5
Weight of filter and residue (mg)	135.8	Weight of filter and residue (mg)	137.4	Weight of filter and residue (mg)	138.6
Effluent Concentration (mg/L)	16.0	Effluent Concentration (mg/L)	20.5	Effluent Concentration (mg/L)	25.5
Temperature at grab (C)	11.4	Temperature at grab (C)	11.4	Temperature at grab (C)	11.8
Time at grab	8:21	Time at grab	5:21	Time at grab	2:05
Effluent Grab Sample ID	16.4	Effluent Grab Sample ID	14.4	Effluent Grab Sample ID	12.4
Initial Weight of Filter (mg)	133.2	Initial Weight of Filter (mg)	132.7	Initial Weight of Filter (mg)	133.4
Weight of filter and residue (mg)	136.8	Weight of filter and residue (mg)	136.6	Weight of filter and residue (mg)	138.4
Effluent Concentration (mg/L)	18.0	Effluent Concentration (mg/L)	19.5	Effluent Concentration (mg/L)	25.0

Date:	12/16/2012	Date:	12/16/2012	Date:	12/16/2012
Run Start Time	11:12	Run Start Time	4:00	Run Start Time	12:24
Flow Rate (GPM)	5	Flow Rate (GPM)	10	Flow Rate (GPM)	15
Target Influent Concentration (mg/L)	100	Target Influent Concentration (mg/L)	100	Target Influent Concentration (mg/L)	100
Slurry Details		**Slurry Details**		**Slurry Details**	
Mass of solids added (g)	134	Mass of solids added (g)	277	Mass of solids added (g)	427
Volume of water used (L)	1.8	Volume of water used (L)	1.8	Volume of water used (L)	1.8
Temperature at grab (C)	15.0	Temperature at grab (C)	12.2	Temperature at grab (C)	13.6
Time at grab	11:32	Time at grab	4:10	Time at grab	12:34
Effluent Grab Sample ID	10.1	Effluent Grab Sample ID	13.1	Effluent Grab Sample ID	11.1
Initial Weight of Filter (mg)	133.7	Initial Weight of Filter (mg)	132.4	Initial Weight of Filter (mg)	133.3
Weight of filter and residue (mg)	140.7	Weight of filter and residue (mg)	139.8	Weight of filter and residue (mg)	142.9
Effluent Concentration (mg/L)	35.0	Effluent Concentration (mg/L)	37.0	Effluent Concentration (mg/L)	48.0
Temperature at grab (C)	15	Temperature at grab (C)	11.9	Temperature at grab (C)	13.2
Time at grab	11:37	Time at grab	4:15	Time at grab	12:37
Effluent Grab Sample ID	10.2	Effluent Grab Sample ID	13.2	Effluent Grab Sample ID	11.2
Initial Weight of Filter (mg)	132.3	Initial Weight of Filter (mg)	133.0	Initial Weight of Filter (mg)	131.6
Weight of filter and residue (mg)	138.9	Weight of filter and residue (mg)	140.8	Weight of filter and residue (mg)	142.1
Effluent Concentration (mg/L)	33.0	Effluent Concentration (mg/L)	39.0	Effluent Concentration (mg/L)	52.5
Temperature at grab (C)	15	Temperature at grab (C)	11.9	Temperature at grab (C)	13
Time at grab	11:38	Time at grab	4:16	Time at grab	12:41
Effluent Grab Sample ID	10.3	Effluent Grab Sample ID	13.3	Effluent Grab Sample ID	11.3
Initial Weight of Filter (mg)	133.0	Initial Weight of Filter (mg)	133.4	Initial Weight of Filter (mg)	132.3
Weight of filter and residue (mg)	139.9	Weight of filter and residue (mg)	141.2	Weight of filter and residue (mg)	142.2
Effluent Concentration (mg/L)	34.5	Effluent Concentration (mg/L)	39.0	Effluent Concentration (mg/L)	49.5
Temperature at grab (C)		Temperature at grab (C)	11.7	Temperature at grab (C)	12.8
Time at grab		Time at grab	4:20	Time at grab	12:44
Effluent Grab Sample ID	10.4	Effluent Grab Sample ID	13.4	Effluent Grab Sample ID	11.4
Initial Weight of Filter (mg)	133.9	Initial Weight of Filter (mg)	131.1	Initial Weight of Filter (mg)	131.0
Weight of filter and residue (mg)	141	Weight of filter and residue (mg)	139.6	Weight of filter and residue (mg)	140.9
Effluent Concentration (mg/L)	35.5	Effluent Concentration (mg/L)	42.5	Effluent Concentration (mg/L)	49.5

