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# EVALUATION OF THE PERFORMANCE OF FLOCCULATION TO ENHANCE SEDIMENT TRAP EFFICIENCY

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THESIS

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ABSTRACT OF THESIS

# EVALUATION OF THE PERFORMANCE OF FLOCCULATION TO ENHANCE SEDIMENT TRAP EFFICIENCY

Weathered sandstone materials have seen increased use in reclamation due to the wide-spread adoption of the Forest Reclamation Approach (FRA) in Appalachia. Runoff from these newly FRA reclaimed sites has the potential to adversely impact aquatic environments without fine sediment retention. To reduce the size and capital investment of settling ponds, flocculant utilization was investigated. Preliminary jar tests were conducted using composite weathered mine spoil samples acquired from a surface coal mine in eastern Kentucky. Four flocculants from the Magnafloc family of products were investigated during the initial screening-level testing. Experiments were conducted at three initial sediment concentrations (500 mg/L, 2,500 mg/L and 5,000 mg/L). A nonionic flocculant, Magnafloc 351, performed best, reducing total suspended sediment to below 50 mg/L. Large scale experiments confirmed that Magnafloc 351 was effective in reducing sediment concentrations. Jar tests were expanded to determine age and environmental effects on a Magnafloc 351 solution. Magnafloc 351 performance was slightly reduced after storage in a controlled building environment for 30 days and significantly decreased after 120 days. Magnafloc 351 solution exposed to UV and high heat (111°F) was ineffective after 30 days, while storage at 4°F and 36°F for 30 days did not adversely influence performance.

KEYWORDS: Flocculation, Weathered Mine Spoil, Coal Mining, Appalachia

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To my wife, Sara, and mother, Tabatha, thank you.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

# CHAPTER 1: INTRODUCTION

## 1.1 Background

The Surface Mining Control and Reclamation Act of 1977 (Congress 1977) requires removal, storage, and utilization of topsoil or best available substitute material during reclamation. In Appalachia, a substitute material is often used due to the thin soil mantle that exists (Daniels and Amos 1985). Weathered brown sandstone, unweathered gray sandstone, or a mixture of the two are the common substitutes that are used for reclamation in conjunction with the Forest Reclamation Approach (FRA) (Burger, Graves et al. 2005). The FRA consists of five steps: 1) use available topsoil or best available material to create a suitable growth medium, 2) create a non-compacted (or minimally compacted) growth medium for root growth, 3) use noncompeting cover for tree growth, 4) plant both early and late successional tree species and 5) use proper tree planting techniques (Burger, Graves et al. 2005). Proper utilization of the FRA with the combination of weathered brown sandstone provides an optimal tree growth medium (Showalter, Burger et al. 2010; Wilson-Kokes, Emerson et al. 2013; Zipper, Burger et al. 2013), while hydrologically mimicking a forested watershed (Angel, Barton et al. 2008; Taylor, Agouridis et al. 2009; Sena, Barton et al. 2014).

The combination of a non-compacted cover and weathered sandstone in reclamation can reduce peak flows and runoff volumes similar to that of a forested watershed (Taylor, Agouridis et al. 2009). Even with these practices, there are time phases within the mining cycle and reclamation that produce significant sediment concentrations during storm events (Bonta 2000). If runoff from these sites goes untreated and is discharged into the environment, fine particles can prove detrimental to aquatic communities (Quinn, Davies-Colley et al. 1992; Sutherland and Meyer 2007). Partnered with settling ponds on site, flocculation has garnered more attention as a possible practice to limit downstream effects of this sediment laden runoff.

Flocculant usage in the water and wastewater treatment industry began primarily as a settling aid in the 1950's. More recently flocculation has been investigated as a low cost measure to reduce the environmental impact of fine sized sediment laden runoff from disturbed lands. Within the mining cycle, there are two critical timeframes that have a high potential to generate substantial quantities of sediment: 1) just after clearing and grubbing and 2) after final spoil placement prior to revegetation. Although settling basins and best management practices (BMPs) are often implemented downstream, the fine sized particles must be treated and removed prior to discharge to avoid habitat disturbance and adverse effects on aquatic wildlife (Wood and Armitage 1997; Sutherland and Meyer 2007). Flocculation is the process in which suspended particles come together, forming a larger mass that will then settle at an increased rate. Increasing the aggregate particle size through flocculation provides a mechanism to increase sediment pond efficiency, without the capital investment caused by increasing the size of sediment ponds (Pillai 1997). Anionic and nonionic polyacrylamide (PAM) flocculants are the most commonly used flocculants when there is a risk of contact with animal or aquatic wildlife, as cationic PAM flocculants have been noted to negatively impact aquatic wildlife (Albassam, Moore et al. 1987) and pose an unneeded risk.

Current literature focuses only on flocculation usage at controlled facilities where a flocculant solution can be created and dispensed within a 48-hour period. Due to mine site constraints, it is often not economically or logistically feasible to treat inflow to sediment ponds with a flocculation solution less than 48-hours old. A feasible flocculation plan would be to mix a large volume of flocculant solution and store it in a central location prior transport and subsequent storage at the flocculant dispersant device that is located near the inflow of sediment ponds. There is an expected degradation of flocculant solution and its’ settling efficiency over time, especially in the presence of environmental conditions that one would expect to encounter on mine sites. There is a current literature gap that exists regarding this degradation. This research addresses the sediment trapping effectiveness of flocculant for a weathered mine spoil retrieved on an active mine site in eastern Kentucky and advances the current seminal level of knowledge about the influence of flocculant storage as influenced by time and environmental conditions.

### 1.2 Project Objectives

The overall goal of this project was to determine the feasibility of utilizing a polyacrylamide flocculant to reduce outflow sediment concentration on a disturbed site using loose dumped weathered spoil per FRA guidelines. Specific objectives were:

1. Determine if a polyacrylamide flocculant reduces sediment concentration in a solution composed of loose dumped weathered mine spoil and detect an optimum dosage at three initial concentrations using laboratory jar tests.

2. Evaluate the settling performance of Magnafloc 351 on weathered spoil solutions at three initial concentrations using laboratory column tests.

3. Evaluate the impact of age and environmental conditions on the settling effectiveness of a polyacrylamide flocculant using laboratory jar tests.

## 1.3 Organization of Thesis

Chapter 1 provides the overall and specific objectives of the research. Chapter 2 presents the results from a screening level test utilizing polyacrylamide flocculants on a weathered mine spoil. Chapter 3 contains an analysis of the settling characteristics of flocculated spoil using laboratory columns. Chapter 4 contains an explanation of the effects of aging and environmental conditions on polyacrylamide flocculant performance. Chapter 5 discusses potential future work.

# CHAPTER 2: SCREENING-LEVEL TESTING OF POLYACRYLAMIDE FLOCCULANTS ON APPALACHIAN WEATHERED MINE SPOIL

## 2.1 Introduction

Surface mining in Central Appalachia (Kentucky, Tennessee, Virginia, and West Virginia) is regularly conducted on steep slopes (Haering, Daniels et al. 2004). The primary method of sediment control on mine operations is sediment ponds either constructed as embankments in valleys or bench ponds located at the perimeter of the mining operation (Norman, Wampler et al. 1997). The introduction of flocculation up-gradient of sediment ponds can enhance sediment trapping efficiency thereby producing lower effluent sediment concentrations (Council 2004). The use of the Forest Reclamation Approach (FRA) up-gradient of sediment ponds not only provides an optimal tree growth medium, but can also create hydrologic characteristics similar to a forested catchment (Angel, Barton et al. 2008; Sena 2014). A critical component of the FRA is placement of no less than 1.2 meter of minimally compacted topsoil or topsoil substitute as a final spoil cover (Burger, Graves et al. 2005). Although the minimally compacted layer reduces surface runoff similar to that of a forested watershed, elevated influent sediment concentrations still occur (Taylor, Agouridis et al. 2009).

Mine construction in Appalachia often leaves exposed, disturbed areas characterized by steep slopes, with the soil/spoil barren for weeks, months, or longer. With large disturbed areas exposed, the generation of sediment-laden runoff is high for the small high intensity, moderate and large rainfall events that are prevalent in Central Appalachia. Common practice is to construct a sediment (or settling) pond(s) to detain sediment laden flow prior to discharging. Topographic site constraints often limit the size of sediment ponds. Due to detention times ranging from minutes (heavy storms with single spillways) to days (smaller storms with passive dewatering systems), not all sediment can be effectively settled.

The Surface Mining Control and Reclamation Act of 1977 (Congress 1977) regulations require the removal of topsoil, or best available soil substitute, and re-establishment of the topsoil layer during reclamation. With topsoil/spoil restored, clays and fine silts (size < 0.015 mm) are present, susceptible to erosion processes and are more likely to enter settling basins during rain events. Many best management practices

(BMPs), such as check dams, turbidity curtains, and brush barriers, used in conjunction with a sediment pond will increase the efficiency of removing a portion of the smaller sized particles such as medium to large silt (0.015 – 0.06 mm), but will often require additional treatment for the removal of the smaller silt and clay size particles (Norman, Wampler et al. 1997). Although BMPs, such as turbidity curtains and baffles can increase residence times thereby removing smaller particles, increasing particle sizes through flocculation provides a mechanism to significantly improve sediment pond efficiency without increasing the size of the sediment pond (Pillai 1997). Flocculation is the process that binds these small particles into larger aggregates that, with an increased particle size, settle at a much faster rate, leading to lower turbid discharge. If fine sediments are not sufficiently treated and released into an ecological environment, adverse effects on fish and aquatic invertebrate communities can occur (Quinn, Davies-Colley et al. 1992; Sutherland and Meyer 2007), as well as habitat disturbance after settling, embeddedness, and lack of light penetration available for photosynthesis.

This chapter addresses a flocculation screening test to determine an optimum flocculant solution and a dose response relationship based on initial sediment concentrations for a weathered mine spoil exposed during clearing and grubbing and employed as a final topsoil/spoil layer on a surface mine in the Appalachian region of eastern Kentucky.

## 2.2 Background

### *2.2.1 FRA Approach and Weathered Brown Sandstone*

The reclamation of disturbed surface mines must restore the lands to the approximate state of pre-mining original contours, complete with concurrent reclamation and a permanent vegetative cover (Congress 1977). The Forest Reclamation Approach (FRA) is a proven and preferred method to reclaim surface mined lands to mimic the pre-mined Appalachian forest condition. The FRA consist of five steps: 1) create a suitable growing medium through topsoil and/or the best available material, 2) reduce compaction on created growth medium, 3) use noncompeting ground cover, 4) plant both early successional species and late successional tree species, and 5) use proper tree planting techniques (Burger, Graves et al. 2005). Researchers have found that coal companies that have implemented the FRA are succeeding in creating favorable site conditions leading to higher survival and early growth (Zipper, Burger et al. 2011).

One potential pitfall in the use of the FRA in Appalachia is the lack of topsoil available for reclamation purposes (Daniels and Amos 1985). SMCRA (Congress 1977) states that when topsoil is not available for restoration, a best available soil substitute can be used in its place during reclamation. An experimental study of three different spoils at the University of Kentucky on reforestation success at a surface coal mine in eastern Kentucky determined that the use of loose graded brown, weathered sandstone created a higher average tree volume index and a higher percentage of natural vegetation and cover than the loose graded gray, unweathered sandstone or a loose graded mix of weathered and unweathered sandstone and shale (Angel, Barton et al. 2008; Sena 2014). Electrical conductivity (EC) was significantly lower for interflow emanating from the brown weathered sandstone compared to the other two spoils after two years (Agouridis, Angel et al. 2012). No significant differences in EC were apparent between the three spoils after 7 years of growth and weathering, all being approximately 500 µS/cm (Sena 2014). The use of brown, weathered sandstone also reduced runoff through the establishment of an excellent ground cover (Sena 2014).

Incorporating the use of loose graded brown weathered sandstone as a component of the FRA is a way to alleviate prior compaction and tree establishment reclamation problems and achieves establishment and tree growth, hydrologic regime, and water quality values that significantly address sustainable mining attributes. The critical periods of initial grubbing and between initial grading and an establishment of substantial ground cover still exists although with diminished severity as compared to traditional compacted spoil mine reclamation methods. Supplemental protection needs to be added, such as flocculation, to reduce fine particles that would otherwise be emanating from the mine site. Flocculation systems, with site specific design and flocculant application techniques, are a new, proposed method to retain fine grained particles, thereby reducing the potential degradation of downstream ecosystems.

### *2.2.2 Flocculant*

Polyacrylamide (PAM) flocculant research originated in the 1950's, focusing on its use as a soil conditioner (Green and Stott 1999). Since then, PAM use has been expanded to applications across the world; now most commonly utilized in mineral processing and water treatment, but research is expanding to encompass construction and mining operations for sediment control (Huang, Lipp et al. 2000; Soupir, Mostaghimi et al. 2004; McLaughlin, King et al. 2009). The use of PAM flocculants have not gained widespread popularity in the construction and mining industries but research has shown their use can be cost effective (Ebeling, Rishel et al. 2005).

Sediment settling can be partitioned into four types of settling: 1) discrete particle settling, 2) flocculant settling, 3) hindered or zone settling, and 4) compression settling. Discrete particle settling occurs when particles fall and settle independently of one another. Flocculant settling occurs when particles interact with one another to combine into larger masses to fall and settle. Zone settling occurs when enough particles have interacted to create a "blanket" of flocculated sediment particles that traps particles beneath this layer, falling at once, showing two distinct "zones" in the settling column. Compression settling occurs when the particles have reached the bottom of the pond, and require compression to reduce pore water pressure and to further compact (Tchobanoglous, Burton et al. 1991). The use of flocculants is to encourage flocculant settling when it would not occur otherwise, and lead to zone settling to remove the finer particles in suspension.

Flocculation is slowly gaining popularity in conjunction with sediment ponds. A study conducted by Zech, Fang et al. (2014) polled state highway agencies regarding their sediment basin design and the accompanying maintenance, installation, and inspection. Thirty seven of the fifty agencies responded to the survey. Of these thirty seven responses, thirty three (89%) had experience with sediment basins. In regards to flocculation, 13 of the 37 state highway agencies use flocculant additives (39%), with 11 of the 13 preferring PAM floc blocks (89%), Figure 2.1.

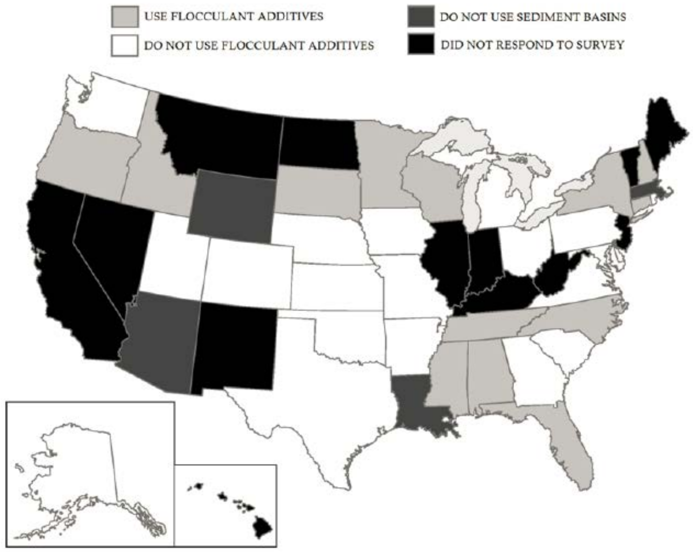


Figure 2.1: Map of State Highway Agencies Usage of Flocculant Additives (Zech, Fang et al. 2014)

Polyacrylamide is currently being utilized primarily as a soil conditioner, to reduce soil erosion and increase infiltration in furrow irrigation and rain fed irrigation, and on construction and mine sites for erosion control (Green and Stott 1999). Common factors that affect flocculation performance are based on "polymer type, ionic strength, water pH, slurry solids, flocculant dilution, shear, molecular weight, and process conditions" (Green and Stott 1999). PAM is produced as cationic (positive charge), anionic (negative charge), and nonionic (no charge).

The effectiveness of PAM in the mining and construction industries often centers around two parameters: charge and molecular weight (Ebeling, Rishel et al. 2005). The charge of the PAM will determine how it interacts with the soil/spoil to form the flocs and also the interactions with the environment and organisms downstream of the sediment pond. Cationic flocculants are not recommended for applications in which there is a possibility for the flocculant solution to be in contact with animal or aquatic life. A study by Albassam, Moore et al. (1987) focused on the effects of cationic flocculant on rainbow trout. They found that the positive charge on the flocculant attached to the negative charge on the epithelial cells of the trout. This, in turn, exposed the plasma membrane to the effects of the flocculant. The damage to the plasma membrane "would result in failure of gas exchange and osmoregulation" at the gills of the trout. At the exposure of a cationic flocculant concentration of 1.0 mg/L and above, the rainbow trout “had marked sever gill changes” with many dying within 96 hours. With the increased regulations and monitoring from outside agencies and potential for adverse community impacts, it has proven an unneeded business risk to consider the use of cationic PAM for control of sediment in the mining industry. Contrarily, nonionic and anionic PAM do not have the same extent of environmental risks and stigmas associated with the use of cationic PAM (Beim and Beim 1994; Kerr, Lumsden et al. 2014).

High molecular weight PAMs are primarily used in the flocculation of runoff due to their higher effectiveness over lower molecular weights. Both an increase in the length of the polymer chain and an increase in viscosity of a PAM solution correlates to an increase in the molecular weight (Green and Stott 1999). A study by Levy and Agassi (1995) on the use of PAM for soil conditioning, found a relationship between soil texture and polymer chain length. They found that in fine textured soils, the difference in polymer chain length was negligible. In more coarse textured soils, with their particles distanced farther apart than their fine textured counterparts, it was found that the higher molecular weight PAMs were more effective. Although the study was on soil conditioning, it can be postulated that longer polymer chains provide larger areas and therefore more sites that additional particles can attach themselves to during flocculation, proving more effective in coarse textured soils. Utilizing this same information, it can be anticipated that the longer polymer chains and attachment areas will provide a higher efficiency of attaching, and therefore settling, smaller silt and clay particles. Using higher molecular weight PAMs does have disadvantages, however, including higher viscosities leading to pump and dispensing issues and the creation of larger and more fragile flocs, which may shear in the presence of turbulent mixing.

### *2.2.3 On-Site Valley Fill Observations*

Previous research conducted at the University of Kentucky focused on valley fills located at a mine in central West Virginia. The research focused on the water quality and sediment emanating from a valley fill from initial clearing to reforestation. The research was halted early, however, due to lack of funding due to a downturn in coal economy and redirected priorities by the funding consortium. The mine plan required that two valley fills (VF-A, VF-B) be constructed in adjacent valleys in such a way that both valley fills would be cleared, filled, and then reforested. VF-A was the first to be constructed, with VF-B to be cleared once the spoil placement began on VF-A. The research was only able to be conducted through the timeframe when VF-A was being filled with weathered mine spoil and VF-B was cleared. Data were collected, but not published, and were utilized in this current research.

Monitoring was conducted by installing galvanized steel flumes down-gradient of proposed VF-A and VF-B and installing portable ISCO samplers (Teledyne) to sample from the flow passing through the flumes located up-gradient of the sediment pond, Figure 2.2. ISCO samplers acquired periodic samples through a tube that was anchored in the flume with sampling initiated by a liquid level actuator. Samplers were set to initiate sampling once the flume water level height reached approximately 1 cm above base flow. The ISCOs were set to acquire 24 1-L samples over a period of six hours after the actuator initiated sampling.


Figure 2.2: ISCO Sampler with Flume at Toe of Valley Fill A

Two storms were acquired in VF-A and three storms in VF-B. Runoff was acquired in VF-A during the filling process, in which the underdrain for the valley fill was completed and the bottom two lifts, each lift being approximately 15 m in height, were being created through end-dumped weathered mine spoil progressing up-gradient from the toe of the fill. The two storm events that were captured by the ISCO sampler at

VF-A were both smaller than the 1 year recurrence interval storm (Hershfield 1961). The three storms in VF-B were captured during the period in which the footprint of the valley fill was denuded but no filling had occurred. The three storm events that were captured by the ISCO sampler at VF-B were all smaller than the 1 year recurrence interval storm (Hershfield 1961). All sample bottles were retrieved on site and returned to the University of Kentucky for total suspended sediment (TSS) analysis over three replicates from each ISCO bottle by the LISST-Portable (3.2.5). The minimum, average and standard deviation, and maximum TSS values were calculated for VF-A and VF-B, Table 2.1.

Table 2.1: TSS from Storm Grab Samples from Valley Fills A and B

| **Valley Fill A – Active Filling** | | | **Valley Fill B – Stripped/Denuded** | |
|---|---|---|---|---|
| **Value** | **TSS (mg/L)** | | **Value** | **TSS (mg/L)** |
| Minimum | 295 | | Minimum | 99 |
| Average | 677 ± 449 | | Average | 318 ± 187 |
| Maximum | 2469 | | Maximum | 736 |

Each constructed valley fill will differ in overall size and geological material. The fundamental dimensions of lift height and bench width are standardized at 15 m and 4.5 m +/- 0.5 m, respectively. The measured sediment concentrations are representative of valley fills having similar lift height and bench width dimensions. Hence, the monitored and modeled TSS results are considered representative of expected values and were used to guide the screening-level flocculation testing program. Utilizing the TSS numbers retrieved from the actively filled valley fill, a "low concentration" of 500 mg/L was determined by finding a mean between the minimum and average values of 295 mg/L and 677 mg/L, respectively. This "low concentration" was considered as a baseline that accounts for the smaller storms that frequently pass through the site. A "medium concentration" of 2,500 mg/L was determined by utilizing the maximum value of 2,469 mg/L, based on the approximate 1-year return period. A "high" concentration of 5,000 mg/L was estimated on the basis that no runoff from a storm larger than the 1 year recurrence interval was captured. It can be assumed that larger storms with higher intensities will produce surface runoffs that have higher TSS concentrations approximating 5,000 mg/L or higher. A study by (Curtis 1973) on the effects of surface mining in eastern Kentucky over two years showed elevated suspended sediment during disturbance with most values smaller than 2,500 mg/L but elevated peaks from 4,000 to 10,000 mg/L. A study by (Bonta 2000) monitored three watersheds in East-Central Ohio from predisturbance through mining and reclamation. Suspended sediment concentrations were higher during mining phases with median concentrations ranging from 1,300 to 38,000 mg/L per mining phase, with most medians being between 3,000 and 9,000 mg/L. Since the results of this experiment are expected to be used in future, larger scaled experiments, it is important to consider a range of TSS that would be expected on a disturbed mine site. Three initial concentrations of 500, 2,500 and 5,000 mg/L (low, medium, high) were utilized in the jar test.

### *2.2.4 Jar Test Procedure*

Jar tests have been the industry standard technique for the evaluation of flocculants and coagulants on water samples. Jar tests provide a timely and cost effective method to predict flocculant effectiveness in both qualitative and quantitative terms. Jar tests are often conducted to determine flocculant dosage, mixing time, mixing speed, settling time, and facilitate sample withdrawal to determine water quality parameters (Herbert and Wagner 1981). Using transparent jars enables visual assessments that provide immediate qualitative results. Sample withdrawal, commonly drawn through a motorized pippetter, allows for TSS and water quality tests to be performed.

The jar tests were conducted on a Phipps and Bird PB-700 Jartester with six paddle stirrers and an illuminated base at the laboratories of the University of Kentucky. Jar tests were conducted with six one-liter glass beakers filled with deionized water. Previous flocculant screening research conducted at the University of Kentucky showed that if tap water was used, ions were present that aided in the flocculation process; thus, deionized water was used in all experiments. All samples were prepared using soil that had been processed through the #100 sieve, 0.15 mm; thus removing all particles that would naturally settle without flocculation. The needed time for particles of different diameters to settle a distance of 0.5 meter using Stokes Law for Reynolds numbers <0.5 (Equation 2-1) and an equation determined by Wilson, Barfield et al. (1981) for Reynolds numbers >0.5 (Equation 2-2) ranges from a couple of seconds to months, Table 2.2.

$$V_s = \frac{1}{18}\left[\frac{d^2 g}{v}(SG-1)\right]$$ Equation 2-1

Where:

$V_s$= settling velocity of the particle, cm/sec

d= particle diameter, cm

g= gravity, cm/sec²

v= kinematic viscosity, cm²/sec

SG= specific gravity

$$\log_{10} V_s = -0.34246(\log_{10} d)^2 + 0.98912 \log_{10} d + 1.14613$$ Equation 2-2

Where:

$V_s$= settling velocity of the particle, cm/sec

d= particle diameter, cm

Table 2.2: Effect of Particle Size on Settling Rate (Adapted from Haan, Barfield et al. 1994)

| **Particle Diameter (mm)** | **Order of Size** | **Settling Velocity (mm/s)** | **Time Required to Settle 0.5 m*** |
|---|---|---|---|
| 2 | Very Fine Gravel | 277.9 | 1.8 Seconds |
| 0.2 | Fine Sand | 19.4 | 25.7 Seconds |
| 0.02 | Silt | 0.358 | 23 Minutes |
| 0.002 | Clay | $3.58 \times 10^{-3}$ | 39 Hours |
| 0.0002 | Colloid | $3.58 \times 10^{-5}$ | 162 Days |

*Calculation based on a sphere with S.G. 2.65 at 20°C

The following protocol was used during the jar tests:

1. Soil sample sieved through #100 sieve and fines were weighed to produce tested concentrations
2. Beaker filled with 1 L of deionized water

3. Measured soil sample added to filled beaker to achieve desired initial concentration
4. Flocculant dosage measured in syringe for ease of measurement and application
5. Beaker placed on jar tester and stirred for 2 min at approximately 200 RPM
6. Flocculant injected to surface of mixture and stirred for 2 min at approximately 200 RPM
7. After blended flocculant and soil has mixed for 2 minutes, the stirrer is turned off and removed from the beaker
8. Allow flocculated particles to settle for 10 min without disturbance
9. Using motorized pippetter, withdraw 200 mL of sample from supernatant (approximately 1 cm below surface) and transfer to clean container.
10. Use 200 mL sample to test of TSS and particle size distribution with LISST-Portable Particle Size Analyzer (PSA).

ASTM D2035-08 Standard (2008) specifies rapid mixing at approximately 120 rpm for 1 minute, followed by a slow mix period of twenty minutes before paddle removal and undisturbed settling. Typical sediment pond construction does not provide adequate space to create a mixing zone that will enable twenty minutes of constant mixing. Based on-site observations and dry tracer testing in a prototype laboratory settling pond, it was determined that rapid mixing at a duration of two minutes followed by a settling period of 10 to 20 minutes would be the most accurate representation of what could be accomplished in a mine setting (M. L. Griffin 1985). This most closely resembles a generic site in which flocculant is introduced upstream of a pond in a rock riprap channel and rapidly mixed as it is conveyed to the sediment pond. The flocculated particles would then slowly pass through the length of the pond until they reach the discharge structure, which was conservatively assumed to take approximately 10 minutes for supernatant sampling.

### *2.2.5 LISST*

Jar test samples were analyzed using a LISST-Portable manufactured by Sequoia Scientific, Inc. The LISST Portable is a portable, self-contained, battery powered particle size analyzer. It uses a method of laser diffraction to measure the size and concentration of particles suspended in a solution, which is quickly displayed as a size distribution and volume concentration. With its rapid analysis and display of results, it was chosen to be used to process the supernatant samples collected from jar tests. The immediate results of the concentration of the sample allowed the tests to be adjusted on a rep by rep basis that saved time and laboratory resources.

The LISST-Portable was configured before operation to analyze random shaped particles for a 30 second duration. The LISST can be set to analyze spherical or random particles, with random being the preferred when measuring samples containing soil particles. The LISST was operated as follows on the supernatant samples acquired from the jar tests:

1. Clean mixing chamber sufficiently with deionized water and, if needed, hand soap, cotton swabs, and rinse.
2. Obtain a background reading using deionized water compared to the factory background measurement.
3. Drain background water and add 200 mL sample to mixing chamber, making sure that all sample has been suspended and poured into the chamber.
4. Allow sample to become thoroughly mixed in the chamber and determine if sample needs to be diluted to achieve an accurate reading based on screen reported laser transmission values.
5. Once the sample is mixed, the LISST proceeds to obtain a measurement average at 25 Hz.
6. The measurement averages are then analyzed by the LISST to compute the size distribution from the averaged data.
7. While the size distribution is being computed, the sample can be drained and cleaned in preparation for the next sample.

The results from the LISST are output as a particle size distribution and a volume concentration (μL/L), which is easily converted to a mass concentration (mg/L) by multiplying the volume concentration by the specific gravity of the sample.

### 2.3 Experimental Procedure

BASF (www.basf.com) provided granular powder samples of PAM from their Magnafloc® family of flocculants for screening-level testing at the University of Kentucky. The flocculants with the charge and molecular weight of the products were obtained from the Material Safety Data Sheets supplied by BASF, Table 2.3.

Table 2.3: Characteristics of Flocculants Used in Screening Level Testing

| Product Name | Charge | Molecular Weight |
|---|---|---|
| Magnafloc 351 | Nonionic | High |
| Magnafloc 5250 | Anionic | High |
| Magnafloc 336 | Anionic | Very High |
| Magnafloc 10 | Slightly Anionic | Very High |

Due to the high potential for adverse environmental effects, cationic flocculants were not included in this study. These four PAM flocculants were chosen to investigate three types of charges (nonionic, slightly anionic and anionic), while retaining a high (or very high) molecular weight. High and very high molecular weight flocculants were chosen based on the longer polymer chains they form, which leads to more attachment sites. Only BASF products were considered due to previous studies being performed at the Biosystems and Agricultural Engineering Department at the University of Kentucky utilizing their products, fostering a good working relationship between the two entities, and wide availability of their products if future research is conducted at another location.

Flocculants were mixed at a 0.1% solution with deionized water 24 hours before each screening test. Flocculants were mixed by combining 1.0 gram of dry flocculant in 1.0 liter of deionized water using a Phipps and Bird PB-700 Jartester at a speed of 200 rpm for 60 minutes. After 60 minutes, the paddle stirrer was turned off and the flocculant was allowed to rest until tests the next day. It was important to follow a simple and cost effective mechanical mixing process that could be replicated on mine sites.

A laboratory experiment was conducted at the labs of University of Kentucky to determine the most effective flocculant at reducing TSS from a weathered, loose dumped mine spoil retrieved from a surface mine in eastern Kentucky. The spoil was retrieved on site in 2013 and sieved to a maximum particle size of 0.150 mm (#100 sieve). The initial screening tests focused on the four flocculants at a 0.1% solution.

For the initial screening test, the sample sediment concentration was generated at 500 mg/L in each jar. The full screening range of flocculant dosage, 0.5 to 3.0 mL, was conducted only for the sediment concentration of 500 mg/L, with subsequent tests, for the 2,500 and 5,000 mg/L concentrations, based on the dosage results from the 500 mg/L concentration. Each flocculant was screened over six jars with increasing flocculant dosages. For the 500 mg/L sediment concentration, the flocculant dosage began at 0.5 mL of 0.1% solution and dosage incrementally increased by 0.5 mL with progressing jars (0.5 mL to 3.0 mL). Flocculant dosages were introduced with 10 mL syringes that were rinsed multiple times with DI water between uses. Flocculant dosages greater than 3.0 mL were not explored during the 500 mg/L screening test due to future operational cost considerations for future site installation. It was assumed that flocculant dosage requirements increase with sample sediment concentration and an initial dosage of 3.0 mL at 500 mg/L would lead to a dosage that may be cost prohibitive for 2,500 mg/L and 5,000 mg/L. It was imperative to keep this project economically feasible for potential future applications. Knowledge from prior flocculant screening tests suggested that an optimal dosage of less than 3.0 mL could be achieved for the 500 mg/L concentration.

After each jar test was completed, 200 mL of supernatant, approximately 1 cm below the water surface, was withdrawn for analysis by the LISST-Portable and jars visually assessed and photographically codified. The sample was withdrawn near the surface to mimic an outlet structure that dewaters near the pond surface, such as a drop inlet riser or a floating siphon. Each flocculant was analyzed for six jars over three replicates, with the TSS concentration averaged over the three replicates. Both visual analysis and TSS were the criteria at which the optimum flocculant and dosage was chosen at the 500 mg/L concentration.

The lowest (starting) flocculant dosage for the 2,500 mg/L concentration was based on an increase of the lowest dosage from the 500 mg/L and incrementally increased by 1.0 mL to 6.0 mL (increasing by 1.0 mL). At the 5,000 mg/L concentration, flocculant dosages were based on an increase of the lowest dosage from the 2,500 mg/L test and ranged from 2.0 mL to 7.0 mL (increasing by 1.0 mL). These increases correspond to the initial thought that an increase in initial concentration would require an increase in dosage. Optimum dosages were chosen by visual analysis and TSS as with the previous jar test.

The statistical analysis was performed using the PROC GLM procedure available within SAS™ (Version 9.3, SAS Institute Inc., Cary, NC, USA). To determine the optimum flocculant, mean TSS levels and standard errors were determined across each flocculant for all dosages. Least square means (LSMEANS) was used to determine the significant differences ($p<0.05$) that exist between the flocculants utilizing Bonferroni adjustment, due to its conservative nature. Additional analysis was performed to determine dosage effects of the optimal flocculant at varying initial concentrations. Mean TSS levels and standard errors were determined for each dosage at each initial concentration. Least square means (LSMEANS) was used to determine the significant differences ($p<0.05$) that exist between the dosages utilizing Bonferroni adjustment, due to its conservative nature, for each initial concentration.

## 2.4 Results

### *2.4.1 Specific Gravity*

The specific gravity of the weathered mine spoil sample was conducted, according to ASTM D854-10 Standard (2010), over three replicates. The mean specific gravity was determined to be 2.74 $g/cm^3$. The LISST portable outputs concentration results in mL/L, therefore the specific gravity must be used to convert the units to the more commonly used mg/L.

### *2.4.2 Initial Flocculant Screening Test*

An initial flocculant screening test was conducted at an initial concentration of 500 mg/L using the four prepared flocculants and a control of no flocculant. The final TSS concentrations (mg/L) were analyzed over all six dosages and three replicates for each flocculant and control, Figure 2.3 and Table 2.4.

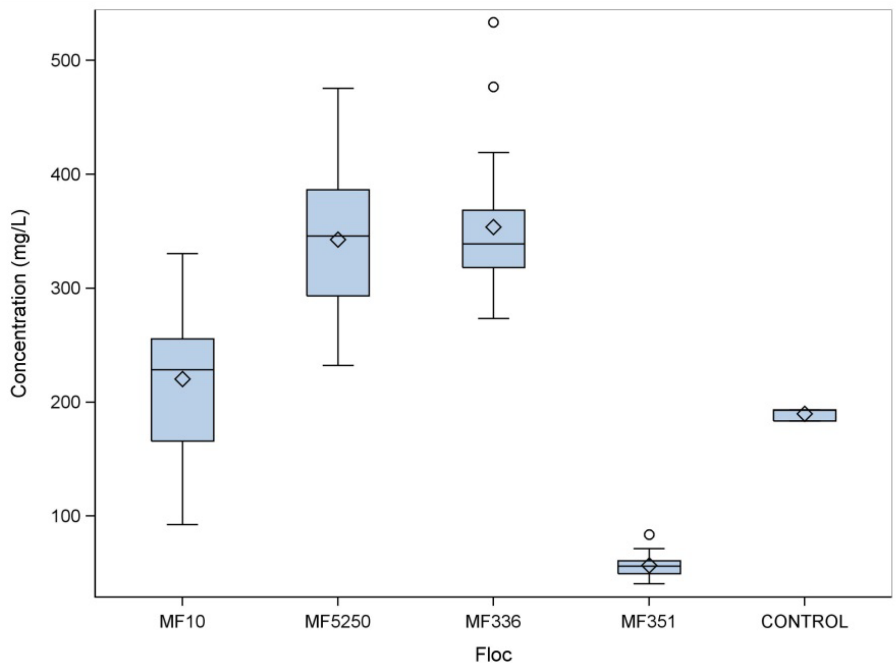


Figure 2.3: Final TSS Concentration Results (mg/L) for Flocculant Screening at 500 mg/L Initial Concentration after 10 Minutes Settling

Table 2.4: Mean Results of Final TSS Concentration for Flocculant Screening at 500 mg/L Initial Concentration after 10 Minutes Settling

| | Concentration (mg/L) |
|---|---|
| Control | 189.9b ± 5.6 |
| MF10 | 220.4b ± 68.5 |
| MF336 | 353.7a ± 66.9 |
| MF 351 | 56.7c ± 9.9 |
| MF5250 | 342.9a ± 66.3 |

Different letters represent statistically different means at $p < 0.05$

From Figure 2.3 and Table 2.4, Magnafloc 10 and the control produced final TSS concentrations that were not statistically different. Magnafloc 336 and Magnafloc 5250 produced final concentrations that were not statistically different from each other. However, MF 336 and MF 5250 were statistically different than MF 10 and the control, having higher final TSS concentrations. Magnafloc 351 produced final TSS concentrations that were statistically different than the four other treatments, proving an optimal treatment for the objective of decreasing final concentration. A display of TSS concentration (mg/L) by flocculant dosage rate (mL) further portrays MF 351 as the optimum flocculant, Figure 2.4.

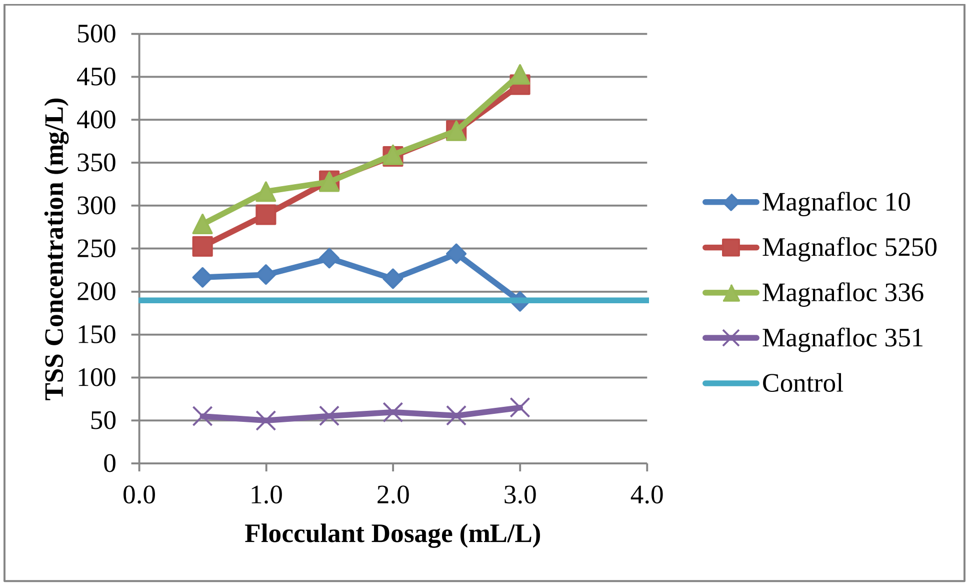


Figure 2.4: TSS Results across Tested Dosages for Flocculant Screening at 500 mg/L Initial Concentration after 10 Minutes Settling

Magnafloc 351 reduced the TSS from an initial sediment concentration of 500 mg/L to an average of 56 mg/L, a 10-fold decrease. The control resulted in an average concentration of 190 mg/L. Thus, compared to the control a 70% reduction was achieved by MF 351. Magnafloc 10 produced results not significantly different to the control and Magnafloc 5250 and Magnafloc 336 both produced results that were worse than the control. Magnafloc 5250 and Magnafloc 336 also showed an increase in TSS as the dosage was increased. This can be attributed to the double layer on each particle, negative in nature, which causes these particles to repel each other. The addition of an anionic solution increases the amount of negative charge, further increasing the repelling force. For these flocculants to be viable options for treatment, coagulation would first have to occur, performing destabilization to reduce the negative energy barrier on the particles in suspension. Magnafloc 351, the optimum flocculant, is a nonionic flocculant, holding no charge. Magnafloc 10, a slightly anionic flocculant, produced the second best results, while the two anionic flocculants were not effective.

### 2.4.3 *Magnafloc 351 Screening Test at 500 mg/L Initial Concentration*

With the determination that MF 351 was the optimum flocculant of the four flocculants tested, the results from the 500 mg/L initial sediment concentration were analyzed to determine if there was an optimum dosage that best reduced the TSS concentration after 10 minutes of settling. The final TSS concentrations (mg/L) were analyzed over the six dosages and control, three replicates each, for MF 351, Table 2.5.

Table 2.5: Mean TSS Concentration Results for Dosages of MF 351 at Initial Concentration 500 mg/L after 10 Minutes Settling

| Dosage | Concentration (mg/L) | Percent Decrease from Control |
|---|---|---|
| 0 | 189.9a ± 5.6 | |
| 0.5 | 54.9b ± 2.9 | 71.1% |
| 1.0 | 49.9b ± 10.2 | 73.7% |
| 1.5 | 55.4b ± 14.0 | 70.9% |
| 2.0 | 59.5b ± 4.7 | 68.7% |
| 2.5 | 55.8b ± 3.1 | 70.6% |
| 3.0 | 64.9b ± 17.4 | 65.8% |

Different letters represent statistically different means at $p < 0.05$

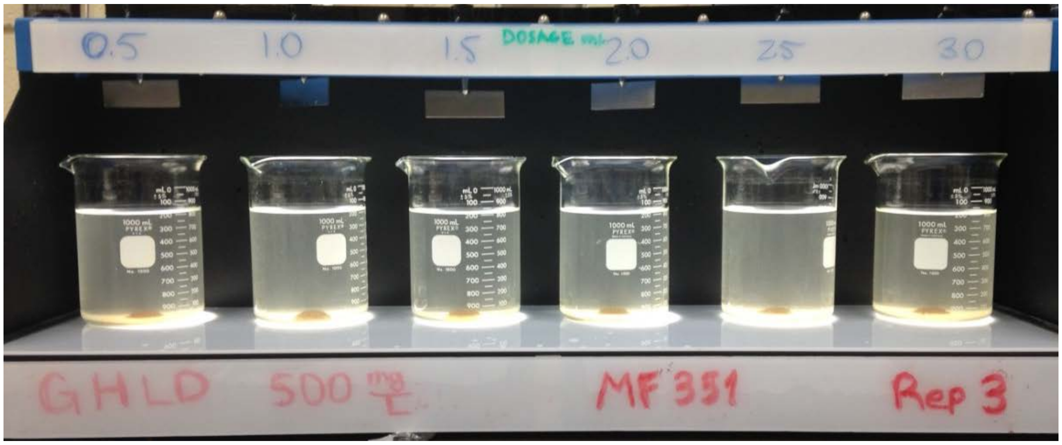


Figure 2.5: Visual Results of MF 351 at 500 mg/L Initial Concentration after 10 Minutes Settling

Results for Magnafloc 351 reveal that all dosages were statistically different from the control but were not statistically different from dosage to dosage. All dosages, 0.5 to 3.0 mL, performed equally in their settling performance after 10 minutes. Further analysis was performed using a 0.5 mL dosage for a 500 mg/L initial concentration based on it being the lowest dosage tested and produced similar results as the higher dosages.

