High Rate Microcarrier-Weighted Coagulation for Treating Wet Weather Flow

By

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ABSTRACT

In wet-weather flow (WWF) a significant amount of toxic pollutants are associated with colloidal solids. Sedimentation with coagulation is considered to be an effective method of removing large quantities of suspended solids from water and wastewater. A new high-rate settling process, using microsand or a microcarrier (MC) as a settling carrier of colloids, has been developed and applied for treating both wet- and dry-weather flows (WWF/DWF). The addition and recirculation of the MC results in higher settling velocities and allowable tank overflow rates. The MC plays a crucial role in enhancing settling properties, and in particular, the removal of colloidal particles and associated contaminants.

A detailed testing procedure and a method of experimental analysis using a modified jar test for the MC process have been developed. A series of MC weighted jar tests were undertaken on parking lot storm runoff, synthetic samples, and combined sewer overflow (CSO) mixed with a MC, coagulant and coagulant aid. Two particle analyzers with a range of 0.002 to 5 micrometers (μm) and 0.1 to 2,000 μm, respectively, were used to determine the full range of particle size distribution. Different materials were used as the MC in this study. The operational parameters evaluated include coagulant dosage, coagulant aid type and dosage, mixing- and flocculation-induced hydraulic shear or velocity gradients and duration, and characteristics of the MC. The pH, turbidity, particle size distribution, total solids, total volatile solids, suspended solids, and zeta potential were determined. The experimental results revealed that MC weighted coagulation dramatically reduced coagulation-flocculation duration (< 3min) and settling time (< 8 min) producing flocs with high settling velocity and high quality supernatant. Reductions of turbidity from > 80 NTU (raw samples) to < 2 NTU (supernatant samples) were achieved.

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INTRODUCTION

A significant amount of toxic pollutants in wet weather flow (WWF) are associated with smaller particles (< 10 μm), including toxic-organic chemicals (e.g., benzene, polynuclear aromatic hydrocarbons [PAH], and polychlorinated biphenyls [PCB]) and heavy metals (e.g., arsenic, cadmium, chromium, copper, lead, mercury, and zinc). Sedimentation with coagulation is generally considered to be an economical method of removing large quantities of suspended solids (SS) from water and wastewater. A new high-rate settling process, using microsand or a microcarrier (MC) as a settling carrier of colloids, has been developed and applied for treating both wet- and dry-weather flows (WWF/DWF). The addition and recirculation of MC will result higher settling velocities and allowable tank overflow rates. This process is also known as "ballasted-coagulation." It has been reported that an MC unit would increase solids removal by more than 80% at a range of overflow rates of 50 to 100 $m^3/h/m^2$ (20 to 40 gpm/ft^2). This high-rate process consists of the addition of MC, coagulant, and coagulant aid with the influent in a mixing chamber followed by coagulation-flocculation and sedimentation. The MC plays a crucial role in enhancing settling properties, and in particular, the removal of colloidal particles and associated contaminants.

Objectives. The objectives of this investigation were:

- Evaluate the applicability of conventional jar test procedure to the MC weighted coagulation, and if needed, modify the jar test procedure for screening MCs, coagulants, and coagulant aids;
- Test the effects of different types and dosages of coagulant and coagulant aid in conjunction with MC for selection of the most effective combination;
- Investigate the effect of MC on particle size distributions and zeta potential of colloids in urban WWF by using the modified jar test procedure.

METHODOLOGY

Materials

MC. Ottawa sand was selected, due to its abrasion resistance, and small and uniform size. The size range of Ottawa sand tested was between 100 and 500 μm. The MC size ranges and concentrations were determined by prescreening tests.

Coagulants. Alum (aluminum sulfate, $Al_2(SO_4)_3 \bullet 18H_2O$)and ferric chloride ($FeCl_3 \bullet 6H_2O$) were used as the coagulants for this study.