Appendix

Date:	12/14/2012	Date:	12/15/2012	Date:	12/16/2012
Run Start Time	2:27	Run Start Time	12:45	Run Start Time	6:25
Flow Rate (GPM)	5	Flow Rate (GPM)	10	Flow Rate (GPM)	15
Target Influent Concentration (mg/L)	200	Target Influent Concentration (mg/L)	200	Target Influent Concentration (mg/L)	200
Slurry Details		**Slurry Details**		**Slurry Details**	
Mass of solids added (g)	276	Mass of solids added (g)	589	Mass of solids added (g)	730
Volume of water used (L)	1.8	Volume of water used (L)	1.8	Volume of water used (L)	1.4
Temperature at grab (C)	18.0	Temperature at grab (C)	18	Temperature at grab (C)	11
Time at grab	2:48	Time at grab	2:48	Time at grab	6:31
Effluent Grab Sample ID	7.1	Effluent Grab Sample ID	8.1	Effluent Grab Sample ID	15.1
Initial Weight of Filter (mg)	132.1	Initial Weight of Filter (mg)	132.5	Initial Weight of Filter (mg)	132.3
Weight of filter and residue (mg)	145.0	Weight of filter and residue (mg)	149.3	Weight of filter and residue (mg)	151.8
Effluent Concentration (mg/L)	64.5	Effluent Concentration (mg/L)	84.0	Effluent Concentration (mg/L)	97.5
Temperature at grab (C)	18.3	Temperature at grab (C)	17.9	Temperature at grab (C)	11
Time at grab	2:53	Time at grab	12:59	Time at grab	6:32
Effluent Grab Sample ID	7.2	Effluent Grab Sample ID	8.2	Effluent Grab Sample ID	15.2
Initial Weight of Filter (mg)	132.7	Initial Weight of Filter (mg)	132.7	Initial Weight of Filter (mg)	131.3
Weight of filter and residue (mg)	145.8	Weight of filter and residue (mg)	150.4	Weight of filter and residue (mg)	150.8
Effluent Concentration (mg/L)	65.5	Effluent Concentration (mg/L)	88.5	Effluent Concentration (mg/L)	97.5
Temperature at grab (C)	18.3	Temperature at grab (C)	17.7	Temperature at grab (C)	10.9
Time at grab	2:54	Time at grab	1:03	Time at grab	6:36
Effluent Grab Sample ID	7.3	Effluent Grab Sample ID	8.3	Effluent Grab Sample ID	15.3
Initial Weight of Filter (mg)	132.3	Initial Weight of Filter (mg)	133.2	Initial Weight of Filter (mg)	132.8
Weight of filter and residue (mg)	145.1	Weight of filter and residue (mg)	151.6	Weight of filter and residue (mg)	154.7
Effluent Concentration (mg/L)	64.0	Effluent Concentration (mg/L)	92.0	Effluent Concentration (mg/L)	109.5
Temperature at grab (C)	18.3	Temperature at grab (C)	17.7	Temperature at grab (C)	10.8
Time at grab	2:58	Time at grab	1:08	Time at grab	6:40
Effluent Grab Sample ID	7.4	Effluent Grab Sample ID	8.4	Effluent Grab Sample ID	15.4
Initial Weight of Filter (mg)	133.2	Initial Weight of Filter (mg)	131.8	Initial Weight of Filter (mg)	133.3
Weight of filter and residue (mg)	146.6	Weight of filter and residue (mg)	151.6	Weight of filter and residue (mg)	155
Effluent Concentration (mg/L)	67.0	Effluent Concentration (mg/L)	99.0	Effluent Concentration (mg/L)	108.5