The average cumulative volume distribution of supernatant at a 500 mg/L initial concentration is contrasted between the control jar and that treated with 0.5 mL of MF 351, Figure 2.6. The cumulative volume distribution is generated from the LISST for each sample and was averaged over three replicates. MF 351 increased the $D_{50}$ particle size from approximately 0.008 mm in the control to 0.02 mm, Figure 2.6. Assuming a sediment pond depth of one meter and taking into account that a 0.01 mm particle will settle one meter in approximately three hours, MF 351 would settle out approximately 70% of the remaining fine sediment particles in that time, compared to approximately 35% in the control jar.

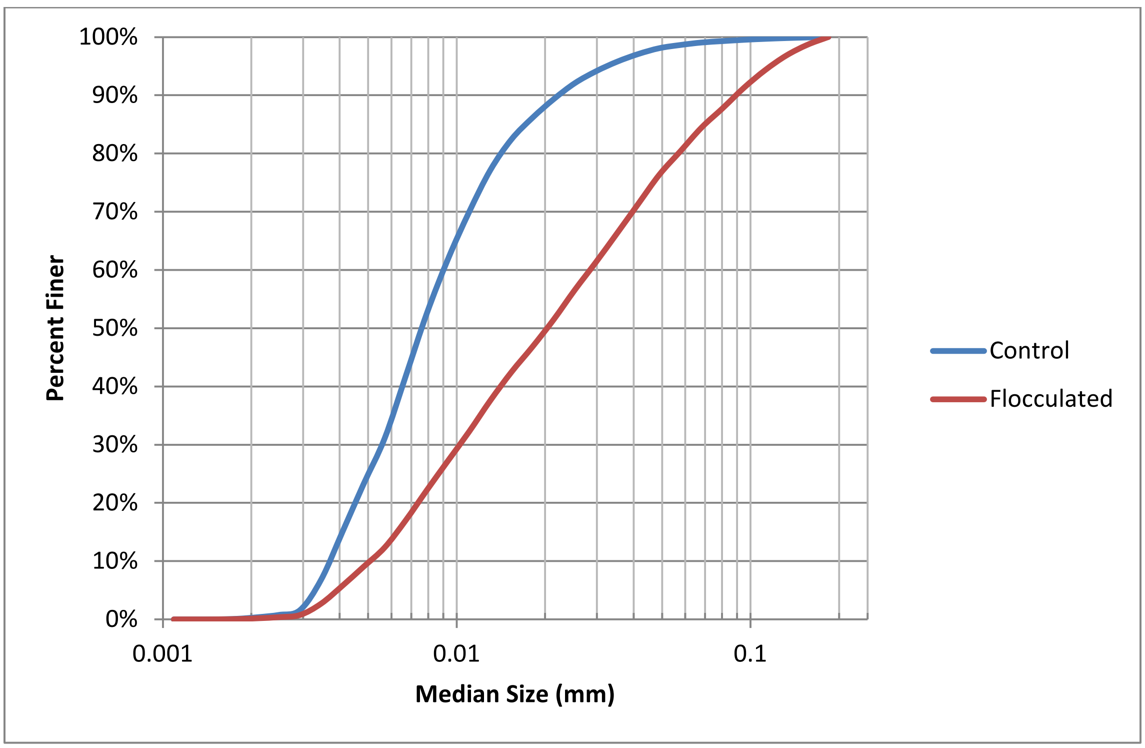


Figure 2.6: Average Particle Size Distribution Comparison between Flocculated with 0.5 mL MF 351 and Control at 500 mg/L Initial Sediment Concentration after 10 Minutes Settling

### 2.4.4 *Magnafloc 351 Screening Test at 2,500 mg/L Initial Concentration*

With the determination that MF 351 was the optimum flocculant of the four flocculants tested and the results from the 500 mg/L initial sediment concentration, jar tests were continued at an initial concentration of 2,500 mg/L. MF 351 was introduced at a starting dosage of 1.0 mL and increased in 1.0 mL increments to a maximum dosage of 6.0 mL. The starting dosage of 1.0 mL was chosen based on the 500 mg/L initial concentration test and the assumption that an increase in the initial sediment concentration may require an increase in dosage. The final TSS concentrations (mg/L) were analyzed over the six dosages and control, three replicates each, for MF 351, Table 2.6.

Table 2.6: Mean TSS Concentration Results for Dosages of MF 351 at Initial Concentration 2,500 mg/L after 10 Minutes Settling

| Dosage | Concentration (mg/L) | Percent Decrease from Control |
|---|---|---|
| 0 | 630.1a ± 39.7 | |
| 1.0 | 25.6b ± 7.3 | 95.9% |
| 2.0 | 16.5b ± 3.2 | 97.4% |
| 3.0 | 21.1b ± 2.3 | 96.7% |
| 4.0 | 17.5b ± 1.8 | 97.2% |
| 5.0 | 20.0b ± 7.8 | 96.8% |
| 6.0 | 28.5b ± 7.8 | 95.5% |

Different letters represent statistically different means at $p < 0.05$

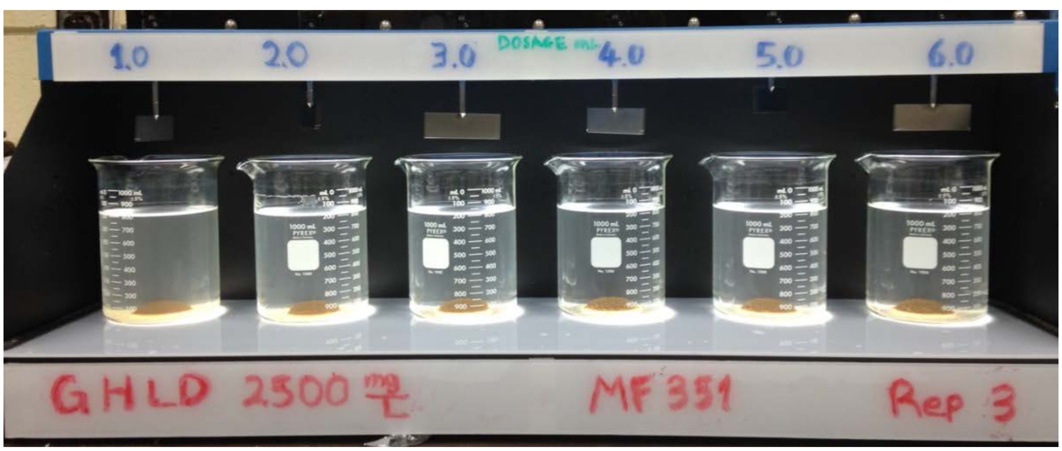


Figure 2.7: Visual Results for MF 351 at 2,500 mg/L Initial Concentration after 10 Minutes Settling

Results for Magnafloc 351 at 2,500 mg/L initial concentration reveal that all dosages are statistically different from the control but are not statistically different from dosage to dosage. All dosages, 1.0 to 6.0 mL, performed equally in their settling performance. Further analysis was performed using a 1.0 mL dosage for a 2,500 mg/L initial concentration due to it being the lowest dosage tested and showing similar results to the higher dosages. A comparison of the average cumulative volume distribution of supernatant at a 2,500 mg/L initial concentration between the control jar and the jar treated with 1.0 mL of MF 351 was conducted, Figure 2.8. The cumulative volume distribution is generated from the LISST for each sample and was averaged over three replicates. From Figure 2.8, MF 351 increased the $D_{50}$ particle size from approximately 0.005 mm in the control to 0.060 mm. Assuming a sediment pond depth of one meter and taking into account that a 0.010 mm particle will settle one meter in approximately three hours, MF 351 should settle out approximately 75% of the remaining fine sediment particles in that time, compared to approximately only 10% based on the control jar.

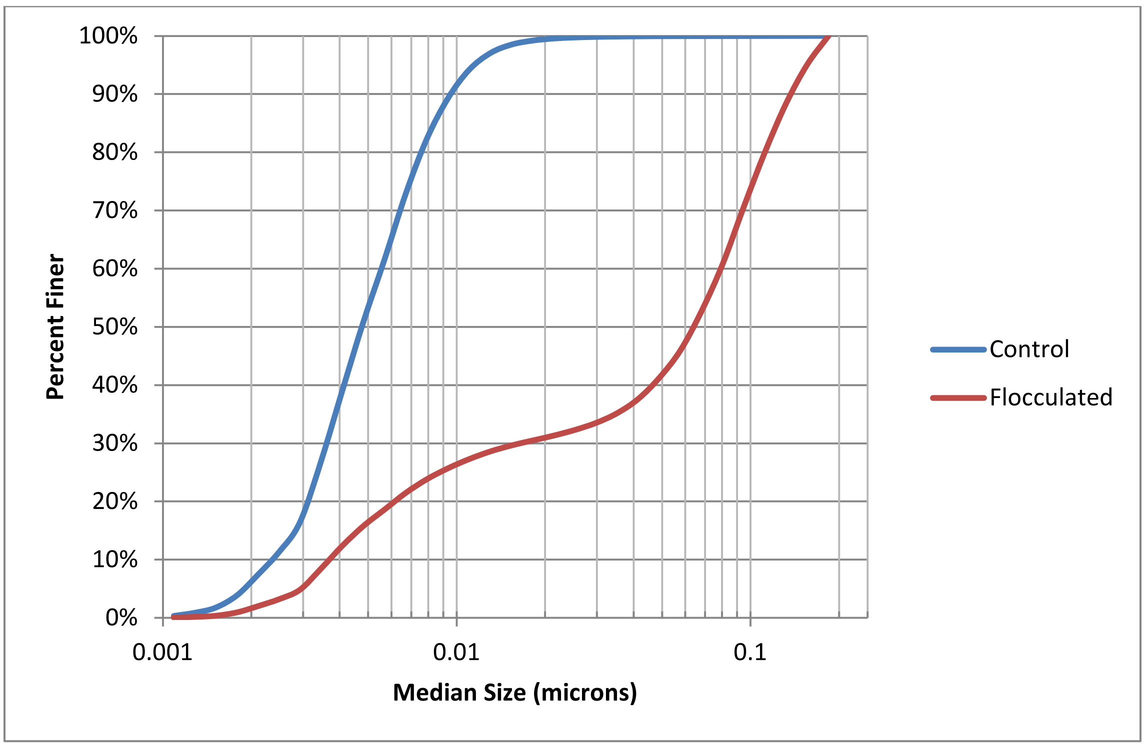


Figure 2.8: Average Particle Size Distribution Comparison Between Flocculated with 1.0 mL MF 351 and Control at 2,500 mg/L Initial Sediment Concentration after 10 Minutes Settling

### 2.4.5 *Magnafloc 351 Screening Test at 5,000 mg/L Initial Concentration*

The final screening test was performed at an initial concentration of 5,000 mg/L. MF 351 was introduced at a starting dosage of 2.0 mL and increased in 1.0 mL increments to a maximum dosage of 7.0 mL. The starting dosage of 2.0 mL was chosen based on the 2,500 mg/L initial concentration test and the assumption that an increase in initial concentration may require an increase in dosage. The final TSS concentrations (mg/L) were analyzed over the six dosages and control, three replicates each, for MF 351, Table 2.7.

Table 2.7: Mean TSS Concentration Results for Dosages of MF 351 at Initial Concentration 5,000 mg/L after 10 Minutes Settling

| **Dosage** | **Concentration (mg/L)** | **Percent Decrease from Control** |
|---|---|---|
| 0 | 1344.5a ± 116.6 | |
| 2.0 | 23.3b ± 15.0 | 98.3% |
| 3.0 | 17.9b ± 2.5 | 98.7% |
| 4.0 | 18.9b ± 11.3 | 98.6% |
| 5.0 | 15.2b ± 14.7 | 98.9% |
| 6.0 | 29.0b ± 16.1 | 97.8% |
| 7.0 | 21.4b ± 14.4 | 98.4% |

Different letters represent statistically different means at $p < 0.05$

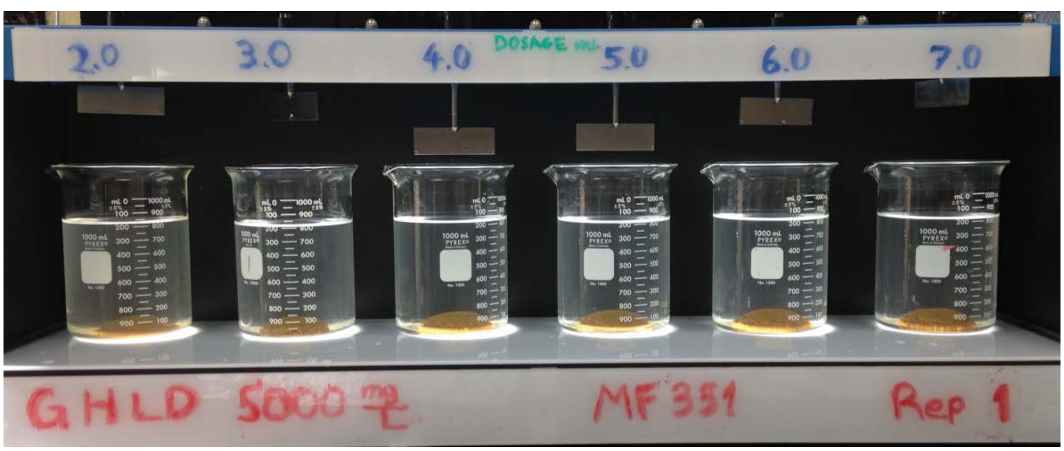


Figure 2.9: Visual Results of MF 351 at 5,000 mg/L Initial Concentration after 10 Minutes Settling

As before results for Magnafloc 351 at 5,000 mg/L initial concentration reveal that all dosages are statistically different from the control but are not statistically different from dosage to dosage. All dosages, 2.0 to 7.0 mL, performed equally in their settling performance. Further analysis was performed using a 2.0 mL dosage for a 5,000 mg/L initial concentration due to it being the lowest tested dosage and performing similar to the higher dosages.

A comparison was conducted of the average cumulative volume distribution of supernatant at a 5,000 mg/L initial concentration between the control jar and the jar treated with 2.0 mL of MF 351, Figure 2.10. The cumulative volume distribution is generated from the LISST for each sample and was averaged over three replicates. From Figure 2.10, Magnafloc 351 increased the $D_{50}$ particle size from approximately 0.005 mm in the control to 0.060 mm. Assuming a sediment pond depth and taking into account that a 0.01 mm particle will settle one meter in approximately three hours, Magnafloc 351 should settle out approximately 80% of the remaining sediment in that time, compared to approximately 10% in the control jar.

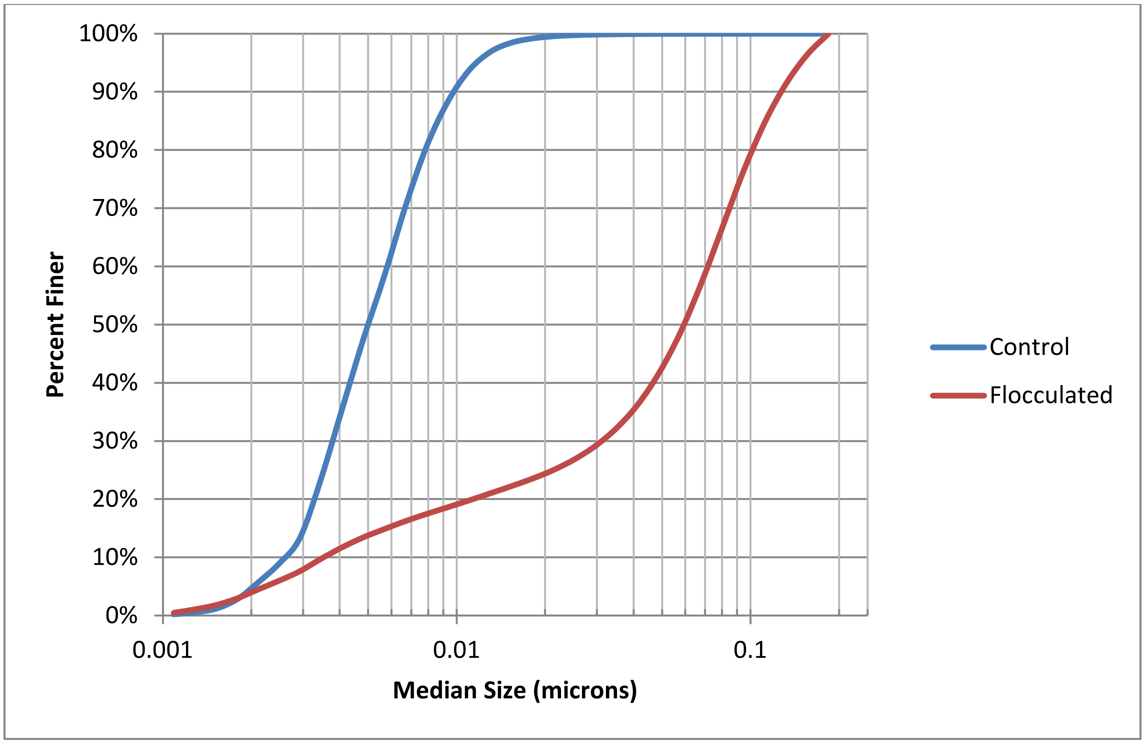


Figure 2.10: Average Particle Size Distribution Comparison Between Flocculated with 2.0 mL MF 351 and Control at 5,000 mg/L Initial Sediment Concentration after 10 Minutes Settling

## 2.5 Conclusions

Four flocculants from the Magnafloc family of products (Magnafloc 10, 5250, 336, 351) were screened on loose dumped weathered mine spoil retrieved from a surface coal mine in eastern Kentucky. An initial small scale screening test was performed in the laboratories of the University of Kentucky with flocculants mixed at concentrations of 0.1% solution. The initial concentration was created with fines (<#100 sieve) at 500 mg/L. The results from the initial screening test showed that Magnafloc 351, a nonionic flocculant, was the optimum flocculant, producing final TSS concentration results statistically better than the control and the three other flocculants tested. Analyzing the results from a 0.5 mL dosage of MF 351, a reduction of the final TSS concentration of approximately 71% occurred compared to the control with no flocculant addition.

Magnafloc 5250 and 336, both anionic flocculants, produced results that were worse than the control jars with no treatment. Magnafloc 10, a slightly anionic flocculant, produced results that were not statistically different than the control jars results.  A trend in the initial flocculant screening shows that a flocculant with a higher anionic charge has less of an effect on the settling of fine particles than a lower anionic charge or no charge at all for the spoil tested.  This is likely due to the negative charge from the double layer on the particles in suspension and would require the use of a coagulant to reduce the charge before flocculation.  Due to potential adverse impacts on fish and aquatic invertebrates, a cationic flocculant should not be utilized at any ponds that are expected to discharge and, thus, were not used in this initial screening.

Based on the initial screening at 500 mg/L results, higher initial concentrations of 2,500 and 5,000 mg/L were screened with Magnafloc 351.  Magnafloc 351 performed exceptionally well for all concentrations. All flocculant dosages produced final concentration results that were not statistically different.  Approximately 97% and 99% more sediment was settled at the analyzed dosages of 1.0 mL/L and 2.0 mL/L, respectively, at the  2,500 mg/L and 5,000 mg/L initial sediment concentrations compared to the control with no flocculant added.  Settling efficiencies substantially increased with an increase in initial sediment concentrations; this is due to the way high molecular weight flocculants create large, branching flocs that interact and grow larger with more available particles.  These available particles join together to form a "blanket" that will then prompt zone settling, which aids in capturing and settling the finer particles At all initial concentrations, settling efficiency is expected to increase over time due to particle size remaining in suspension.

In larger scale experiments, it can be expected that settling efficiencies will be lessened, due to a lower precision in the introduction of flocculant, less uniform mixing of the solution, and varied inflow sediment concentration.  Screening tests, however, indicate that a wide range of dosages of Magnafloc 351 for each initial concentration reduces the final concentration to acceptable levels much lower than the control.  The wide range of acceptable flocculant dosages will prove very important when scaling the test up and in field applications.  Flocculant dosage, mixing precision and differences in incoming sediment concentrations will alter the performance and the wide acceptable dosage range will prove beneficial in mine site applications.

# CHAPTER 3: LARGE SCALE COLUMN SETTLING TESTS OF POLYACRYLAMIDE FLOCCULANTS ON APPALACHIAN WEATHERED MINE SPOIL

## 3.1 Introduction

Appalachian surface mining often exposes weathered sandstone during clearing and grubbing operations, which, in combination with topsoil, is used in direct haul and subsequent placement of the final cover during reclamation (Zipper, Burger et al. 2013). The abundance of these weathered brown sandstones, location in the upper strata of the soil profile, propensity to produce low electrical conductivity values due to historical leaching, compaction properties conducive to construction of isolation barrier and weep berms, and providing excellent tree growth attributes balancing water holding capacity and infiltration, all play key roles in its selection for reclamation (Emerson, Skousen et al. 2009; Taylor, Agouridis et al. 2009; Agouridis, Angel et al. 2012; Sena, Barton et al. 2014). Loose dumped weather brown sandstone, combined with the Forest Reclamation Approach (FRA), creates hydrologic, hydraulic, and ecologic conditions that mimic pre-mining forested conditions.

Polyacrylamide (PAM) flocculants have traditionally been used as cost-effective settling aids in both mineral processing and water treatment. Its research and use has expanded to encompass sediment control in the construction industry and, more recently, mining operations (Soupir, Mostaghimi et al. 2004; McLaughlin, King et al. 2009). When spoil is loose dumped off the working face during reclamation, fine particles are transported during runoff producing events to settling ponds where passive treatment by gravity occurs prior to effluent being discharged into the environment. PAM flocculants are designed to aid in the settling process, increasing the efficiency of particle settling, to enable higher quality water to be discharged with substantially fewer fines, thereby minimizing potentially detrimental effects on the downstream aquatic environment.

Previous applied research conducted at the University of Kentucky assessed the efficiency of particle settling of four PAM flocculants from the Magnafloc family of products (BASF) through screening test on loose dumped weathered mine sandstone retrieved on an Appalachian surface mine. Results revealed that Magnafloc 351 (MF 351), a nonionic PAM flocculant, excelled at increasing particle settling rates in the small scale laboratory test utilizing one liter beakers. Large columns (117 L) were designed and fabricated at the University of Kentucky laboratories to create a large scale testing apparatus to further examine the effectiveness of MF 351 at increasing settling efficiencies of weathered mine sandstone.

This chapter addresses the experiments and results of using Magnafloc 351, a polyacrylamide flocculant, to increase settling efficiencies of weathered mine spoil utilizing large scale columns.

## 3.2 Background

### *3.2.1 Jar Test Procedure*

Jar tests were conducted at the University of Kentucky on composite samples of loose dumped weathered mine spoil retrieved from a surface mining operation located in eastern Kentucky using a Phipps and Bird PB-700 Jartester and 1 liter glass beakers. All spoil samples were processed through the #100 sieve (0.15 mm) removing all particles that would be deposited in transit to a settling basin or would be expected to rapidly settle without flocculation.

Preliminary jar tests were conducted applying a suite of flocculants manufactured by Magnafloc (www.basf.com) to determine the effect of flocculation on settling rates of suspended weathered mine spoil particles in deionized water. Initial jar tests were conducted at an initial sediment concentration of 500 mg/L to determine the optimum performing flocculant at removing TSS concentration in suspension for each sample. With the optimum performing flocculant chosen, a suite of dosages were tested to determine settling performance at 500 mg/L, 2,500 mg/L, and 5,000 mg/L initial sediment concentrations. The range of tested initial sediment concentrations were based on a monitoring program of sediment laden runoff generated at both a recently cleared and grubbed operation and an active valley fill utilizing loose dumped weathered mine spoil in West Virginia.

Each flocculant was introduced to the suspended samples at six dosages. Upon introduction, the flocculant and the sediment solution was allowed to continue to mix for an additional 2 minutes. When mixing was complete, the paddles were removed and the flocculant and sediment solution was allowed to settle for 10 minutes. After the settling period, 200 mL of supernatant, approximately 1 cm below the water surface was withdrawn for TSS and particle size analysis using a LISST-Portable, manufactured by Sequoia Scientific, Inc. The LISST uses a method of laser diffraction to measure the size and concentration of particles suspended in a solution, which is analyzed and displayed as a size distribution and volume concentration. Samples withdrawn during the column analysis were also analyzed using the LISST, due to its rapid analysis and ease of use for finding both concentration and particle size distribution.

### *3.2.2 Jar Test Results*

Jar tests were conducted with weathered mine spoil, sieved through #100 (< 0.15 mm), and Magnafloc 351 at three initial sediment concentrations: 500 mg/L, 2,500 mg/L, and 5,000 mg/L. These jar tests were conducted to determine how settling effectiveness changed over a range of dosages after 10 minutes of settling. Results were tabulated to determine the mean TSS concentration after 10 minutes, as well as the percent decrease from the control jar with no flocculant addition, Tables 3.1-3.3.

Table 3.1: Mean TSS Concentration Results for Dosages of MF 351 at Initial Concentration 500 mg/L after 10 Minutes Settling

| Dosage | Concentration (mg/L) | Percent Decrease from Control |
|---|---|---|
| 0 | 189.9a ± 5.6 | |
| 0.5 | 54.9b ± 2.9 | 71.1% |
| 1.0 | 49.9b ± 10.2 | 73.7% |
| 1.5 | 55.4b ± 14.0 | 70.9% |
| 2.0 | 59.5b ± 4.7 | 68.7% |
| 2.5 | 55.8b ± 3.1 | 70.6% |
| 3.0 | 64.9b ± 17.4 | 65.8% |

Different letters represent statistically different means ($p < 0.05$)

Table 3.2: Mean TSS Concentration Results for Dosages of MF 351 at Initial Concentration 2,500 mg/L after 10 Minutes Settling

| Dosage | Concentration (mg/L) | Percent Decrease from Control |
|---|---|---|
| 0 | 630.1a ± 39.7 | |
| 1.0 | 25.6b ± 7.3 | 95.9% |
| 2.0 | 16.5b ± 3.2 | 97.4% |
| 3.0 | 21.1b ± 2.3 | 96.7% |
| 4.0 | 17.5b ± 1.8 | 97.2% |
| 5.0 | 20.0b ± 7.8 | 96.8% |
| 6.0 | 28.5b ± 7.8 | 95.5% |

Different letters represent statistically different means ($p < 0.05$)

Table 3.3: Mean TSS Concentration Results for Dosages of MF 351 at Initial Concentration 5,000 mg/L after 10 Minutes Settling

| Dosage | Concentration (mg/L) | Percent Decrease from Control |
|---|---|---|
| 0 | 1344.5a ± 116.6 | |
| 2.0 | 23.3b ± 15.0 | 98.3% |
| 3.0 | 17.9b ± 2.5 | 98.7% |
| 4.0 | 18.9b ± 11.3 | 98.6% |
| 5.0 | 15.2b ± 14.7 | 98.9% |
| 6.0 | 29.0b ± 16.1 | 97.8% |
| 7.0 | 21.4b ± 14.4 | 98.4% |

Different letters represent statistically different means ($p < 0.05$)

Results from the jar tests showed that the addition of MF 351 proved superior to the control with no flocculant. At each initial concentration (500 mg/L, 2,500 mg/L, 5,000 mg/L), there was not a statistical difference between each dosage. To choose the 'optimum' dosage to conduct column testing, an on-site flocculant dosage device with three switches/valves was considered. These devices would introduce flocculant solution based on a reading of passing flow and turbidity, introducing a higher dosage as higher concentrations entered the pond. Three solenoid valves were designed to open as different of levels of concentrations passed, hence the choosing of three dosages for the column analysis. A prototype of this device has been built at the University of Kentucky and is waiting more testing before field deployment. To minimize cost but still provide a buffer from the smallest dosage tested, 1.0 mL/L was chosen for the 500 mg/L initial concentration. At 2,500 mg/L initial concentration, it was considered that an increase in incoming concentration should be dosed at a higher rate while still keeping dosage low and 2.0 mL/L was chosen. At 5,000 mg/L initial concentration, the dosage was chosen to not only reduce concentration at 5,000 mg/L, but also to accommodate higher concentrations that may be experienced on site, reducing risk for both the researcher and cooperator. This dosage was chosen as 5.0 mL. From jar test results, flocculant dosages of 0.5 mL/L, 1.0 mL/L, and 2.0 mL/L could have been chosen for column testing; however to add a factor of safety and reduce risk for both involved parties in future on-site testing, all flocculant dosages were increased.

The column tests were designed to be a large scale advancement of the jar tests based on flocculant dosages of 1.0 mL/L, 2.0 mL/L, and 5.0 mL/L, for a 500 mg/L, 2,500 mg/L, and 5,000 mg/L initial sediment concentration, respectively.

### *3.2.3 Settling Column Tests*

Column tests are large scale, laboratory settling experiments used to quantify the efficiency of flocculants on settling suspended sediment concentrations. Column tests allow the determination of particle and flocculation interactions, as well as settling characteristics and efficiencies, at a much larger scale than typical jar tests; thus more closely approaching sediment basin efficiencies. The main advantages of utilizing jar tests is the low cost and wide availability of equipment, ease of operation, and small amount of sample material needed for each repetition. The main disadvantages of using jar tests are the wall and adhesion effects that often appear when heavy concentrations are used, as well as the presence of shear effects from mechanical mixing. These effects could negatively alter results due to not being representative of sediment pond processes.

Large scale settling columns provide a settling environment that more closely represents a sediment pond, Figure 3.1. The settling columns are 2 meters tall, 30 cm diameter clear plexiglass cylindrical tubes fitted with five vertical sampling ports incrementally spaced at 250 mm along the length of the column, Table 3.4. Solenoid valves are installed at each sampling port, enabling simultaneous sampling at all five ports. Mixing is achieved by pressurized air forced through a circular array of nozzles located at the base of the column. The selection of pressurized air, as opposed to mechanical mixing in the jar test, is to reduce segregation and floc shear effects. A drainage line is attached at the base of the columns for draining and cleaning with minimal labor.

Figure 3.1: Settling Columns at the University of Kentucky

Table 3.4: Location of Sampling Ports on Settling Columns

| Port # | Height (mm)[(a)] | Depth (mm)[(b)] |
|---|---|---|
| 1 | 1,250 | 450 |
| 2 | 1,000 | 700 |
| 3 | 750 | 950 |
| 4 | 500 | 1,200 |
| 5 | 250 | 1,450 |

Notes: [(a)] height measured from the bottom of the column

[(b)] depth measured from the water surface that was initially set at 1,700 mm (time = 0)

A pair of columns was used to conduct side-by-side settling tests, concurrent sample analysis and visual comparison. In this research, the settling performance of particles was observed and analyzed with one column having a flocculant added and the control column with no flocculant addition.

### 3.3 Settling Column Experimental Procedure

Magnafloc 351 (MF 351) was mixed at a 0.1% solution with deionized water 24 hours before each experiment. MF 351 was mixed by combining 1.0 gram of dry flocculant in 1.0 liter of deionized water using a Phipps and Bird PB-700 Jartester at a speed of 200 rpm for 60 minutes. After 60 minutes, the paddle stirrer was turned off and the flocculant was allowed to rest until tests the next day. It was important to follow a simple and cost effective process that could be replicated on mine sites, if future work continues to hold promising results.

Soil samples were prepared identically to the jar test by using the same weathered mine composite spoil sieved to a maximum particle size of 0.15 mm (#100 sieve). The column tests can be considered 'worst case' where the incoming spoil has already deposited the coarser size fraction prior to entering the flocculation treatment sediment pond. This would be the case where effective best management practices have been applied as source reduction controls or perhaps with two ponds in series with the up-gradient pond being a contour bench pond.

The testing protocol for the column tests was as follows:

1. Fill the column with approximately 117 L of deionized water at room temperature to a water level height of 1,700 mm in the column.
2. A pre-weighed amount of sediment (<0.15 mm) is introduced through the top of the column to obtain the desired initial total solids concentration (500 mg/L, 2,500 mg/L, 5,000 mg/L).
3. The pressurized air is turned on, thoroughly mixing the solution throughout the column height. Initial mixing is conducted for three minutes.
4. For the flocculated column, a pre-measured amount of flocculant is added to the slurry mixture at a dosage determined from the initial jar tests (1.0 mL/L, 2.0 mL/L, 5.0 mL/L). Once flocculant is added, additional mixing of two minutes occurs to form flocs.
5. After three minutes (control) or five minutes (flocculated) of initial mixing occurs, the air is turned off.
6. Once all air bubbles have risen to the top of the column, the timer is started and sampling begins. Samples are concurrently taken at each of the five ports, approximately 200 mL each, at times of 0, 5, 10, 15, 30, and 60 minutes.
7. Particle size distribution is determined by the LISST and total solids are determined by the oven method, SM 2540 B (Federation and Association 2005).

To ensure no contamination occurs between samples, a flush event was performed prior to sampling. The flush consists of a sample of approximately 50 mL taken to clear the solenoid valves and sampling tubes of any particles that may have settled from the previous sample. The analyzed samples are taken shortly after the flush samples (2-3 seconds), at which time the flush samples are discarded.

For each of the three sediment concentrations there are 4 replicate experiments conducted for both the flocculated and control columns, totaling 24 individual column experiments. Three replicates were utilized to determine the total solids concentration of each sample and one replicate was used to determine the particle size distribution on the LISST.

Since the settling columns are designed to mimic sediment pond conditions, many different assumptions can be made about discharge structures at a given pond. For this research, it will be assumed that a discharge structure will dewater near the top of the water surface level (i.e. floating siphon, fixed siphon, drop-inlet). Such surface withdrawal is encouraged to discharge the cleaner water thereby minimizing potential adverse impacts due to higher effluent sediment concentrations. It was also important to withdraw at a depth low enough from the surface so that no vortex occurs, proving problematic assuming a siphon would be installed. Particle size analysis, along with statistical analysis, was conducted for samples taken at Port 2 (700 mm depth) to mimic surface withdrawal.

The statistical analysis was performed using the PROC GLM procedure available within SAS™ (Version 9.3, SAS Institute Inc., Cary, NC, USA). To determine the settling effects of Magnafloc 351 in the column tests, mean total solids and standard errors were determined across each sampling time at Port 2 for all initial concentrations. Least square means (LSMEANS) was used to determine if a significant difference ($p<0.05$) existed between the flocculated and control column across all sampling times at Port 2. Bonferroni adjustment was also used in the analysis.

## 3.4 Results

### *3.4.1 Column Results Overview*

Each set of initial column concentrations (500 mg/L, 2,500 mg/L, 5,000 mg/L) were conducted on a pair wise basis (one flocculated, one control) over three replicates for a total of six columns at each initial concentration. The amount of flocculant (MF 351) added for each initial concentration, Table 3.5, was determined from the jar test results and the column volume. The control column contained no flocculant or other settling aid.

Table 3.5: Addition of MF 351 to Flocculated Columns

| **Initial Concentration (mg/L)** | **Flocculant Dosage Rate (mL/L)** | **Total Flocculant Added (mL)** |
|---|---|---|
| 500 | 1.0 | 117 |
| 2,500 | 2.0 | 234 |
| 5,000 | 5.0 | 585 |

Analysis was first conducted to determine the total solids concentration (mg/L) of each sample that was withdrawn at each port and time, Table 3.6. The concentrations were averaged over three replicates at each port and time.

Table 3.6: Total Solids Concentration (mg/L) from Column Tests Averaged over Three Replicates for All Initial Concentrations with and without the Addition of Magnafloc 351

| **500 mg/L Initial Concentration** | | | **2,500 mg/L Initial Concentration** | | | **5,000 mg/L Initial Concentration** | | |
|---|---|---|---|---|---|---|---|---|
| **Time Lapsed** | | **0 Min** | **Time Lapsed** | | **0 Min** | **Time Lapsed** | | **0 Min** |
| | Control | Floc | | Control | Floc | | Control | Floc |
| Port 1 | 472.3 ± 18.8 | 471.0 ± 10.1 | Port 1 | 2283.1 ± 62.1 | 2149.4 ± 41.1 | Port 1 | 4555.8 ± 166.4 | 3955.4 ± 260.7 |
| Port 2 | 481.9 ± 20.5 | 480.4 ± 19.7 | Port 2 | 2324.5 ± 45.6 | 2137.2 ± 86.2 | Port 2 | 4620.5 ± 156.8 | 4240.3 ± 185.1 |
| Port 3 | 485.6 ± 19.8 | 480.6 ± 21.9 | Port 3 | 2323.1 ± 32.8 | 2203.1 ± 44.5 | Port 3 | 4666.3 ± 170.7 | 4337.5 ± 181.5 |
| Port 4 | 490.3 ± 18.4 | 481.8 ± 20.9 | Port 4 | 2364.9 ± 25.1 | 2313.7 ± 104.2 | Port 4 | 4682.2 ± 152.6 | 4339.9 ± 370.1 |
| Port 5 | 490.4 ± 17.3 | 502.6 ± 16.8 | Port 5 | 2385.5 ± 26.6 | 2391.7 ± 23.0 | Port 5 | 4725.0 ± 140.7 | 4466.1 ± 352.8 |
| **Time Lapsed** | | **5 Min** | **Time Lapsed** | | **5 Min** | **Time Lapsed** | | **5 Min** |
| | Control | Floc | | Control | Floc | | Control | Floc |
| Port 1 | 356.2 ± 15.5 | 90.3 ± 8.5 | Port 1 | 1653.7 ± 43.2 | 47.9 ± 14.1 | Port 1 | 3428.0 ± 133.6 | 32.1 ± 7.8 |
| Port 2 | 383.6 ± 19.5 | 118.8 ± 8.8 | Port 2 | 1803.7 ± 43.1 | 68.5 ± 14.1 | Port 2 | 3771.2 ± 124.8 | 44.5 ± 10.1 |
| Port 3 | 408.9 ± 20.8 | 135.3 ± 9.0 | Port 3 | 1902.3 ± 44.1 | 80.7 ± 9.4 | Port 3 | 3915.8 ± 170.0 | 48.4 ± 8.0 |
| Port 4 | 422.4 ± 19.1 | 144.2 ± 10.8 | Port 4 | 1984.1 ± 42.7 | 88.1 ±10.9 | Port 4 | 4082.5 ± 162.6 | 56.7 ± 10.6 |
| Port 5 | 431.3 ± 20.0 | 151.2 ± 11.5 | Port 5 | 2061.8 ± 32.8 | 89.9 ± 11.4 | Port 5 | 4210.1 ± 152.8 | 63.3 ± 5.4 |
| **Time Lapsed** | | **10 Min** | **Time Lapsed** | | **10 Min** | **Time Lapsed** | | **10 Min** |
| | Control | Floc | | Control | Floc | | Control | Floc |
| Port 1 | 296.2 ± 13.3 | 49.6 ± 3.8 | Port 1 | 1386.9 ± 42.8 | 25.8 ± 7.8 | Port 1 | 2879.2 ± 89.3 | 23.3 ± 3.3 |
| Port 2 | 355.8 ± 48.4 | 64.6 ± 2.9 | Port 2 | 1601.7 ± 57.3 | 33.5 ± 10.7 | Port 2 | 3271.9 ± 166.0 | 26.4 ± 3.6 |
| Port 3 | 358.9 ± 15.6 | 73.0 ± 4.1 | Port 3 | 1653.7 ± 66.2 | 40.4 ± 11.5 | Port 3 | 3443.8 ± 138.0 | 29.9 ± 3.7 |
| Port 4 | 371.8 ± 13.8 | 81.4 ± 5.5 | Port 4 | 1755.1 ± 61.8 | 45.4 ± 9.8 | Port 4 | 3644.9 ± 143.1 | 33.6 ± 5.0 |
| Port 5 | 386.7 ± 17.5 | 96.7 ± 19.9 | Port 5 | 1812.5 ± 71.8 | 50.4 ± 9.5 | Port 5 | 3792.1 ± 142.7 | 35.3 ± 5.0 |
| **Time Lapsed** | | **15 Min** | **Time Lapsed** | | **15 Min** | **Time Lapsed** | | **15 Min** |
| | Control | Floc | | Control | Floc | | Control | Floc |
| Port 1 | 265.5 ± 7.7 | 39.9 ± 2.8 | Port 1 | 1227.9 ± 39.0 | 22.6 ± 3.2 | Port 1 | 2527.3 ± 81.5 | 21.6 ± 5.4 |
| Port 2 | 300.0 ± 12.7 | 48.4 ± 3.7 | Port 2 | 1387.4 ± 56.2 | 25.7 ± 4.3 | Port 2 | 2920.7 ± 132.0 | 22.6 ± 2.2 |
| Port 3 | 326.5 ± 12.0 | 53.0 ± 4.6 | Port 3 | 1496.2 ± 67.8 | 30.8 ± 4.1 | Port 3 | 3119.8 ± 105.0 | 25.8 ± 5.6 |
| Port 4 | 357.7 ± 9.0 | 59.6 ± 5.1 | Port 4 | 1592.5 ± 73.1 | 35.7 ± 4.4 | Port 4 | 3334.3 ± 112.8 | 27.1 ± 5.7 |
| Port 5 | 354.8 ± 14.7 | 63.0 ± 7.2 | Port 5 | 1656.8 ± 86.2 | 37.1 ± 4.4 | Port 5 | 3483.0 ± 140.0 | 28.1 ± 4.0 |

Table 3.6: Total Solids Concentration (mg/L) from Column Tests Averaged over Three Replicates for All Initial Concentrations with and without the Addition of Magnafloc 351 (Continued)

| **Time Lapsed** | | **30 Min** | **Time Lapsed** | | **30 Min** | **Time Lapsed** | | **30 Min** |
|---|---|---|---|---|---|---|---|---|
| | Control | Floc | | Control | Floc | | Control | Floc |
| Port 1 | 256.3 ± 72.6 | 30.6 ± 3.0 | Port 1 | 972.0 ± 27.8 | 20.9 ± 3.3 | Port 1 | 2041.4 ± 83.0 | 21.5 ± 4.6 |
| Port 2 | 287.4 ± 76.6 | 33.0 ± 3.6 | Port 2 | 1124.3 ± 48.6 | 23.6 ± 4.3 | Port 2 | 2488.7 ± 70.6 | 20.1 ± 3.6 |
| Port 3 | 269.4 ± 7.6 | 33.7 ± 4.7 | Port 3 | 1221.6 ± 60.9 | 21.6 ± 5.3 | Port 3 | 2567.8 ± 71.1 | 20.4 ± 3.1 |
| Port 4 | 284.0 ± 2.4 | 39.5 ± 4.8 | Port 4 | 1320.4 ± 70.8 | 23.3 ± 2.3 | Port 4 | 2802.0 ± 80.6 | 20.3 ± 1.7 |
| Port 5 | 282.7 ± 18.6 | 37.7 ± 4.9 | Port 5 | 1408.5 ± 104.3 | 23.4 ± 2.3 | Port 5 | 2969.2 ± 161.8 | 18.3 ± 1.6 |
| **Time Lapsed** | | **60 Min** | **Time Lapsed** | | **60 Min** | **Time Lapsed** | | **60 Min** |
| | Control | Floc | | Control | Floc | | Control | Floc |
| Port 1 | 163.2 ± 20.5 | 25.7 ± 5.1 | Port 1 | 768.6 ± 18.3 | 19.2 ± 2.9 | Port 1 | 1606.9 ± 66.8 | 17.8 ± 6.0 |
| Port 2 | 186.0 ± 19.0 | 25.7 ± 5.3 | Port 2 | 895.4 ± 38.6 | 19.9 ± 4.6 | Port 2 | 2055.7 ± 184.7 | 18.6 ± 7.7 |
| Port 3 | 200.1 ± 14.5 | 26.5 ± 4.9 | Port 3 | 979.5 ± 36.6 | 19.1 ± 3.8 | Port 3 | 2097.2 ± 59.5 | 19.7 ± 5.4 |
| Port 4 | 206.9 ± 24.9 | 29.0 ± 5.6 | Port 4 | 1077.6 ± 45.7 | 21.0 ± 3.4 | Port 4 | 2364.2 ± 46.7 | 20.1 ± 4.6 |
| Port 5 | 224.6 ± 21.1 | 29.5 ± 8.2 | Port 5 | 1189.2 ± 80.4 | 20.4 ± 5.7 | Port 5 | 2497.2 ± 109.6 | 17.8 ± 2.7 |

Analyzing the results shows that at the instant the mixing is turned off and air bubbles have dissipated, the first samples are withdrawn, the results appear similar for the flocculated and control columns at all initial concentrations. In the analysis at Port 2, for the initial concentration, time = 0, comparing the flocculated and control columns, the results are not statistically different at 500 mg/L but are different at 2,500 mg/L and 5,000 mg/L, Table 3.7. This is due to the amount of flocs that have formed and began settling in the higher concentrations due to the increased sediment and, therefore, more available sites for attachment. When mixing is stopped, the time allowed for bubbles to rise in the column is extended at higher initial concentrations due to the particle settling and air bubbles rising counteracting one another, totaling approximately 5 seconds at 500 mg/L and 15 seconds at 2,500 and 5,000 mg/L. In the time that mixing is stopped and the bubbles are allowed to rise, significant settling has already occurred in the flocculated column at 2,500 and 5,000 initial concentrations, prompting lower total solids concentrations in the samples at the 0 minute sample.