Coagulant Aids. Five polyelectrolytes from two different manufacturers were used in the experiments. Among them, four (POL-EZ-2466, POL-EZ-3466, POL-EZ-2696, and POL-EZ-7736, by Calgon Corporation, Pittsburgh, Pennsylvania) were used in surface runoff tests and one (309C, by Polydyne, Inc., Riceboro, Georgia) for combined sewer overflow (CSO) tests.

Apparatus and Instruments

The descriptions for the major test apparatus and analytical instruments used for the investigation, including the measured parameters, range, model number, and manufacturer, are briefly described as follows:

- Particle size analyzer I, designated as PSA-I (Master-Sizer X, Malvern Instruments Inc.), is a large particle size analyzer with a measurement range from 0.1 to 2000 μm.
- Particle size analyzer II, designated as PSA-II (90Plus with ZetaPlus, Brookhaven Instruments Corporation), is a small particle size analyzer with a measurement range from 0.002 to 5 μm. PSA-II is equipped with disposable sample cells that eliminates the cross sample residue influence.
- The zeta potential meter and PSA-II are integrated in one unit. The measurement range of the zeta potential meter is from 0.1 to 200 mV with the particle size range from 0.002 to 30 μm. The resolution is sample dependent and in the range of 0.1% to 5%.
- Jar test apparatus: A Phipps and Bird (Model PB-700^{TM}). Dimensions of each jar are 11.5 X 11.5 X 21 cm depth which is capable of testing a water sample volume of 2,000 ml. Each mixer is equipped with a flat stirring paddle (7.6 X 2.5 cm or 19.3 cm^2). The area of the paddle was increased to 38.7 cm^2 for the MC jar test in order to generate more rigorous turbulence for keeping the microsand in suspension.
- Turbidity meter.
- pH meter.
- Balance.

MC Weighted Jar Test

The procedures include the following steps:

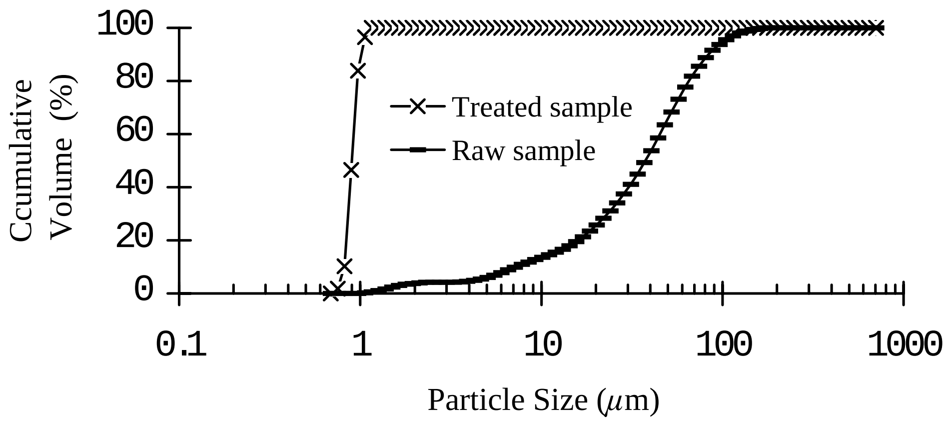
1. Collect storm surface runoff sample, prepare synthetic sample, or CSO sample. Measure the sample for pH and turbidity.
2. Pour 1,000 ml of the water sample into each two-liter jar of the jar-test apparatus and check stirrer operation. A light table facilitated viewing the contents of the jars.
3. Add controlled amounts (dosages) of MC, coagulant, and coagulant aid to the jars.
4. Flash mix for 20 to 60 s at 100 to 200 rpm.
5. Slow mix for 10 to 120 s at 30 to 60 rpm. Record the elapsed time before a visible floc is formed. If large flocs are formed, reduce the paddle speed. Record the appearance of the floc formed.
6. After flocculation, remove paddles and settle for 2 to 30 min.