Table 3.7: Mean and Standard Deviation of Total Solids Sample at Port 2, Time = 0, after All Air Bubbles have Dissipated

| **Initial Concentration (mg/L)** | **Control Column (mg/L)** | **Floc Column (mg/L)** | **Statistically Different?** |
|---|---|---|---|
| 500 | 481.9 ± 20.5 | 480.4 ± 19.7 | No |
| 2,500 | 2324.5 ± 45.6 | 2137.2 ± 86.2 | Yes |
| 5,000 | 4620.5 ± 156.8 | 4240.4 ± 185.1 | Yes |

### *3.4.2 Column Results at 500 mg/L – Port 2*

Column results at the initial sediment concentration of 500 mg/L were analyzed over time at Port 2 to determine if there was an effect on reducing total concentration with the addition of flocculant, Table 3.8. Results show that approximately 5 seconds after mixing is stopped and bubbles are allowed to dissipate (time = 0 min sample), there is no statistical difference of the total solids between the control and flocculated columns. The sample withdrawn at time = 5 min, shows a statistical difference between the control and flocculated columns and this difference is apparent at each sampling time thereafter.

Table 3.8: Mean and Standard Deviation of Total Solids at 500 mg/L Initial Concentration, Port 2

| **Time** | **Control Column (mg/L)** | **Floc Column (mg/L)** | **Statistically Different?** |
|---|---|---|---|
| 0 min | 481.9 ± 20.5 | 480.4 ± 19.7 | No |
| 5 min | 383.6 ± 19.5 | 118.8 ± 8.8 | Yes |
| 10 min | 355.8 ± 48.4 | 64.6 ± 2.9 | Yes |
| 15 min | 300.0 ± 12.7 | 48.4 ± 3.7 | Yes |
| 30 min | 287.4 ± 76.6 | 33.0 ± 3.6 | Yes |
| 60 min | 186.0 ± 19.0 | 25.7 ± 5.4 | Yes |

Statistical Significance Determined at $p < 0.05$

Utilizing a 50 mg/L total solids guideline (IFC 2007) that is often enacted at international mining operations, it can be noted that the flocculated sample is below this threshold after 15 minutes of settling while the control column exceeds this threshold by greater than a factor of three even after 60 minutes of settling, Figure 3.2. The flocculated column increases the settling efficiency in the period after 15 minutes, but it is important to note that a total solids concentration less than 50 mg/L can be achieved in just 15 minutes after mixing has occurred.

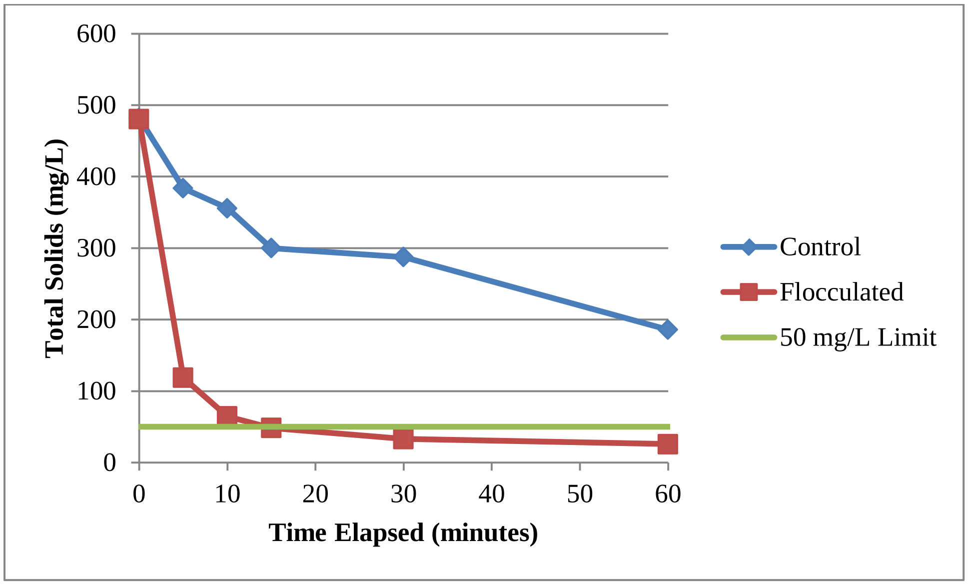


Figure 3.2: Control and Flocculated Column Total Solids Comparison at 500 mg/L Initial Concentration, Port 2

Focusing on the flocculated column only at Port 2 at initial concentration of 500 mg/L depicts a decrease in total concentration over time, Table 3.8. Results show, however, that after the initial sample is taken at time = 0 minutes, the following samples at time = 5, 10, 15, 30, and 60 minutes are not statistically different. This follows the theory that a sweep flocculation mechanism is occurring during the settling process. Sweep flocculation is defined as the soil particles become bridged together by flocculant; they join to become a larger precipitate “blanket” which settles in unison due to gravity. It is often characterized by a noticeable interface, where clearer water appears above the interface and flocculated masses appear below. At the five minute sample, the sweep has already occurred settling a large amount of sediment and only the residual particles remain in suspension, Figure 3.3. This is much more apparent at the higher initial concentrations and will be noted.


Figure 3.3: Column Comparison at 500 mg/L Initial Concentration at Time=0 min (left) and Time=5 min (right)

Utilizing the particle size distribution (PSD) data obtained through the LISST, there is a noticeable difference in the shape of curves between the two columns and that the control column PSD contain a higher percentage of finer particles than the flocculated column, Figure 3.4 and Figure 3.5. At the 60 minute sample, the $D_{50}$ of the control column is approximately 0.08 mm while the $D_{50}$ of the flocculated column is approximately 4 times larger in diameter at 0.30 mm.

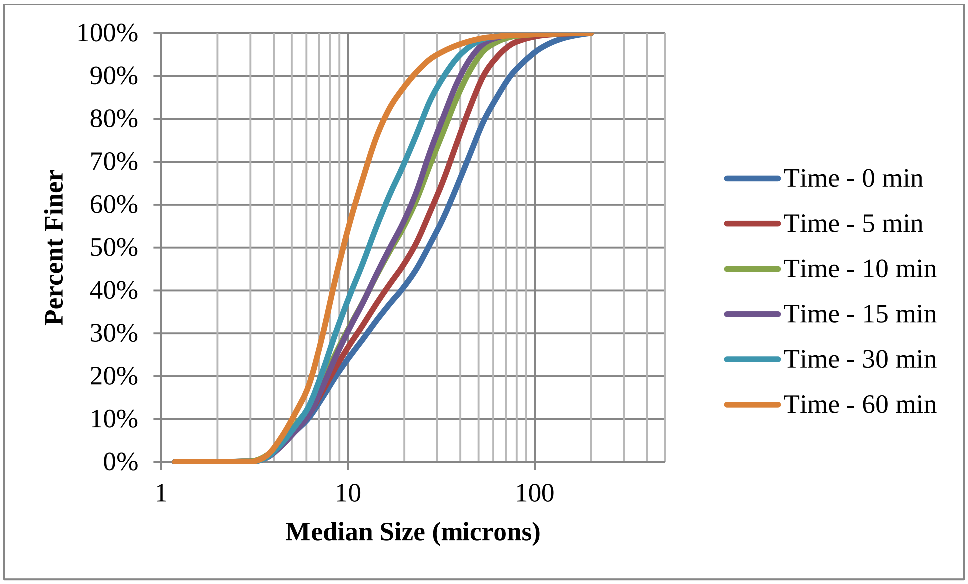


Figure 3.4: Cumulative Particle Size Distributions at Port 2 for the Control Column at 500 mg/L Initial Concentration

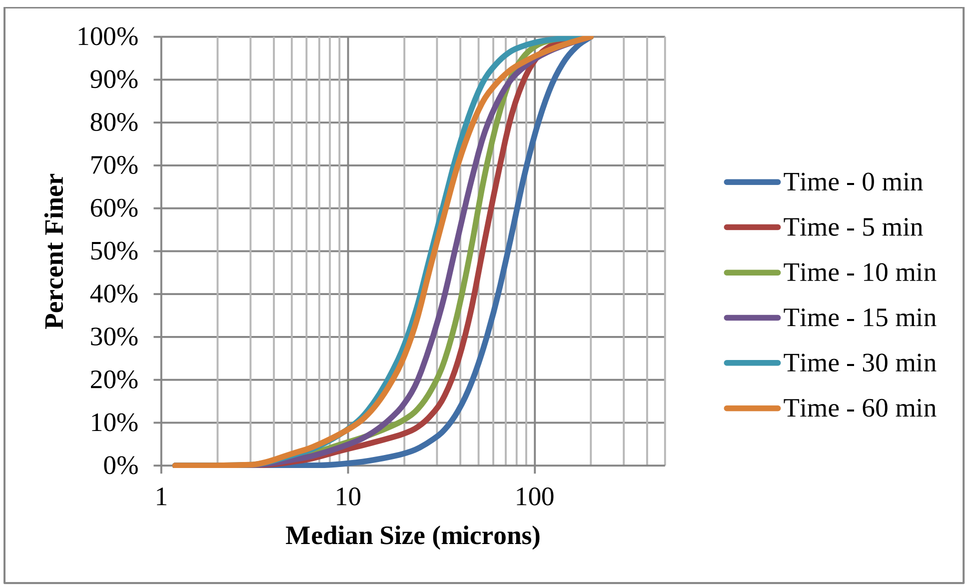


Figure 3.5: Cumulative Particle Size Distributions at Port 2 for the Flocculated Column at 500 mg/L Initial Concentration

### *3.4.3 Column Results at 2,500 mg/L – Port 2*

Column results at the initial sediment concentration of 2,500 mg/L were analyzed over time at Port 2 to determine if there was an effect on reducing total concentration with the addition of flocculant, Table 3.9. Results show that approximately 15 seconds after mixing is stopped and bubbles are allowed to dissipate (time = 0 min sample), there is a statistical difference of the total solids between the control and flocculated columns. This is different from the 500 mg/L initial concentration and is due to the settling that occurs during the time period at which the air mixing is turned off and sampling has commenced. The statistical difference between the two columns exists for all samples at each time period.

Table 3.9: Mean and Standard Deviation of Total Solids at 2,500 mg/L Initial Concentration, Port 2

| Time | Control Column (mg/L) | Floc Column (mg/L) | Statistically Different? |
|---|---|---|---|
| 0 min | 2324.5 ± 45.6 | 2137.2 ± 86.2 | Yes |
| 5 min | 1803.8 ± 43.1 | 68.5 ± 14.1 | Yes |
| 10 min | 1601.7 ± 57.3 | 33.5 ± 10.7 | Yes |
| 15 min | 1387.4 ± 56.2 | 25.7 ± 4.3 | Yes |
| 30 min | 1124.3 ± 48.7 | 23.6 ± 4.3 | Yes |
| 60 min | 895.4 ± 38.7 | 19.9 ± 4.6 | Yes |

Statistical Significance Determined at $p < 0.05$

Utilizing a 50 mg/L total solids guideline (IFC), the flocculated column sample is below this threshold after 10 minutes of settling while the control column exceeds this threshold nearly 20-fold after 60 minutes of settling, Figure 3.6. The flocculated column increases the settling efficiency in the period after 10 minutes, but it is important to note that a total solids concentration less than 50 mg/L can be achieved in just 10 minutes after mixing has occurred at 2,500 mg/L initial concentration.

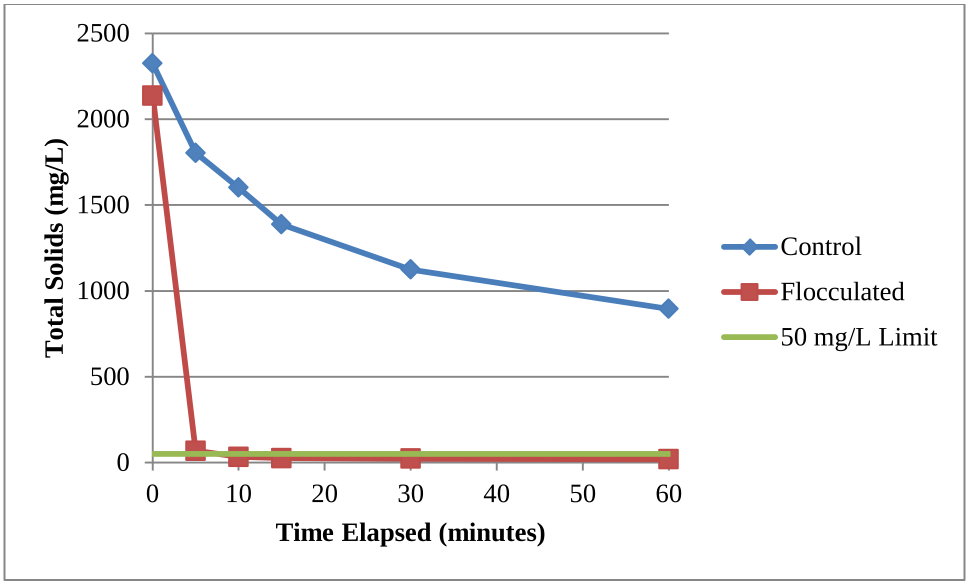


Figure 3.6: Control and Flocculated Column Total Solids Comparison at 2,500 mg/L Initial Concentration, Port 2

Focusing on the flocculated column only at port 2 at initial concentration of 2,500 mg/L depicts a decrease in total concentration over time, Table 3.9. Results show, however, that after the initial sample is taken at time = 0 minutes, the following samples at time = 5, 10, 15, 30, and 60 minutes are not statistically different within themselves. This follows the notion that sweep flocculation is occurring during the settling process. At the five minute sample, the sweep has already occurred settling a large amount of sediment and only the residual particles remain in suspension, resulting in a heavily contrasted soil/water interface, Figure 3.7. At 10 minutes the flocculated sediment concentration is approximately 25 mg/L whereas the control sample is nearly 1,400 mg/L.

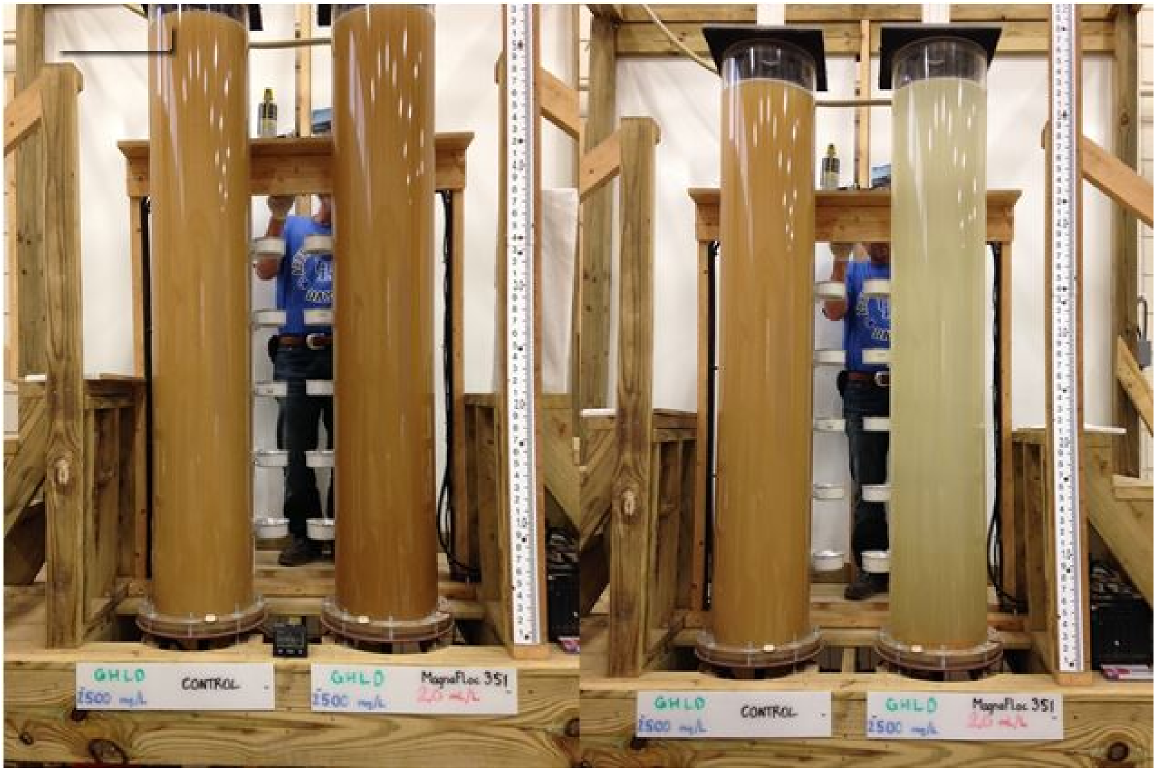


Figure 3.7: Column Comparison at 2,500 mg/L Initial Concentration at Time=0 min (left) and Time=5 min (right)

Utilizing particle size distribution information obtained through the LISST, there is a noticeable difference in the shape of curves between the two columns and the control column PSD contain a higher percentage of finer materials than the flocculated column, Figure 3.8 and Figure 3.9. At the 60 minute sample, the $D_{50}$ of the control column is approximately 0.08 mm while the $D_{50}$ of the flocculated column is 0.65 mm, nearing 8 times larger in diameter.

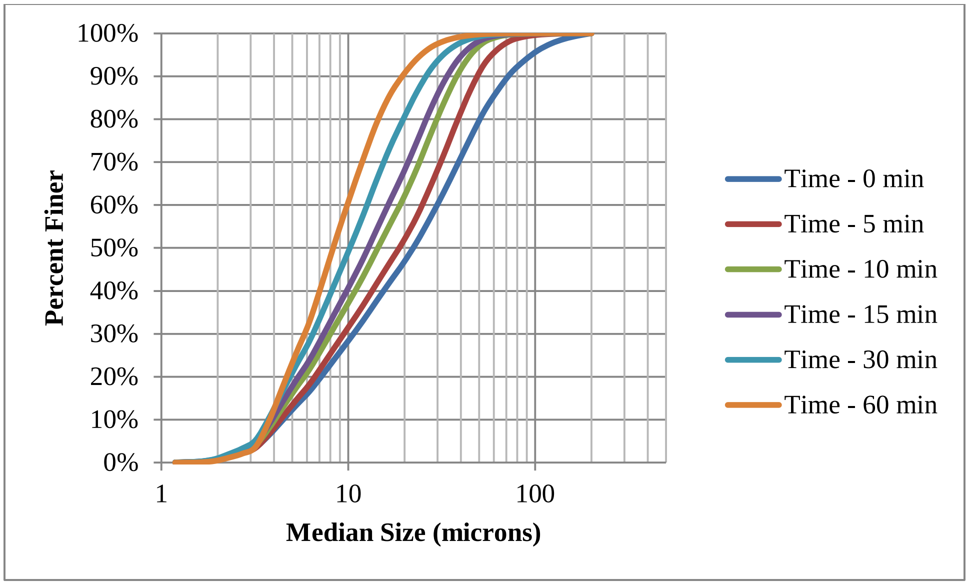


Figure 3.8: Cumulative Particle Size Distributions at Port 2 for the Control Column at 2,500 mg/L Initial Concentration

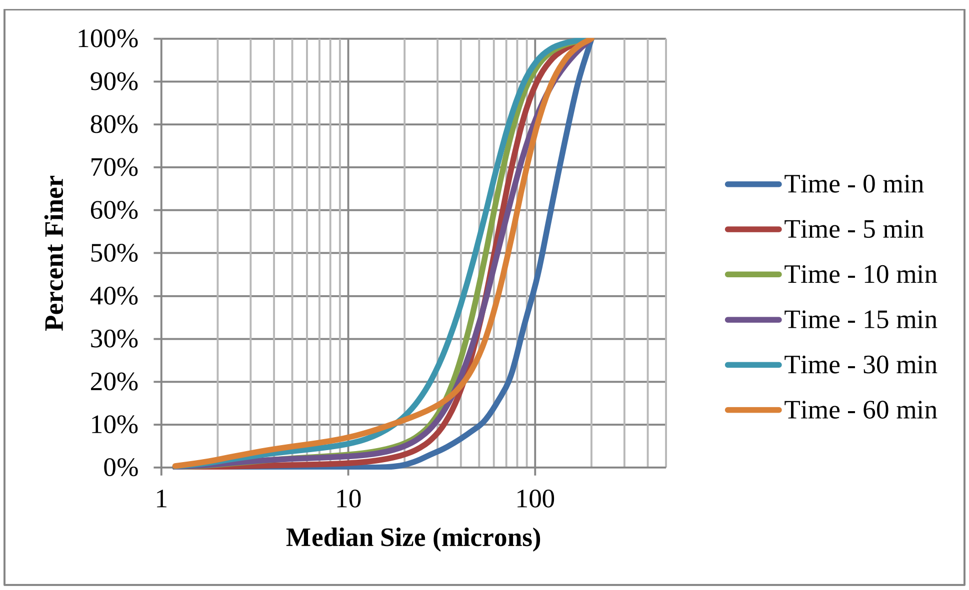


Figure 3.9: Cumulative Particle Size Distributions at Port 2 for the Flocculated Column at 2,500 mg/L Initial Concentration

### *3.4.4 Column Results at 5,000 mg/L – Port 2*

Column results at the initial sediment concentration of 5,000 mg/L were analyzed over time at Port 2 to determine if there was an effect on reducing total concentration with the addition of flocculant, Table 3.10. Results show that approximately 15 seconds after mixing is stopped and bubbles are allowed to dissipate (time = 0 min sample), there is a statistical difference of the total solids between the control and flocculated columns. This is different from the 500 mg/L initial concentration, but similar to the 2,500 mg/L initial concentration in that it is due to the settling that occurs during the time period at which the air mixing is turned off and the sampling has commenced. The statistical difference between the two columns exists for all samples at each time period.

Table 3.10: Mean and Standard Deviation of Total Solids at 5,000 mg/L Initial Concentration, Port 2

| Time | Control Column (mg/L) | Floc Column (mg/L) | Statistically Different? |
|---|---|---|---|
| 0 min | 4620.5 ± 156.8 | 4240.4 ± 185.1 | Yes |
| 5 min | 3771.2 ± 124.8 | 44.5 ± 10.1 | Yes |
| 10 min | 3271.9 ± 166.0 | 26.4 ± 3.6 | Yes |
| 15 min | 2920.7 ± 132.0 | 22.6 ± 2.2 | Yes |
| 30 min | 2488.7 ± 70.6 | 20.1 ± 3.6 | Yes |
| 60 min | 2055.7 ± 184.8 | 18.6 ± 7.7 | Yes |

Statistical Significance Determined at $p < 0.05$

Utilizing a 50 mg/L total solids guideline (IFC), the flocculated sample is below this threshold after 5 minutes of settling while the control column does not reach this threshold after 60 minutes of settling, Figure 3.10. The flocculated column increases the settling efficiency in the period after 5 minutes, but it is important to note that a total solids concentration less than 50 mg/L can be achieved in just 5 minutes after mixing has occurred.

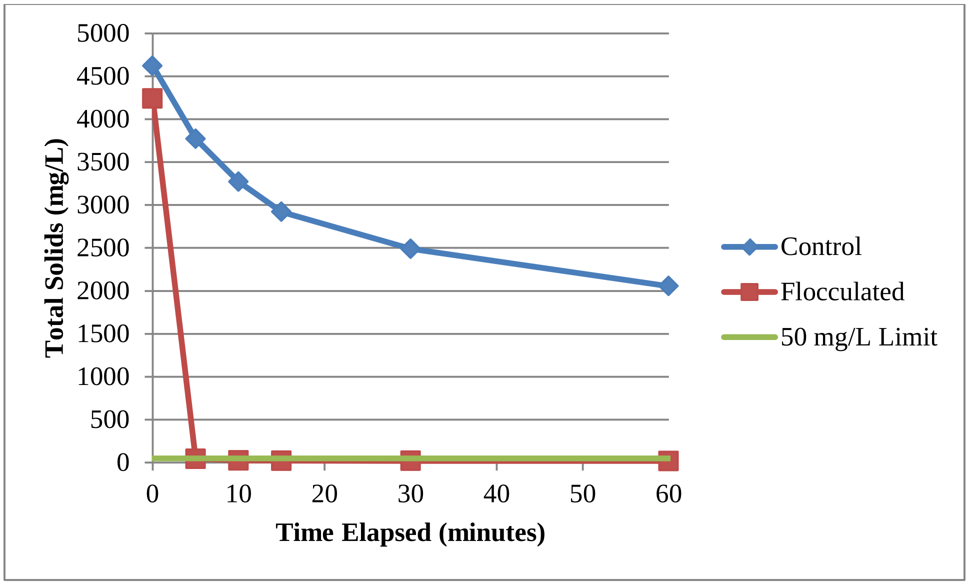


Figure 3.10: Control and Flocculated Column Total Solids Comparison at 5,000 mg/L Initial Concentration, Port 2

Focusing on the flocculated column only at Port 2 at initial concentration of 5,000 mg/L depicts a decrease in total concentration over time, Table 3.10. Results show, however, that after the initial sample is taken at time = 0 minutes, the following samples at time = 5, 10, 15, 30, and 60 minutes are not statistically different, within themselves. This, as was apparent at the 2,500 mg/L initial concentration, follows the notion that sweep flocculation is occurring during the settling process, Figure 3.11.


Figure 3.11: Column Comparison at 5,000 mg/L Initial Concentration at Time=0 min (left) and Time=5 min (right)

Utilizing particle size distribution information obtained through the LISST, it is noted there is a noticeable difference in the shape of curves between the two columns and the control column PSD contain a higher percentage of finer materials than the flocculated column, Figure 3.12 and Figure 3.13. The cumulative PSD for the flocculated column contains curves that do not follow as expected for the 30 and 60 minute samples. This is most likely attributed to the small sediment concentrations in suspension at this time which means if any larger particles or flocs were lingering at the surface or on the wall of the column and were captured in the samples, it would heavily skew the PSD results. At the 60 minute sample, the $D_{50}$ of the control column is approximately 0.07 mm while the $D_{50}$ of the flocculated column is approximately 0.50 mm, 7 times larger in diameter.

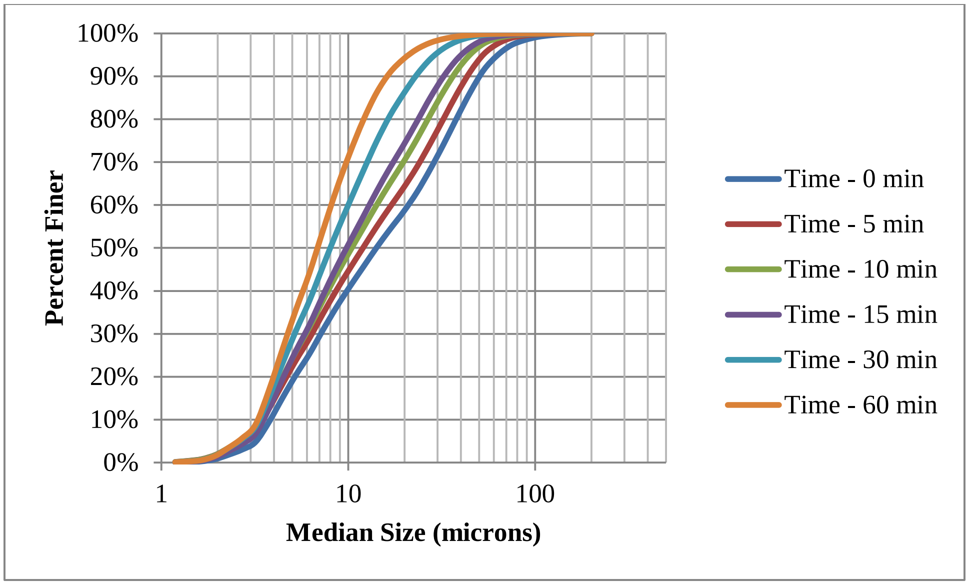


Figure 3.12: Cumulative Particle Size Distributions at Port 2 for the Control Column at 5,000 mg/L Initial Concentration

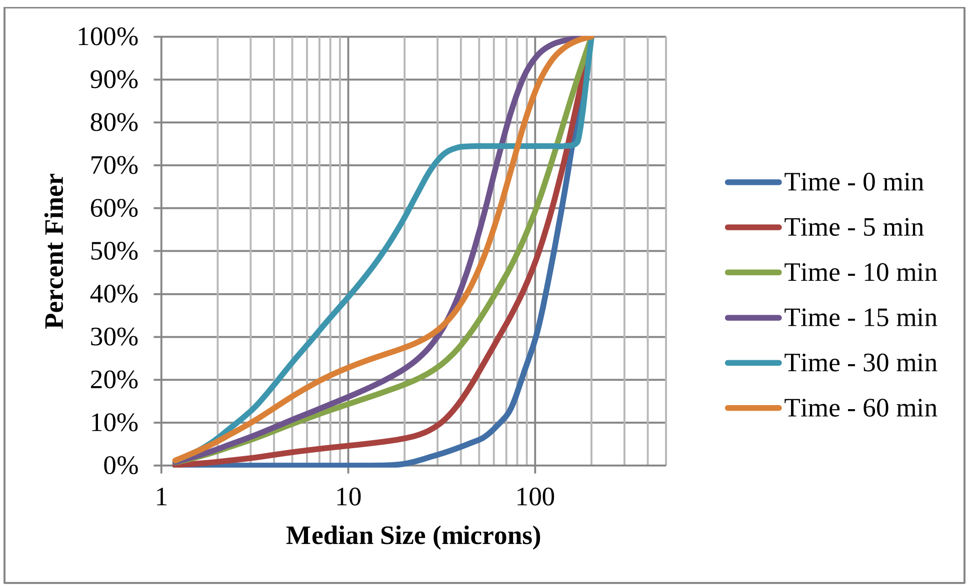


Figure 3.13: Cumulative Particle Size Distributions at Port 2 for the Flocculated Column at 5,000 mg/L Initial Concentration

### *3.4.5 Flocculated Column Comparison*

Combining the percent reduction from initial concentration of the samples from Port 2 from the flocculated columns at each initial condition into a single table,

Table 3.11, portrays how efficient MF 351 is at reducing total solids over time. At all sampling times, the higher initial concentrations correspond to a higher percent reduction. Initially at the sample time of 0 min, a larger percent reduction exists at 2,500 and 5,000 mg/L initial concentration due to the extended time allowed for air bubbles to rise after mixing is turned off.

Table 3.11: Percent Reduction from Initial Concentration for Samples at Port 2 for Flocculated Column over Time

| **Time** | **500 mg/L Initial Concentration** | **2,500 mg/L Initial Concentration** | **5,000 mg/L Initial Concentration** |
|---|---|---|---|
| 0 min | 3.9 | 14.5 | 15.2 |
| 5 min | 76.2 | 97.3 | 99.1 |
| 10 min | 87.1 | 98.7 | 99.5 |
| 15 min | 90.3 | 99.0 | 99.5 |
| 30 min | 93.4 | 99.1 | 99.6 |
| 60 min | 94.9 | 99.2 | 99.6 |

It is worth noting that the percent reduction increases as the initial concentration increases at any given time. For example, at time = 5 minutes, the percent reduction is 76.2%, 97.3%, and 99.1% for the 500 mg/L, 2,500 mg/L, and 5,000 mg/L initial concentrations, respectively. This can be attributed to the sweep floc mechanism that occurs over the course of settling. With a higher initial concentration, the flocculant has more particle sites to attach to, making a thicker blanket of flocculated particles that settles. With a thicker blanket of flocs formed and settling in a uniform motion, the smaller particles remaining in suspension below it will more likely be collected and settled at the base of the column, resulting in a lower total solids reading.

## 3.5 Conclusions

Using findings gathered from preliminary jar tests on weathered mine spoil, column tests were performed utilizing Magnafloc 351 at three initial concentrations. Magnafloc 351 (0.1% solution) was introduced into initial sediment concentrations of 500 mg/L, 2,500 mg/L, and 5,000 mg/L at a rate of 1.0 mL/L, 2.0 mL/L, and 5,0 mL/L, respectively, for each settling column test. Columns were operated on a pairwise basis, with a flocculated column and a control column (no flocculant added) conducted side-by-side to observe differences. Results from the column tests reproduced those from the initial jar tests, that MF 351 performs as desired to increase particle size and reduce total solids concentration in the columns.

The total solids concentration is reduced to <50 mg/L in all initial sediment concentrations after 15 minutes of settling with the introduction of MF 351. Without the introduction of MF 351, total solids concentrations reach 185 mg/L, 895 mg/L, and 2055 mg/L after 60 minutes of settling for an initial sediment concentration of 500 mg/L, 2,500 mg/L, and 5,000 mg/L, respectively. The introduction of MF 351 at an initial sediment concentration of 5,000 mg/L shows a higher settling efficiency than 500 mg/L and 2,500 mg/L due to the increased amount of attachment sites for the flocculant leading to the sweep flocculation mechanism that occurs. At all initial concentrations, settling efficiency is expected to increase over time at a higher rate in the flocculated column than the control column due to the increased particle size of the particles remaining in suspension.

If flocculation is translated to an on-site setting, it can be expected that settling efficiencies will be lessened, due to less precision in flocculant application, less uniform mixing of the flocculant-soil solution, and varied inflow sediment concentration, as well as inflow water chemistry. Column tests indicate that flocculation can decrease the total solids to levels <50 mg/L for incoming concentrations between 500 mg/L and 5,000 mg/L with the appropriate application and mixing. The rapidity at which the flocculated particles are settled can prove very cost effective in mine site applications, reducing the size, and possibly the number, of sediment and bench ponds located on site.

# CHAPTER 4: THE INFLUENCE OF AGING AND ENVIRONMENTAL CONDITIONS ON THE SETTLING EFFECTIVENESS OF POLYACRYLAMIDE FLOCCULANTS

## 4.1 Introduction

Polyacrylamide (PAM) flocculants are used at mining and construction sites to enhance particle settling during storm events. PAM flocculants bind fine sediment particles together to form larger agglomerates that are rapidly settled within a sediment control structure. The use of PAM provides potential capital cost savings due to downsizing sediment control structures and also reduces effluent sediment concentration that may otherwise degrade the downstream aquatic environment.

PAM is shipped from the manufacturer often as a dry, granular powder. PAM must be converted to a liquid solution, often 0.1% solution, before application. The manufacturer's recommended shelf life of most PAM solutions is often no more than 2 days (BASF 2013). When traditionally used in water and wastewater treatment facilities such a limited shelf life is not an issue, but usage of PAM at construction or mining sites, introduced during storm events, generates numerous logistical problems. Many mine sites span extensive areas and may have dozens of sediment control facilities in rather remote and difficult to access locations in the Appalachian region. Furthermore, the demand for flocculant is driven by the size and frequency of storms and the extent of active land disturbing operations. It is cost prohibitive to provide flocculant to such dispersed sites that have a variable demand for flocculant and meet the 2-day shelf life constraint.

There is very limited research on the aging effect of PAM and no literature was found that associated aging and/or environmental conditions with effectiveness in sediment settling. Previous applied research conducted at the University of Kentucky addressed a screening analysis utilizing a PAM flocculant, Magnafloc 351 (MF 351), and its efficiency for particle settling on loose dumped weathered mine spoil retrieved from a surface mine in eastern Kentucky. All PAM solutions were mixed and allowed to age for approximately 24 hours before commencing testing, per manufacturer's guidelines. To expand on this research, PAM solutions were created and stored for different periods of time (aged) and exposed to various environmental conditions. The initial screening tests were then recreated, utilizing these aged and exposed solutions, to determine what effects, if any, they may have on the settling efficiency.

This chapter addresses the effect that different time and environmental treatments have on the settling efficiency of Magnafloc 351 on loose dumped weathered mine spoil.

## 4.2 Background

### *4.2.1 Aging Effects on PAM Flocculant Solutions*

On an active disturbed site, a PAM flocculant solution would need to be located and ready to dispense at sediment control structures prior to each storm event to properly treat sediment-laden inflow. Due to site constraints, it is not economically or logistically feasible to treat inflow with a flocculant solution that is less than 48 hours old. A feasible flocculation plan would be to mix a large volume of flocculant solution to be stored in a central location; a sufficient quantity of flocculant solution would then be transported and stored at the flocculant dispersant device near the inflow of sediment ponds. A large pre-mixed volume housed in the storage building would enable deployment to sediment ponds with limited delays. A large tank at each pond would reduce the frequency of filling, as well as provide the ability to treat multiple sequential storm events before the on-site storage tank would need to again be refilled. The obvious tradeoffs are among the age of the flocculant prior to use, the size of on-site storage tanks, and the frequency of transportation and filling. This system would require limited planning and cost; only requiring a centralized mixing unit and storage tank, along with the transport and refilling of on-site tanks once a specified depletion level has been reached. The current unknowns with respect to PAM's sediment settling effectiveness are: 1) how long can a mixed flocculant be contained in an indoor storage building, 2) how long can flocculant be stored outside in an exposed on-site tank, 3) what type of on-site tank is acceptable and 4) what environmental conditions adversely affect performance? This research provides a preliminary assessment to generate initial insights to possible answers to these questions.

Limited research has been conducted on the effect of storage time (age) and environmental storage on PAM flocculant performance. Narkis and Rebhun (1966) determined that an increase in flocculant age correlated to a decrease in viscosity, not necessarily due to degradation but to molecular changes through chain disentanglement within the flocculant solution. Gardner, Murphy et al. (1978) also found that PAM solution viscosity decreased for approximately 160-180 hours, predominantly occurring between 5 and 24 hours, at 30°C. Owen, Fawell et al. (2002) conducted a study on the minimum dosage to induce noticeable flocculation in a mineral slurry and found that PAM solution performed optimally after 72 hours in a lab setting. This study, however, only considered flocculants aged up to 6 days. None of this research considered environmental effects or times greater than a week, in relation to settling performance.