7. Collect the supernatant from the sampling port on each jar and measure turbidity; the settled solids should not be disturbed during sampling. Select and record the dosage of coagulant and coagulant aid based on the supernatant clarity and settleability of floc.

RESULTS

The followings summarize the results of MC jar tests with surface runoff and CSO:

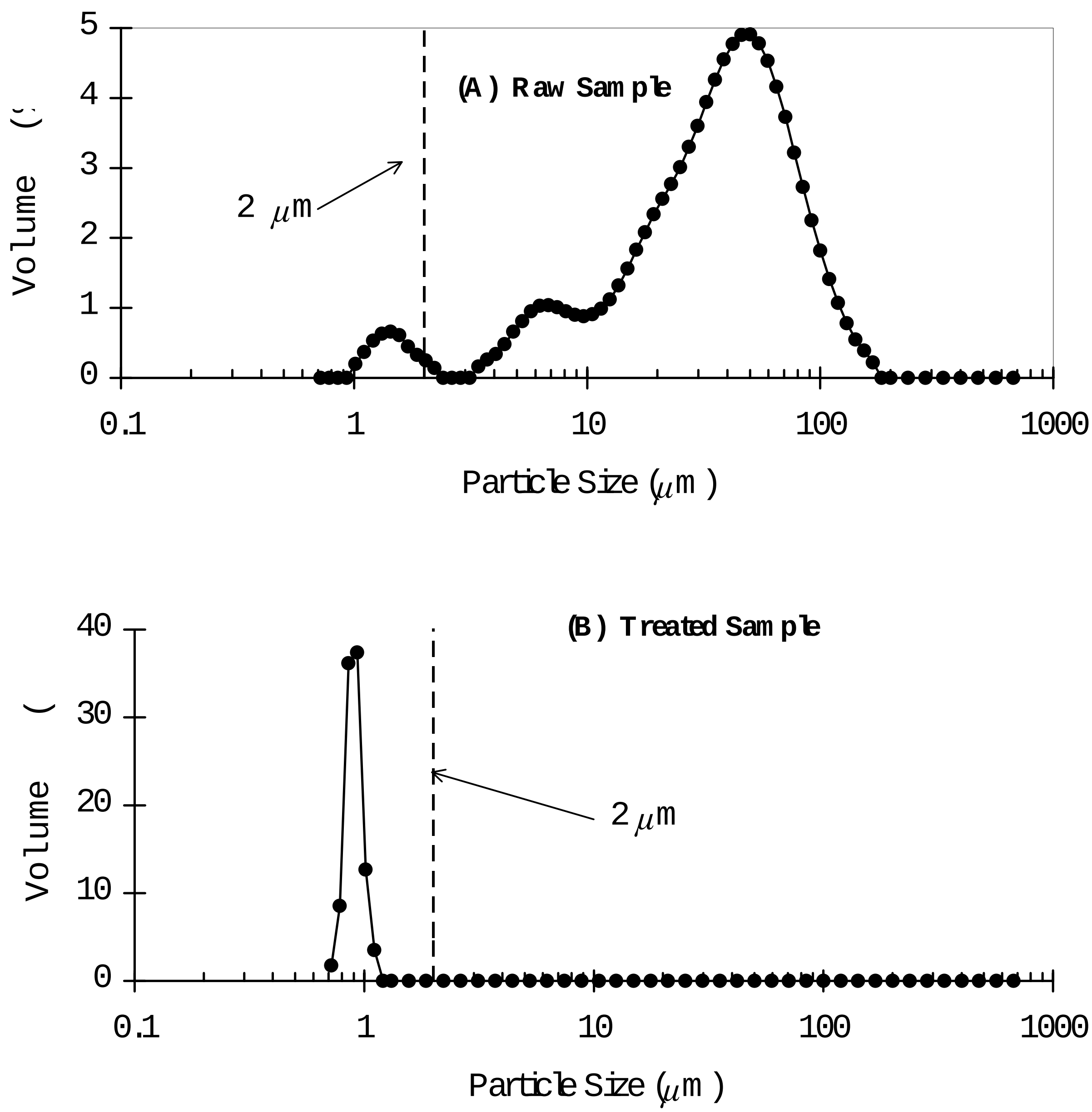
Surface Runoff
Figure 1 illustrates cumulative volume distributions versus particle size before and after the MC weighted coagulation. For the raw sample (before treatment), the measurable range of particle size is from 1 to 170 μm which consists of 81% from 10 to 100 μm and 14% smaller than 10 μm. After the MC coagulation, the particles in the supernatant of the jar were found to be < 2 μm, which indicated that all particles > 2 μm were removed.