#### *4.2.2 Jar Test Procedure*

Jar tests have been the industry standard technique for the evaluation of flocculants and coagulants on water samples. Jar tests provide a timely and cost effective method to predict flocculant effectiveness in both qualitative and quantitative terms. Jar tests are often conducted to determine flocculant dosage, mixing time, mixing speed, settling time, and facilitate sample withdrawal to determine water quality parameters (Herbert and Wagner 1981). Using transparent jars enables visual assessments that provide immediate qualitative results. Sample withdrawal, commonly drawn through a motorized pippetter, allows for TSS and water quality tests to be performed.

The jar tests were conducted on a Phipps and Bird PB-700 Jartester with six paddle stirrers and an illuminated base at the laboratories of the University of Kentucky. Jar tests were conducted with six one-liter glass beakers filled with deionized water. Previous flocculant screening research conducted at the University of Kentucky showed that if tap water was used, ions were present that aided in the flocculation process; thus, deionized water was used in all experiments. All samples were prepared using soil that had been processed through the #100 sieve, 0.15 mm; thus removing all particles that would naturally settle without flocculation.

The following protocol was used during the jar tests:

1. Soil sample sieved through #100 sieve and fines were weighed to produce tested concentrations
2. Beaker filled with 1 L of deionized water
3. Measured soil sample added to filled beaker to achieve desired initial concentration
4. Flocculant dosage measured in syringe for ease of measurement and application
5. Beaker placed on jar tester and stirred for 2 min at approximately 200 RPM

6. Flocculant injected to surface of mixture and stirred for 2 min at approximately 200 RPM
7. After blended flocculant and soil has mixed for 2 minutes, the stirrer is turned off and removed from the beaker
8. Allow flocculated particles to settle for 10 min without disturbance
9. Using motorized pippetter, withdraw 200 mL of sample from supernatant (approximately 1 cm below surface) and transfer to clean container.
10. Use 200 mL sample to test of TSS and particle size distribution with LISST-Portable Particle Size Analyzer (PSA).

ASTM D2035-08 Standard (2008) specifies rapid mixing at approximately 120 rpm for 1 minute, followed by a slow mix period of twenty minutes before paddle removal and undisturbed settling. Typical sediment pond construction does not provide adequate space to create a mixing zone that will enable twenty minutes of constant mixing. Based on-site observations and dry tracer testing in a prototype laboratory settling pond, it was determined that rapid mixing at a duration of two minutes followed by a settling period of 10 to 20 minutes would be the most accurate representation of what could be accomplished in a mine setting (M. L. Griffin 1985). This most closely resembles a generic site in which flocculant is introduced upstream of a pond in a rock riprap channel and rapidly mixed as it is conveyed to the sediment pond. The flocculated particles would then slowly pass through the length of the pond until they reach the discharge structure, which was conservatively assumed to take approximately 10 minutes for supernatant sampling.

#### *4.2.3 LISST*

Samples withdrawn during the jar settling analysis were analyzed using a LISST-Portable manufactured by Sequoia Scientific, Inc. The LISST uses a method of laser diffraction to measure the size and concentration of particles suspended in a solution, which is analyzed and displayed as a size distribution and volume concentration. Due to the LISST's rapid analysis and ease of use, it was chosen to analyze samples withdrawn from the column to determine particle size distributions. The LISST was also used in the previous initial jar test study to determine the optimum flocculant and dosages for weathered mine spoil.

### *4.2.4 Jar Test Results with 1 Day Old Flocculant Solution*

Prior research conducted at the University of Kentucky focused on the screening of four PAM flocculants to determine their effectiveness in settling particles generated from mine spoil composed of weathered mine sandstone. This prior research utilized PAM solutions that had been mixed then aged for 24 hours prior to use (Inside 1 treatment). For the current research assessing environmental and aging effects, the results from the screening test using Magnafloc 351 (MF 351) and an initial sediment concentration of 2,500 mg/L were further investigated. Results were tabulated to establish the mean TSS concentration after 10 minutes of settling, as well as the percent decrease from the control jar with no flocculant introduced, Table 4.1.

Table 4.1: Mean TSS Concentration Results for Dosages of Inside 1 MF 351 at 2,500 mg/L Initial Concentration after 10 Minutes of Settling

| Dosage | Concentration (mg/L) | Percent Decrease from Control |
|---|---|---|
| 0 | 630.09a ± 39.74 | NA |
| 1.0 | 25.65b ± 7.32 | 95.9% |
| 2.0 | 16.48b ± 3.24 | 97.4% |
| 3.0 | 21.10b ± 2.33 | 96.7% |
| 4.0 | 17.53b ± 1.83 | 97.2% |
| 5.0 | 19.97b ± 7.79 | 96.8% |
| 6.0 | 28.52b ± 7.77 | 95.5% |

Different letters represent statistically different means ($p < 0.05$)

## 4.3 Experimental Procedure

Magnafloc 351 (MF 351) was prepared to a 0.1% solution with deionized water by combining 1.0 gram of dry flocculant in 1.0 liter of deionized water using a Phipps and Bird PB-700 Jartester at a speed of 200 rpm for 60 minutes. After 60 minutes, the paddle stirrer was turned off and the flocculant was allowed to rest until the next day. After the resting period of approximately 24 hours, 0.5 L of MF 351 solution was transferred to 1.0 L Nalgene polyethylene bottles, which remained capped at all times, to be subjected to aging and environmental conditions.

The experiment was segmented into two distinct components studying the effects of: 1) time and 2) environmental conditions after 30 days. The initial experiments focusing on the effect of time for a flocculant solution stored inside up to 210 days, Table 4.2. The flocculant was stored inside the Biosystems and Agricultural Engineering labs (approximately 75°F) and out of direct sunlight. These results were compared to the Inside 1 flocculant solution and the control (no flocculant) generated from earlier research.

Table 4.2: Flocculant Solutions Stored in an Inside Controlled Environment

| Solution ID | Date Initially Stored | Date Tested | Time Elapsed (days) |
|---|---|---|---|
| Inside 30 | December 2014 | January 2015 | 30 |
| Inside 120 | September 2014 | January 2015 | 120 |
| Inside 210 | June 2014 | January 2015 | 210 |

The second part of the experiment focused on the effect of exposure to various environmental conditions during a 30 day period, Table 4.3. The purpose of this investigation was to gain insights to environmental conditions that may degrade the settling performance of flocculants thereby exploring needed on-site storage tank facility design considerations. These results were then compared to the Inside 30 results from Part 1, as well as the Inside 1 solution and control from previous research.

Table 4.3: Magnafloc 351 Flocculant Solution Treatments for Comparison After 30 Days

| Solution ID | Description |
|---|---|
| Inside 30 | Inside climate controlled chamber 75°F, very limited UV exposure |
| Outside | Subject to temperature changes, freeze-thaw cycle, UV Exposure (January 2015) |
| Freezer 4 | Constant temperature of 4°F in laboratory freezer, no UV exposure |
| Freezer 36 | Constant temperature of 36°F in laboratory freezer, no UV exposure |
| Oven 111 | Constant temperature of 111°F in laboratory oven, no UV Exposure |
| UV Exposed | Constant temperature of 77°F in environmental chamber, constant UV exposure of 254, 302, 365 nm cycled every three days |

For both experiments, flocculant solutions were removed from their respective treatments 24 hours before jar tests were conducted and placed on a lab bench to ensure uniform temperature for all treatments before testing. For each flocculant solution that was treated, jar tests were conducted at an initial sediment concentration of 2,500 mg/L (particles < 0.15 mm). Flocculant solution was introduced at a starting dosage of 1.0 mL and increased in 1.0 mL increments to cover a range from 1.0 mL to 6.0 mL. After each jar test was completed, 200 mL of supernatant, approximately 1 cm below the water surface, was withdrawn for analysis by the LISST-Portable and pictures were taken for visual assessment. The sample was withdrawn near the surface to mimic an outlet structure that discharges near the pond surface. Each flocculant was analyzed for six jars over three replicates, with the TSS concentration averaged over the three replicates. Both visual analysis and LISST results (TSS concentration, particle size distribution) were utilized in analysis.

The statistical analysis was performed using the PROC GLM procedure available within SAS™ (Version 9.3, SAS Institute Inc., Cary, NC, USA). To determine the how the efficiency of Magnafloc 351 changes over time, mean TSS levels and standard errors were determined at the 2.0 mL dosage across each storage time at a 2,500 mg/L initial concentration. Least square means (LSMEANS) was used to determine the significant differences ($p<0.05$) that exist between the storage times utilizing Bonferroni adjustment, due to its conservative nature. Additional analysis was performed to determine environmental effects on the storage of Magnafloc 351 at a 2.0 mL dosage and 2,500 mg/L initial concentration. Mean TSS levels and standard errors were determined for each environmental condition at the 2.0 mL dosage. Least square means (LSMEANS) was used to determine the significant differences ($p<0.05$) that exist between the environmental storage conditions and a one day old solution utilizing Bonferroni adjustment.

## 4.4 Results

### *4.4.1 Specific Gravity*

The specific gravity of the loose dumped weathered mine spoil sample was conducted, according to ASTM D854 Standard (2010), over three replicates. The mean specific gravity was determined to be 2.74 g/cm$^3$. The LISST portable outputs concentration results in mL/L, therefore the specific gravity must be used to convert the units to the more commonly used mg/L.

*4.4.2 Flocculant Solution Inside Aging: Effects of Flocculant Dosage and Age*

Magnafloc 351 flocculant solution was mixed to a 0.1% solution and stored inside for extended periods of time from 1 day to 210 days, Table 4.2. Jar tests were conducted and the final total solids concentrations (mg/L), after 10 minutes of settling, were analyzed over all six dosages and three replicates, as well as the Inside 1 and Control, Table 4.4 and Figure 4.1.

Table 4.4: Mean TSS Results for MF 351 Stored Inside at Different Time Periods at 2,500 mg/L Initial Concentration after 10 Minutes of Settling

| Dosage | Inside 1 Day | Inside 30 Day | Inside 120 Day | Inside 210 Day | Control |
|---|---|---|---|---|---|
| 1.0 | 25.6 ± 7.3 | 64.1 ± 6.1 | 81.7 ± 30.4 | 196.4 ± 26.6 | 630.1 ± 39.7 |
| 2.0 | 16.5 ± 3.2 | 25.6 ± 3.4 | 52.4 ± 22.8 | 157.6 ± 7.3 | 630.1 ± 39.7 |
| 3.0 | 21.1 ± 2.3 | 14.9 ± 3.8 | 28.6 ± 9.8 | 109.2 ± 8.5 | 630.1 ± 39.7 |
| 4.0 | 17.5 ± 1.8 | 11.0 ± 4.2 | 30.6 ± 8.7 | 88.7 ± 22.0 | 630.1 ± 39.7 |
| 5.0 | 20/0 ± 7.8 | 12.0 ± 5.1 | 27.2 ± 8.6 | 87.7 ± 4.3 | 630.1 ± 39.7 |
| 6.0 | 28.5 ± 7.8 | 10.0 ± 1.1 | 26.2 ± 4.1 | 84.2 ± 2.7 | 630.1 ± 39.7 |

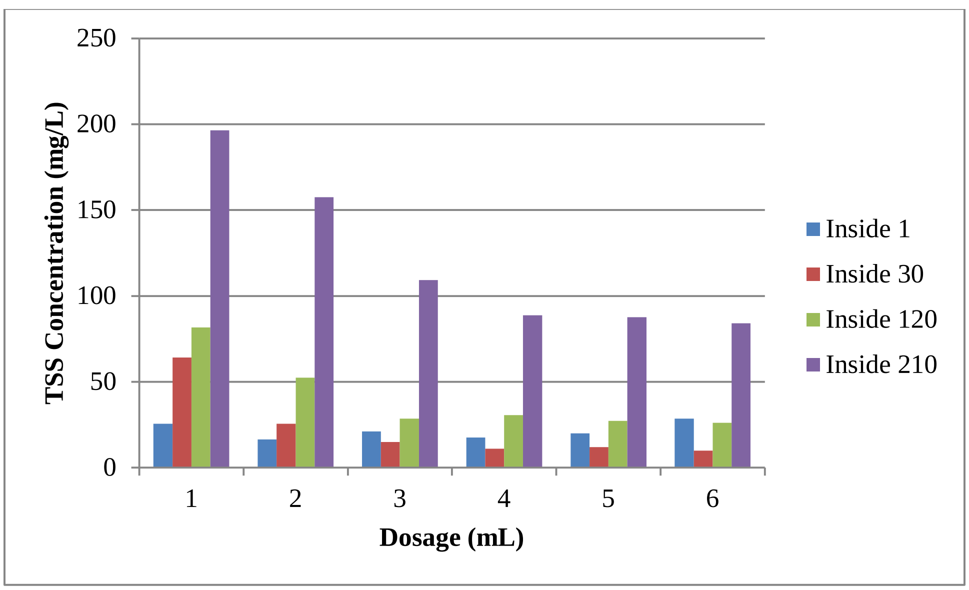


Figure 4.1: Mean Final TSS Concentration Results for MF 351 Stored Inside at 2,500 mg/L Initial Concentration after 10 Minutes Settling

From Table 4.4 and Figure 4.1, it can be noted that settling performance decreases as storage time increases for MF 351 stored inside. All storage times and dosages performed substantially better than the control (no flocculant added) at reducing final sediment concentration after 10 minutes of quiescent settling. It is worth noting that from 30 days to 210 days of inside aging, the settling performance increases with dosage, as all figures follow an exponential decay curve (Figure 4.1). This increase is not apparent in Inside 1. This may be occurring due to the polymer degrading over time, producing a less potent flocculant solution that requires a higher dosage to achieve desired results. Inside 30 performs better at high dosages (3.0-6.0 mL) than Inside 1 but performs much worse at a 1.0 mL dosage compared to Inside 1. Inside 120 performed worse than Inside 30 and produced comparable results to Inside 1 only at the higher dosages of 5.0-6.0 mL. Inside 210 performed better than the control but was not as effective as the lesser aging times.

### *4.4.3 Flocculant Solution Inside Aging: Effects of Time for 2.0 mL Dosage Flocculant*

Previous research with column settling tests utilized a 2.0 mL dosage of MF 351 provided both an acceptable settling performance and a cost-effective solution for an initial sediment concentration of 2,500 mg/L. Analysis was conducted at this dosage level for a time period of 1 to 210 days, Table 4.5.

Table 4.5: Mean TSS Concentration for 2.0 mL Dosage of MF 351 Stored Inside at 2,500 mg/L Initial Concentration after 10 Minutes Settling

| **Condition** | **Mean Concentration (mg/L)** |
|---|---|
| Inside 1 | 16.5**c** ± 3.2 |
| Inside 30 | 25.6**c** ± 3.4 |
| Inside 120 | 52.4**c** ± 22.8 |
| Inside 210 | 157.6**b** ± 7.3 |
| Control | 630.1**a** ± 39.7 |

Different letters represent statistically different means at $p<0.05$

It is worth noting that Inside 1, Inside 30, and Inside 120 produced final sediment concentrations that are not statistically different at the 2.0 mL dosage, although there is an increase in final concentration with an increase in storage time. Inside 210 produces a final concentration statistically worse than the other three timeframes but was statistically better than the control of no MF 351 added at reducing final sediment concentration.

From this data assessment, it can be deduced that for a MF 351 flocculant solution stored inside, there is a time between 120 and 210 days that the solution degrades to generate results statistically different than that of newly created solution. With an understanding of how time affects a MF 351 flocculant solution at a controlled environmental condition, the experiment was expanded to investigate what environmental conditions affected the settling ability of MF 351 after 30 days.

#### *4.4.4 Flocculant Solution Aging: Environmental Conditions Effects after 30 Days*

Magnafloc 351 flocculant solution was mixed to a 0.1% solution and stored under various environmental conditions for 30 days, Table 4.3. Jar tests were conducted and the total solids concentrations (mg/L), after 10 minutes of settling, were analyzed over all six dosages and three replicates, as well as the Inside 1 and Control,

Table 4.6 and Figure 4.2.

Table 4.6: Mean TSS Concentration Results for MF 351 Stored for 30 Days at 2,500 mg/L Initial Concentration after 10 Minutes of Settling

| Dosage | Inside 1 | Inside 30 | Outside 30 | Freezer 30 - 4°F | Freezer 30 - 36°F | Oven 30 - 111°F | UV Exposed 30 | Control |
|---|---|---|---|---|---|---|---|---|
| 1 | 25.6 ± 7.3 | 64.1 ± 6.1 | 836.4 ± 80.5 | 24.5 ± 1.9 | 33.6 ± 9.6 | 811.7 ± 82.3 | 979.6 ± 42.9 | 630.1 ± 39.7 |
| 2 | 16.5 ± 3.2 | 25.6 ± 3.4 | 830.3 ± 48.6 | 10.2 ± 0.2 | 16.6 ± 6.6 | 703.0 ± 94.5 | 884.0 ± 60.3 | 630.1 ± 39.7 |
| 3 | 21.1 ± 2.3 | 14.9 ± 3.8 | 693.1 ± 20.2 | 8.8 ± 2.5 | 15.7 ± 5.4 | 605.8 ± 76.8 | 992.6 ± 43.4 | 630.1 ± 39.7 |
| 4 | 17.5 ± 1.8 | 11.0 ± 4.3 | 511.0 ± 45.0 | 9.8 ± 2.7 | 18.2 ± 4.8 | 482.7 ± 129.4 | 899.0 ± 17.1 | 630.1 ± 39.7 |
| 5 | 20.0 ± 7.8 | 12.0 ± 5.1 | 456.8 ± 46.7 | 10.7 ± 2.3 | 19.5 ± 4.8 | 351.4 ± 37.4 | 986.6 ± 73.4 | 630.1 ± 39.7 |
| 6 | 28.5 ± 7.8 | 10.0 ± 1.1 | 331.4 ± 173.1 | 13.9 ± 4.9 | 23.8 ± 2.0 | 292.8 ± 37.2 | 830.8 ± 52.7 | 630.1 ± 39.7 |

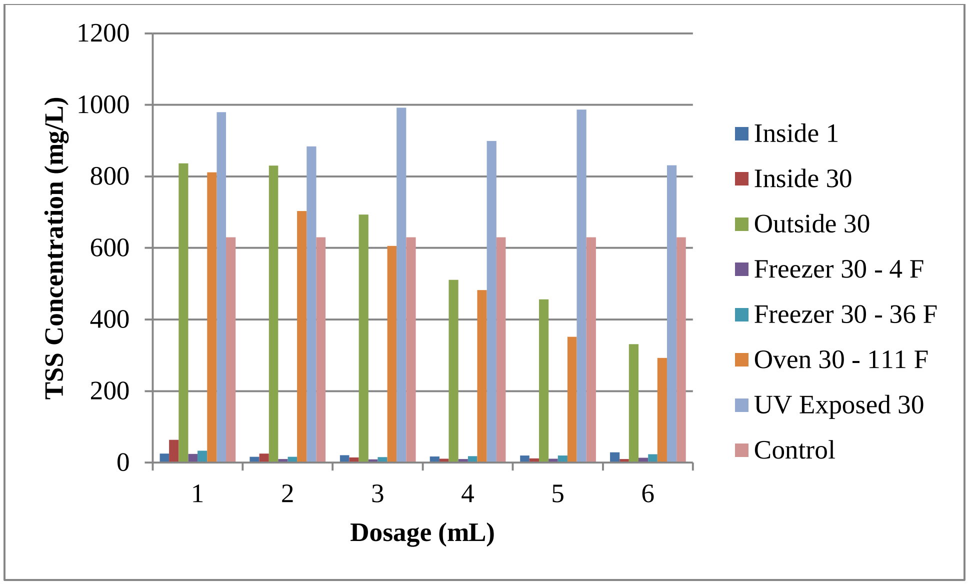


Figure 4.2: Mean TSS Concentration Results for MF 351 Stored for 30 Days Under Environmental Conditions at 2,500 mg/L Initial Concentration after 10 Minutes of Settling

Upon analysis of the results, there is confirmation of flocculant solution degradation that occurs after 30 days which was found for the inside storage scenario. All environmental treatments except for the UV Exposed 30, which was uniformly ineffective, resulted in better settling performance with an increase in flocculant dosage. Treatments Inside 30, Freezer 30 - 4°F, and Freezer 30 - 36°F produce sediment concentrations that are comparable or better than those produced by the Inside 1 treatment across all dosages (1.0 – 6.0 mL). Conversely, Outside 30, Oven 30 - 111°F, and UV Exposed 30 produce sediment concentrations that are comparable or lower than those produced by a control of no flocculant, especially in the lower dosage range (1.0 – 3.0 mL).

### *4.4.5 Flocculant Solution Aging: Effects of Environmental Conditions for 2.0 mL Dosage Flocculant*

Comparisons are provided for the alternative environmental conditions at a flocculant dosage rate of 2.0 mL MF 351 for an initial sediment concentration of 2,500 mg/L. Further analysis was conducted at this dosage level to generate a comparison against a manufacturer recommended 1-day solution, Table 4.7.

Table 4.7: Mean TSS Concentration for 2.0 mL Dosage of MF 351 Stored for 30 Days Under Environmental Conditions at 2,500 mg/L Initial Concentration after 10 Minutes of Settling

| **Treatment** | **Mean Concentration (mg/L)** | **Statistically Different than Inside 1?** |
|---|---|---|
| Inside 1 | 16.5 ± 3.2 | -- |
| Inside 30 | 25.6 ± 3.4 | No |
| Outside 30 | 830.3 ± 48.6 | Yes |
| Freezer 30 - 4°F | 10.2 ± 0.2 | No |
| Freezer 30 - 36°F | 16.6 ± 6.6 | No |
| Oven 30 - 111°F | 703.0 ± 94.5 | Yes |
| UV Exposed 30 | 884.0 ± 60.3 | Yes |
| Control | 630.1 ± 39.7 | Yes |

MF 351 flocculant solutions aged in environmental treatments Inside 30, Freezer 30 - 4°F, and Freezer 30 - 36°F produced final concentration results at a 2.0 mL dosage that were not statistically different than the Inside 1 solution. Two environmental treatments, Freezer 30 - 4°F and Freezer 30 - 36°F, produced sediment concentration results that were lower than Inside 1, even though they were not statistically different. MF 351 flocculant solutions aged in treatment Oven 30 - 111°F produced results that were not statistically different than Control (no flocculant), yet both Outside 30 and UV Exposed 30 produced results that were statistically worse than Control. The cumulative particle size distributions (PSD), Figure 4.3, describe similar results for all treatments. Oven 30 - 111°F, UV Exposed 30, and Control have PSDs that overlay one another, indicating that no flocculation is occurring in these treatments. Inside 30, Outside 30, Freezer 30 - 4°F, and Freezer 30 - 36°F have PSDs that are closely bound, indicating similar settling results past the 10 minute experiment time. From the PSD data, Inside 1 would have the highest settling efficiency after the initial 10 minutes, proving to be superior to all other treatments at settling efficiency as settling time increases.

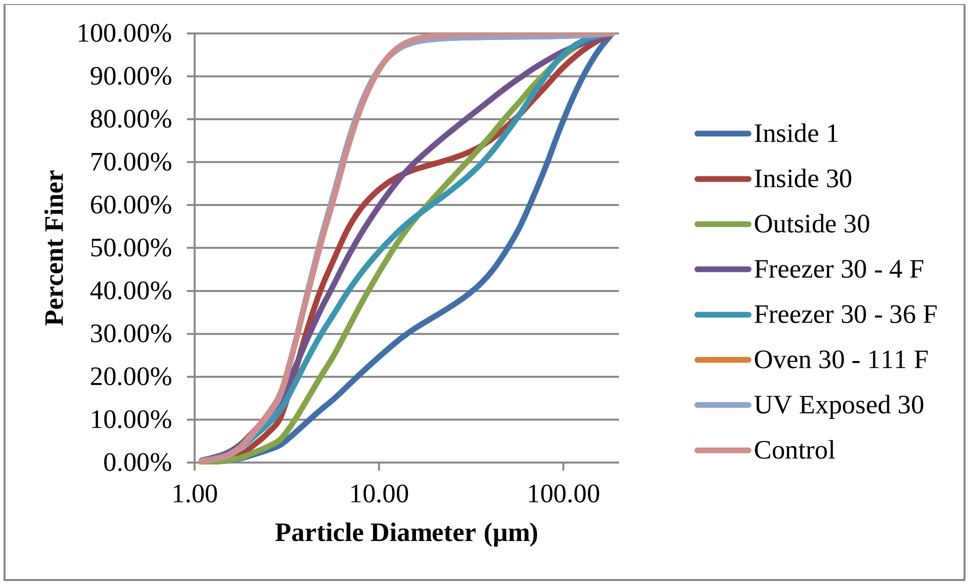


Figure 4.3: Particle Size Distributions for 2.0 mL Dosage of MF 351 Stored for 30 Days at 2,500 mg/L Initial Concentration after 10 Minutes of Settling

### 4.5 Analysis

Due to increased costs in flocculant preparation equipment, lack of access to settling or bench ponds, and the variability of storm events, flocculant solutions would be needed to be mixed in larger volumes and stored at a central location or at each pond in preparation for storm runoff. The focus of this research was to gain insights to the sediment treatment effectiveness of flocculants mixed and stored over time and held in a typical building controlled environment. Additionally, the influence of environmental factors on flocculant effectiveness was investigated. Results from these investigations provides actionable decision criteria on the storage time and outside environmental conditions that are acceptable or need to be avoided to have an effective flocculant solution.

The particle settling effectiveness of a 0.1% flocculant solution of MF 351 decreases over time. Flocculant solutions that were stored inside for 30 days and beyond experienced a decrease in sediment concentration with an increase in dosage. A higher dosage rate was needed, as time increased, to achieve higher settling efficiencies. These higher dosage rates were required to achieve similar effectiveness to that of the one day old solution, Table 4.4. Unlike these aged solutions, the one day old solution produced uniform results across all dosages tested. Utilizing this information, coupled with figures similar to Figure 4.4, site managers could determine what dosage may be required to achieve a desired final concentration based on the age of the solution at hand. Further analysis with this data, and also that of future experiments, could create a family of curves that could span different time periods and dosages depending on the age of the flocculant solution at hand to effectively treat storm events. While not completely conclusive, this data indicates that after 210 days the solution had deteriorated performance that may signal the end of a 0.1% solution's productive life when stored in a climate controlled environment with no UV exposure.

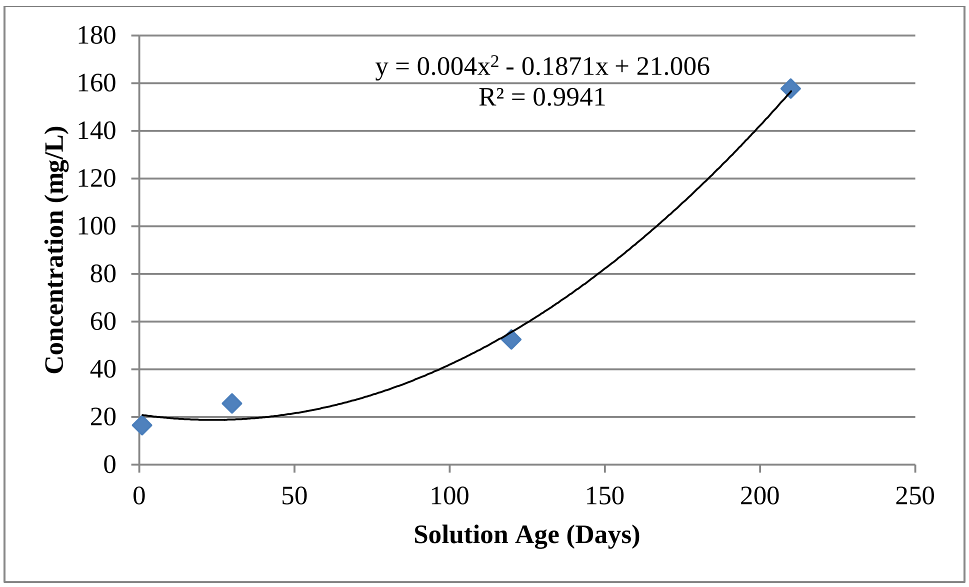


Figure 4.4: Mean TSS Concentration of 2.0 mL Dosage of MF 351 after Inside Storage at 2,500 mg/L Initial Concentration and 10 Minutes Settling

If the flocculant solution were to be mixed at an off-site or central location that would require solution transportation and storage, UV exposure would need to be avoided. One month of outside storage and one month of UV exposure (separate treatments) produced final concentrations that were worse than no flocculant treatment at all. Exposure to high heat also degrades settling efficiency after a 30 day period, although not to the same degree as UV exposure. A climate controlled environment, between 4°F and 75°F (per analysis), allows proper flocculation solution storage after 30 days and produces results similar to those of a one day old solution. Whether stored at a central location for easy deployment or at the inflow of a pond, these are certain constraints that must be taken into account for storage to retain flocculant effectiveness.

It is yet to be seen how long a MF 351 flocculant solution can be stored at a constant temperature of 4°F or 36°F past 30 days. Results showed that when stored inside at room temperature, the settling effectiveness was reduced after 120 days. It may be possible that if stored at or below freezing, the flocculant solution may maintain its effectiveness after a 120 day period, proving to be an optimal storage environment. This would prove beneficial to site planners in that a solution could be stored for long periods of time and be ready for dosing at a pond after a short thaw time. Future research could also be expanded to different polyacrylamide flocculants, to determine if these environmental effects have the same response through all types of flocculants.

### 4.6 Conclusions

Expanding upon results from previous flocculation screening, an analysis was conducted to determine the effects that time and environmental conditions had on the effectiveness of Magnafloc 351 on reducing total sediment concentration of weathered mine spoil at an initial sediment concentration of 2,500 mg/L. Initially, a 0.1% MF 351 solution was stored in a climate controlled environment indoors and allowed to age for 30, 120, and 210 days. As these flocculant solutions aged over time, the effectiveness of reducing the final sediment concentration was reduced for a given dosage. Each treatment: Inside 30, Inside 120, and Inside 210, further reduced a final concentration as the dosage of flocculant solution was increased, from 1.0 mL to 6.0 mL. Inside 30 and Inside 120 produced final concentrations that were not statistically different than Inside 1 at a 2.0 mL dosage, while all three treatments produced final concentrations that were statistically better than the control, with no flocculant solution introduced, at the same 2.0 mL dosage.

Expanding on the analysis of MF 351 stored inside, a 0.1% MF 351 solution was stored in different environmental treatments for a period of 30 days. When applied to an initial sediment concentration of 2,500 mg/L of weathered mine spoil, flocculant solutions exposed to treatments Inside, Freezer 30 - 4°F, and Freezer 30 - 36°F effectively reduced final concentration comparable to Inside 1 MF 351 solution. The treatments Outside 30, Oven 30 - 111°F, and UV Exposed 30 proved ineffective at reducing final concentration and at lower concentrations (1.0 – 3.0 mL) responded similarly to that of no flocculant addition at all. For both parts of the experiment, an increase in dosage corresponded with an increase effectiveness of reducing final concentration, except in the treatment UV Exposed 30. This is likely due to degradation occurring over time within the flocculant solution and constant UV exposure rendering the solution ineffective.

# CHAPTER 5: FUTURE WORK

To gain a better understanding of Magnafloc 351 (MF 351) effectiveness on reducing effluent sediment concentration of runoff from loose dumped weathered mine spoil, further analysis needs to be performed on both a larger laboratory scale and through an on-site assessment. The laboratory experiment should be conducted in a settling pond enabling observation of a more random flocculant solution-sediment particle interaction as well three dimensional settling. Besides sediment pond length to width ratios the type, size, and spatial location of spillways will significantly influence the overall sediment trap efficiency.

An on-site experiment should encompass: field solution storage, field sensors that provide flocculant dosage information, flocculant solution applicators, a suitable mixing zone for sufficient solution-sediment interaction, and the length of flow path needed for flocculant growth. Research addressing methods to introduce flocculant should take into account field constraints, as preliminary designs have utilized gravity fed or solar powered application devices. More rigorous application technologies entail the use of either flow, turbidity, or a combination of the two measurements to determine the needed dosing rate as a function of flow and sediment concentration.

It is of interest to determine if all polyacrylamide flocculants behave in the same manner when exposed to the same aging and environmental conditions as this study. Different soils/spoils would have to be used in these future analyses, as not all flocculants are effective for each soil/spoil, as evident in Chapter 3. It would also be of interest to determine how well flocculant solutions perform after storage for more than 30 days at low temperatures (4-36°F). Treatments in these temperatures performed very well after 30 days and may prove to be an optimum storage technique for a flocculant solution.

Measurement of residual flocculant, that which is discharged from a sediment control structure, would provide guidance on acceptable application rates with respect to potential impact on the aquatic environment. It is postulated that if there is a 99% retention of fine sediment particles within a sediment pond then the effluent would contain a flocculate dosage of approximately 1% of the dosage entering a sediment pond. The concentration of flocculant was not measured from samples taken at sampling intervals and vertical ports. In hindsight, measuring the concentration of flocculant may have provided evidence that the majority of applied flocculant was associated with the settled particles and therefore would not be discharged if the ports functioned as spillways.

# APPENDICES

## Appendix A. Characteristics of Appalachian Weathered Mine Spoil

### A.1. **Methods**

#### *A.1.1 Sample Collection*

Weathered mine spoil composite samples were collected at three locations on a surface mining operation located in eastern Kentucky. The mine was in the process of loose dumping weathered mine spoil off of the working surface for a final uncompacted cover before revegetation. Composite samples were hand retrieved from the loose dumped face and placed into 20 L buckets for transport to the Biosystems and Agricultural Engineering soil laboratory at the University of Kentucky. Samples were oven dried for 48 hours at approximately 105°C, to remove excess moisture. Once oven dried, samples were combined to create a composite sample to use in analysis, Figure A.1.

Figure A.1: Oven Dried Weathered Mine Spoil Material

Samples were also retrieved from the base of two weep berms installed on the perimeter of the disturbed mine site, Figure A.2. These samples were combined to create a composite sample and represent the fraction of loose dumped weathered spoil material that has been transported by surface runoff off of the face of the back fill, approximately

1.4:1 slope, and to the weep berm. From the layout of the backfill and weep berm, only loose dumped material was transported and deposited in the 3 m gap between the base of the backfill and the base of the weep berm. The weep berm retained all transported sediment; so no discharge occurred. The total deposited soil thickness was approximately 12 cm at the base of the weep berm and sediment cores were extracted to a depth of 10 cm. During core extraction samples were intentionally taken to approximately 2 cm above the base material to preclude mixing depositional and base soils. These samples were retrieved to compare to the results determined from the rainfall simulator run.

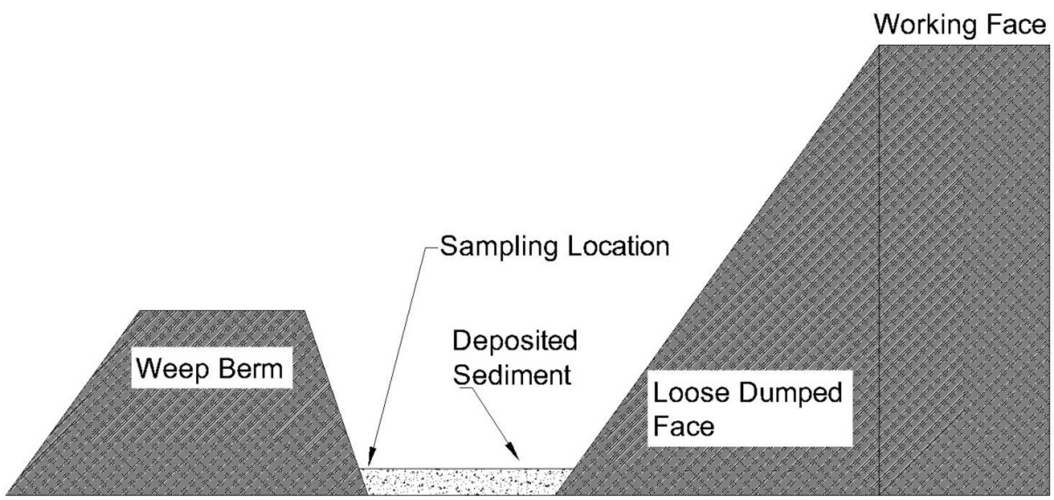


Figure A.2: Schematic of Depositional Sediment Sampling Location (Not to Scale)

### *A.1.2 Rainfall Simulator*

A rainfall simulator developed by the University of Kentucky Biosystems and Agricultural Engineering Department was used to generate eroded particle size distribution data for the loose dumped weathered mine spoil. The simulator was constructed from aluminum square tubing, approximately 6.5 m by 2.8 m, with a variable height adjustment, Figure A.3. For this experiment, eight nozzles were positioned approximately 3.5 m above the surface of the composite loose dumped samples.

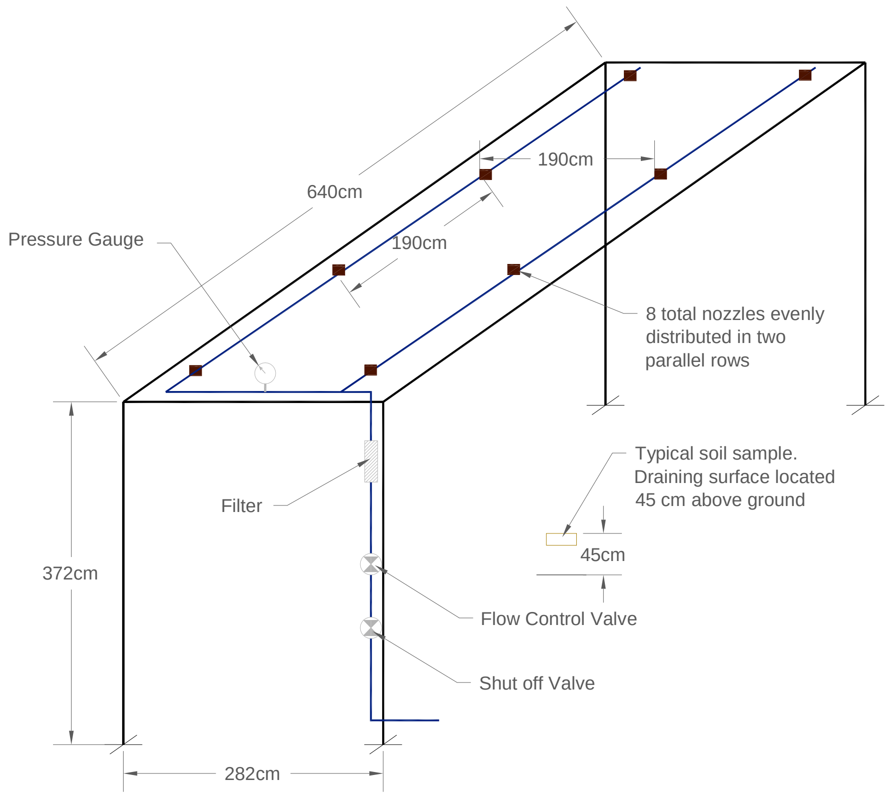


Figure A.3: Schematic of Rainfall Simulator

To perform the eroded particle size distribution analysis, the simulator was calibrated to a 56 mm/hour rainfall rate by utilizing a 2 seconds on, 3 seconds off pulse at a nozzle pressure of 48 kPa. The 56 mm/hour rainfall rate corresponds approximately to the 25- year, 1-hour storm recurrence interval for eastern Kentucky (Hershfield 1961). The 'design storm' also includes the most intense 1 hour rainfall rate of the 10-year, 24-hour NRCS Type II event. The rainfall simulator was operated for one hour, to generate a sufficient quantity of sediment laden runoff needed to conduct an eroded particle size analysis. This rainfall rate was chosen to achieve a conservative estimate of a high intensity rainfall that would produce ample energy and runoff to cause particle dislodgement for analysis. The eroded particle size distribution is preferred over the parent particle size distribution because the parent particle size distribution often overestimates the percentage of larger particles in the runoff sample. These larger particles are more difficult to dislodge and are not representative of the runoff expected to be transported on site.

### *A.1.3 Particle Size Analyzer*

The particle size analyzer used in this analysis was a SEDIGRAPH 5100 produced by MICROMERITICS, Figure A.4, maintained and calibrated by University of Kentucky personnel. The SEDIGRAPH 5100 operates by the sedimentation technique, utilizing x-ray absorption and Stokes' Law combined with known liquid properties, such as density and viscosity, to determine mass concentration of particles in the liquid sample. The SEDIGRAPH 5100 is able to conduct particle analysis on diameters from 0.300 mm to 0.0001 mm, but only the diameter range of 0.150 mm to 0.0001 mm was used for this research.

Figure A.4: SEDIGRAPH 5100 Particle Size Analyzer

## A.2. **Procedure**

### *A.2.1 Parent Particle Size Distribution (PPSD)*

Parent particle size distributions, three replicates, were conducted following ASTM Standard D422-63 (ASTM International 2007). Samples of approximately 1.2 kg were obtained by taking composite samples of the weathered mine spoil. The samples were hand crushed to break up large agglomerates using a rubber mortar and pestle. Each sample was then introduced into a rack of sieves consisting of the #4 (4.75 mm), #10 (2.00 mm), #20 (0.850 mm), #40 (0.425 mm), #60 (0.250 mm), and #100 (0.150 mm), with a pan on the bottom to collect the finer particles that fall through. The sieves were mechanically shaken for approximately 10 minutes, Figure A.5. The material retained on each sieve was weighed to determine the particle size distribution larger than 0.150 mm. Fine particles that were smaller than 0.150 mm were chemically dispersed using a 0.1% solution of sodium hexametaphosphate (ASTM International 2010) and then analyzed using the SEDIGRAPH 5100.


Figure A.5: Mechanical Shaker Used in Parent Particle Size Distribution Analysis

*A.2.2 Eroded Particle Size Distribution (EPSD)*

Samples (weathered mine spoil) were lightly packed by hand in rectangular containers with an approximate surface area of 540 cm² (30 cm by 18 cm), Figure A.6, for a total of three replicates. The sample in each container was wetted via water hose to achieve a near saturated state, allowing the majority of the rainfall to become runoff and reduce simulation time. Each container was placed above a clean 19 liter (5 gallon) bucket to collect runoff. The samples and buckets were placed at a 9% slope, to conform to standard practice, with rain gauges in front of and behind for rainfall calculation, Figure A.6.

Figure A.6: Sample Placement for Rainfall Simulator

The rainfall simulator rained on the samples for approximately one hour, at which time it was determined that a sufficient quantity of runoff had been collected to conduct wet sieving.  Wet sieving was conducted utilizing a pneumatic wet sieving device developed at the University of Kentucky, Figure A.7.  The wet sieving was conducted to obtain that portion of the particles that were retained in the #20 (0.850 mm), #40 (0.425 mm), #60 (0.250 mm), and #100 (0.150 mm) sieves.  Wet sieving was performed for approximately 20 minutes, after which the sieves were separated.  The portion contained in each of the sieves was dried and weighed, with the remainder of the finer particles oven dried in the 19 L bucket.  Once the fine particles were dried, the SEDIGRAPH 5100 was used to determine the distribution smaller than 0.150 mm.

Figure A.7: Pneumatic Wet Sieving Device Used in Eroded Particle Size Analysis

## A.3. **Results**

### *A.3.1 Parent Particle Size Distribution (PPSD)*

The sieve results for the weathered spoil demonstrate a high percentage of large size particles. The larger size fragments create macropores that allow for infiltration, water storage and interflow, as well as provide a good tree growth medium associated with the sand size and finer fraction of particles. The higher percentage of larger size fragments also reduce the amount of particles that are available to be transported through surface runoff, limiting ecological impacts downstream (Wood and Armitage 1997).

Table A.1: Mechanical Sieve Results for Weathered Mine Spoil

| Sieve No | Sieve Opening (mm) | Average Soil Retained (g) | Average Percent Finer |
|---|---|---|---|
| 4 | 4.750 | 345.5 | 69.71 |
| 10 | 2.000 | 284.6 | 44.76 |
| 20 | 0.850 | 214.5 | 25.96 |
| 40 | 0.425 | 100.4 | 17.17 |
| 60 | 0.250 | 49.7 | 12.81 |
| 100 | 0.150 | 28.5 | 10.31 |

The fine particles that passed through the #100 sieve were processed through the SEDIGRAPH 5100, Figure A.8.

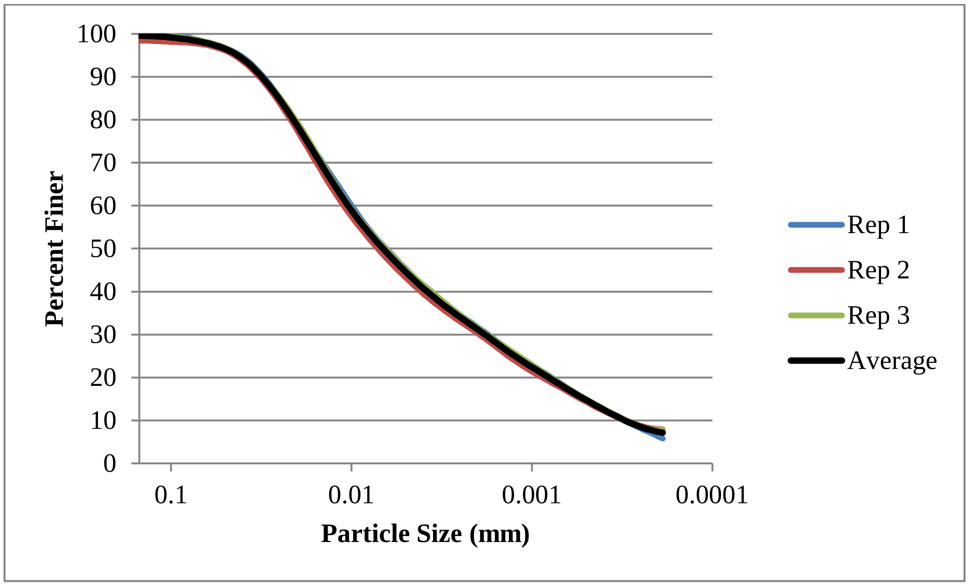


Figure A.8: Fine Fraction of Parent Particle Size Distribution of Weathered Mine Spoil

Combining the sieving data, Table A.1Table A.1: Mechanical Sieve Results for Weathered , with the fine fraction PPSD, Figure A.8, a full spectrum primary particle size distribution (PPSD) was generated, Figure A.9.

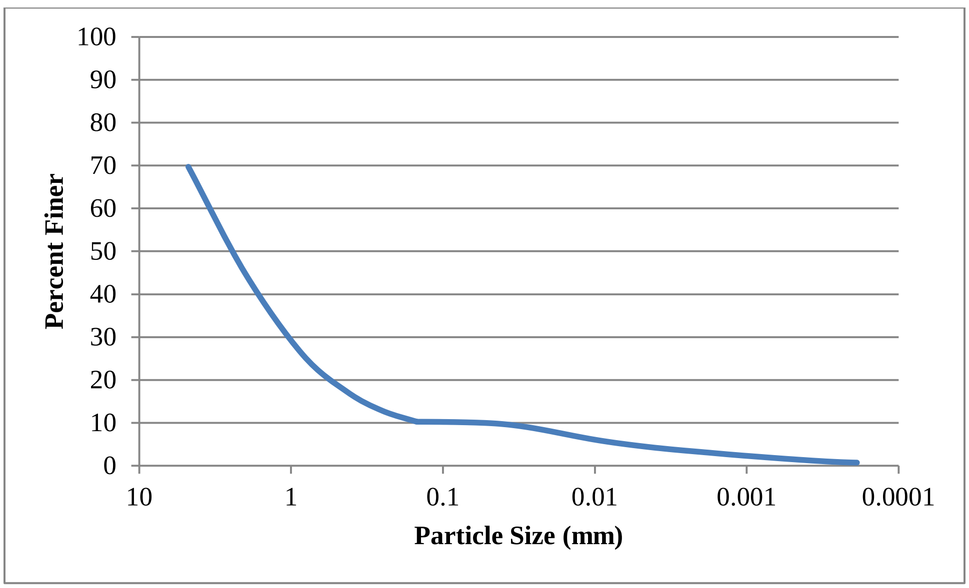


Figure A.9: Average Parent Particle Size Distribution of Weathered Mine Spoil

### *A.3.2 Eroded Particle Size Distribution (EPSD)*

Rainfall simulation was performed as outlined in the previous section. The EPSD is preferred over the PPSD for sediment runoff and flocculant analyses due to the PPSD not being representative of what particles may actually be transported during surface runoff. The wet sieve results clearly show that the majority of eroded particles consisted of fines smaller than the #100 sieve, 0.150 mm, Table A.2. Only approximately 7% of the runoff particles were larger than 0.150 mm.

Table A.2: Wet Sieve Results for Weathered Mine Spoil from Rainfall Simulator

| **Sieve No** | **Sieve Opening (mm)** | **Average Soil Retained (g)** | **Average Percent Finer** |
|---|---|---|---|
| 20 | 0.850 | 0.12 | 99.37 |
| 40 | 0.425 | 0.38 | 97.41 |
| 60 | 0.250 | 0.40 | 95.38 |
| 100 | 0.150 | 0.41 | 93.30 |

The fine particles that washed through the #100 sieve were then dried in an oven at 105°C and processed through the SEDIGRAPH 5100 to determine the EPSD smaller than 0.150 mm, Figure A.10.

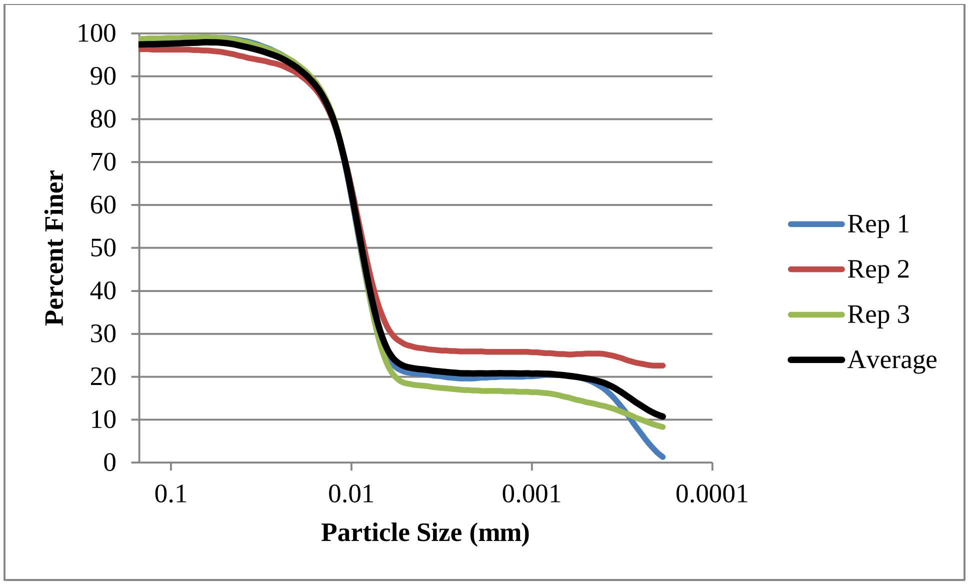


Figure A.10: Fine Fraction of Eroded Particle Size Distribution of Weathered Mine Spoil from Rainfall Simulator

Combining the wet sieving data, Table A.2, with the fine fraction EPSD, Figure A.10, a full spectrum EPSD was generated, Figure A.11.

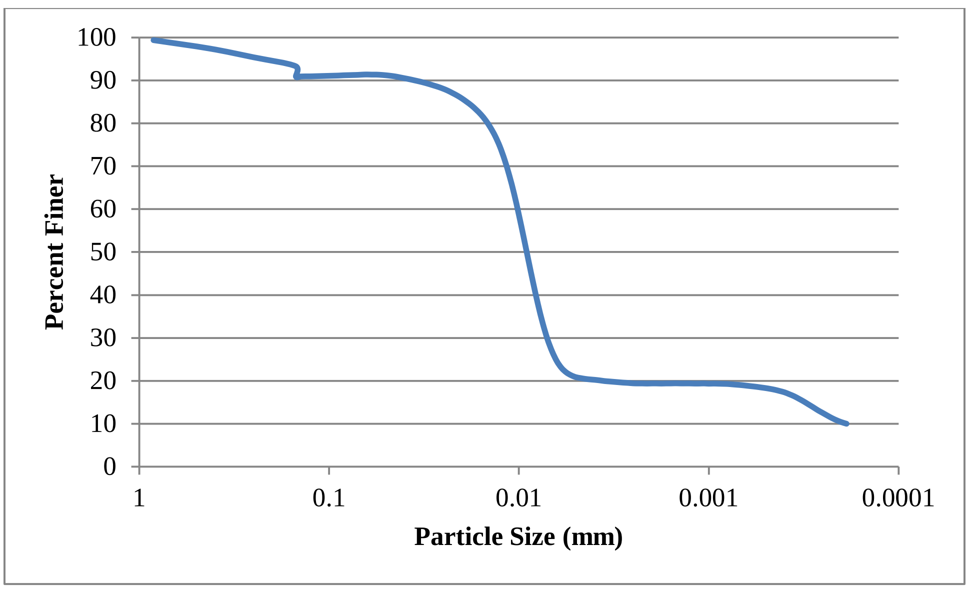


Figure A.11: Average Eroded Particle Size Distribution of Weathered Mine Spoil from Rainfall Simulator

There is a noticeable singularity that occurs at the 0.150 mm point. This is due to the wet sieve data producing a line with four points combining with a smooth curve that is generated from the many data points of the SEDIGRAPH 5100 and the error associated with both. The point could be smoothed out to form a better curve, but would not be an accurate representation of the data.

### *A.3.3 Mine Site Generated Eroded Particle Size Distribution*

Weathered mine spoil samples that were retrieved from the base of weep berms were also analyzed to compare rainfall simulated and actual eroded particle size distributions. The retrieved mine site samples were analyzed utilizing the same protocol for wet sieving, Table A.3, and the SEDIGRAPH 5100 was used to determine the particle size distribution of fine particles smaller than 0.150 mm, Figure A.12.

Table A.3: Wet Sieve Results for Deposited Weathered Mine Spoil Retrieved from Weep Berm

| **Sieve No** | **Sieve Opening (mm)** | **Average Soil Retained (g)** | **Average Percent Finer** |
|---|---|---|---|
| 20 | 0.850 | 1.14 | 98.17 |
| 40 | 0.425 | 2.51 | 94.15 |
| 60 | 0.250 | 2.92 | 89.47 |
| 100 | 0.150 | 3.45 | 83.94 |

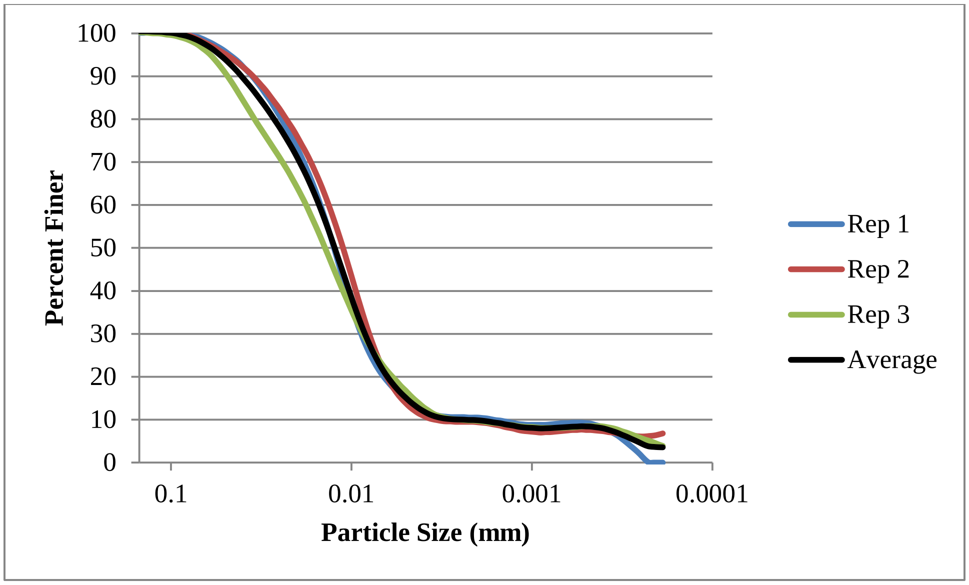


Figure A.12: Fine Fraction of Eroded Particle Size Distribution of Deposited Weathered Mine Spoil from Weep Berm

Combining the wet sieving results, Table A.3: Wet Sieve Results for Deposited Weathered Mine Spoil Retrieved from , with the fine fraction EPSD results, Figure A.12, a full spectrum EPSD was generated for the weep berm samples and compared to the rainfall simulator generated EPSD, Figure A.13.

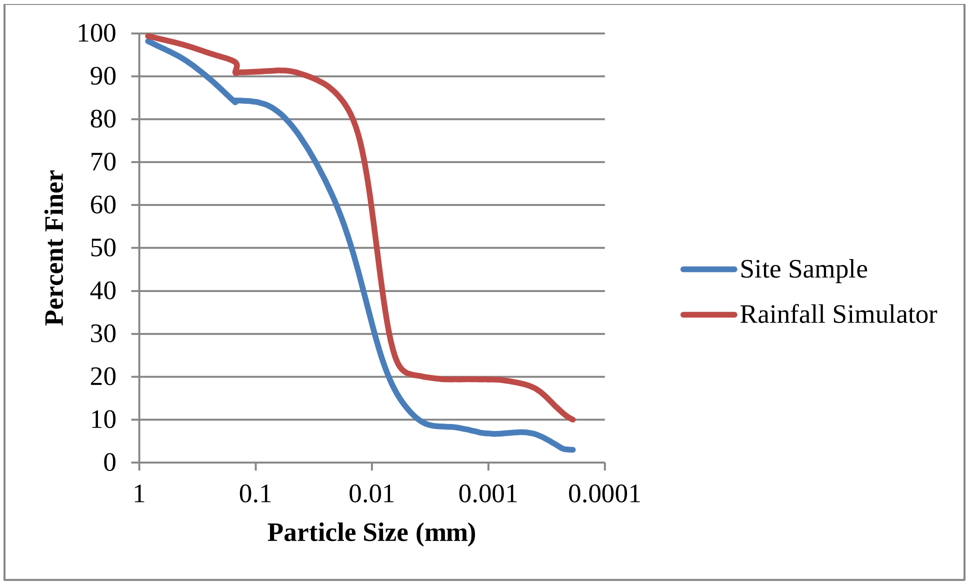


Figure A.13: Eroded Particle Size Distribution Comparison for Deposited Weep Berm Site Sample and Rainfall Simulator Sample

The comparison of the rainfall simulator generated EPSD to the mine site EPSD shows the curves following a similar shape but a gap exists between the two, with the rainfall simulator generated EPSD containing a larger percentage of finer particles than the mine site depositional sample. This is most likely due to the way core soil samples were collected on site and the time period in which they were collected. Earlier rainfall events would erode, transport, and deposit the finer size fraction of particles; referred to as the first flush. Multiple rainstorms of varying intensities, most being smaller than the simulated event, had occurred prior to the soil samples being collected on the mine site. Mine site sediment samples were collected approximately 2 cm above the base of the sediment control (to preclude mixing of base and deposited soils), which did not account for the first flush effect. It can be assumed that the finest (first flush) particles would be deposited in the first storms events. As subsequent storms occurred, the larger particles would be left to dislodge and deposit on top of the collection of fines and the mine site collected soil samples reflects this phenomenon.

# Appendix B. Particle Size Distributions for Initial Jar Testing

## B.1. **Optimal Flocculant Determination**

Table B.1: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 10 at 500 mg/L Initial Concentration after 10 Minutes Settling

| **Median Size (microns)** | 0.5 mL | | | 1.0 mL | | | 1.5 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 |
| 2.11 | 0.04 | 0.01 | 0.02 | 0.03 | 0.02 | 0.05 | 0.04 | 0.01 | 0.03 |
| 2.49 | 0.09 | 0.04 | 0.04 | 0.06 | 0.04 | 0.11 | 0.09 | 0.03 | 0.08 |
| 2.93 | 0.25 | 0.10 | 0.11 | 0.17 | 0.11 | 0.29 | 0.25 | 0.09 | 0.22 |
| 3.46 | 2.20 | 1.14 | 1.35 | 1.77 | 1.24 | 2.49 | 2.28 | 1.16 | 2.19 |
| 4.09 | 6.73 | 3.93 | 4.72 | 5.75 | 4.33 | 7.20 | 6.87 | 4.22 | 6.74 |
| 4.82 | 12.10 | 7.48 | 8.96 | 10.55 | 8.32 | 12.41 | 12.04 | 8.16 | 11.90 |
| 5.69 | 18.00 | 11.65 | 13.83 | 15.88 | 13.00 | 17.84 | 17.46 | 12.74 | 17.34 |
| 6.71 | 27.37 | 18.87 | 22.10 | 24.53 | 21.09 | 26.15 | 25.81 | 20.62 | 25.81 |
| 7.92 | 37.52 | 27.30 | 31.20 | 33.88 | 30.33 | 34.90 | 34.53 | 29.34 | 34.60 |
| 9.35 | 46.17 | 34.89 | 38.87 | 41.74 | 38.38 | 42.37 | 41.89 | 36.62 | 41.82 |
| 11.03 | 53.57 | 41.69 | 45.44 | 48.37 | 45.37 | 48.90 | 48.24 | 42.73 | 47.84 |
| 13.02 | 60.75 | 48.87 | 52.15 | 54.87 | 52.51 | 55.45 | 54.62 | 48.80 | 53.63 |
| 15.36 | 66.57 | 55.10 | 57.96 | 60.19 | 58.58 | 60.96 | 59.99 | 53.85 | 58.26 |
| 18.13 | 71.30 | 60.51 | 63.05 | 64.58 | 63.78 | 65.62 | 64.54 | 58.11 | 62.04 |
| 21.39 | 76.15 | 66.40 | 68.79 | 69.22 | 69.44 | 70.65 | 69.44 | 62.75 | 66.08 |
| 25.25 | 81.43 | 73.03 | 75.82 | 74.50 | 75.99 | 76.49 | 75.07 | 68.29 | 70.93 |
| 29.79 | 85.83 | 78.44 | 81.82 | 79.05 | 81.51 | 81.64 | 79.94 | 73.07 | 75.48 |
| 35.16 | 90.04 | 83.49 | 87.84 | 83.70 | 86.92 | 86.84 | 84.81 | 78.09 | 80.65 |
| 41.49 | 93.63 | 87.57 | 92.81 | 87.97 | 91.47 | 91.42 | 89.14 | 82.71 | 85.95 |
| 48.96 | 96.39 | 90.63 | 96.44 | 91.67 | 94.97 | 95.07 | 92.74 | 86.74 | 90.93 |
| 57.77 | 97.84 | 92.31 | 98.15 | 93.95 | 96.81 | 97.03 | 94.87 | 89.27 | 94.11 |
| 68.18 | 98.82 | 93.61 | 99.16 | 95.86 | 98.09 | 98.36 | 96.58 | 91.52 | 96.63 |
| 80.45 | 99.29 | 94.44 | 99.56 | 97.04 | 98.74 | 99.00 | 97.59 | 93.10 | 97.99 |
| 94.94 | 99.62 | 95.34 | 99.79 | 98.09 | 99.23 | 99.44 | 98.47 | 94.77 | 98.95 |
| 112.04 | 99.80 | 96.26 | 99.90 | 98.84 | 99.55 | 99.69 | 99.09 | 96.30 | 99.47 |
| 132.21 | 99.91 | 97.36 | 99.95 | 99.39 | 99.76 | 99.84 | 99.53 | 97.77 | 99.76 |
| 156.02 | 99.97 | 98.58 | 99.98 | 99.75 | 99.89 | 99.93 | 99.81 | 98.99 | 99.91 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table B.1: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 10 at 500 mg/L Initial Concentration after 10 Minutes of Settling (Continued)

| Median Size (microns) | 2.0 mL | | | 2.5 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 |
| 2.11 | 0.01 | 0.01 | 0.03 | 0.07 | 0.01 | 0.02 | 0.05 | 0.04 | 0.03 |
| 2.49 | 0.03 | 0.03 | 0.07 | 0.17 | 0.02 | 0.05 | 0.11 | 0.10 | 0.07 |
| 2.93 | 0.10 | 0.10 | 0.18 | 0.43 | 0.08 | 0.13 | 0.29 | 0.28 | 0.18 |
| 3.46 | 1.28 | 1.44 | 1.93 | 3.58 | 1.20 | 1.48 | 2.68 | 2.96 | 1.78 |
| 4.09 | 4.64 | 5.37 | 6.02 | 9.97 | 4.52 | 4.85 | 7.94 | 8.96 | 5.44 |
| 4.82 | 8.97 | 10.46 | 10.67 | 16.46 | 8.84 | 8.86 | 13.63 | 15.41 | 9.55 |
| 5.69 | 14.02 | 16.32 | 15.59 | 22.46 | 13.85 | 13.23 | 19.15 | 21.69 | 13.83 |
| 6.71 | 22.78 | 26.24 | 23.27 | 30.30 | 22.60 | 20.20 | 26.77 | 30.49 | 20.35 |
| 7.92 | 32.61 | 36.47 | 31.21 | 36.88 | 32.16 | 27.41 | 33.38 | 38.16 | 26.88 |
| 9.35 | 41.00 | 44.21 | 37.63 | 41.38 | 40.09 | 33.12 | 37.94 | 43.39 | 32.01 |
| 11.03 | 48.22 | 50.05 | 42.86 | 44.63 | 46.85 | 37.65 | 41.21 | 47.06 | 36.05 |
| 13.02 | 55.58 | 55.19 | 47.72 | 47.38 | 53.90 | 41.78 | 43.92 | 50.01 | 39.67 |
| 15.36 | 61.81 | 59.07 | 51.49 | 49.49 | 60.17 | 44.96 | 45.93 | 52.09 | 42.39 |
| 18.13 | 67.08 | 62.09 | 54.47 | 51.27 | 65.73 | 47.50 | 47.54 | 53.68 | 44.50 |
| 21.39 | 72.74 | 65.29 | 57.61 | 53.34 | 72.06 | 50.27 | 49.34 | 55.37 | 46.72 |
| 25.25 | 79.16 | 69.25 | 61.47 | 56.40 | 79.67 | 53.89 | 51.86 | 57.62 | 49.53 |
| 29.79 | 84.30 | 72.93 | 65.29 | 60.07 | 85.59 | 57.80 | 54.74 | 60.09 | 52.52 |
| 35.16 | 89.19 | 77.28 | 69.98 | 65.23 | 90.94 | 63.16 | 58.80 | 63.38 | 56.60 |
| 41.49 | 93.18 | 81.87 | 75.35 | 71.54 | 94.83 | 69.93 | 64.01 | 67.32 | 61.94 |
| 48.96 | 96.16 | 86.42 | 81.11 | 78.50 | 97.37 | 77.85 | 70.37 | 71.66 | 68.63 |
| 57.77 | 97.67 | 89.54 | 85.46 | 83.76 | 98.46 | 84.19 | 75.93 | 74.98 | 74.68 |
| 68.18 | 98.69 | 92.40 | 89.69 | 88.69 | 99.11 | 90.21 | 82.14 | 78.44 | 81.48 |
| 80.45 | 99.19 | 94.35 | 92.64 | 92.03 | 99.39 | 94.07 | 87.17 | 81.25 | 86.89 |
| 94.94 | 99.54 | 96.15 | 95.31 | 94.99 | 99.60 | 96.93 | 92.08 | 84.64 | 91.93 |
| 112.04 | 99.75 | 97.52 | 97.22 | 97.07 | 99.74 | 98.51 | 95.62 | 88.18 | 95.44 |
| 132.21 | 99.88 | 98.60 | 98.58 | 98.53 | 99.85 | 99.35 | 97.98 | 92.16 | 97.78 |
| 156.02 | 99.96 | 99.39 | 99.43 | 99.44 | 99.93 | 99.76 | 99.29 | 96.20 | 99.15 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.01 | 100.00 |

Table B.2: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 336 at 500 mg/L Initial Concentration after 10 Minutes Settling

| **Median Size (microns)** | **0.5 mL** | | | **1.0 mL** | | | **1.5 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.01 | 0.03 | 0.01 | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 |
| 2.11 | 0.06 | 0.11 | 0.06 | 0.07 | 0.06 | 0.08 | 0.03 | 0.07 | 0.08 |
| 2.49 | 0.13 | 0.24 | 0.14 | 0.17 | 0.13 | 0.18 | 0.08 | 0.17 | 0.18 |
| 2.93 | 0.34 | 0.57 | 0.35 | 0.42 | 0.33 | 0.43 | 0.21 | 0.42 | 0.42 |
| 3.46 | 2.90 | 3.68 | 2.86 | 3.17 | 2.69 | 3.08 | 2.18 | 3.05 | 2.92 |
| 4.09 | 8.32 | 9.41 | 8.06 | 8.60 | 7.58 | 8.19 | 6.72 | 8.00 | 7.68 |
| 4.82 | 14.20 | 15.31 | 13.68 | 14.28 | 12.86 | 13.53 | 11.91 | 13.00 | 12.64 |
| 5.69 | 20.23 | 21.18 | 19.45 | 19.96 | 18.26 | 18.86 | 17.38 | 17.87 | 17.57 |
| 6.71 | 29.35 | 29.66 | 28.18 | 28.29 | 26.41 | 26.65 | 25.99 | 24.85 | 24.76 |
| 7.92 | 38.86 | 38.54 | 37.39 | 36.91 | 34.92 | 34.81 | 35.01 | 32.01 | 32.25 |
| 9.35 | 47.04 | 46.45 | 45.44 | 44.42 | 42.29 | 42.11 | 42.66 | 38.30 | 38.95 |
| 11.03 | 54.38 | 53.78 | 52.72 | 51.22 | 49.00 | 48.99 | 49.43 | 44.14 | 45.25 |
| 13.02 | 61.98 | 61.44 | 60.29 | 58.29 | 56.10 | 56.51 | 56.51 | 50.44 | 52.14 |
| 15.36 | 68.60 | 68.13 | 66.86 | 64.44 | 62.50 | 63.49 | 62.81 | 56.16 | 58.57 |
| 18.13 | 74.27 | 73.86 | 72.46 | 69.73 | 68.18 | 69.89 | 68.37 | 61.36 | 64.55 |
| 21.39 | 80.29 | 79.80 | 78.30 | 75.35 | 74.45 | 77.00 | 74.52 | 67.20 | 71.40 |
| 25.25 | 86.73 | 85.96 | 84.47 | 81.49 | 81.55 | 84.82 | 81.61 | 73.96 | 79.38 |
| 29.79 | 91.54 | 90.66 | 89.15 | 86.43 | 87.15 | 90.77 | 87.17 | 79.66 | 86.02 |
| 35.16 | 95.36 | 94.44 | 93.02 | 90.79 | 91.96 | 95.32 | 92.07 | 84.79 | 91.75 |
| 41.49 | 97.84 | 97.04 | 95.80 | 94.17 | 95.42 | 98.05 | 95.62 | 88.77 | 95.79 |
| 48.96 | 99.22 | 98.65 | 97.62 | 96.58 | 97.66 | 99.41 | 97.92 | 91.64 | 98.24 |
| 57.77 | 99.69 | 99.31 | 98.45 | 97.78 | 98.64 | 99.80 | 98.90 | 93.12 | 99.20 |
| 68.18 | 99.89 | 99.67 | 98.99 | 98.60 | 99.22 | 99.95 | 99.45 | 94.24 | 99.67 |
| 80.45 | 99.95 | 99.80 | 99.25 | 99.02 | 99.48 | 99.98 | 99.67 | 94.93 | 99.83 |
| 94.94 | 99.98 | 99.89 | 99.47 | 99.36 | 99.66 | 99.99 | 99.82 | 95.70 | 99.91 |
| 112.04 | 99.99 | 99.94 | 99.64 | 99.60 | 99.79 | 100.00 | 99.90 | 96.52 | 99.96 |
| 132.21 | 100.00 | 99.97 | 99.78 | 99.78 | 99.88 | 100.00 | 99.95 | 97.52 | 99.98 |
| 156.02 | 100.00 | 99.98 | 99.89 | 99.90 | 99.94 | 100.00 | 99.98 | 98.66 | 99.99 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table B.2: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 336 at 500 mg/L Initial Concentration after 10 Minutes of Settling (Continued)

| Median Size (microns) | 2.0 mL | | | 2.5 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 |
| 2.11 | 0.06 | 0.08 | 0.06 | 0.04 | 0.06 | 0.03 | 0.03 | 0.02 | 0.04 |
| 2.49 | 0.14 | 0.18 | 0.14 | 0.09 | 0.14 | 0.07 | 0.08 | 0.06 | 0.08 |
| 2.93 | 0.35 | 0.44 | 0.35 | 0.24 | 0.35 | 0.19 | 0.22 | 0.16 | 0.22 |
| 3.46 | 2.71 | 3.09 | 2.60 | 2.25 | 2.71 | 1.99 | 2.09 | 1.60 | 1.93 |
| 4.09 | 7.47 | 8.05 | 7.07 | 6.57 | 7.23 | 6.21 | 6.22 | 4.83 | 5.51 |
| 4.82 | 12.51 | 13.10 | 11.82 | 11.24 | 11.75 | 10.97 | 10.73 | 8.39 | 9.36 |
| 5.69 | 17.58 | 18.06 | 16.60 | 15.99 | 16.09 | 15.98 | 15.25 | 12.04 | 13.27 |
| 6.71 | 25.10 | 25.21 | 23.66 | 23.20 | 22.23 | 23.84 | 21.97 | 17.63 | 19.16 |
| 7.92 | 32.96 | 32.62 | 31.02 | 30.70 | 28.35 | 32.03 | 28.56 | 23.36 | 25.27 |
| 9.35 | 39.88 | 39.21 | 37.54 | 37.19 | 33.60 | 38.97 | 33.93 | 28.12 | 30.48 |
| 11.03 | 46.28 | 45.37 | 43.62 | 43.09 | 38.41 | 45.14 | 38.59 | 32.22 | 35.08 |
| 13.02 | 53.17 | 52.07 | 50.31 | 49.45 | 43.70 | 51.73 | 43.52 | 36.34 | 39.81 |
| 15.36 | 59.45 | 58.21 | 56.64 | 55.25 | 48.72 | 57.75 | 48.15 | 39.84 | 43.87 |
| 18.13 | 65.15 | 63.87 | 62.65 | 60.57 | 53.68 | 63.25 | 52.64 | 42.88 | 47.42 |
| 21.39 | 71.58 | 70.32 | 69.76 | 66.71 | 59.91 | 69.64 | 58.31 | 46.34 | 51.44 |
| 25.25 | 79.02 | 77.90 | 78.37 | 74.16 | 68.36 | 77.49 | 66.28 | 50.87 | 56.52 |
| 29.79 | 85.21 | 84.39 | 85.66 | 80.55 | 76.66 | 84.00 | 73.96 | 55.49 | 61.50 |
| 35.16 | 90.72 | 90.22 | 91.99 | 86.56 | 85.06 | 90.01 | 82.13 | 61.27 | 67.31 |
| 41.49 | 94.82 | 94.59 | 96.30 | 91.31 | 91.81 | 94.50 | 88.98 | 67.88 | 73.47 |
| 48.96 | 97.52 | 97.45 | 98.71 | 94.69 | 96.34 | 97.44 | 94.01 | 75.01 | 79.62 |
| 57.77 | 98.69 | 98.68 | 99.53 | 96.37 | 98.28 | 98.68 | 96.44 | 80.51 | 84.06 |
| 68.18 | 99.36 | 99.36 | 99.86 | 97.52 | 99.28 | 99.36 | 97.93 | 85.86 | 88.21 |
| 80.45 | 99.63 | 99.63 | 99.94 | 98.13 | 99.63 | 99.63 | 98.62 | 89.69 | 91.13 |
| 94.94 | 99.80 | 99.79 | 99.98 | 98.66 | 99.82 | 99.79 | 99.11 | 93.22 | 93.92 |
| 112.04 | 99.89 | 99.89 | 99.99 | 99.09 | 99.91 | 99.88 | 99.43 | 95.84 | 96.11 |
| 132.21 | 99.94 | 99.94 | 100.00 | 99.46 | 99.96 | 99.94 | 99.67 | 97.79 | 97.86 |
| 156.02 | 99.98 | 99.97 | 100.00 | 99.75 | 99.98 | 99.97 | 99.85 | 99.09 | 99.09 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table B.3: Percent Finer Particle Size Distribution of Jar Test Screening of Magnafloc 5250 at 500 mg/L Initial Concentration after 10 Minutes Settling

| **Median Size (microns)** | **0.5 mL** | | | **1.0 mL** | | | **1.5 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.00 | 0.03 | 0.02 | 0.01 | 0.03 | 0.06 | 0.01 | 0.02 | 0.03 |
| 2.11 | 0.02 | 0.14 | 0.09 | 0.06 | 0.11 | 0.20 | 0.06 | 0.06 | 0.12 |
| 2.49 | 0.06 | 0.31 | 0.21 | 0.13 | 0.25 | 0.43 | 0.14 | 0.15 | 0.26 |
| 2.93 | 0.18 | 0.70 | 0.50 | 0.32 | 0.58 | 0.91 | 0.35 | 0.36 | 0.59 |
| 3.46 | 2.03 | 4.17 | 3.40 | 2.48 | 3.59 | 4.34 | 2.62 | 2.67 | 3.35 |
| 4.09 | 6.74 | 10.54 | 8.94 | 7.08 | 9.33 | 9.99 | 7.38 | 7.48 | 8.27 |
| 4.82 | 12.39 | 17.23 | 14.75 | 12.25 | 15.49 | 15.63 | 12.69 | 12.84 | 13.35 |
| 5.69 | 18.63 | 23.98 | 20.59 | 17.70 | 21.79 | 21.10 | 18.22 | 18.42 | 18.39 |
| 6.71 | 28.86 | 33.69 | 29.15 | 26.02 | 31.03 | 28.66 | 26.55 | 26.86 | 25.56 |
| 7.92 | 39.89 | 43.83 | 38.09 | 34.94 | 40.85 | 36.58 | 35.38 | 35.80 | 33.07 |
| 9.35 | 49.18 | 52.73 | 45.99 | 42.84 | 49.64 | 43.91 | 43.12 | 43.66 | 39.90 |
| 11.03 | 57.13 | 60.67 | 53.27 | 50.04 | 57.72 | 51.02 | 50.14 | 50.84 | 46.43 |
| 13.02 | 65.06 | 68.40 | 60.90 | 57.59 | 66.00 | 58.71 | 57.50 | 58.42 | 53.58 |
| 15.36 | 71.60 | 74.62 | 67.63 | 64.24 | 73.10 | 65.80 | 64.01 | 65.25 | 60.32 |
| 18.13 | 76.91 | 79.47 | 73.42 | 70.06 | 78.97 | 72.18 | 69.75 | 71.34 | 66.62 |
| 21.39 | 82.28 | 84.03 | 79.51 | 76.27 | 84.75 | 78.99 | 75.93 | 77.95 | 73.75 |
| 25.25 | 87.82 | 88.32 | 85.88 | 82.95 | 90.25 | 86.02 | 82.71 | 85.16 | 81.81 |
| 29.79 | 91.81 | 91.50 | 90.68 | 88.18 | 94.08 | 91.40 | 88.10 | 90.64 | 88.33 |
| 35.16 | 95.06 | 94.10 | 94.52 | 92.60 | 96.84 | 95.45 | 92.69 | 94.97 | 93.63 |
| 41.49 | 97.31 | 96.07 | 97.14 | 95.80 | 98.53 | 97.97 | 95.98 | 97.73 | 97.09 |
| 48.96 | 98.72 | 97.51 | 98.73 | 97.88 | 99.45 | 99.30 | 98.09 | 99.21 | 98.98 |
| 57.77 | 99.29 | 98.26 | 99.37 | 98.81 | 99.76 | 99.74 | 98.99 | 99.70 | 99.62 |
| 68.18 | 99.63 | 98.81 | 99.71 | 99.36 | 99.91 | 99.92 | 99.49 | 99.91 | 99.88 |
| 80.45 | 99.77 | 99.12 | 99.84 | 99.60 | 99.95 | 99.97 | 99.70 | 99.96 | 99.95 |
| 94.94 | 99.86 | 99.39 | 99.92 | 99.77 | 99.98 | 99.99 | 99.83 | 99.98 | 99.98 |
| 112.04 | 99.92 | 99.60 | 99.95 | 99.87 | 99.99 | 100.00 | 99.90 | 99.99 | 99.99 |
| 132.21 | 99.96 | 99.77 | 99.98 | 99.93 | 99.99 | 100.00 | 99.95 | 100.00 | 100.00 |
| 156.02 | 99.98 | 99.89 | 99.99 | 99.97 | 100.00 | 100.00 | 99.98 | 100.00 | 100.00 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table B.3: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 5250 at 500 mg/L Initial Concentration after 10 Minutes of Settling (Continued)

| Median Size (microns) | 2.0 mL | | | 2.5 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.01 | 0.01 | 0.03 | 0.00 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 |
| 2.11 | 0.03 | 0.03 | 0.13 | 0.02 | 0.05 | 0.09 | 0.02 | 0.03 | 0.04 |
| 2.49 | 0.08 | 0.08 | 0.27 | 0.05 | 0.11 | 0.19 | 0.06 | 0.07 | 0.09 |
| 2.93 | 0.21 | 0.22 | 0.61 | 0.14 | 0.28 | 0.45 | 0.15 | 0.19 | 0.23 |
| 3.46 | 2.15 | 2.08 | 3.46 | 1.56 | 2.31 | 2.79 | 1.61 | 1.84 | 2.00 |
| 4.09 | 6.67 | 6.36 | 8.43 | 5.28 | 6.59 | 7.12 | 5.14 | 5.66 | 5.83 |
| 4.82 | 11.79 | 11.23 | 13.48 | 9.90 | 11.30 | 11.61 | 9.30 | 10.06 | 10.06 |
| 5.69 | 17.22 | 16.43 | 18.40 | 15.06 | 16.18 | 16.04 | 13.78 | 14.70 | 14.39 |
| 6.71 | 25.73 | 24.58 | 25.31 | 23.60 | 23.62 | 22.32 | 20.96 | 21.87 | 20.94 |
| 7.92 | 34.82 | 33.34 | 32.47 | 32.75 | 31.55 | 28.67 | 28.62 | 29.20 | 27.65 |
| 9.35 | 42.67 | 40.96 | 38.95 | 40.46 | 38.58 | 34.13 | 35.21 | 35.19 | 33.37 |
| 11.03 | 49.65 | 47.79 | 45.11 | 47.18 | 45.02 | 39.02 | 41.10 | 40.22 | 38.50 |
| 13.02 | 56.95 | 54.98 | 51.83 | 54.22 | 51.93 | 43.99 | 47.44 | 45.16 | 44.00 |
| 15.36 | 63.25 | 61.32 | 58.10 | 60.60 | 58.13 | 48.33 | 53.28 | 49.30 | 49.13 |
| 18.13 | 68.68 | 66.92 | 63.95 | 66.36 | 63.69 | 52.22 | 58.75 | 52.90 | 54.02 |
| 21.39 | 74.51 | 73.09 | 70.62 | 72.93 | 69.85 | 56.70 | 65.25 | 57.02 | 60.02 |
| 25.25 | 80.94 | 80.10 | 78.38 | 80.80 | 76.82 | 62.47 | 73.41 | 62.46 | 68.10 |
| 29.79 | 86.03 | 85.80 | 85.08 | 86.99 | 82.56 | 68.48 | 80.51 | 68.02 | 75.83 |
| 35.16 | 90.54 | 90.86 | 90.99 | 92.45 | 87.66 | 75.56 | 87.30 | 74.80 | 83.99 |
| 41.49 | 94.00 | 94.66 | 95.31 | 96.25 | 91.59 | 82.93 | 92.58 | 82.05 | 90.92 |
| 48.96 | 96.44 | 97.20 | 98.00 | 98.53 | 94.38 | 89.75 | 96.16 | 88.98 | 95.89 |
| 57.77 | 97.63 | 98.35 | 99.10 | 99.38 | 95.80 | 94.00 | 97.79 | 93.36 | 98.12 |
| 68.18 | 98.46 | 99.06 | 99.63 | 99.77 | 96.83 | 96.99 | 98.76 | 96.58 | 99.27 |
| 80.45 | 98.89 | 99.38 | 99.82 | 99.90 | 97.43 | 98.42 | 99.18 | 98.17 | 99.67 |
| 94.94 | 99.26 | 99.62 | 99.91 | 99.95 | 98.02 | 99.27 | 99.48 | 99.14 | 99.86 |
| 112.04 | 99.52 | 99.77 | 99.95 | 99.98 | 98.56 | 99.66 | 99.68 | 99.60 | 99.94 |
| 132.21 | 99.73 | 99.87 | 99.98 | 99.99 | 99.08 | 99.85 | 99.82 | 99.83 | 99.97 |
| 156.02 | 99.88 | 99.94 | 99.99 | 100.00 | 99.55 | 99.94 | 99.92 | 99.94 | 99.99 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table B.4: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 at 500 mg/L Initial Concentration after 10 Minutes Settling

| **Median Size (microns)** | **0.5 mL** | | | **1.0 mL** | | | **1.5 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.06 | 0.05 | 0.07 | 0.02 | 0.02 | 0.01 | 0.00 | 0.01 | 0.00 |
| 2.11 | 0.19 | 0.17 | 0.24 | 0.07 | 0.09 | 0.06 | 0.02 | 0.03 | 0.02 |
| 2.49 | 0.38 | 0.33 | 0.46 | 0.14 | 0.19 | 0.13 | 0.05 | 0.06 | 0.05 |
| 2.93 | 0.74 | 0.66 | 0.86 | 0.31 | 0.41 | 0.27 | 0.12 | 0.16 | 0.12 |
| 3.46 | 2.74 | 2.56 | 2.84 | 1.55 | 1.89 | 1.27 | 0.95 | 1.12 | 0.76 |
| 4.09 | 5.95 | 5.62 | 5.83 | 3.98 | 4.64 | 3.21 | 2.93 | 3.29 | 2.21 |
| 4.82 | 9.35 | 8.85 | 8.91 | 6.87 | 7.82 | 5.51 | 5.51 | 6.04 | 4.06 |
| 5.69 | 12.88 | 12.19 | 11.99 | 10.13 | 11.38 | 8.08 | 8.63 | 9.29 | 6.25 |
| 6.71 | 17.94 | 16.94 | 16.16 | 15.25 | 16.84 | 12.03 | 13.96 | 14.73 | 9.83 |
| 7.92 | 23.69 | 22.26 | 20.66 | 21.30 | 23.30 | 16.62 | 20.44 | 21.28 | 14.06 |
| 9.35 | 29.36 | 27.41 | 25.00 | 27.17 | 29.65 | 21.06 | 26.58 | 27.51 | 18.03 |
| 11.03 | 35.02 | 32.47 | 29.25 | 32.79 | 35.84 | 25.38 | 32.27 | 33.35 | 21.68 |
| 13.02 | 41.09 | 37.87 | 33.81 | 38.68 | 42.52 | 30.07 | 38.25 | 39.53 | 25.49 |
| 15.36 | 46.61 | 42.75 | 38.03 | 43.86 | 48.62 | 34.48 | 43.49 | 45.03 | 28.86 |
| 18.13 | 51.51 | 47.10 | 41.90 | 48.36 | 54.18 | 38.62 | 48.06 | 49.90 | 31.84 |
| 21.39 | 56.65 | 51.74 | 46.08 | 53.08 | 60.28 | 43.32 | 52.97 | 55.22 | 35.09 |
| 25.25 | 62.10 | 56.86 | 50.81 | 58.24 | 67.24 | 49.00 | 58.55 | 61.38 | 38.91 |
| 29.79 | 66.98 | 61.67 | 55.40 | 62.90 | 73.74 | 54.65 | 63.55 | 67.00 | 42.59 |
| 35.16 | 71.79 | 66.74 | 60.42 | 67.75 | 80.37 | 61.16 | 68.90 | 72.97 | 46.93 |
| 41.49 | 76.34 | 71.88 | 65.84 | 72.52 | 86.43 | 68.21 | 74.16 | 78.70 | 51.91 |
| 48.96 | 80.54 | 77.06 | 71.51 | 77.05 | 91.45 | 75.45 | 79.13 | 83.89 | 57.45 |
| 57.77 | 83.70 | 81.24 | 76.28 | 80.47 | 94.51 | 81.22 | 82.76 | 87.47 | 62.42 |
| 68.18 | 86.74 | 85.48 | 81.18 | 83.79 | 96.72 | 86.61 | 86.24 | 90.61 | 68.00 |
| 80.45 | 89.22 | 88.92 | 85.22 | 86.50 | 97.93 | 90.51 | 88.96 | 92.82 | 73.15 |
| 94.94 | 91.88 | 92.35 | 89.61 | 89.45 | 98.78 | 94.04 | 91.80 | 94.89 | 79.33 |
| 112.04 | 94.33 | 95.15 | 93.41 | 92.31 | 99.31 | 96.60 | 94.36 | 96.59 | 85.52 |
| 132.21 | 96.56 | 97.35 | 96.51 | 95.12 | 99.64 | 98.34 | 96.64 | 98.02 | 91.52 |
| 156.02 | 98.40 | 98.89 | 98.69 | 97.66 | 99.85 | 99.40 | 98.48 | 99.12 | 96.50 |
| 184.11 | 100.01 | 100.00 | 100.00 | 100.01 | 100.01 | 100.00 | 100.00 | 99.99 | 99.99 |