MC Size Range: 53 to 150 μm; MC Concentration: 3 g/L
Aluminum Sulfate Concentration: 40 mg/L
Cationic Polyelectrolyte (POL-EZ-2466) Concentration: 1 mg/L

Figure 1. Particle Sizes of Raw and Treated Surface Runoff Samples (Cumulative)

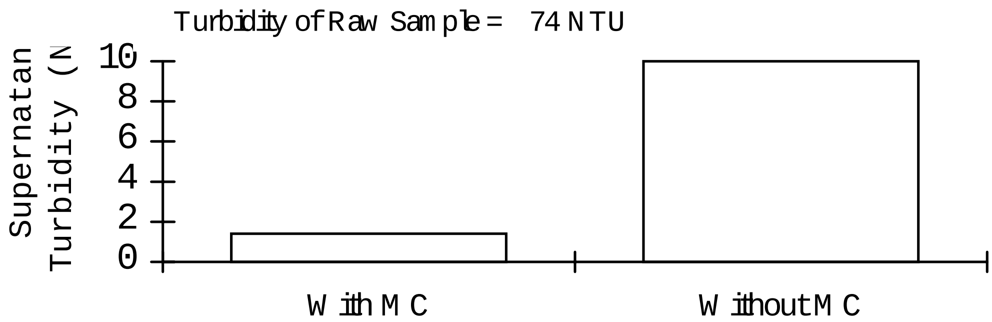
Figure 2 (A) and (B) illustrate the particle size distribution characteristics of the raw sample and supernatant sample after MC treatment, respectively. For the raw sample, the distribution peak is at approximate 50 μm while the small particles (from 0.7 to 2 μm) were either undetectable or only at a low percentage compared to the peak. After treatment, only particles < 2 μm remained in the supernatant. Since the larger particles were all removed from the raw sample, the percentage of particles < 2 μm increased significantly. The removal efficiency for particles < 2 μm was measured by the particle count rate (PCR) that is directly related to the number of particles counted per unit time in a solution expressed as kilo-count per second (kcps). Results of PCR are indicated in Figure 3.



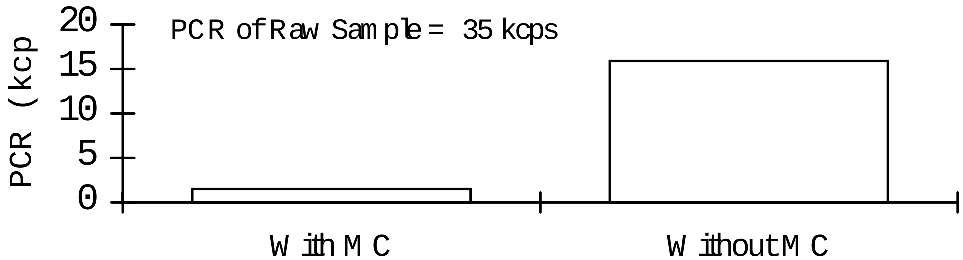
MC Size Range: 53 to 150 μm; MC Concentration: 3 g/L
Aluminum Sulfate Concentration: 40 mg/L
Cationic Polyelectrolyte (POL-EZ-2466) Concentration: 1 mg/L

Figure 2. Particle Size of Raw and Treated Surface Runoff Samples (Distributions)

MC jar tests were conducted with both coagulants and coagulant aids. Figure 3 (A) and (B) present supernatant turbidity and PCR results with and without MC. Both turbidity and PCR of supernatant samples with MC are much lower than those without MC. It is apparent that the addition of MC improves the treatment process effectively.