Table B.4: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 at 500 mg/L Initial Concentration after 10 Minutes of Settling (Continued)

| Median Size (microns) | 2.0 mL | | | 2.5 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.79 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.11 | 0.01 | 0.04 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | 0.02 | 0.01 |
| 2.49 | 0.03 | 0.09 | 0.05 | 0.03 | 0.01 | 0.03 | 0.04 | 0.04 | 0.03 |
| 2.93 | 0.08 | 0.20 | 0.11 | 0.08 | 0.04 | 0.08 | 0.09 | 0.12 | 0.07 |
| 3.46 | 0.73 | 1.24 | 0.80 | 0.86 | 0.59 | 0.77 | 0.87 | 1.15 | 0.68 |
| 4.09 | 2.45 | 3.54 | 2.47 | 2.98 | 2.31 | 2.64 | 2.90 | 3.78 | 2.27 |
| 4.82 | 4.79 | 6.37 | 4.66 | 5.84 | 4.84 | 5.17 | 5.60 | 7.20 | 4.39 |
| 5.69 | 7.67 | 9.66 | 7.29 | 9.34 | 8.14 | 8.23 | 8.86 | 11.26 | 6.95 |
| 6.71 | 12.74 | 14.99 | 11.70 | 15.53 | 14.33 | 13.55 | 14.49 | 18.20 | 11.29 |
| 7.92 | 18.86 | 21.25 | 16.96 | 22.90 | 21.90 | 19.81 | 21.13 | 26.28 | 16.31 |
| 9.35 | 24.48 | 27.09 | 21.89 | 29.53 | 28.58 | 25.45 | 27.13 | 33.45 | 20.74 |
| 11.03 | 29.53 | 32.48 | 26.46 | 35.37 | 34.32 | 30.47 | 32.47 | 39.73 | 24.60 |
| 13.02 | 34.79 | 38.10 | 31.38 | 41.35 | 40.17 | 35.76 | 38.04 | 46.06 | 28.52 |
| 15.36 | 39.40 | 43.09 | 35.89 | 46.49 | 45.18 | 40.49 | 42.93 | 51.41 | 31.91 |
| 18.13 | 43.48 | 47.57 | 40.08 | 50.96 | 49.60 | 44.81 | 47.31 | 56.02 | 34.88 |
| 21.39 | 48.04 | 52.60 | 44.90 | 55.92 | 54.70 | 49.81 | 52.28 | 61.09 | 38.21 |
| 25.25 | 53.62 | 58.70 | 50.90 | 61.98 | 61.31 | 56.17 | 58.47 | 67.16 | 42.33 |
| 29.79 | 58.89 | 64.65 | 56.81 | 67.64 | 67.75 | 62.33 | 64.35 | 72.81 | 46.36 |
| 35.16 | 65.03 | 71.29 | 63.76 | 74.09 | 75.48 | 69.57 | 70.98 | 79.03 | 51.24 |
| 41.49 | 71.53 | 77.89 | 71.31 | 80.64 | 83.33 | 77.13 | 77.58 | 85.03 | 56.76 |
| 48.96 | 78.12 | 83.94 | 78.93 | 86.74 | 90.37 | 84.34 | 83.67 | 90.32 | 62.76 |
| 57.77 | 83.19 | 88.07 | 84.70 | 90.83 | 94.60 | 89.27 | 87.80 | 93.64 | 67.81 |
| 68.18 | 88.06 | 91.54 | 89.87 | 94.21 | 97.47 | 93.32 | 91.33 | 96.18 | 73.29 |
| 80.45 | 91.68 | 93.83 | 93.32 | 96.27 | 98.78 | 95.75 | 93.68 | 97.62 | 78.08 |
| 94.94 | 94.88 | 95.80 | 96.16 | 97.87 | 99.48 | 97.64 | 95.77 | 98.66 | 83.60 |
| 112.04 | 97.13 | 97.30 | 98.00 | 98.87 | 99.78 | 98.79 | 97.36 | 99.28 | 88.85 |
| 132.21 | 98.60 | 98.48 | 99.11 | 99.47 | 99.91 | 99.46 | 98.56 | 99.66 | 93.69 |
| 156.02 | 99.46 | 99.34 | 99.70 | 99.80 | 99.97 | 99.82 | 99.39 | 99.87 | 97.45 |
| 184.11 | 100.00 | 100.02 | 100.00 | 100.01 | 100.00 | 100.00 | 100.00 | 100.01 | 100.00 |

B.2. **Expanding Jar Test Screening with Magnafloc 351**

Table B.5: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 at 2,500 mg/L Initial Concentration after 10 Minutes Settling

| **Median Size (microns)** | **1.0 mL** | | | **2.0 mL** | | | **3.0 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.05 | 0.06 | 0.09 | 0.08 | 0.07 | 0.12 | 0.01 | 0.01 | 0.03 |
| 1.28 | 0.12 | 0.15 | 0.23 | 0.21 | 0.18 | 0.30 | 0.04 | 0.04 | 0.08 |
| 1.51 | 0.26 | 0.33 | 0.50 | 0.44 | 0.36 | 0.59 | 0.11 | 0.11 | 0.17 |
| 1.79 | 0.66 | 0.87 | 1.32 | 1.02 | 0.78 | 1.27 | 0.31 | 0.31 | 0.42 |
| 2.11 | 1.37 | 1.89 | 2.80 | 2.02 | 1.45 | 2.37 | 0.69 | 0.71 | 0.87 |
| 2.49 | 2.16 | 3.04 | 4.47 | 3.12 | 2.16 | 3.56 | 1.13 | 1.17 | 1.37 |
| 2.93 | 3.20 | 4.61 | 6.71 | 4.58 | 3.05 | 5.04 | 1.76 | 1.86 | 2.06 |
| 3.46 | 5.42 | 8.30 | 11.80 | 7.70 | 4.74 | 7.86 | 3.40 | 3.81 | 3.74 |
| 4.09 | 7.75 | 12.25 | 17.28 | 11.21 | 6.61 | 10.94 | 5.48 | 6.33 | 5.79 |
| 4.82 | 9.76 | 15.63 | 22.02 | 14.56 | 8.43 | 13.89 | 7.63 | 8.92 | 7.91 |
| 5.69 | 11.46 | 18.46 | 26.01 | 17.72 | 10.18 | 16.68 | 9.84 | 11.53 | 10.09 |
| 6.71 | 13.18 | 21.29 | 29.96 | 21.34 | 12.16 | 19.81 | 12.67 | 14.81 | 12.85 |
| 7.92 | 14.68 | 23.64 | 33.18 | 25.03 | 14.16 | 22.94 | 15.85 | 18.35 | 15.95 |
| 9.35 | 15.95 | 25.53 | 35.67 | 28.56 | 16.10 | 25.93 | 19.09 | 21.80 | 19.14 |
| 11.03 | 17.07 | 27.13 | 37.67 | 32.00 | 17.98 | 28.76 | 22.37 | 25.17 | 22.34 |
| 13.02 | 18.05 | 28.50 | 39.25 | 35.28 | 19.80 | 31.40 | 25.72 | 28.47 | 25.52 |
| 15.36 | 18.87 | 29.60 | 40.43 | 38.13 | 21.41 | 33.61 | 28.73 | 31.35 | 28.24 |
| 18.13 | 19.56 | 30.55 | 41.35 | 40.55 | 22.88 | 35.44 | 31.37 | 33.83 | 30.48 |
| 21.39 | 20.25 | 31.52 | 42.21 | 42.85 | 24.40 | 37.17 | 34.00 | 36.31 | 32.53 |
| 25.25 | 21.06 | 32.70 | 43.14 | 45.20 | 26.13 | 38.92 | 36.77 | 38.98 | 34.44 |
| 29.79 | 22.08 | 34.20 | 44.24 | 47.62 | 28.22 | 40.83 | 39.61 | 41.84 | 36.28 |
| 35.16 | 23.51 | 36.34 | 45.69 | 50.36 | 30.99 | 43.18 | 42.82 | 45.26 | 38.30 |
| 41.49 | 25.73 | 39.44 | 47.73 | 53.65 | 34.80 | 46.38 | 46.60 | 49.51 | 40.79 |
| 48.96 | 29.22 | 43.98 | 50.63 | 57.54 | 39.97 | 50.85 | 50.95 | 54.78 | 44.11 |
| 57.77 | 34.16 | 49.65 | 54.20 | 61.64 | 46.34 | 56.47 | 55.32 | 60.46 | 48.32 |
| 68.18 | 41.76 | 57.34 | 59.17 | 66.63 | 54.44 | 63.92 | 60.42 | 67.29 | 54.60 |
| 80.45 | 51.63 | 65.85 | 65.09 | 72.12 | 63.21 | 72.06 | 65.80 | 74.10 | 62.65 |
| 94.94 | 63.96 | 75.47 | 72.66 | 78.91 | 72.69 | 80.50 | 72.54 | 81.44 | 72.79 |
| 112.04 | 75.68 | 84.05 | 80.53 | 85.69 | 81.32 | 87.51 | 79.76 | 87.93 | 82.57 |
| 132.21 | 85.87 | 91.15 | 88.28 | 91.62 | 88.87 | 92.96 | 87.02 | 93.25 | 90.69 |
| 156.02 | 93.94 | 96.43 | 94.95 | 96.34 | 95.16 | 97.00 | 93.90 | 97.22 | 96.38 |
| 184.11 | 100.01 | 100.02 | 99.99 | 100.02 | 99.99 | 100.00 | 100.00 | 100.03 | 100.02 |

Table B.5: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 at 2,500 mg/L Initial Concentration after 10 Minutes of Settling (Continued)

| Median Size (microns) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.02 | 0.09 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.01 |
| 1.51 | 0.03 | 0.06 | 0.19 | 0.01 | 0.02 | 0.08 | 0.00 | 0.00 | 0.05 |
| 1.79 | 0.13 | 0.22 | 0.46 | 0.07 | 0.09 | 0.29 | 0.03 | 0.05 | 0.16 |
| 2.11 | 0.35 | 0.58 | 1.00 | 0.20 | 0.29 | 0.77 | 0.11 | 0.16 | 0.41 |
| 2.49 | 0.63 | 0.99 | 1.60 | 0.38 | 0.54 | 1.35 | 0.22 | 0.32 | 0.72 |
| 2.93 | 1.09 | 1.65 | 2.46 | 0.69 | 0.98 | 2.26 | 0.42 | 0.62 | 1.22 |
| 3.46 | 2.77 | 3.73 | 4.65 | 2.11 | 2.84 | 5.38 | 1.44 | 2.13 | 2.89 |
| 4.09 | 5.15 | 6.55 | 7.43 | 4.32 | 5.70 | 9.68 | 3.13 | 4.63 | 5.27 |
| 4.82 | 7.73 | 9.56 | 10.39 | 6.75 | 8.87 | 14.23 | 5.06 | 7.49 | 7.84 |
| 5.69 | 10.47 | 12.69 | 13.51 | 9.36 | 12.30 | 18.96 | 7.20 | 10.66 | 10.59 |
| 6.71 | 14.21 | 16.87 | 17.60 | 13.04 | 17.17 | 25.36 | 10.33 | 15.33 | 14.34 |
| 7.92 | 18.49 | 21.58 | 22.37 | 17.23 | 22.82 | 32.61 | 13.98 | 20.82 | 18.69 |
| 9.35 | 22.75 | 26.31 | 27.38 | 21.32 | 28.45 | 39.85 | 17.59 | 26.25 | 23.10 |
| 11.03 | 26.92 | 31.02 | 32.47 | 25.23 | 33.94 | 47.00 | 21.08 | 31.49 | 27.43 |
| 13.02 | 31.08 | 35.76 | 37.62 | 29.07 | 39.46 | 54.06 | 24.61 | 36.80 | 31.70 |
| 15.36 | 34.64 | 39.94 | 42.08 | 32.26 | 44.18 | 60.04 | 27.65 | 41.38 | 35.29 |
| 18.13 | 37.61 | 43.57 | 45.81 | 34.81 | 48.13 | 64.82 | 30.20 | 45.27 | 38.18 |
| 21.39 | 40.50 | 47.23 | 49.30 | 37.21 | 52.01 | 69.12 | 32.73 | 49.21 | 40.87 |
| 25.25 | 43.50 | 51.11 | 52.59 | 39.56 | 55.99 | 72.86 | 35.40 | 53.39 | 43.38 |
| 29.79 | 46.45 | 55.06 | 55.70 | 41.65 | 59.78 | 75.78 | 37.93 | 57.40 | 45.70 |
| 35.16 | 49.82 | 59.50 | 58.99 | 43.85 | 63.90 | 78.28 | 40.73 | 61.74 | 48.19 |
| 41.49 | 53.82 | 64.56 | 62.71 | 46.25 | 68.47 | 80.46 | 43.93 | 66.44 | 51.13 |
| 48.96 | 58.44 | 70.26 | 66.99 | 48.92 | 73.58 | 82.43 | 47.61 | 71.48 | 54.85 |
| 57.77 | 62.90 | 75.73 | 71.38 | 51.47 | 78.39 | 83.97 | 51.23 | 75.97 | 59.12 |
| 68.18 | 68.00 | 81.65 | 76.49 | 54.70 | 83.77 | 85.61 | 55.78 | 80.87 | 65.09 |
| 80.45 | 72.99 | 86.76 | 81.50 | 58.37 | 88.47 | 87.21 | 60.78 | 85.20 | 72.07 |
| 94.94 | 79.03 | 91.61 | 86.73 | 64.00 | 93.00 | 89.28 | 67.73 | 89.76 | 80.32 |
| 112.04 | 85.09 | 95.22 | 91.24 | 71.36 | 96.26 | 91.69 | 75.77 | 93.62 | 87.71 |
| 132.21 | 90.81 | 97.65 | 94.94 | 80.43 | 98.32 | 94.41 | 84.51 | 96.62 | 93.54 |
| 156.02 | 95.86 | 99.10 | 97.78 | 90.46 | 99.43 | 97.22 | 92.91 | 98.66 | 97.45 |
| 184.11 | 99.99 | 99.97 | 100.00 | 100.00 | 100.02 | 100.00 | 100.01 | 99.98 | 99.99 |

Table B.6: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 at 5,000 mg/L Initial Concentration after 10 Minutes Settling

| Median Size (microns) | 2.0 mL | | | 3.0 mL | | | 4.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.10 | 0.58 | 0.75 | 0.46 | 0.46 | 0.32 | 0.19 | 1.10 | 0.08 |
| 1.28 | 0.25 | 1.23 | 1.67 | 0.97 | 0.97 | 0.69 | 0.39 | 2.34 | 0.21 |
| 1.51 | 0.49 | 1.97 | 2.89 | 1.55 | 1.56 | 1.17 | 0.64 | 3.79 | 0.39 |
| 1.79 | 1.05 | 2.95 | 4.85 | 2.31 | 2.32 | 1.92 | 0.98 | 5.73 | 0.73 |
| 2.11 | 1.94 | 4.09 | 7.44 | 3.18 | 3.22 | 2.86 | 1.41 | 8.07 | 1.22 |
| 2.49 | 2.90 | 5.16 | 9.97 | 4.03 | 4.08 | 3.78 | 1.82 | 10.36 | 1.74 |
| 2.93 | 4.08 | 6.22 | 12.62 | 4.87 | 4.95 | 4.77 | 2.25 | 12.78 | 2.36 |
| 3.46 | 6.22 | 7.30 | 15.84 | 5.78 | 5.89 | 5.98 | 2.79 | 15.60 | 3.34 |
| 4.09 | 8.45 | 8.21 | 18.66 | 6.63 | 6.76 | 7.09 | 3.34 | 18.38 | 4.36 |
| 4.82 | 10.44 | 8.94 | 21.02 | 7.36 | 7.52 | 8.05 | 3.87 | 20.93 | 5.29 |
| 5.69 | 12.16 | 9.53 | 22.98 | 7.99 | 8.19 | 8.87 | 4.37 | 23.27 | 6.12 |
| 6.71 | 13.91 | 10.05 | 24.82 | 8.58 | 8.82 | 9.61 | 4.88 | 25.56 | 6.93 |
| 7.92 | 15.47 | 10.49 | 26.49 | 9.12 | 9.40 | 10.27 | 5.39 | 27.63 | 7.66 |
| 9.35 | 16.87 | 10.90 | 28.16 | 9.65 | 9.96 | 10.91 | 5.92 | 29.57 | 8.31 |
| 11.03 | 18.17 | 11.31 | 29.93 | 10.22 | 10.53 | 11.54 | 6.48 | 31.47 | 8.92 |
| 13.02 | 19.40 | 11.75 | 31.90 | 10.88 | 11.09 | 12.24 | 7.11 | 33.23 | 9.51 |
| 15.36 | 20.51 | 12.22 | 34.03 | 11.68 | 11.65 | 12.98 | 7.82 | 34.82 | 10.09 |
| 18.13 | 21.54 | 12.75 | 36.36 | 12.70 | 12.23 | 13.83 | 8.67 | 36.27 | 10.68 |
| 21.39 | 22.64 | 13.42 | 39.08 | 14.08 | 12.87 | 14.90 | 9.75 | 37.73 | 11.37 |
| 25.25 | 23.97 | 14.31 | 42.39 | 16.20 | 13.68 | 16.39 | 11.29 | 39.36 | 12.30 |
| 29.79 | 25.63 | 15.66 | 46.43 | 19.42 | 14.83 | 18.51 | 13.49 | 41.47 | 13.54 |
| 35.16 | 27.93 | 17.76 | 51.25 | 24.57 | 16.64 | 21.58 | 16.94 | 44.47 | 15.24 |
| 41.49 | 31.18 | 21.07 | 56.89 | 32.14 | 19.59 | 25.98 | 22.15 | 48.79 | 17.47 |
| 48.96 | 35.77 | 26.29 | 63.34 | 42.00 | 24.45 | 32.08 | 29.19 | 54.83 | 20.31 |
| 57.77 | 41.69 | 34.23 | 70.16 | 53.97 | 32.01 | 40.04 | 38.20 | 62.27 | 23.67 |
| 68.18 | 49.71 | 44.90 | 77.21 | 66.23 | 42.27 | 49.76 | 48.27 | 70.38 | 27.90 |
| 80.45 | 59.23 | 57.84 | 83.61 | 77.62 | 54.75 | 60.31 | 59.00 | 78.45 | 33.05 |
| 94.94 | 70.18 | 70.22 | 89.25 | 86.70 | 66.88 | 70.92 | 69.69 | 84.88 | 40.18 |
| 112.04 | 80.48 | 80.49 | 93.57 | 92.94 | 77.42 | 80.39 | 79.33 | 89.69 | 49.79 |
| 132.21 | 89.12 | 88.59 | 96.59 | 96.73 | 86.31 | 88.31 | 87.72 | 93.39 | 62.93 |
| 156.02 | 95.63 | 94.99 | 98.62 | 98.91 | 93.84 | 94.86 | 94.83 | 96.52 | 80.40 |
| 184.11 | 99.99 | 99.99 | 100.00 | 100.00 | 99.99 | 99.98 | 100.00 | 99.91 | 100.00 |

Table B.6: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 at 5,000 mg/L Initial Concentration after 10 Minutes of Settling (Continued)

| Median Size (microns) | 5.0 mL | | | 6.0 mL | | | 7.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.11 | 0.34 | 0.34 | 0.10 | 0.33 | 0.04 | 0.07 | 0.06 | 0.09 |
| 1.28 | 0.25 | 0.78 | 0.79 | 0.22 | 0.74 | 0.09 | 0.15 | 0.15 | 0.23 |
| 1.51 | 0.44 | 1.34 | 1.41 | 0.36 | 1.24 | 0.17 | 0.27 | 0.31 | 0.46 |
| 1.79 | 0.76 | 2.28 | 2.54 | 0.55 | 2.03 | 0.31 | 0.48 | 0.68 | 0.97 |
| 2.11 | 1.22 | 3.53 | 4.06 | 0.79 | 3.05 | 0.52 | 0.77 | 1.28 | 1.77 |
| 2.49 | 1.68 | 4.81 | 5.64 | 1.03 | 4.07 | 0.74 | 1.07 | 1.95 | 2.64 |
| 2.93 | 2.23 | 6.24 | 7.45 | 1.29 | 5.21 | 0.99 | 1.44 | 2.84 | 3.75 |
| 3.46 | 3.06 | 8.30 | 10.10 | 1.64 | 6.76 | 1.41 | 2.04 | 4.70 | 5.81 |
| 4.09 | 3.97 | 10.46 | 12.92 | 2.02 | 8.41 | 1.88 | 2.76 | 6.88 | 8.14 |
| 4.82 | 4.85 | 12.49 | 15.74 | 2.41 | 10.06 | 2.35 | 3.49 | 9.04 | 10.39 |
| 5.69 | 5.67 | 14.39 | 18.50 | 2.79 | 11.69 | 2.82 | 4.20 | 11.15 | 12.53 |
| 6.71 | 6.50 | 16.36 | 21.60 | 3.19 | 13.47 | 3.36 | 4.98 | 13.58 | 14.89 |
| 7.92 | 7.27 | 18.23 | 24.93 | 3.59 | 15.32 | 3.94 | 5.76 | 16.06 | 17.24 |
| 9.35 | 7.98 | 20.01 | 28.48 | 4.01 | 17.17 | 4.54 | 6.49 | 18.38 | 19.47 |
| 11.03 | 8.66 | 21.70 | 32.32 | 4.43 | 19.03 | 5.15 | 7.21 | 20.56 | 21.63 |
| 13.02 | 9.35 | 23.29 | 36.44 | 4.89 | 20.81 | 5.78 | 7.93 | 22.57 | 23.74 |
| 15.36 | 10.04 | 24.73 | 40.61 | 5.38 | 22.38 | 6.39 | 8.65 | 24.21 | 25.67 |
| 18.13 | 10.77 | 26.01 | 44.84 | 5.92 | 23.76 | 6.99 | 9.37 | 25.55 | 27.49 |
| 21.39 | 11.63 | 27.32 | 49.41 | 6.58 | 25.08 | 7.63 | 10.21 | 26.78 | 29.42 |
| 25.25 | 12.81 | 28.82 | 54.43 | 7.48 | 26.40 | 8.36 | 11.33 | 28.02 | 31.65 |
| 29.79 | 14.40 | 30.75 | 59.84 | 8.73 | 27.95 | 9.22 | 12.83 | 29.39 | 34.36 |
| 35.16 | 16.80 | 33.59 | 65.71 | 10.65 | 30.03 | 10.32 | 15.06 | 31.27 | 37.85 |
| 41.49 | 20.42 | 37.81 | 71.97 | 13.74 | 33.16 | 11.84 | 18.49 | 34.16 | 42.61 |
| 48.96 | 25.38 | 43.90 | 78.34 | 18.25 | 38.08 | 14.07 | 23.31 | 39.00 | 49.07 |
| 57.77 | 31.73 | 51.45 | 84.15 | 24.61 | 45.43 | 17.41 | 29.67 | 46.36 | 56.93 |
| 68.18 | 39.40 | 59.73 | 89.45 | 32.64 | 55.54 | 22.96 | 37.76 | 57.45 | 66.61 |
| 80.45 | 48.38 | 67.78 | 93.40 | 42.50 | 67.58 | 31.55 | 47.52 | 70.49 | 76.28 |
| 94.94 | 59.59 | 74.65 | 96.39 | 54.71 | 78.40 | 44.26 | 60.03 | 82.30 | 85.27 |
| 112.04 | 71.42 | 80.46 | 98.25 | 67.43 | 86.53 | 59.55 | 73.03 | 90.20 | 91.82 |
| 132.21 | 82.91 | 86.08 | 99.21 | 79.90 | 92.35 | 75.51 | 84.89 | 95.09 | 95.98 |
| 156.02 | 92.93 | 92.23 | 99.72 | 91.19 | 96.60 | 89.63 | 94.17 | 98.05 | 98.46 |
| 184.11 | 100.00 | 99.94 | 99.94 | 100.00 | 99.97 | 100.01 | 100.01 | 100.02 | 99.91 |

# Appendix C. Particle Size Distributions for Inside Aging Jar Test Screening at 2,500 mg/L Initial Concentration with Magnafloc 351

Table C.1: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 1 Day after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.05 | 0.06 | 0.09 | 0.08 | 0.07 | 0.12 | 0.01 | 0.01 | 0.03 |
| 1.28 | 0.12 | 0.15 | 0.23 | 0.21 | 0.18 | 0.30 | 0.04 | 0.04 | 0.08 |
| 1.51 | 0.26 | 0.33 | 0.50 | 0.44 | 0.36 | 0.59 | 0.11 | 0.11 | 0.17 |
| 1.79 | 0.66 | 0.87 | 1.32 | 1.02 | 0.78 | 1.27 | 0.31 | 0.31 | 0.42 |
| 2.11 | 1.37 | 1.89 | 2.80 | 2.02 | 1.45 | 2.37 | 0.69 | 0.71 | 0.87 |
| 2.49 | 2.16 | 3.04 | 4.47 | 3.12 | 2.16 | 3.56 | 1.13 | 1.17 | 1.37 |
| 2.93 | 3.20 | 4.61 | 6.71 | 4.58 | 3.05 | 5.04 | 1.76 | 1.86 | 2.06 |
| 3.46 | 5.42 | 8.30 | 11.80 | 7.70 | 4.74 | 7.86 | 3.40 | 3.81 | 3.74 |
| 4.09 | 7.75 | 12.25 | 17.28 | 11.21 | 6.61 | 10.94 | 5.48 | 6.33 | 5.79 |
| 4.82 | 9.76 | 15.63 | 22.02 | 14.56 | 8.43 | 13.89 | 7.63 | 8.92 | 7.91 |
| 5.69 | 11.46 | 18.46 | 26.01 | 17.72 | 10.18 | 16.68 | 9.84 | 11.53 | 10.09 |
| 6.71 | 13.18 | 21.29 | 29.96 | 21.34 | 12.16 | 19.81 | 12.67 | 14.81 | 12.85 |
| 7.92 | 14.68 | 23.64 | 33.18 | 25.03 | 14.16 | 22.94 | 15.85 | 18.35 | 15.95 |
| 9.35 | 15.95 | 25.53 | 35.67 | 28.56 | 16.10 | 25.93 | 19.09 | 21.80 | 19.14 |
| 11.03 | 17.07 | 27.13 | 37.67 | 32.00 | 17.98 | 28.76 | 22.37 | 25.17 | 22.34 |
| 13.02 | 18.05 | 28.50 | 39.25 | 35.28 | 19.80 | 31.40 | 25.72 | 28.47 | 25.52 |
| 15.36 | 18.87 | 29.60 | 40.43 | 38.13 | 21.41 | 33.61 | 28.73 | 31.35 | 28.24 |
| 18.13 | 19.56 | 30.55 | 41.35 | 40.55 | 22.88 | 35.44 | 31.37 | 33.83 | 30.48 |
| 21.39 | 20.25 | 31.52 | 42.21 | 42.85 | 24.40 | 37.17 | 34.00 | 36.31 | 32.53 |
| 25.25 | 21.06 | 32.70 | 43.14 | 45.20 | 26.13 | 38.92 | 36.77 | 38.98 | 34.44 |
| 29.79 | 22.08 | 34.20 | 44.24 | 47.62 | 28.22 | 40.83 | 39.61 | 41.84 | 36.28 |
| 35.16 | 23.51 | 36.34 | 45.69 | 50.36 | 30.99 | 43.18 | 42.82 | 45.26 | 38.30 |
| 41.49 | 25.73 | 39.44 | 47.73 | 53.65 | 34.80 | 46.38 | 46.60 | 49.51 | 40.79 |
| 48.96 | 29.22 | 43.98 | 50.63 | 57.54 | 39.97 | 50.85 | 50.95 | 54.78 | 44.11 |
| 57.77 | 34.16 | 49.65 | 54.20 | 61.64 | 46.34 | 56.47 | 55.32 | 60.46 | 48.32 |
| 68.18 | 41.76 | 57.34 | 59.17 | 66.63 | 54.44 | 63.92 | 60.42 | 67.29 | 54.60 |
| 80.45 | 51.63 | 65.85 | 65.09 | 72.12 | 63.21 | 72.06 | 65.80 | 74.10 | 62.65 |
| 94.94 | 63.96 | 75.47 | 72.66 | 78.91 | 72.69 | 80.50 | 72.54 | 81.44 | 72.79 |
| 112.04 | 75.68 | 84.05 | 80.53 | 85.69 | 81.32 | 87.51 | 79.76 | 87.93 | 82.57 |
| 132.21 | 85.87 | 91.15 | 88.28 | 91.62 | 88.87 | 92.96 | 87.02 | 93.25 | 90.69 |
| 156.02 | 93.94 | 96.43 | 94.95 | 96.34 | 95.16 | 97.00 | 93.90 | 97.22 | 96.38 |
| 184.11 | 100.01 | 100.02 | 99.99 | 100.02 | 99.99 | 100.00 | 100.00 | 100.03 | 100.02 |

Table C.1: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 1 Day after 10 Minutes Settling (Continued)

| Median Size (microns ) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.00 | 0.02 | 0.09 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.01 |
| 1.51 | 0.03 | 0.06 | 0.19 | 0.01 | 0.02 | 0.08 | 0.00 | 0.00 | 0.05 |
| 1.79 | 0.13 | 0.22 | 0.46 | 0.07 | 0.09 | 0.29 | 0.03 | 0.05 | 0.16 |
| 2.11 | 0.35 | 0.58 | 1.00 | 0.20 | 0.29 | 0.77 | 0.11 | 0.16 | 0.41 |
| 2.49 | 0.63 | 0.99 | 1.60 | 0.38 | 0.54 | 1.35 | 0.22 | 0.32 | 0.72 |
| 2.93 | 1.09 | 1.65 | 2.46 | 0.69 | 0.98 | 2.26 | 0.42 | 0.62 | 1.22 |
| 3.46 | 2.77 | 3.73 | 4.65 | 2.11 | 2.84 | 5.38 | 1.44 | 2.13 | 2.89 |
| 4.09 | 5.15 | 6.55 | 7.43 | 4.32 | 5.70 | 9.68 | 3.13 | 4.63 | 5.27 |
| 4.82 | 7.73 | 9.56 | 10.39 | 6.75 | 8.87 | 14.23 | 5.06 | 7.49 | 7.84 |
| 5.69 | 10.47 | 12.69 | 13.51 | 9.36 | 12.30 | 18.96 | 7.20 | 10.66 | 10.59 |
| 6.71 | 14.21 | 16.87 | 17.60 | 13.04 | 17.17 | 25.36 | 10.33 | 15.33 | 14.34 |
| 7.92 | 18.49 | 21.58 | 22.37 | 17.23 | 22.82 | 32.61 | 13.98 | 20.82 | 18.69 |
| 9.35 | 22.75 | 26.31 | 27.38 | 21.32 | 28.45 | 39.85 | 17.59 | 26.25 | 23.10 |
| 11.03 | 26.92 | 31.02 | 32.47 | 25.23 | 33.94 | 47.00 | 21.08 | 31.49 | 27.43 |
| 13.02 | 31.08 | 35.76 | 37.62 | 29.07 | 39.46 | 54.06 | 24.61 | 36.80 | 31.70 |
| 15.36 | 34.64 | 39.94 | 42.08 | 32.26 | 44.18 | 60.04 | 27.65 | 41.38 | 35.29 |
| 18.13 | 37.61 | 43.57 | 45.81 | 34.81 | 48.13 | 64.82 | 30.20 | 45.27 | 38.18 |
| 21.39 | 40.50 | 47.23 | 49.30 | 37.21 | 52.01 | 69.12 | 32.73 | 49.21 | 40.87 |
| 25.25 | 43.50 | 51.11 | 52.59 | 39.56 | 55.99 | 72.86 | 35.40 | 53.39 | 43.38 |
| 29.79 | 46.45 | 55.06 | 55.70 | 41.65 | 59.78 | 75.78 | 37.93 | 57.40 | 45.70 |
| 35.16 | 49.82 | 59.50 | 58.99 | 43.85 | 63.90 | 78.28 | 40.73 | 61.74 | 48.19 |
| 41.49 | 53.82 | 64.56 | 62.71 | 46.25 | 68.47 | 80.46 | 43.93 | 66.44 | 51.13 |
| 48.96 | 58.44 | 70.26 | 66.99 | 48.92 | 73.58 | 82.43 | 47.61 | 71.48 | 54.85 |
| 57.77 | 62.90 | 75.73 | 71.38 | 51.47 | 78.39 | 83.97 | 51.23 | 75.97 | 59.12 |
| 68.18 | 68.00 | 81.65 | 76.49 | 54.70 | 83.77 | 85.61 | 55.78 | 80.87 | 65.09 |
| 80.45 | 72.99 | 86.76 | 81.50 | 58.37 | 88.47 | 87.21 | 60.78 | 85.20 | 72.07 |
| 94.94 | 79.03 | 91.61 | 86.73 | 64.00 | 93.00 | 89.28 | 67.73 | 89.76 | 80.32 |
| 112.04 | 85.09 | 95.22 | 91.24 | 71.36 | 96.26 | 91.69 | 75.77 | 93.62 | 87.71 |
| 132.21 | 90.81 | 97.65 | 94.94 | 80.43 | 98.32 | 94.41 | 84.51 | 96.62 | 93.54 |
| 156.02 | 95.86 | 99.10 | 97.78 | 90.46 | 99.43 | 97.22 | 92.91 | 98.66 | 97.45 |
| 184.11 | 99.99 | 99.97 | 100.00 | 100.00 | 100.02 | 100.00 | 100.01 | 99.98 | 99.99 |

Table C.2: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 30 Days after 10 Minutes Settling

| **Median Size (microns )** | **1.0 mL** | | | **2.0 mL** | | | **3.0 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.03 | 0.03 | 0.02 | 0.09 | 0.14 | 0.12 | 0.47 | 0.28 | 0.27 |
| 1.28 | 0.08 | 0.09 | 0.07 | 0.25 | 0.37 | 0.32 | 1.17 | 0.70 | 0.66 |
| 1.51 | 0.20 | 0.23 | 0.20 | 0.59 | 0.80 | 0.72 | 2.33 | 1.39 | 1.33 |
| 1.79 | 0.78 | 0.83 | 0.74 | 1.81 | 2.04 | 1.89 | 5.14 | 2.95 | 2.89 |
| 2.11 | 2.16 | 2.19 | 1.96 | 4.34 | 4.27 | 4.06 | 9.70 | 5.44 | 5.42 |
| 2.49 | 3.94 | 3.91 | 3.54 | 7.36 | 6.80 | 6.57 | 14.71 | 8.15 | 8.23 |
| 2.93 | 6.96 | 6.73 | 6.18 | 11.85 | 10.26 | 10.05 | 21.14 | 11.59 | 11.83 |
| 3.46 | 18.94 | 16.91 | 16.27 | 24.75 | 18.19 | 18.48 | 33.96 | 18.09 | 18.96 |
| 4.09 | 34.81 | 30.05 | 29.80 | 39.31 | 26.69 | 27.74 | 47.91 | 25.01 | 26.65 |
| 4.82 | 49.10 | 41.87 | 42.27 | 51.42 | 33.76 | 35.54 | 60.54 | 31.07 | 33.42 |
| 5.69 | 61.15 | 51.81 | 52.95 | 61.06 | 39.37 | 41.78 | 71.60 | 36.22 | 39.14 |
| 6.71 | 73.58 | 61.91 | 64.03 | 70.27 | 44.50 | 47.61 | 82.41 | 41.16 | 44.68 |
| 7.92 | 82.79 | 69.43 | 72.35 | 77.04 | 48.25 | 51.91 | 90.61 | 45.19 | 49.21 |
| 9.35 | 88.67 | 74.32 | 77.71 | 81.69 | 50.90 | 54.94 | 95.77 | 48.40 | 52.81 |
| 11.03 | 92.45 | 77.53 | 81.18 | 85.08 | 52.88 | 57.17 | 98.68 | 51.04 | 55.78 |
| 13.02 | 94.78 | 79.57 | 83.34 | 87.51 | 54.35 | 58.81 | 99.71 | 53.16 | 58.20 |
| 15.36 | 96.09 | 80.76 | 84.58 | 89.14 | 55.42 | 59.96 | 99.97 | 54.78 | 60.09 |
| 18.13 | 96.85 | 81.51 | 85.33 | 90.30 | 56.25 | 60.82 | 100.03 | 56.05 | 61.62 |
| 21.39 | 97.42 | 82.12 | 85.92 | 91.31 | 57.06 | 61.60 | 100.03 | 57.24 | 63.05 |
| 25.25 | 97.92 | 82.74 | 86.49 | 92.33 | 58.04 | 62.48 | 100.03 | 58.45 | 64.55 |
| 29.79 | 98.37 | 83.45 | 87.11 | 93.39 | 59.33 | 63.55 | 100.03 | 59.79 | 66.25 |
| 35.16 | 98.80 | 84.37 | 87.88 | 94.56 | 61.20 | 64.99 | 100.03 | 61.41 | 68.27 |
| 41.49 | 99.22 | 85.66 | 88.91 | 95.87 | 63.92 | 66.97 | 100.03 | 63.44 | 70.77 |
| 48.96 | 99.59 | 87.42 | 90.30 | 97.23 | 67.78 | 69.67 | 100.03 | 66.04 | 73.84 |
| 57.77 | 99.78 | 89.22 | 91.68 | 98.21 | 72.26 | 72.68 | 100.03 | 69.05 | 77.03 |
| 68.18 | 99.90 | 91.41 | 93.34 | 98.97 | 77.79 | 76.49 | 100.03 | 72.96 | 80.64 |
| 80.45 | 99.95 | 93.35 | 94.78 | 99.40 | 83.23 | 80.50 | 100.03 | 77.42 | 84.21 |
| 94.94 | 99.97 | 95.38 | 96.28 | 99.65 | 88.60 | 85.16 | 100.03 | 82.72 | 87.97 |
| 112.04 | 99.99 | 96.97 | 97.48 | 99.77 | 92.84 | 89.57 | 100.03 | 87.99 | 91.42 |
| 132.21 | 99.99 | 98.22 | 98.45 | 99.84 | 96.05 | 93.63 | 100.03 | 92.86 | 94.56 |
| 156.02 | 99.99 | 99.19 | 99.26 | 99.89 | 98.33 | 97.06 | 100.03 | 96.87 | 97.35 |
| 184.11 | 100.00 | 99.99 | 100.00 | 99.99 | 100.01 | 100.01 | 100.03 | 99.97 | 100.00 |