(A) Coagulant Aid (Anionic Polyelectrolyte [POL-EZ-7736])



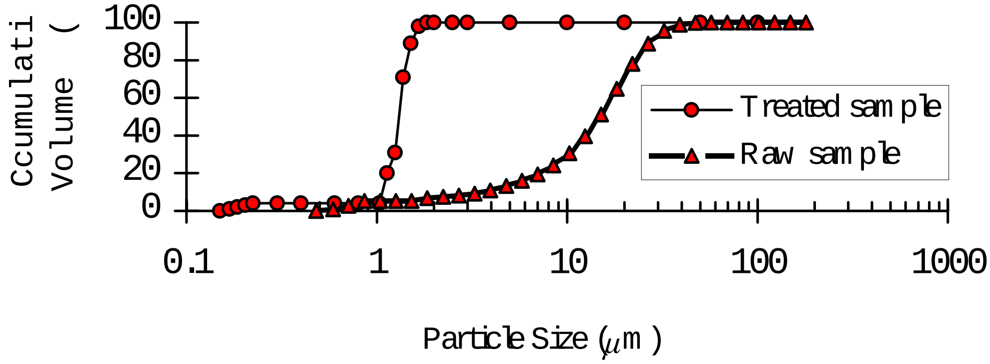
(B) Coagulant Aid (Non-ionic Polyelectrolyte [POL-EZ-2696])

MC Size Range: 53 to 150 µm; MC Concentration: 3 g/L
Aluminum Sulfate Concentration: 40 mg/L
(A) and (B) Coagulant Aid Concentration = 1 mg/L

Figure 3. Effectiveness of the MC Process (Surface Runoff Samples)

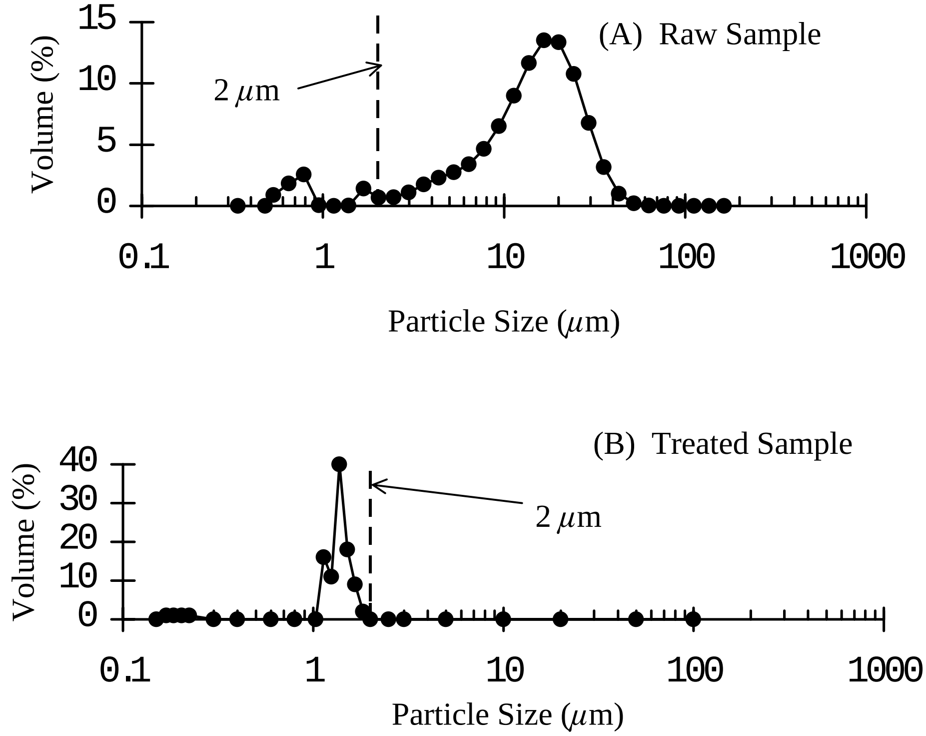
CSO

Figures 4 and 5 illustrate cumulative and discrete volume distributions versus particle size of raw sample and supernatant after MC weighted coagulation, respectively. For the raw sample (before treatment), the measurable range of particle size is from 0.5 to 60 µm with 93% (by volume) > 2 µm. After the MC coagulation, the particles in the supernatant of the jar were found to be < 2 µm, indicating all particles > 2 µm were removed.



MC Size Range: 53 to 75 μm; MC Concentration: 3 g/L
Ferric Chloride Concentration: 40 mg/L(as Fe^{+++})
Cationic Polyelectrolyte (309C) Concentration: 1.5 mg/L

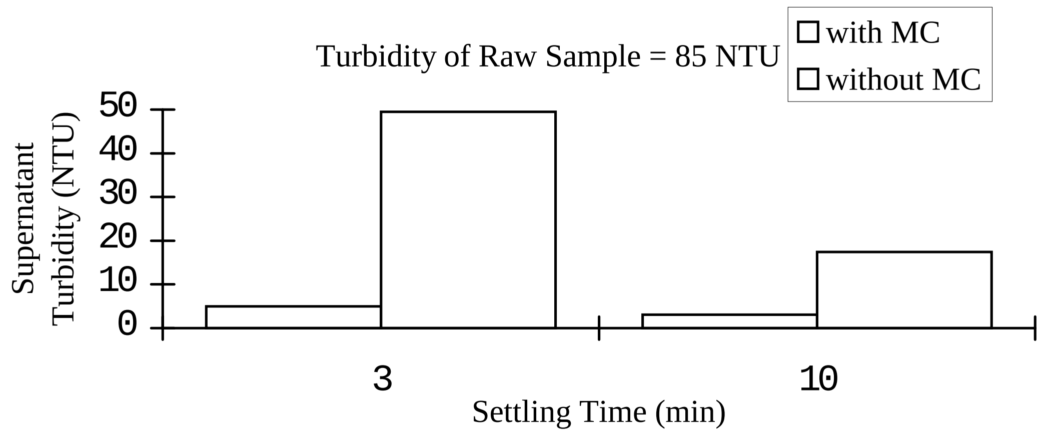
Figure 4. Particle Sizes of Raw and Treated CSO Samples (Cumulative)



MC Size Range: 53 to 75 μm; MC Concentration: 3g/L
Ferric Chloride Concentration: 40 mg/L (as Fe^{+++})
Cationic Polyelectrolyte (309C) Concentration: 1.5 mg/L