Table C.2: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 30 Days after 10 Minutes Settling (Continued)

| Median Size (microns) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.70 | 0.31 | 0.34 | 0.67 | 0.15 | 0.21 | 0.17 | 0.17 | 0.24 |
| 1.28 | 1.71 | 0.76 | 0.81 | 1.66 | 0.38 | 0.51 | 0.41 | 0.44 | 0.61 |
| 1.51 | 3.25 | 1.47 | 1.53 | 3.10 | 0.76 | 0.96 | 0.83 | 0.86 | 1.16 |
| 1.79 | 6.40 | 3.08 | 3.00 | 5.97 | 1.62 | 1.86 | 1.88 | 1.79 | 2.35 |
| 2.11 | 11.14 | 5.62 | 5.22 | 10.20 | 3.00 | 3.20 | 3.70 | 3.27 | 4.19 |
| 2.49 | 16.18 | 8.39 | 7.62 | 14.65 | 4.52 | 4.64 | 5.74 | 4.89 | 6.21 |
| 2.93 | 22.32 | 11.89 | 10.60 | 20.04 | 6.48 | 6.39 | 8.48 | 6.98 | 8.78 |
| 3.46 | 33.03 | 18.49 | 15.88 | 29.29 | 10.34 | 9.43 | 14.44 | 11.04 | 13.67 |
| 4.09 | 44.52 | 25.62 | 21.58 | 39.49 | 14.71 | 12.78 | 21.32 | 15.74 | 19.27 |
| 4.82 | 55.26 | 32.09 | 26.76 | 49.64 | 18.85 | 15.96 | 27.87 | 20.36 | 24.74 |
| 5.69 | 65.22 | 37.78 | 31.33 | 59.84 | 22.73 | 18.95 | 33.91 | 24.83 | 30.03 |
| 6.71 | 75.57 | 43.55 | 35.87 | 71.47 | 27.00 | 22.19 | 40.54 | 29.92 | 35.93 |
| 7.92 | 84.47 | 48.64 | 39.83 | 82.79 | 31.20 | 25.39 | 46.78 | 35.16 | 41.87 |
| 9.35 | 90.92 | 53.01 | 43.23 | 91.69 | 35.16 | 28.49 | 52.28 | 40.25 | 47.55 |
| 11.03 | 95.04 | 56.87 | 46.23 | 97.53 | 38.94 | 31.55 | 57.19 | 45.22 | 53.03 |
| 13.02 | 96.71 | 60.28 | 48.85 | 99.60 | 42.57 | 34.56 | 61.50 | 50.04 | 58.23 |
| 15.36 | 97.15 | 63.11 | 51.02 | 100.00 | 45.78 | 37.30 | 64.95 | 54.27 | 62.72 |
| 18.13 | 97.24 | 65.50 | 52.83 | 100.00 | 48.61 | 39.73 | 67.63 | 57.95 | 66.51 |
| 21.39 | 97.24 | 67.80 | 54.55 | 100.00 | 51.37 | 42.05 | 69.95 | 61.49 | 70.00 |
| 25.25 | 97.24 | 70.18 | 56.28 | 100.00 | 54.14 | 44.26 | 72.00 | 64.89 | 73.21 |
| 29.79 | 97.24 | 72.75 | 58.13 | 100.00 | 56.92 | 46.36 | 73.79 | 68.13 | 76.24 |
| 35.16 | 97.24 | 75.67 | 60.24 | 100.00 | 59.81 | 48.47 | 75.45 | 71.40 | 79.24 |
| 41.49 | 97.24 | 78.99 | 62.73 | 100.00 | 62.81 | 50.66 | 77.05 | 74.70 | 82.26 |
| 48.96 | 97.24 | 82.74 | 65.69 | 100.00 | 65.94 | 53.02 | 78.68 | 78.09 | 85.23 |
| 57.77 | 97.24 | 86.35 | 68.80 | 100.00 | 68.93 | 55.39 | 80.14 | 81.26 | 87.74 |
| 68.18 | 97.24 | 90.08 | 72.43 | 100.00 | 72.22 | 58.20 | 81.83 | 84.66 | 90.06 |
| 80.45 | 97.24 | 93.20 | 76.24 | 100.00 | 75.64 | 61.41 | 83.65 | 87.90 | 91.93 |
| 94.94 | 97.24 | 95.81 | 80.55 | 100.00 | 79.67 | 65.62 | 86.03 | 91.17 | 93.61 |
| 112.04 | 97.24 | 97.64 | 85.02 | 100.00 | 84.15 | 70.96 | 88.87 | 94.10 | 95.11 |
| 132.21 | 97.24 | 98.82 | 89.74 | 100.00 | 89.15 | 78.00 | 92.24 | 96.56 | 96.57 |
| 156.02 | 97.32 | 99.53 | 94.70 | 100.00 | 94.43 | 87.47 | 95.86 | 98.48 | 98.13 |
| 184.11 | 100.09 | 100.02 | 100.06 | 100.00 | 99.98 | 100.02 | 100.00 | 100.00 | 100.03 |

Table C.3: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 120 Days after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.05 | 0.06 | 0.07 | 0.09 | 0.14 | 0.23 | 0.38 | 0.15 | 0.63 |
| 1.28 | 0.14 | 0.17 | 0.21 | 0.24 | 0.35 | 0.58 | 0.91 | 0.38 | 1.50 |
| 1.51 | 0.33 | 0.39 | 0.50 | 0.49 | 0.72 | 1.20 | 1.68 | 0.75 | 2.81 |
| 1.79 | 0.98 | 1.17 | 1.53 | 1.13 | 1.68 | 2.71 | 3.20 | 1.65 | 5.41 |
| 2.11 | 2.29 | 2.74 | 3.66 | 2.20 | 3.30 | 5.23 | 5.43 | 3.13 | 9.29 |
| 2.49 | 3.85 | 4.62 | 6.22 | 3.40 | 5.10 | 8.02 | 7.79 | 4.78 | 13.42 |
| 2.93 | 6.17 | 7.43 | 10.10 | 4.98 | 7.44 | 11.66 | 10.63 | 6.92 | 18.46 |
| 3.46 | 12.82 | 15.58 | 21.63 | 8.26 | 12.32 | 19.09 | 15.36 | 11.35 | 27.22 |
| 4.09 | 20.68 | 25.28 | 35.53 | 11.85 | 17.58 | 27.17 | 20.49 | 16.44 | 36.88 |
| 4.82 | 27.53 | 33.79 | 47.87 | 15.02 | 22.17 | 34.35 | 25.31 | 21.29 | 46.07 |
| 5.69 | 33.16 | 40.85 | 58.13 | 17.73 | 26.04 | 40.49 | 29.74 | 25.76 | 54.57 |
| 6.71 | 38.65 | 47.84 | 68.27 | 20.43 | 29.81 | 46.52 | 34.35 | 30.56 | 63.42 |
| 7.92 | 42.79 | 53.16 | 75.77 | 22.68 | 32.87 | 51.43 | 38.62 | 34.97 | 71.45 |
| 9.35 | 45.69 | 56.90 | 80.71 | 24.51 | 35.26 | 55.20 | 42.45 | 38.79 | 78.30 |
| 11.03 | 47.83 | 59.61 | 83.99 | 26.07 | 37.22 | 58.18 | 45.92 | 42.16 | 84.10 |
| 13.02 | 49.44 | 61.55 | 86.01 | 27.42 | 38.81 | 60.43 | 49.01 | 45.10 | 88.58 |
| 15.36 | 50.62 | 62.86 | 87.17 | 28.56 | 40.05 | 62.03 | 51.59 | 47.51 | 91.67 |
| 18.13 | 51.56 | 63.81 | 87.84 | 29.57 | 41.06 | 63.18 | 53.76 | 49.49 | 93.65 |
| 21.39 | 52.52 | 64.66 | 88.32 | 30.65 | 42.03 | 64.14 | 55.80 | 51.36 | 94.96 |
| 25.25 | 53.77 | 65.59 | 88.74 | 31.99 | 43.10 | 65.02 | 57.85 | 53.24 | 95.72 |
| 29.79 | 55.48 | 66.68 | 89.13 | 33.71 | 44.37 | 65.88 | 60.02 | 55.15 | 96.14 |
| 35.16 | 58.03 | 68.10 | 89.55 | 36.07 | 45.96 | 66.76 | 62.45 | 57.23 | 96.35 |
| 41.49 | 61.78 | 69.98 | 90.04 | 39.34 | 47.98 | 67.71 | 65.26 | 59.54 | 96.46 |
| 48.96 | 66.98 | 72.43 | 90.63 | 43.77 | 50.57 | 68.78 | 68.51 | 62.11 | 96.50 |
| 57.77 | 72.61 | 74.97 | 91.18 | 49.01 | 53.43 | 69.80 | 71.89 | 64.65 | 96.52 |
| 68.18 | 79.09 | 78.10 | 91.88 | 55.87 | 57.10 | 71.05 | 75.74 | 67.62 | 96.52 |
| 80.45 | 84.86 | 81.25 | 92.57 | 63.45 | 61.37 | 72.42 | 79.76 | 70.82 | 96.52 |
| 94.94 | 90.18 | 85.05 | 93.54 | 71.95 | 67.05 | 74.44 | 84.16 | 74.90 | 96.52 |
| 112.04 | 94.06 | 88.82 | 94.62 | 79.85 | 73.79 | 77.17 | 88.46 | 79.72 | 96.55 |
| 132.21 | 96.79 | 92.67 | 96.01 | 87.00 | 81.77 | 81.53 | 92.58 | 85.52 | 96.69 |
| 156.02 | 98.65 | 96.44 | 97.82 | 93.72 | 90.66 | 88.95 | 96.34 | 92.32 | 97.38 |
| 184.11 | 100.00 | 100.01 | 100.00 | 100.00 | 100.00 | 100.01 | 100.02 | 100.01 | 100.05 |

Table C.3: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 120 Days after 10 Minutes Settling (Continued)

| Median Size (microns ) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.22 | 0.35 | 0.24 | 0.20 | 0.17 | 0.41 | 0.21 | 0.15 | 0.14 |
| 1.28 | 0.52 | 0.83 | 0.60 | 0.49 | 0.43 | 0.98 | 0.51 | 0.36 | 0.36 |
| 1.51 | 0.98 | 1.57 | 1.19 | 0.95 | 0.85 | 1.85 | 1.02 | 0.72 | 0.77 |
| 1.79 | 1.91 | 3.06 | 2.55 | 1.93 | 1.81 | 3.66 | 2.15 | 1.56 | 1.80 |
| 2.11 | 3.34 | 5.31 | 4.73 | 3.45 | 3.36 | 6.43 | 3.96 | 2.94 | 3.59 |
| 2.49 | 4.86 | 7.73 | 7.15 | 5.12 | 5.09 | 9.43 | 5.97 | 4.49 | 5.64 |
| 2.93 | 6.76 | 10.75 | 10.30 | 7.25 | 7.34 | 13.20 | 8.59 | 6.56 | 8.46 |
| 3.46 | 10.16 | 16.19 | 16.71 | 11.42 | 11.99 | 20.28 | 13.93 | 11.06 | 15.15 |
| 4.09 | 14.00 | 22.36 | 24.24 | 16.35 | 17.56 | 28.59 | 20.33 | 16.61 | 23.58 |
| 4.82 | 17.75 | 28.38 | 31.63 | 21.33 | 23.14 | 36.99 | 26.80 | 22.32 | 32.22 |
| 5.69 | 21.32 | 34.05 | 38.65 | 26.21 | 28.55 | 45.35 | 33.21 | 28.02 | 40.92 |
| 6.71 | 25.23 | 40.19 | 46.42 | 31.80 | 34.69 | 55.00 | 40.63 | 34.73 | 51.42 |
| 7.92 | 29.05 | 46.07 | 53.86 | 37.49 | 40.79 | 64.95 | 48.29 | 41.61 | 62.29 |
| 9.35 | 32.63 | 51.45 | 60.50 | 42.94 | 46.47 | 74.43 | 55.60 | 48.14 | 72.42 |
| 11.03 | 36.00 | 56.41 | 66.41 | 48.20 | 51.77 | 83.26 | 62.51 | 54.32 | 81.68 |
| 13.02 | 39.13 | 60.92 | 71.48 | 53.23 | 56.71 | 90.51 | 68.83 | 60.09 | 89.34 |
| 15.36 | 41.86 | 64.71 | 75.40 | 57.69 | 60.96 | 95.51 | 74.00 | 65.03 | 94.66 |
| 18.13 | 44.21 | 67.90 | 78.29 | 61.56 | 64.59 | 98.28 | 78.07 | 69.13 | 97.73 |
| 21.39 | 46.45 | 70.85 | 80.57 | 65.24 | 68.05 | 99.59 | 81.52 | 72.89 | 99.35 |
| 25.25 | 48.63 | 73.62 | 82.23 | 68.72 | 71.43 | 99.95 | 84.33 | 76.32 | 99.89 |
| 29.79 | 50.79 | 76.24 | 83.35 | 71.90 | 74.65 | 100.02 | 86.58 | 79.30 | 100.00 |
| 35.16 | 53.02 | 78.83 | 84.05 | 74.85 | 77.84 | 100.02 | 88.42 | 82.02 | 100.01 |
| 41.49 | 55.41 | 81.41 | 84.47 | 77.58 | 80.96 | 100.02 | 89.95 | 84.48 | 100.01 |
| 48.96 | 58.00 | 83.99 | 84.71 | 80.05 | 83.94 | 100.02 | 91.23 | 86.70 | 100.01 |
| 57.77 | 60.59 | 86.26 | 84.83 | 82.03 | 86.40 | 100.02 | 92.17 | 88.46 | 100.01 |
| 68.18 | 63.67 | 88.55 | 84.91 | 83.92 | 88.74 | 100.02 | 93.05 | 90.14 | 100.01 |
| 80.45 | 67.17 | 90.64 | 84.97 | 85.65 | 90.73 | 100.02 | 93.82 | 91.61 | 100.01 |
| 94.94 | 71.69 | 92.81 | 85.07 | 87.61 | 92.73 | 100.02 | 94.71 | 93.20 | 100.01 |
| 112.04 | 77.08 | 94.85 | 85.28 | 89.80 | 94.63 | 100.02 | 95.70 | 94.84 | 100.01 |
| 132.21 | 83.55 | 96.75 | 86.01 | 92.43 | 96.46 | 100.02 | 96.85 | 96.53 | 100.01 |
| 156.02 | 91.10 | 98.45 | 89.15 | 95.65 | 98.21 | 100.02 | 98.17 | 98.25 | 100.01 |
| 184.11 | 100.01 | 100.01 | 99.98 | 99.98 | 99.97 | 100.02 | 99.98 | 100.04 | 100.01 |

Table C.4: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 210 Days after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.03 | 0.04 | 0.06 | 0.06 | 0.05 | 0.04 | 0.12 | 0.13 | 0.20 |
| 1.28 | 0.08 | 0.13 | 0.16 | 0.16 | 0.15 | 0.11 | 0.33 | 0.33 | 0.51 |
| 1.51 | 0.21 | 0.30 | 0.37 | 0.38 | 0.34 | 0.27 | 0.71 | 0.72 | 1.06 |
| 1.79 | 0.68 | 0.91 | 1.11 | 1.12 | 0.98 | 0.82 | 1.82 | 1.85 | 2.51 |
| 2.11 | 1.71 | 2.18 | 2.60 | 2.59 | 2.23 | 1.94 | 3.85 | 3.90 | 5.02 |
| 2.49 | 2.98 | 3.71 | 4.38 | 4.32 | 3.70 | 3.28 | 6.15 | 6.22 | 7.79 |
| 2.93 | 4.99 | 6.03 | 7.05 | 6.86 | 5.83 | 5.28 | 9.30 | 9.42 | 11.46 |
| 3.46 | 11.77 | 13.11 | 14.85 | 13.86 | 11.63 | 11.12 | 16.64 | 16.96 | 19.23 |
| 4.09 | 20.75 | 22.08 | 24.50 | 22.10 | 18.43 | 18.16 | 24.80 | 25.48 | 27.71 |
| 4.82 | 29.52 | 30.58 | 33.52 | 29.50 | 24.51 | 24.49 | 32.02 | 33.13 | 35.24 |
| 5.69 | 37.64 | 38.23 | 41.51 | 35.85 | 29.67 | 29.89 | 38.15 | 39.68 | 41.68 |
| 6.71 | 46.95 | 46.55 | 50.05 | 42.42 | 34.90 | 35.45 | 44.32 | 46.30 | 48.12 |
| 7.92 | 55.25 | 53.56 | 57.17 | 47.82 | 39.07 | 39.89 | 49.40 | 51.71 | 53.47 |
| 9.35 | 61.76 | 58.74 | 62.45 | 51.91 | 42.13 | 43.14 | 53.36 | 55.83 | 57.71 |
| 11.03 | 66.86 | 62.55 | 66.35 | 55.08 | 44.43 | 45.58 | 56.53 | 59.06 | 61.16 |
| 13.02 | 70.81 | 65.21 | 69.11 | 57.50 | 46.12 | 47.40 | 59.02 | 61.51 | 63.88 |
| 15.36 | 73.58 | 66.89 | 70.89 | 59.20 | 47.29 | 48.69 | 60.85 | 63.26 | 65.92 |
| 18.13 | 75.54 | 67.97 | 72.07 | 60.45 | 48.15 | 49.66 | 62.24 | 64.54 | 67.49 |
| 21.39 | 77.27 | 68.85 | 73.03 | 61.59 | 48.93 | 50.56 | 63.51 | 65.68 | 68.93 |
| 25.25 | 78.98 | 69.66 | 73.96 | 62.79 | 49.80 | 51.60 | 64.85 | 66.82 | 70.42 |
| 29.79 | 80.70 | 70.51 | 74.93 | 64.18 | 50.84 | 52.83 | 66.37 | 68.06 | 72.06 |
| 35.16 | 82.63 | 71.53 | 76.09 | 65.96 | 52.26 | 54.47 | 68.26 | 69.54 | 73.97 |
| 41.49 | 84.92 | 72.90 | 77.61 | 68.39 | 54.28 | 56.70 | 70.75 | 71.41 | 76.24 |
| 48.96 | 87.59 | 74.82 | 79.60 | 71.69 | 57.09 | 59.60 | 73.98 | 73.75 | 78.86 |
| 57.77 | 90.04 | 77.02 | 81.72 | 75.38 | 60.24 | 62.65 | 77.45 | 76.17 | 81.33 |
| 68.18 | 92.67 | 80.07 | 84.45 | 80.04 | 64.26 | 66.39 | 81.62 | 79.09 | 84.00 |
| 80.45 | 94.81 | 83.44 | 87.22 | 84.70 | 68.50 | 70.23 | 85.66 | 82.01 | 86.40 |
| 94.94 | 96.77 | 87.63 | 90.50 | 89.61 | 73.68 | 74.99 | 89.87 | 85.45 | 89.03 |
| 112.04 | 98.13 | 91.55 | 93.49 | 93.56 | 79.19 | 80.12 | 93.37 | 88.90 | 91.54 |
| 132.21 | 99.04 | 95.06 | 96.12 | 96.54 | 85.44 | 85.98 | 96.17 | 92.51 | 94.13 |
| 156.02 | 99.60 | 97.83 | 98.25 | 98.56 | 92.45 | 92.66 | 98.30 | 96.22 | 96.91 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table C.4: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 210 Days after 10 Minutes Settling (Continued)

| **Median Size (microns)** | **4.0 mL** | | | **5.0 mL** | | | **6.0 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.18 | 0.45 | 0.13 | 0.24 | 0.38 | 0.31 | 0.35 | 0.29 | 0.29 |
| 1.28 | 0.47 | 1.08 | 0.35 | 0.60 | 0.93 | 0.78 | 0.86 | 0.73 | 0.73 |
| 1.51 | 0.97 | 2.07 | 0.76 | 1.23 | 1.80 | 1.53 | 1.67 | 1.44 | 1.45 |
| 1.79 | 2.29 | 4.17 | 1.86 | 2.77 | 3.73 | 3.27 | 3.49 | 3.11 | 3.11 |
| 2.11 | 4.56 | 7.40 | 3.83 | 5.36 | 6.76 | 6.05 | 6.39 | 5.81 | 5.79 |
| 2.49 | 7.06 | 10.83 | 6.04 | 8.18 | 10.01 | 9.06 | 9.49 | 8.74 | 8.68 |
| 2.93 | 10.33 | 15.03 | 9.03 | 11.81 | 14.07 | 12.86 | 13.35 | 12.45 | 12.34 |
| 3.46 | 17.13 | 22.41 | 15.80 | 19.10 | 21.50 | 20.08 | 20.47 | 19.63 | 19.33 |
| 4.09 | 24.50 | 30.33 | 23.46 | 27.04 | 29.55 | 27.99 | 28.20 | 27.53 | 27.03 |
| 4.82 | 31.08 | 37.63 | 30.44 | 34.28 | 36.98 | 35.35 | 35.40 | 34.88 | 34.20 |
| 5.69 | 36.78 | 44.11 | 36.57 | 40.66 | 43.65 | 41.95 | 41.89 | 41.50 | 40.66 |
| 6.71 | 42.57 | 50.64 | 42.90 | 47.26 | 50.53 | 48.78 | 48.65 | 48.38 | 47.41 |
| 7.92 | 47.55 | 56.30 | 48.32 | 53.09 | 56.69 | 54.87 | 54.78 | 54.54 | 53.48 |
| 9.35 | 51.63 | 60.95 | 52.66 | 57.98 | 61.94 | 60.03 | 60.08 | 59.77 | 58.69 |
| 11.03 | 55.05 | 64.80 | 56.23 | 62.19 | 66.45 | 64.48 | 64.73 | 64.26 | 63.25 |
| 13.02 | 57.85 | 67.80 | 59.13 | 65.72 | 70.18 | 68.22 | 68.67 | 67.99 | 67.14 |
| 15.36 | 59.98 | 69.98 | 61.36 | 68.47 | 73.04 | 71.17 | 71.80 | 70.91 | 70.28 |
| 18.13 | 61.63 | 71.60 | 63.11 | 70.65 | 75.25 | 73.52 | 74.30 | 73.20 | 72.85 |
| 21.39 | 63.15 | 72.96 | 64.77 | 72.67 | 77.20 | 75.65 | 76.61 | 75.29 | 75.27 |
| 25.25 | 64.69 | 74.25 | 66.56 | 74.70 | 79.06 | 77.75 | 78.87 | 77.37 | 77.73 |
| 29.79 | 66.39 | 75.60 | 68.56 | 76.85 | 80.98 | 79.86 | 81.22 | 79.55 | 80.33 |
| 35.16 | 68.42 | 77.14 | 70.96 | 79.25 | 83.07 | 82.07 | 83.74 | 81.98 | 83.15 |
| 41.49 | 71.00 | 79.01 | 73.86 | 82.00 | 85.45 | 84.40 | 86.51 | 84.77 | 86.21 |
| 48.96 | 74.25 | 81.29 | 77.24 | 85.08 | 88.07 | 86.80 | 89.42 | 87.84 | 89.37 |
| 57.77 | 77.71 | 83.64 | 80.47 | 87.91 | 90.44 | 88.87 | 91.97 | 90.63 | 92.06 |
| 68.18 | 81.78 | 86.36 | 83.90 | 90.78 | 92.76 | 90.92 | 94.35 | 93.32 | 94.54 |
| 80.45 | 85.66 | 88.92 | 86.92 | 93.12 | 94.57 | 92.62 | 96.12 | 95.37 | 96.36 |
| 94.94 | 89.66 | 91.61 | 89.98 | 95.23 | 96.18 | 94.37 | 97.56 | 97.07 | 97.84 |
| 112.04 | 93.03 | 93.98 | 92.70 | 96.84 | 97.40 | 95.92 | 98.54 | 98.22 | 98.79 |
| 132.21 | 95.82 | 96.14 | 95.20 | 98.06 | 98.38 | 97.34 | 99.19 | 99.00 | 99.38 |
| 156.02 | 98.09 | 98.13 | 97.61 | 99.05 | 99.22 | 98.67 | 99.63 | 99.55 | 99.74 |
| 184.11 | 100.01 | 100.01 | 100.01 | 100.00 | 100.00 | 100.00 | 99.99 | 100.00 | 100.00 |

## Appendix D. Particle Size Distribution for 30 Day Exposure to Environmental Conditions Jar Test Screening at 2,500 mg/L Initial Concentration with Magnafloc 351

Table D.1: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 30 Days after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.03 | 0.03 | 0.02 | 0.09 | 0.14 | 0.12 | 0.47 | 0.28 | 0.27 |
| 1.28 | 0.08 | 0.09 | 0.07 | 0.25 | 0.37 | 0.32 | 1.17 | 0.70 | 0.66 |
| 1.51 | 0.20 | 0.23 | 0.20 | 0.59 | 0.80 | 0.72 | 2.33 | 1.39 | 1.33 |
| 1.79 | 0.78 | 0.83 | 0.74 | 1.81 | 2.04 | 1.89 | 5.14 | 2.95 | 2.89 |
| 2.11 | 2.16 | 2.19 | 1.96 | 4.34 | 4.27 | 4.06 | 9.70 | 5.44 | 5.42 |
| 2.49 | 3.94 | 3.91 | 3.54 | 7.36 | 6.80 | 6.57 | 14.71 | 8.15 | 8.23 |
| 2.93 | 6.96 | 6.73 | 6.18 | 11.85 | 10.26 | 10.05 | 21.14 | 11.59 | 11.83 |
| 3.46 | 18.94 | 16.91 | 16.27 | 24.75 | 18.19 | 18.48 | 33.96 | 18.09 | 18.96 |
| 4.09 | 34.81 | 30.05 | 29.80 | 39.31 | 26.69 | 27.74 | 47.91 | 25.01 | 26.65 |
| 4.82 | 49.10 | 41.87 | 42.27 | 51.42 | 33.76 | 35.54 | 60.54 | 31.07 | 33.42 |
| 5.69 | 61.15 | 51.81 | 52.95 | 61.06 | 39.37 | 41.78 | 71.60 | 36.22 | 39.14 |
| 6.71 | 73.58 | 61.91 | 64.03 | 70.27 | 44.50 | 47.61 | 82.41 | 41.16 | 44.68 |
| 7.92 | 82.79 | 69.43 | 72.35 | 77.04 | 48.25 | 51.91 | 90.61 | 45.19 | 49.21 |
| 9.35 | 88.67 | 74.32 | 77.71 | 81.69 | 50.90 | 54.94 | 95.77 | 48.40 | 52.81 |
| 11.03 | 92.45 | 77.53 | 81.18 | 85.08 | 52.88 | 57.17 | 98.68 | 51.04 | 55.78 |
| 13.02 | 94.78 | 79.57 | 83.34 | 87.51 | 54.35 | 58.81 | 99.71 | 53.16 | 58.20 |
| 15.36 | 96.09 | 80.76 | 84.58 | 89.14 | 55.42 | 59.96 | 99.97 | 54.78 | 60.09 |
| 18.13 | 96.85 | 81.51 | 85.33 | 90.30 | 56.25 | 60.82 | 100.03 | 56.05 | 61.62 |
| 21.39 | 97.42 | 82.12 | 85.92 | 91.31 | 57.06 | 61.60 | 100.03 | 57.24 | 63.05 |
| 25.25 | 97.92 | 82.74 | 86.49 | 92.33 | 58.04 | 62.48 | 100.03 | 58.45 | 64.55 |
| 29.79 | 98.37 | 83.45 | 87.11 | 93.39 | 59.33 | 63.55 | 100.03 | 59.79 | 66.25 |
| 35.16 | 98.80 | 84.37 | 87.88 | 94.56 | 61.20 | 64.99 | 100.03 | 61.41 | 68.27 |
| 41.49 | 99.22 | 85.66 | 88.91 | 95.87 | 63.92 | 66.97 | 100.03 | 63.44 | 70.77 |
| 48.96 | 99.59 | 87.42 | 90.30 | 97.23 | 67.78 | 69.67 | 100.03 | 66.04 | 73.84 |
| 57.77 | 99.78 | 89.22 | 91.68 | 98.21 | 72.26 | 72.68 | 100.03 | 69.05 | 77.03 |
| 68.18 | 99.90 | 91.41 | 93.34 | 98.97 | 77.79 | 76.49 | 100.03 | 72.96 | 80.64 |
| 80.45 | 99.95 | 93.35 | 94.78 | 99.40 | 83.23 | 80.50 | 100.03 | 77.42 | 84.21 |
| 94.94 | 99.97 | 95.38 | 96.28 | 99.65 | 88.60 | 85.16 | 100.03 | 82.72 | 87.97 |
| 112.04 | 99.99 | 96.97 | 97.48 | 99.77 | 92.84 | 89.57 | 100.03 | 87.99 | 91.42 |
| 132.21 | 99.99 | 98.22 | 98.45 | 99.84 | 96.05 | 93.63 | 100.03 | 92.86 | 94.56 |
| 156.02 | 99.99 | 99.19 | 99.26 | 99.89 | 98.33 | 97.06 | 100.03 | 96.87 | 97.35 |
| 184.11 | 100.00 | 99.99 | 100.00 | 99.99 | 100.01 | 100.01 | 100.03 | 99.97 | 100.00 |

Table D.1: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Inside 30 Days after 10 Minutes Settling (Continued)

| Median Size (microns) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.70 | 0.31 | 0.34 | 0.67 | 0.15 | 0.21 | 0.17 | 0.17 | 0.24 |
| 1.28 | 1.71 | 0.76 | 0.81 | 1.66 | 0.38 | 0.51 | 0.41 | 0.44 | 0.61 |
| 1.51 | 3.25 | 1.47 | 1.53 | 3.10 | 0.76 | 0.96 | 0.83 | 0.86 | 1.16 |
| 1.79 | 6.40 | 3.08 | 3.00 | 5.97 | 1.62 | 1.86 | 1.88 | 1.79 | 2.35 |
| 2.11 | 11.14 | 5.62 | 5.22 | 10.20 | 3.00 | 3.20 | 3.70 | 3.27 | 4.19 |
| 2.49 | 16.18 | 8.39 | 7.62 | 14.65 | 4.52 | 4.64 | 5.74 | 4.89 | 6.21 |
| 2.93 | 22.32 | 11.89 | 10.60 | 20.04 | 6.48 | 6.39 | 8.48 | 6.98 | 8.78 |
| 3.46 | 33.03 | 18.49 | 15.88 | 29.29 | 10.34 | 9.43 | 14.44 | 11.04 | 13.67 |
| 4.09 | 44.52 | 25.62 | 21.58 | 39.49 | 14.71 | 12.78 | 21.32 | 15.74 | 19.27 |
| 4.82 | 55.26 | 32.09 | 26.76 | 49.64 | 18.85 | 15.96 | 27.87 | 20.36 | 24.74 |
| 5.69 | 65.22 | 37.78 | 31.33 | 59.84 | 22.73 | 18.95 | 33.91 | 24.83 | 30.03 |
| 6.71 | 75.57 | 43.55 | 35.87 | 71.47 | 27.00 | 22.19 | 40.54 | 29.92 | 35.93 |
| 7.92 | 84.47 | 48.64 | 39.83 | 82.79 | 31.20 | 25.39 | 46.78 | 35.16 | 41.87 |
| 9.35 | 90.92 | 53.01 | 43.23 | 91.69 | 35.16 | 28.49 | 52.28 | 40.25 | 47.55 |
| 11.03 | 95.04 | 56.87 | 46.23 | 97.53 | 38.94 | 31.55 | 57.19 | 45.22 | 53.03 |
| 13.02 | 96.71 | 60.28 | 48.85 | 99.60 | 42.57 | 34.56 | 61.50 | 50.04 | 58.23 |
| 15.36 | 97.15 | 63.11 | 51.02 | 100.00 | 45.78 | 37.30 | 64.95 | 54.27 | 62.72 |
| 18.13 | 97.24 | 65.50 | 52.83 | 100.00 | 48.61 | 39.73 | 67.63 | 57.95 | 66.51 |
| 21.39 | 97.24 | 67.80 | 54.55 | 100.00 | 51.37 | 42.05 | 69.95 | 61.49 | 70.00 |
| 25.25 | 97.24 | 70.18 | 56.28 | 100.00 | 54.14 | 44.26 | 72.00 | 64.89 | 73.21 |
| 29.79 | 97.24 | 72.75 | 58.13 | 100.00 | 56.92 | 46.36 | 73.79 | 68.13 | 76.24 |
| 35.16 | 97.24 | 75.67 | 60.24 | 100.00 | 59.81 | 48.47 | 75.45 | 71.40 | 79.24 |
| 41.49 | 97.24 | 78.99 | 62.73 | 100.00 | 62.81 | 50.66 | 77.05 | 74.70 | 82.26 |
| 48.96 | 97.24 | 82.74 | 65.69 | 100.00 | 65.94 | 53.02 | 78.68 | 78.09 | 85.23 |
| 57.77 | 97.24 | 86.35 | 68.80 | 100.00 | 68.93 | 55.39 | 80.14 | 81.26 | 87.74 |
| 68.18 | 97.24 | 90.08 | 72.43 | 100.00 | 72.22 | 58.20 | 81.83 | 84.66 | 90.06 |
| 80.45 | 97.24 | 93.20 | 76.24 | 100.00 | 75.64 | 61.41 | 83.65 | 87.90 | 91.93 |
| 94.94 | 97.24 | 95.81 | 80.55 | 100.00 | 79.67 | 65.62 | 86.03 | 91.17 | 93.61 |
| 112.04 | 97.24 | 97.64 | 85.02 | 100.00 | 84.15 | 70.96 | 88.87 | 94.10 | 95.11 |
| 132.21 | 97.24 | 98.82 | 89.74 | 100.00 | 89.15 | 78.00 | 92.24 | 96.56 | 96.57 |
| 156.02 | 97.32 | 99.53 | 94.70 | 100.00 | 94.43 | 87.47 | 95.86 | 98.48 | 98.13 |
| 184.11 | 100.09 | 100.02 | 100.06 | 100.00 | 99.98 | 100.02 | 100.00 | 100.00 | 100.03 |