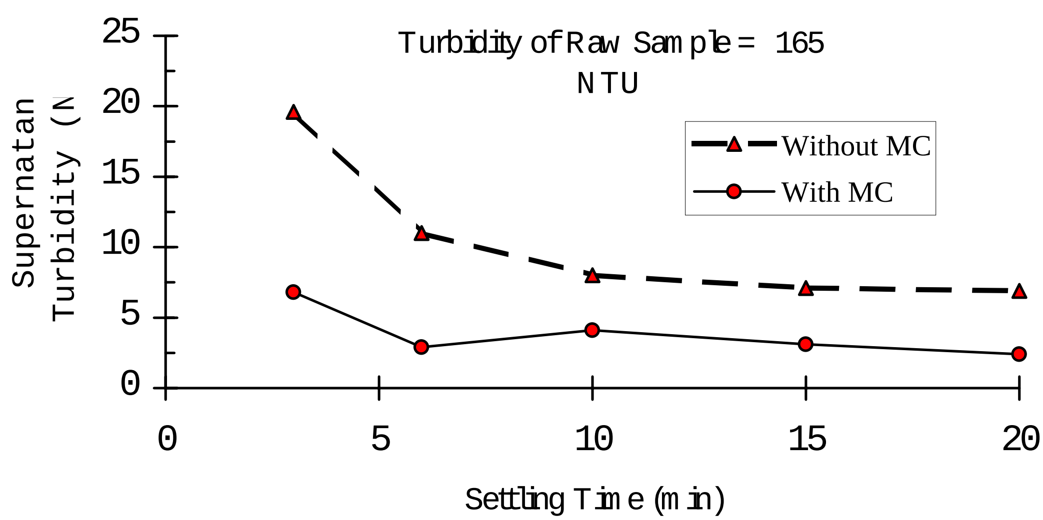
Figure 5. Particle Sizes of Raw and Treated CSO Samples (Distributions)

The effect of the MC was evaluated using turbidity and particle size distribution as indicating parameters. Figure 6 presents results of supernatant turbidity versus settling time with and without MC.



MC Size Range: 53 to 75 µm; MC Concentration: 3 g/L
Ferric Chloride Concentration: 40 mg/L (as Fe^{+++})
Cationic Polyelectrolyte (309C) Concentration: 1 mg/L

Figure 6. Effect of MC on CSO Samples



MC Size Range: 53 to 75 µm; MC Concentration: 3 g/L
Ferric Chloride Concentration: 40 mg/L (as Fe^{+++})
Cationic Polyelectrolyte (309C) Concentration: 1 mg/L

Figure 7. Turbidity versus Setting Time

CONCLUSIONS

Based on the results described above, conclusions can be summarized:

1. A testing procedure for experimental analysis of the MC process has been developed.
2. The MC process was found to be effective in reducing coagulation-sedimentation time, which, in turn, will reduce the sizing requirements of the process needed compared to a conventional physical-chemical treatment facility. The total treatment time could reduce to $<$ 10 min utilizing the MC-weighted coagulation-sedimentation process. Although stormwater and CSO samples with varying influent characteristics can be anticipated to react differently to the MC process, it is expected that the tremendous reduction in settling time found in this study will generally extend (in varying degrees) to all storm runoff and CSO samples.
3. In performing the MC-weighted jar tests (i.e., the modified jar test developed under this study), three stages of mixing, with 10 s duration in each stage, were used: (1) 150 rpm to lift the MC from the bottom of the jar into suspension, (2) 100 rpm to keep the MC in suspension, and (3) 60 rpm for the coagulation-flocculation process to treat storm runoff samples. For CSO treatment, the third stage duration for coagulation-flocculation was found to be optimal at 1 to 2 min.
4. The best combination coagulant/coagulant aid in the surface runoff MC study, was found to be 40 mg/L aluminum sulfate (coagulant) and 1 mg/L cationic polyelectrolyte, POL-EZ-2466 (coagulant aid). For CSO 40 mg/L coagulant (ferric chloride, as Fe^{+++}) with 1 mg/L coagulant aid (cationic polyelectrolyte, 309C) resulted in the best turbidity removal.
5. In the MC size and concentration study, the range of 53 to 150 μm at a dosage of 10 g/L yielded the best results for surface runoff. For CSO treatment, MC in a size range of 53 to 75 μm at a dosage of 3 g/L resulted in the lowest supernatant turbidity.

RECOMMENDATIONS

The following is recommended for the future:

1. Additional jar tests to refine the MC coagulation process for removal of toxic pollutants and microorganisms in urban WWF with different types of coagulant and coagulant aid.
2. Pilot studies to verify and expand upon the present bench-scale level (i.e., jar testing) in order to provide engineering design and operational procedures for full-scale MC systems.

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