Table D.2: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Outside 30 Days after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.45 | 0.45 | 0.42 | 0.14 | 0.05 | 0.11 | 0.12 | 0.10 | 0.10 |
| 1.28 | 1.06 | 1.08 | 0.99 | 0.36 | 0.12 | 0.29 | 0.32 | 0.26 | 0.27 |
| 1.51 | 1.98 | 2.01 | 1.82 | 0.73 | 0.26 | 0.58 | 0.67 | 0.55 | 0.56 |
| 1.79 | 3.78 | 3.85 | 3.42 | 1.64 | 0.68 | 1.32 | 1.61 | 1.31 | 1.32 |
| 2.11 | 6.47 | 6.58 | 5.76 | 3.16 | 1.45 | 2.57 | 3.27 | 2.65 | 2.64 |
| 2.49 | 9.34 | 9.51 | 8.27 | 4.87 | 2.34 | 3.97 | 5.15 | 4.18 | 4.14 |
| 2.93 | 12.88 | 13.15 | 11.38 | 7.16 | 3.62 | 5.87 | 7.75 | 6.30 | 6.20 |
| 3.46 | 19.20 | 19.71 | 16.92 | 12.16 | 6.90 | 10.14 | 13.88 | 11.37 | 11.03 |
| 4.09 | 26.55 | 27.43 | 23.51 | 18.22 | 11.01 | 15.39 | 21.37 | 17.62 | 16.94 |
| 4.82 | 34.01 | 35.29 | 30.33 | 24.29 | 15.11 | 20.70 | 28.75 | 23.81 | 22.76 |
| 5.69 | 41.38 | 43.04 | 37.13 | 30.18 | 19.07 | 25.90 | 35.72 | 29.68 | 28.27 |
| 6.71 | 49.74 | 51.71 | 44.85 | 36.98 | 23.72 | 31.93 | 43.56 | 36.28 | 34.44 |
| 7.92 | 58.30 | 60.33 | 52.69 | 43.83 | 28.37 | 38.01 | 50.94 | 42.53 | 40.27 |
| 9.35 | 66.49 | 68.21 | 60.05 | 50.31 | 32.66 | 43.67 | 57.34 | 47.95 | 45.34 |
| 11.03 | 74.21 | 75.24 | 66.78 | 56.50 | 36.66 | 48.92 | 62.91 | 52.64 | 49.75 |
| 13.02 | 81.07 | 81.09 | 72.59 | 62.42 | 40.40 | 53.74 | 67.69 | 56.64 | 53.54 |
| 15.36 | 86.55 | 85.46 | 77.14 | 67.62 | 43.59 | 57.77 | 71.46 | 59.75 | 56.52 |
| 18.13 | 90.67 | 88.59 | 80.56 | 72.16 | 46.30 | 61.09 | 74.42 | 62.21 | 58.90 |
| 21.39 | 93.90 | 91.00 | 83.34 | 76.58 | 48.98 | 64.19 | 77.10 | 64.46 | 61.10 |
| 25.25 | 96.19 | 92.79 | 85.56 | 80.91 | 51.79 | 67.18 | 79.67 | 66.67 | 63.30 |
| 29.79 | 97.73 | 94.17 | 87.39 | 84.94 | 54.71 | 70.07 | 82.12 | 68.92 | 65.57 |
| 35.16 | 98.72 | 95.27 | 89.00 | 88.70 | 58.07 | 73.09 | 84.62 | 71.41 | 68.12 |
| 41.49 | 99.34 | 96.21 | 90.51 | 92.06 | 62.06 | 76.37 | 87.24 | 74.31 | 71.12 |
| 48.96 | 99.70 | 97.03 | 91.99 | 94.87 | 66.88 | 79.97 | 89.95 | 77.69 | 74.70 |
| 57.77 | 99.86 | 97.64 | 93.28 | 96.75 | 71.91 | 83.43 | 92.27 | 81.10 | 78.39 |
| 68.18 | 99.94 | 98.20 | 94.60 | 98.10 | 77.74 | 87.15 | 94.53 | 84.95 | 82.66 |
| 80.45 | 99.97 | 98.63 | 95.78 | 98.86 | 83.33 | 90.49 | 96.27 | 88.57 | 86.78 |
| 94.94 | 99.98 | 99.04 | 96.97 | 99.37 | 88.82 | 93.67 | 97.74 | 92.19 | 90.95 |
| 112.04 | 99.99 | 99.37 | 97.99 | 99.66 | 93.15 | 96.13 | 98.74 | 95.12 | 94.35 |
| 132.21 | 100.00 | 99.63 | 98.82 | 99.82 | 96.31 | 97.90 | 99.36 | 97.33 | 96.93 |
| 156.02 | 100.00 | 99.82 | 99.46 | 99.92 | 98.45 | 99.11 | 99.74 | 98.86 | 98.71 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table D.2: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Outside 30 Days after 10 Minutes Settling (Continued)

| **Median Size (microns)** | **4.0 mL** | | | **5.0 mL** | | | **6.0 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.11 | 0.10 | 0.12 | 0.11 | 0.13 | 0.08 | 0.16 | 0.17 | 0.08 |
| 1.28 | 0.29 | 0.27 | 0.32 | 0.30 | 0.35 | 0.21 | 0.44 | 0.44 | 0.21 |
| 1.51 | 0.64 | 0.59 | 0.68 | 0.67 | 0.76 | 0.48 | 0.97 | 0.93 | 0.49 |
| 1.79 | 1.69 | 1.49 | 1.68 | 1.77 | 2.00 | 1.32 | 2.64 | 2.30 | 1.39 |
| 2.11 | 3.66 | 3.15 | 3.47 | 3.85 | 4.31 | 2.92 | 5.79 | 4.75 | 3.15 |
| 2.49 | 5.95 | 5.07 | 5.54 | 6.25 | 6.96 | 4.81 | 9.41 | 7.53 | 5.23 |
| 2.93 | 9.21 | 7.77 | 8.43 | 9.66 | 10.68 | 7.56 | 14.41 | 11.34 | 8.27 |
| 3.46 | 17.58 | 14.51 | 15.48 | 18.37 | 19.88 | 14.98 | 26.24 | 20.20 | 16.61 |
| 4.09 | 27.64 | 22.64 | 24.07 | 28.77 | 30.48 | 24.04 | 38.21 | 30.36 | 26.57 |
| 4.82 | 37.04 | 30.28 | 32.31 | 38.40 | 39.95 | 32.48 | 47.05 | 39.53 | 35.57 |
| 5.69 | 45.38 | 37.12 | 39.82 | 46.84 | 47.93 | 39.90 | 53.00 | 47.37 | 43.28 |
| 6.71 | 54.17 | 44.34 | 47.87 | 55.56 | 55.80 | 47.67 | 57.47 | 55.20 | 51.19 |
| 7.92 | 61.58 | 50.52 | 54.92 | 62.71 | 61.93 | 54.08 | 59.90 | 61.55 | 57.60 |
| 9.35 | 67.32 | 55.39 | 60.54 | 68.03 | 66.36 | 58.93 | 61.20 | 66.37 | 62.41 |
| 11.03 | 71.84 | 59.27 | 65.05 | 72.05 | 69.64 | 62.67 | 61.98 | 70.15 | 66.14 |
| 13.02 | 75.34 | 62.32 | 68.59 | 74.97 | 72.02 | 65.52 | 62.46 | 73.05 | 69.04 |
| 15.36 | 77.88 | 64.56 | 71.17 | 76.96 | 73.64 | 67.57 | 62.77 | 75.16 | 71.16 |
| 18.13 | 79.77 | 66.27 | 73.08 | 78.34 | 74.79 | 69.10 | 63.01 | 76.76 | 72.77 |
| 21.39 | 81.45 | 67.83 | 74.77 | 79.51 | 75.79 | 70.47 | 63.25 | 78.21 | 74.25 |
| 25.25 | 83.12 | 69.45 | 76.42 | 80.64 | 76.81 | 71.89 | 63.63 | 79.68 | 75.79 |
| 29.79 | 84.81 | 71.21 | 78.07 | 81.80 | 77.90 | 73.36 | 64.29 | 81.23 | 77.39 |
| 35.16 | 86.65 | 73.30 | 79.87 | 83.12 | 79.21 | 75.05 | 65.53 | 82.96 | 79.15 |
| 41.49 | 88.68 | 75.88 | 81.90 | 84.72 | 80.88 | 77.03 | 67.82 | 84.93 | 81.12 |
| 48.96 | 90.90 | 79.02 | 84.19 | 86.67 | 83.02 | 79.37 | 71.68 | 87.13 | 83.30 |
| 57.77 | 92.82 | 82.23 | 86.37 | 88.63 | 85.27 | 81.67 | 76.55 | 89.15 | 85.26 |
| 68.18 | 94.75 | 85.90 | 88.80 | 90.95 | 88.03 | 84.39 | 82.73 | 91.32 | 87.44 |
| 80.45 | 96.28 | 89.32 | 91.10 | 93.13 | 90.74 | 87.09 | 88.50 | 93.23 | 89.48 |
| 94.94 | 97.67 | 92.75 | 93.57 | 95.42 | 93.66 | 90.22 | 93.55 | 95.20 | 91.86 |
| 112.04 | 98.65 | 95.47 | 95.72 | 97.23 | 96.05 | 93.18 | 96.67 | 96.86 | 94.15 |
| 132.21 | 99.30 | 97.52 | 97.53 | 98.55 | 97.87 | 95.85 | 98.48 | 98.19 | 96.35 |
| 156.02 | 99.71 | 98.94 | 98.90 | 99.40 | 99.10 | 98.08 | 99.45 | 99.19 | 98.27 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table D.3: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Freezer 4°F 30 Days after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.17 | 0.16 | 0.27 | 0.40 | 0.65 | 0.54 | 0.53 | 0.31 | 0.51 |
| 1.28 | 0.48 | 0.43 | 0.68 | 0.99 | 1.52 | 1.28 | 1.25 | 0.75 | 1.20 |
| 1.51 | 1.06 | 0.95 | 1.39 | 1.96 | 2.69 | 2.34 | 2.28 | 1.46 | 2.11 |
| 1.79 | 2.87 | 2.54 | 3.19 | 4.22 | 4.78 | 4.30 | 4.29 | 2.96 | 3.67 |
| 2.11 | 6.27 | 5.52 | 6.21 | 7.84 | 7.65 | 7.07 | 7.17 | 5.31 | 5.82 |
| 2.49 | 10.22 | 8.97 | 9.54 | 11.79 | 10.63 | 10.01 | 10.25 | 7.84 | 8.07 |
| 2.93 | 15.79 | 13.81 | 13.86 | 16.81 | 14.11 | 13.49 | 14.00 | 11.01 | 10.73 |
| 3.46 | 29.68 | 25.72 | 22.56 | 26.43 | 19.38 | 19.12 | 20.34 | 16.81 | 14.91 |
| 4.09 | 44.98 | 38.86 | 31.60 | 36.72 | 24.95 | 25.16 | 27.40 | 23.17 | 19.64 |
| 4.82 | 57.74 | 49.96 | 39.13 | 45.88 | 30.15 | 30.81 | 34.35 | 29.14 | 24.44 |
| 5.69 | 67.86 | 58.85 | 45.13 | 53.83 | 34.90 | 36.01 | 41.06 | 34.61 | 29.27 |
| 6.71 | 77.23 | 67.12 | 50.56 | 61.80 | 39.73 | 41.37 | 48.61 | 40.43 | 34.80 |
| 7.92 | 83.97 | 73.09 | 54.60 | 68.71 | 44.20 | 46.37 | 56.43 | 45.95 | 40.73 |
| 9.35 | 88.55 | 77.11 | 57.52 | 74.51 | 48.28 | 50.99 | 64.21 | 51.02 | 46.87 |
| 11.03 | 91.81 | 79.92 | 59.74 | 79.59 | 52.04 | 55.34 | 71.99 | 55.76 | 53.20 |
| 13.02 | 94.01 | 81.80 | 61.42 | 83.91 | 55.46 | 59.45 | 79.43 | 60.15 | 59.53 |
| 15.36 | 95.42 | 83.00 | 62.64 | 87.35 | 58.41 | 63.12 | 85.73 | 63.89 | 65.27 |
| 18.13 | 96.32 | 83.79 | 63.57 | 90.03 | 60.97 | 66.39 | 90.63 | 67.03 | 70.29 |
| 21.39 | 97.00 | 84.43 | 64.40 | 92.34 | 63.43 | 69.57 | 94.42 | 69.95 | 74.84 |
| 25.25 | 97.56 | 85.06 | 65.27 | 94.31 | 65.91 | 72.75 | 96.93 | 72.69 | 78.69 |
| 29.79 | 98.04 | 85.71 | 66.23 | 95.92 | 68.52 | 75.90 | 98.41 | 75.30 | 81.89 |
| 35.16 | 98.44 | 86.48 | 67.33 | 97.18 | 71.42 | 79.03 | 99.17 | 77.88 | 84.51 |
| 41.49 | 98.79 | 87.45 | 68.64 | 98.15 | 74.69 | 82.10 | 99.58 | 80.51 | 86.73 |
| 48.96 | 99.07 | 88.66 | 70.16 | 98.82 | 78.34 | 85.01 | 99.77 | 83.21 | 88.58 |
| 57.77 | 99.23 | 89.91 | 71.68 | 99.17 | 82.03 | 87.49 | 99.85 | 85.70 | 90.04 |
| 68.18 | 99.35 | 91.53 | 73.49 | 99.38 | 85.95 | 89.72 | 99.89 | 88.33 | 91.42 |
| 80.45 | 99.43 | 93.20 | 75.49 | 99.52 | 89.60 | 91.57 | 99.89 | 90.80 | 92.65 |
| 94.94 | 99.50 | 95.13 | 78.26 | 99.60 | 93.03 | 93.31 | 99.89 | 93.36 | 94.00 |
| 112.04 | 99.56 | 96.73 | 81.77 | 99.68 | 95.72 | 94.89 | 99.89 | 95.63 | 95.42 |
| 132.21 | 99.65 | 98.08 | 86.47 | 99.76 | 97.68 | 96.44 | 99.89 | 97.51 | 96.91 |
| 156.02 | 99.78 | 99.13 | 92.42 | 99.84 | 99.03 | 98.01 | 99.92 | 98.92 | 98.33 |
| 184.11 | 100.00 | 100.01 | 99.97 | 100.03 | 100.05 | 100.00 | 100.04 | 100.02 | 99.85 |

Table D.3: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Freezer 4°F 30 Days after 10 Minutes Settling (Continued)

| Median Size (microns) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.29 | 0.11 | 0.27 | 0.17 | 0.12 | 0.11 | 0.09 | 0.09 | 0.04 |
| 1.28 | 0.70 | 0.28 | 0.63 | 0.40 | 0.31 | 0.26 | 0.20 | 0.21 | 0.11 |
| 1.51 | 1.36 | 0.56 | 1.17 | 0.77 | 0.62 | 0.50 | 0.43 | 0.43 | 0.24 |
| 1.79 | 2.76 | 1.33 | 2.15 | 1.65 | 1.32 | 1.09 | 1.05 | 0.97 | 0.61 |
| 2.11 | 4.93 | 2.65 | 3.59 | 3.07 | 2.45 | 2.08 | 2.14 | 1.87 | 1.28 |
| 2.49 | 7.32 | 4.15 | 5.14 | 4.65 | 3.70 | 3.17 | 3.39 | 2.90 | 2.06 |
| 2.93 | 10.37 | 6.20 | 7.03 | 6.74 | 5.33 | 4.62 | 5.19 | 4.32 | 3.20 |
| 3.46 | 16.25 | 10.97 | 10.31 | 11.15 | 8.72 | 7.72 | 9.69 | 7.65 | 6.18 |
| 4.09 | 23.13 | 16.72 | 14.23 | 16.61 | 12.87 | 11.55 | 15.50 | 11.90 | 10.01 |
| 4.82 | 30.04 | 22.39 | 18.36 | 22.34 | 17.24 | 15.56 | 21.68 | 16.46 | 13.94 |
| 5.69 | 36.95 | 27.88 | 22.69 | 28.37 | 21.78 | 19.72 | 28.29 | 21.25 | 17.94 |
| 6.71 | 45.11 | 34.30 | 27.95 | 36.02 | 27.43 | 24.92 | 37.07 | 27.40 | 22.93 |
| 7.92 | 53.93 | 40.88 | 33.96 | 44.98 | 33.86 | 30.88 | 47.58 | 34.49 | 28.39 |
| 9.35 | 62.90 | 47.21 | 40.42 | 54.72 | 40.71 | 37.20 | 58.92 | 41.99 | 33.87 |
| 11.03 | 71.95 | 53.32 | 47.20 | 65.13 | 47.86 | 43.85 | 70.80 | 49.79 | 39.39 |
| 13.02 | 80.59 | 59.18 | 54.11 | 75.71 | 55.33 | 50.88 | 82.14 | 57.84 | 45.00 |
| 15.36 | 87.68 | 64.21 | 60.36 | 84.80 | 62.22 | 57.48 | 90.77 | 65.17 | 50.08 |
| 18.13 | 92.83 | 68.38 | 65.68 | 91.58 | 68.32 | 63.41 | 96.04 | 71.53 | 54.54 |
| 21.39 | 96.47 | 72.16 | 70.37 | 96.36 | 74.06 | 69.12 | 98.89 | 77.48 | 58.91 |
| 25.25 | 98.49 | 75.54 | 74.17 | 98.75 | 79.13 | 74.31 | 99.80 | 82.77 | 63.16 |
| 29.79 | 99.45 | 78.43 | 77.13 | 99.66 | 83.33 | 78.67 | 99.97 | 87.09 | 67.01 |
| 35.16 | 99.85 | 81.03 | 79.49 | 99.93 | 86.84 | 82.34 | 99.97 | 90.65 | 70.70 |
| 41.49 | 100.00 | 83.45 | 81.41 | 100.00 | 89.70 | 85.38 | 99.97 | 93.53 | 74.23 |
| 48.96 | 100.04 | 85.74 | 83.02 | 100.00 | 91.98 | 87.86 | 99.97 | 95.77 | 77.61 |
| 57.77 | 100.04 | 87.66 | 84.33 | 100.00 | 93.59 | 89.67 | 99.97 | 97.21 | 80.51 |
| 68.18 | 100.04 | 89.67 | 85.65 | 100.00 | 94.91 | 91.27 | 99.97 | 98.26 | 83.55 |
| 80.45 | 100.04 | 91.53 | 86.97 | 100.00 | 95.89 | 92.60 | 99.97 | 98.90 | 86.43 |
| 94.94 | 100.04 | 93.59 | 88.64 | 100.00 | 96.83 | 94.00 | 99.97 | 99.36 | 89.69 |
| 112.04 | 100.04 | 95.53 | 90.73 | 100.00 | 97.65 | 95.45 | 99.97 | 99.63 | 92.91 |
| 132.21 | 100.04 | 97.28 | 93.30 | 100.00 | 98.44 | 96.94 | 99.97 | 99.81 | 95.86 |
| 156.02 | 100.04 | 98.74 | 96.29 | 100.00 | 99.21 | 98.42 | 99.97 | 99.91 | 98.24 |
| 184.11 | 100.04 | 100.00 | 99.97 | 100.00 | 100.07 | 100.02 | 99.97 | 100.00 | 100.03 |

Table D.4: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Freezer 36°F 30 Days after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.13 | 0.20 | 0.24 | 0.37 | 0.67 | 0.22 | 0.25 | 0.42 | 0.25 |
| 1.28 | 0.35 | 0.53 | 0.64 | 0.87 | 1.58 | 0.56 | 0.59 | 0.95 | 0.58 |
| 1.51 | 0.77 | 1.15 | 1.34 | 1.61 | 2.92 | 1.12 | 1.08 | 1.71 | 1.07 |
| 1.79 | 2.01 | 2.94 | 3.24 | 3.02 | 5.47 | 2.39 | 1.99 | 3.07 | 2.09 |
| 2.11 | 4.30 | 6.21 | 6.58 | 5.07 | 9.16 | 4.42 | 3.32 | 4.98 | 3.59 |
| 2.49 | 6.92 | 9.95 | 10.33 | 7.23 | 13.05 | 6.65 | 4.73 | 6.99 | 5.22 |
| 2.93 | 10.53 | 15.10 | 15.37 | 9.80 | 17.72 | 9.50 | 6.41 | 9.36 | 7.23 |
| 3.46 | 19.08 | 27.18 | 26.43 | 13.92 | 25.30 | 15.02 | 9.18 | 13.12 | 10.80 |
| 4.09 | 28.25 | 40.29 | 38.40 | 18.13 | 33.35 | 21.09 | 12.19 | 17.27 | 14.83 |
| 4.82 | 35.82 | 51.28 | 48.60 | 21.84 | 40.77 | 26.65 | 15.04 | 21.35 | 18.77 |
| 5.69 | 41.75 | 60.05 | 56.89 | 25.01 | 47.43 | 31.58 | 17.66 | 25.27 | 22.57 |
| 6.71 | 47.15 | 68.15 | 64.61 | 28.05 | 54.15 | 36.61 | 20.40 | 29.56 | 26.80 |
| 7.92 | 51.07 | 74.11 | 70.42 | 30.61 | 60.23 | 41.02 | 22.98 | 33.87 | 31.08 |
| 9.35 | 53.84 | 78.27 | 74.58 | 32.80 | 65.68 | 44.77 | 25.38 | 38.09 | 35.25 |
| 11.03 | 55.94 | 81.34 | 77.69 | 34.75 | 70.70 | 48.05 | 27.68 | 42.22 | 39.38 |
| 13.02 | 57.58 | 83.54 | 79.96 | 36.53 | 75.28 | 50.94 | 29.92 | 46.21 | 43.49 |
| 15.36 | 58.84 | 85.05 | 81.56 | 38.13 | 79.23 | 53.35 | 32.04 | 49.80 | 47.33 |
| 18.13 | 59.89 | 86.14 | 82.73 | 39.62 | 82.62 | 55.44 | 34.07 | 52.99 | 50.92 |
| 21.39 | 60.98 | 87.09 | 83.78 | 41.22 | 85.75 | 57.49 | 36.24 | 56.03 | 54.59 |
| 25.25 | 62.39 | 88.04 | 84.88 | 43.18 | 88.67 | 59.73 | 38.78 | 59.03 | 58.52 |
| 29.79 | 64.30 | 89.06 | 86.15 | 45.63 | 91.34 | 62.24 | 41.73 | 62.02 | 62.59 |
| 35.16 | 67.08 | 90.22 | 87.70 | 48.99 | 93.64 | 65.28 | 45.54 | 65.21 | 67.05 |
| 41.49 | 71.06 | 91.56 | 89.67 | 53.54 | 95.64 | 69.03 | 50.47 | 68.78 | 71.90 |
| 48.96 | 76.34 | 93.07 | 92.02 | 59.45 | 97.22 | 73.69 | 56.68 | 72.91 | 77.16 |
| 57.77 | 81.91 | 94.39 | 94.12 | 66.27 | 98.25 | 78.70 | 63.81 | 77.33 | 82.24 |
| 68.18 | 87.92 | 95.75 | 96.16 | 74.04 | 98.94 | 84.39 | 71.87 | 82.43 | 87.34 |
| 80.45 | 92.65 | 96.79 | 97.51 | 81.56 | 99.33 | 89.59 | 79.70 | 87.43 | 91.62 |
| 94.94 | 96.30 | 97.78 | 98.55 | 88.61 | 99.58 | 94.12 | 87.18 | 92.18 | 95.15 |
| 112.04 | 98.27 | 98.51 | 99.13 | 93.75 | 99.72 | 97.09 | 92.77 | 95.73 | 97.48 |
| 132.21 | 99.29 | 99.08 | 99.49 | 97.14 | 99.81 | 98.73 | 96.59 | 97.99 | 98.84 |
| 156.02 | 99.77 | 99.56 | 99.77 | 99.09 | 99.89 | 99.55 | 98.87 | 99.29 | 99.59 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.04 | 99.97 | 100.00 | 99.97 | 100.07 | 100.02 |

Table D.4: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Freezer 36°F 30 Days after 10 Minutes Settling (Continued)

| Median Size (microns ) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.13 | 0.17 | 0.10 | 0.04 | 0.04 | 0.11 | 0.04 | 0.06 | 0.02 |
| 1.28 | 0.33 | 0.40 | 0.24 | 0.12 | 0.12 | 0.25 | 0.11 | 0.15 | 0.06 |
| 1.51 | 0.61 | 0.78 | 0.44 | 0.26 | 0.26 | 0.49 | 0.22 | 0.30 | 0.13 |
| 1.79 | 1.17 | 1.56 | 0.83 | 0.59 | 0.67 | 0.98 | 0.53 | 0.66 | 0.37 |
| 2.11 | 2.02 | 2.79 | 1.44 | 1.17 | 1.42 | 1.76 | 1.07 | 1.26 | 0.85 |
| 2.49 | 2.92 | 4.12 | 2.09 | 1.84 | 2.28 | 2.62 | 1.70 | 1.93 | 1.42 |
| 2.93 | 4.04 | 5.81 | 2.91 | 2.77 | 3.49 | 3.74 | 2.58 | 2.83 | 2.28 |
| 3.46 | 6.06 | 9.05 | 4.44 | 4.94 | 6.50 | 6.03 | 4.75 | 4.84 | 4.85 |
| 4.09 | 8.43 | 12.90 | 6.31 | 7.68 | 10.26 | 8.92 | 7.56 | 7.41 | 8.30 |
| 4.82 | 10.84 | 16.85 | 8.32 | 10.50 | 14.04 | 12.05 | 10.52 | 10.15 | 11.87 |
| 5.69 | 13.22 | 20.80 | 10.44 | 13.31 | 17.79 | 15.35 | 13.52 | 13.03 | 15.51 |
| 6.71 | 15.96 | 25.45 | 13.04 | 16.67 | 22.37 | 19.51 | 17.24 | 16.67 | 20.17 |
| 7.92 | 18.84 | 30.47 | 16.00 | 20.17 | 27.23 | 24.31 | 21.25 | 20.83 | 25.35 |
| 9.35 | 21.76 | 35.60 | 19.15 | 23.58 | 32.10 | 29.41 | 25.26 | 25.23 | 30.64 |
| 11.03 | 24.75 | 40.93 | 22.46 | 26.95 | 37.01 | 34.76 | 29.25 | 29.79 | 36.09 |
| 13.02 | 27.86 | 46.55 | 25.93 | 30.41 | 42.10 | 40.41 | 33.36 | 34.58 | 41.97 |
| 15.36 | 30.92 | 51.99 | 29.21 | 33.74 | 46.88 | 45.80 | 37.22 | 39.09 | 47.64 |
| 18.13 | 33.89 | 57.19 | 32.27 | 36.91 | 51.29 | 50.85 | 40.81 | 43.21 | 53.01 |
| 21.39 | 37.05 | 62.58 | 35.32 | 40.32 | 55.82 | 56.00 | 44.58 | 47.31 | 58.73 |
| 25.25 | 40.58 | 68.08 | 38.39 | 44.20 | 60.48 | 61.19 | 48.73 | 51.35 | 64.85 |
| 29.79 | 44.38 | 73.38 | 41.42 | 48.29 | 64.86 | 66.17 | 53.05 | 55.13 | 70.70 |
| 35.16 | 48.93 | 78.48 | 44.65 | 53.14 | 69.10 | 71.20 | 58.07 | 58.85 | 76.48 |
| 41.49 | 54.37 | 83.30 | 48.25 | 58.79 | 73.08 | 76.25 | 63.86 | 62.58 | 81.88 |
| 48.96 | 60.70 | 87.72 | 52.48 | 65.24 | 76.77 | 81.29 | 70.29 | 66.40 | 86.74 |
| 57.77 | 67.42 | 91.23 | 57.32 | 71.72 | 79.82 | 85.74 | 76.47 | 70.07 | 90.36 |
| 68.18 | 74.67 | 94.27 | 63.49 | 78.64 | 82.89 | 89.92 | 82.81 | 74.22 | 93.41 |
| 80.45 | 81.47 | 96.41 | 70.66 | 84.87 | 85.70 | 93.20 | 88.13 | 78.57 | 95.54 |
| 94.94 | 88.05 | 98.01 | 78.88 | 90.75 | 88.90 | 95.91 | 92.93 | 83.67 | 97.26 |
| 112.04 | 93.13 | 98.99 | 86.63 | 95.03 | 92.14 | 97.77 | 96.26 | 88.84 | 98.44 |
| 132.21 | 96.70 | 99.51 | 92.87 | 97.77 | 95.19 | 98.91 | 98.33 | 93.48 | 99.21 |
| 156.02 | 98.90 | 99.81 | 97.20 | 99.30 | 97.82 | 99.58 | 99.47 | 97.20 | 99.69 |
| 184.11 | 99.99 | 100.00 | 100.00 | 99.99 | 99.99 | 100.02 | 99.98 | 100.01 | 100.01 |

Table D.5: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Oven 111°F 30 Days after 10 Minutes Settling

| **Median Size (microns)** | **1.0 mL** | | | **2.0 mL** | | | **3.0 mL** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** | **Rep 1** | **Rep 2** | **Rep 3** |
| 1.09 | 0.01 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.28 | 0.04 | 0.02 | 0.06 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 |
| 1.51 | 0.08 | 0.05 | 0.13 | 0.04 | 0.03 | 0.03 | 0.01 | 0.03 | 0.01 |
| 1.79 | 0.26 | 0.17 | 0.36 | 0.13 | 0.10 | 0.10 | 0.03 | 0.11 | 0.05 |
| 2.11 | 0.61 | 0.41 | 0.82 | 0.36 | 0.27 | 0.28 | 0.11 | 0.31 | 0.17 |
| 2.49 | 1.06 | 0.72 | 1.36 | 0.65 | 0.50 | 0.51 | 0.23 | 0.57 | 0.32 |
| 2.93 | 1.76 | 1.21 | 2.18 | 1.16 | 0.88 | 0.92 | 0.46 | 1.05 | 0.63 |
| 3.46 | 4.11 | 2.96 | 4.59 | 3.31 | 2.49 | 2.71 | 1.94 | 3.18 | 2.31 |
| 4.09 | 7.44 | 5.46 | 7.89 | 6.57 | 4.95 | 5.56 | 4.51 | 6.48 | 5.19 |
| 4.82 | 10.98 | 8.13 | 11.38 | 10.05 | 7.61 | 8.73 | 7.31 | 10.04 | 8.43 |
| 5.69 | 14.65 | 10.89 | 14.98 | 13.64 | 10.37 | 12.09 | 10.20 | 13.72 | 11.87 |
| 6.71 | 19.48 | 14.53 | 19.61 | 18.45 | 14.12 | 16.72 | 14.19 | 18.67 | 16.70 |
| 7.92 | 24.87 | 18.56 | 24.75 | 23.64 | 18.25 | 21.77 | 18.29 | 23.98 | 21.83 |
| 9.35 | 30.32 | 22.57 | 29.95 | 28.53 | 22.23 | 26.48 | 21.81 | 28.89 | 26.40 |
| 11.03 | 35.90 | 26.59 | 35.19 | 33.07 | 26.07 | 30.82 | 24.79 | 33.42 | 30.39 |
| 13.02 | 41.89 | 30.82 | 40.64 | 37.46 | 29.93 | 34.95 | 27.47 | 37.74 | 34.04 |
| 15.36 | 47.62 | 34.75 | 45.67 | 41.14 | 33.32 | 38.39 | 29.56 | 41.34 | 36.94 |
| 18.13 | 53.01 | 38.33 | 50.21 | 44.18 | 36.27 | 41.21 | 31.21 | 44.33 | 39.26 |
| 21.39 | 58.77 | 42.04 | 54.82 | 47.15 | 39.30 | 43.93 | 32.84 | 47.28 | 41.52 |
| 25.25 | 64.92 | 45.89 | 59.45 | 50.18 | 42.51 | 46.71 | 34.64 | 50.37 | 43.94 |
| 29.79 | 70.69 | 49.44 | 63.70 | 53.03 | 45.63 | 49.28 | 36.46 | 53.33 | 46.30 |
| 35.16 | 76.32 | 52.95 | 67.79 | 56.05 | 49.00 | 51.98 | 38.68 | 56.52 | 48.97 |
| 41.49 | 81.53 | 56.37 | 71.65 | 59.32 | 52.63 | 54.87 | 41.39 | 59.95 | 52.03 |
| 48.96 | 86.18 | 59.75 | 75.28 | 62.93 | 56.60 | 58.05 | 44.77 | 63.65 | 55.51 |
| 57.77 | 89.62 | 62.68 | 78.26 | 66.40 | 60.38 | 61.08 | 48.29 | 67.05 | 58.90 |
| 68.18 | 92.58 | 65.91 | 81.22 | 70.62 | 64.87 | 64.75 | 53.02 | 70.97 | 63.02 |
| 80.45 | 94.70 | 69.20 | 83.88 | 75.06 | 69.57 | 68.74 | 58.40 | 74.91 | 67.44 |
| 94.94 | 96.51 | 73.50 | 86.90 | 80.62 | 75.50 | 74.06 | 65.89 | 79.84 | 73.30 |
| 112.04 | 97.86 | 78.68 | 90.07 | 86.38 | 81.94 | 80.22 | 74.47 | 85.13 | 79.97 |
| 132.21 | 98.84 | 85.01 | 93.43 | 91.94 | 88.62 | 87.11 | 83.88 | 90.64 | 87.49 |
| 156.02 | 99.50 | 92.23 | 96.74 | 96.48 | 94.72 | 93.82 | 92.64 | 95.66 | 94.32 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table D.5: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored Oven 111°F 30 Days after 10 Minutes Settling (Continued)

| Median Size (microns) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 |
| 1.28 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.03 | 0.02 | 0.05 |
| 1.51 | 0.04 | 0.02 | 0.02 | 0.05 | 0.07 | 0.10 | 0.07 | 0.04 | 0.12 |
| 1.79 | 0.18 | 0.09 | 0.10 | 0.20 | 0.28 | 0.37 | 0.26 | 0.18 | 0.45 |
| 2.11 | 0.51 | 0.27 | 0.28 | 0.57 | 0.76 | 1.00 | 0.73 | 0.53 | 1.20 |
| 2.49 | 0.95 | 0.51 | 0.53 | 1.06 | 1.39 | 1.80 | 1.35 | 1.00 | 2.16 |
| 2.93 | 1.75 | 0.96 | 1.00 | 1.95 | 2.50 | 3.15 | 2.42 | 1.88 | 3.79 |
| 3.46 | 5.45 | 3.25 | 3.33 | 6.00 | 7.23 | 8.51 | 7.02 | 6.19 | 10.12 |
| 4.09 | 11.04 | 6.91 | 7.09 | 12.13 | 14.20 | 16.14 | 13.72 | 12.81 | 18.99 |
| 4.82 | 16.80 | 10.82 | 11.19 | 18.44 | 21.36 | 23.85 | 20.42 | 19.60 | 27.74 |
| 5.69 | 22.43 | 14.80 | 15.41 | 24.58 | 28.31 | 31.30 | 26.75 | 26.18 | 35.95 |
| 6.71 | 29.53 | 20.12 | 21.08 | 32.28 | 36.89 | 40.36 | 34.29 | 34.42 | 45.59 |
| 7.92 | 36.29 | 25.58 | 26.88 | 39.57 | 44.99 | 48.92 | 41.03 | 42.15 | 54.24 |
| 9.35 | 41.73 | 30.35 | 31.89 | 45.45 | 51.51 | 55.87 | 46.17 | 48.27 | 60.94 |
| 11.03 | 46.05 | 34.49 | 36.16 | 50.14 | 56.68 | 61.43 | 50.06 | 53.11 | 66.09 |
| 13.02 | 49.51 | 38.24 | 39.94 | 53.94 | 60.80 | 65.87 | 53.02 | 57.03 | 70.04 |
| 15.36 | 51.94 | 41.19 | 42.88 | 56.66 | 63.69 | 69.01 | 55.05 | 59.85 | 72.77 |
| 18.13 | 53.69 | 43.55 | 45.21 | 58.66 | 65.78 | 71.26 | 56.49 | 61.95 | 74.72 |
| 21.39 | 55.26 | 45.86 | 47.47 | 60.50 | 67.65 | 73.25 | 57.81 | 63.94 | 76.47 |
| 25.25 | 56.90 | 48.35 | 49.92 | 62.41 | 69.55 | 75.20 | 59.23 | 66.11 | 78.28 |
| 29.79 | 58.58 | 50.84 | 52.35 | 64.37 | 71.46 | 77.11 | 60.81 | 68.39 | 80.16 |
| 35.16 | 60.61 | 53.68 | 55.11 | 66.64 | 73.63 | 79.18 | 62.81 | 71.12 | 82.33 |
| 41.49 | 63.13 | 56.91 | 58.22 | 69.33 | 76.17 | 81.47 | 65.41 | 74.36 | 84.84 |
| 48.96 | 66.25 | 60.57 | 61.61 | 72.45 | 79.06 | 83.96 | 68.69 | 78.05 | 87.62 |
| 57.77 | 69.34 | 63.95 | 64.72 | 75.31 | 81.69 | 86.09 | 71.93 | 81.28 | 89.95 |
| 68.18 | 73.14 | 67.91 | 68.20 | 78.57 | 84.63 | 88.34 | 75.77 | 84.69 | 92.29 |
| 80.45 | 76.96 | 71.83 | 71.68 | 81.63 | 87.27 | 90.28 | 79.42 | 87.57 | 94.11 |
| 94.94 | 81.68 | 76.78 | 76.24 | 85.28 | 90.26 | 92.42 | 83.67 | 90.62 | 95.88 |
| 112.04 | 86.52 | 82.22 | 81.51 | 88.98 | 93.08 | 94.45 | 87.85 | 93.34 | 97.28 |
| 132.21 | 91.45 | 88.23 | 87.82 | 92.82 | 95.73 | 96.42 | 92.09 | 95.86 | 98.41 |
| 156.02 | 96.00 | 94.26 | 94.03 | 96.52 | 98.01 | 98.23 | 96.18 | 98.04 | 99.27 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table D.6: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored UV Exposed 30 Days after 10 Minutes Settling

| Median Size (microns) | 1.0 mL | | | 2.0 mL | | | 3.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.12 | 0.20 | 0.19 | 0.21 | 0.32 | 0.40 | 0.23 | 0.21 | 0.19 |
| 1.28 | 0.32 | 0.53 | 0.52 | 0.56 | 0.82 | 1.00 | 0.60 | 0.56 | 0.51 |
| 1.51 | 0.71 | 1.13 | 1.10 | 1.18 | 1.68 | 1.99 | 1.27 | 1.19 | 1.08 |
| 1.79 | 1.88 | 2.81 | 2.76 | 2.90 | 3.82 | 4.29 | 3.06 | 2.91 | 2.68 |
| 2.11 | 4.09 | 5.83 | 5.74 | 5.95 | 7.43 | 8.04 | 6.21 | 5.96 | 5.52 |
| 2.49 | 6.64 | 9.24 | 9.11 | 9.39 | 11.43 | 12.12 | 9.75 | 9.40 | 8.73 |
| 2.93 | 10.27 | 13.94 | 13.78 | 14.08 | 16.71 | 17.41 | 14.53 | 14.09 | 13.14 |
| 3.46 | 19.60 | 25.05 | 24.90 | 24.93 | 27.96 | 28.04 | 25.40 | 24.97 | 23.49 |
| 4.09 | 30.90 | 38.24 | 38.20 | 37.70 | 41.00 | 40.33 | 38.13 | 37.84 | 35.83 |
| 4.82 | 41.62 | 50.82 | 50.93 | 49.81 | 53.41 | 52.20 | 50.24 | 50.18 | 47.78 |
| 5.69 | 51.15 | 62.15 | 62.40 | 60.64 | 64.54 | 63.05 | 61.14 | 61.36 | 58.79 |
| 6.71 | 61.03 | 73.96 | 74.34 | 71.85 | 75.85 | 74.24 | 72.47 | 73.11 | 70.63 |
| 7.92 | 68.88 | 83.58 | 84.01 | 80.98 | 84.96 | 83.57 | 81.82 | 82.84 | 80.78 |
| 9.35 | 74.27 | 90.35 | 90.73 | 87.46 | 91.32 | 90.33 | 88.55 | 89.82 | 88.31 |
| 11.03 | 77.86 | 94.89 | 95.17 | 91.87 | 95.52 | 94.94 | 93.19 | 94.59 | 93.63 |
| 13.02 | 79.97 | 97.47 | 97.66 | 94.47 | 97.85 | 97.56 | 95.96 | 97.34 | 96.81 |
| 15.36 | 81.09 | 98.74 | 98.86 | 95.81 | 98.96 | 98.85 | 97.40 | 98.72 | 98.45 |
| 18.13 | 81.67 | 99.33 | 99.41 | 96.48 | 99.46 | 99.43 | 98.12 | 99.35 | 99.22 |
| 21.39 | 82.03 | 99.63 | 99.68 | 96.86 | 99.71 | 99.71 | 98.54 | 99.67 | 99.62 |
| 25.25 | 82.28 | 99.79 | 99.82 | 97.09 | 99.84 | 99.85 | 98.78 | 99.83 | 99.81 |
| 29.79 | 82.49 | 99.87 | 99.90 | 97.25 | 99.90 | 99.92 | 98.94 | 99.91 | 99.91 |
| 35.16 | 82.68 | 99.92 | 99.94 | 97.36 | 99.94 | 99.95 | 99.06 | 99.95 | 99.95 |
| 41.49 | 82.90 | 99.95 | 99.96 | 97.47 | 99.96 | 99.97 | 99.15 | 99.98 | 99.98 |
| 48.96 | 83.18 | 99.97 | 99.98 | 97.57 | 99.98 | 99.99 | 99.24 | 99.99 | 99.99 |
| 57.77 | 83.47 | 99.98 | 99.99 | 97.65 | 99.98 | 99.99 | 99.30 | 100.00 | 100.00 |
| 68.18 | 83.94 | 99.99 | 99.99 | 97.75 | 99.99 | 99.99 | 99.37 | 100.00 | 100.00 |
| 80.45 | 84.61 | 99.99 | 99.99 | 97.86 | 99.99 | 100.00 | 99.43 | 100.00 | 100.00 |
| 94.94 | 85.93 | 99.99 | 100.00 | 98.05 | 99.99 | 100.00 | 99.51 | 100.00 | 100.00 |
| 112.04 | 88.01 | 99.99 | 100.00 | 98.33 | 100.00 | 100.00 | 99.61 | 100.00 | 100.00 |
| 132.21 | 91.20 | 100.00 | 100.00 | 98.74 | 100.00 | 100.00 | 99.72 | 100.00 | 100.00 |
| 156.02 | 95.27 | 100.00 | 100.00 | 99.29 | 100.00 | 100.00 | 99.85 | 100.00 | 100.00 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table D.6: Percent Finer Particle Size Distribution of Jar Test Screening for Magnafloc 351 Stored UV Exposed 30 Days after 10 Minutes Settling (Continued)

| Median Size (microns) | 4.0 mL | | | 5.0 mL | | | 6.0 mL | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 | Rep 1 | Rep 2 | Rep 3 |
| 1.09 | 0.40 | 0.43 | 0.43 | 0.34 | 0.21 | 0.26 | 0.30 | 0.35 | 0.33 |
| 1.28 | 1.00 | 1.07 | 1.07 | 0.87 | 0.54 | 0.66 | 0.78 | 0.90 | 0.84 |
| 1.51 | 1.97 | 2.11 | 2.11 | 1.75 | 1.16 | 1.37 | 1.60 | 1.81 | 1.72 |
| 1.79 | 4.24 | 4.52 | 4.54 | 3.91 | 2.87 | 3.21 | 3.73 | 4.03 | 3.90 |
| 2.11 | 7.92 | 8.39 | 8.47 | 7.50 | 5.92 | 6.37 | 7.37 | 7.73 | 7.58 |
| 2.49 | 11.95 | 12.62 | 12.75 | 11.45 | 9.38 | 9.90 | 11.42 | 11.80 | 11.65 |
| 2.93 | 17.14 | 18.06 | 18.27 | 16.62 | 14.10 | 14.62 | 16.82 | 17.14 | 17.03 |
| 3.46 | 27.59 | 28.86 | 29.28 | 27.34 | 25.18 | 25.03 | 28.59 | 28.27 | 28.51 |
| 4.09 | 39.72 | 41.28 | 41.93 | 39.74 | 38.25 | 37.30 | 42.22 | 41.16 | 41.85 |
| 4.82 | 51.48 | 53.19 | 54.04 | 51.65 | 50.70 | 49.18 | 55.06 | 53.47 | 54.53 |
| 5.69 | 62.29 | 64.01 | 65.00 | 62.49 | 61.93 | 60.11 | 66.38 | 64.55 | 65.86 |
| 6.71 | 73.50 | 75.03 | 76.10 | 73.73 | 73.65 | 71.71 | 77.68 | 75.83 | 77.26 |
| 7.92 | 82.92 | 84.11 | 85.13 | 83.11 | 83.28 | 81.58 | 86.48 | 84.94 | 86.25 |
| 9.35 | 89.81 | 90.63 | 91.49 | 89.92 | 90.12 | 88.88 | 92.40 | 91.32 | 92.36 |
| 11.03 | 94.56 | 95.05 | 95.70 | 94.60 | 94.76 | 93.98 | 96.18 | 95.55 | 96.28 |
| 13.02 | 97.30 | 97.56 | 98.00 | 97.29 | 97.42 | 97.00 | 98.18 | 97.87 | 98.34 |
| 15.36 | 98.67 | 98.79 | 99.09 | 98.63 | 98.74 | 98.54 | 99.12 | 98.98 | 99.28 |
| 18.13 | 99.31 | 99.36 | 99.56 | 99.26 | 99.35 | 99.26 | 99.52 | 99.48 | 99.67 |
| 21.39 | 99.63 | 99.65 | 99.79 | 99.58 | 99.66 | 99.62 | 99.73 | 99.72 | 99.85 |
| 25.25 | 99.79 | 99.79 | 99.89 | 99.74 | 99.82 | 99.80 | 99.83 | 99.84 | 99.93 |
| 29.79 | 99.87 | 99.87 | 99.94 | 99.83 | 99.90 | 99.89 | 99.88 | 99.90 | 99.97 |
| 35.16 | 99.92 | 99.92 | 99.97 | 99.88 | 99.94 | 99.94 | 99.91 | 99.94 | 99.98 |
| 41.49 | 99.95 | 99.94 | 99.98 | 99.92 | 99.97 | 99.97 | 99.94 | 99.96 | 99.99 |
| 48.96 | 99.97 | 99.96 | 99.99 | 99.94 | 99.98 | 99.98 | 99.95 | 99.97 | 100.00 |
| 57.77 | 99.98 | 99.97 | 100.00 | 99.95 | 99.99 | 99.99 | 99.96 | 99.98 | 100.00 |
| 68.18 | 99.99 | 99.98 | 100.00 | 99.96 | 99.99 | 99.99 | 99.97 | 99.99 | 100.00 |
| 80.45 | 99.99 | 99.98 | 100.00 | 99.97 | 100.00 | 100.00 | 99.97 | 99.99 | 100.00 |
| 94.94 | 99.99 | 99.99 | 100.00 | 99.97 | 100.00 | 100.00 | 99.98 | 99.99 | 100.00 |
| 112.04 | 99.99 | 99.99 | 100.00 | 99.98 | 100.00 | 100.00 | 99.98 | 99.99 | 100.00 |
| 132.21 | 100.00 | 99.99 | 100.00 | 99.99 | 100.00 | 100.00 | 99.99 | 100.00 | 100.00 |
| 156.02 | 100.00 | 100.00 | 100.00 | 99.99 | 100.00 | 100.00 | 99.99 | 100.00 | 100.00 |
| 184.11 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

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