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MONITORING AND RESEARCH DEPARTMENT

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EVALUATION OF POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT

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EVALUATION OF POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT

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TABLE OF CONTENTS

Page

LIST OF TABLES vi

LIST OF FIGURES ix

LIST OF ABBREVIATIONS xi

ACKNOWLEDGMENTS xii

DISCLAIMER xii

EXECUTIVE SUMMARY xiii

- Phase I xiii
- Phase II xv
- Phase III xvi

EVALUATION FOR POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT – PHASE I 1

- Introduction 1
- Background 1
    - Overview of Solids Processes 1
    - Polymer Conditioning in the Post-Centrifuge Operations 2
    - Current Operations at the Post-Centrifuge Facility 2
        - Existing Procedure for Preparation of Dilute Polymer 2
        - Existing Procedure for Centrifuge Operation 4
- Objectives 6
- Materials and Methods 7
    - Review and Document Current Operations 7

TABLE OF CONTENTS (Continued)

Page

Quality Control for Sample Handling and Data Analysis 7

Verification of Polymer Quality 8

Baseline Centrifuge Operations and Polymer Consumption 9

Identification of Better-Performing Machines 9

Optimization of Polymer Demand by Adjusting Machine/ Operational Settings 9

Laboratory-Scale Tests for Potential Polymer Savings 11

Evaluation of Switch in Dilution Water 11

Evaluation of Surface Tension as an Indicator of Excess Polymer Use 11

Results and Discussion 12

Verification of Polymer Quality 12

Baseline Centrifuge Operations and Polymer Consumption 17

Baseline Centrifuge Operation 17

Baseline Polymer Consumption 24

Identification of Better-Performing Machines 27

Optimization of Polymer Demand by Adjusting Machine/ Operational Settings 29

Laboratory-Scale Tests for Potential Polymer Savings 34

Evaluation of Switch in Dilution Water 34

Evaluation of Surface Tension as an Indicator of Excess Polymer Use 34

Phase I Conclusions and Recommendations 34

TABLE OF CONTENTS (Continued)

Page

Conclusions 34

Recommendations 42

References 43

EVALUATION FOR POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT – PHASE II: SIDE-BY-SIDE TESTS 44

Background 44

Materials and Methods 44

Results 48

Comparison of Centrifuge Feed, Digester Draw, and Polymer Characteristics Between the Baseline and Testing Periods 48

Overall Comparison Between Maintenance and Operations Department- Versus Monitoring and Research Department-Run Machines Based on Hourly Data Collected During the Testing Period 49

Pair-wise Comparison Between Maintenance and Operations Department- Versus Monitoring and Research Department-Run Machines During the Testing Period 51

Torque 51

Sludge Flow 51

Polymer Flow 56

Polymer to Sludge Flow Ratios 56

Overall and Pair-Wise Comparison Between Testing and Non-Testing Periods for Maintenance and Operations Department- and Monitoring and Research Department-Run Machines 57

Phase II Conclusions and Recommendations 65

TABLE OF CONTENTS (Continued)

Page

Conclusions 65

Recommendations 69

EVALUATION FOR POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT – PHASE III: LABORATORY TESTS AND HISTORIC DATA REVIEW 70

Background 70

Materials and Methods 70

Objective 4: Compare Monthly Measured Dilute Polymer Consumption Versus Monthly Polymer Purchase Records 70

Laboratory-Scale Tests for Potential Polymer Savings (Objective Numbers 8a, 8c, 8d, and 8e) 70

Objective 8a: Comparison of City Water Versus Stickney Secondary Treated Effluent for Dilute Polymer Preparation – Additional Tests 70

Objective 8c: Laboratory-Scale Evaluation of Variations in Dilute Polymer Charge to Determine Maximum Allowable Storage Time Before Use 71

Objective 8d: Full-Scale Evaluation of Centrifuge Machines at Lower Dilute Polymer Strength 71

Objective 8e: Evaluation of Centrifuge Feed Characteristics (Historic Data Review) 72

Results and Discussion 72

Objective 4: Compare Monthly Measured Dilute Polymer Consumption Versus Monthly Polymer Purchase Records 72

Laboratory-Scale Tests for Potential Polymer Savings (Objective Numbers 8a, 8c, 8d, and 8e) 74

TABLE OF CONTENTS (Continued)

Page

Objective 8a: Comparison of City Water Versus Stickney Secondary Treated Effluent for Dilute Polymer Preparation – Additional Tests 74

Objective 8c: Laboratory-Scale Evaluation of Variations in Dilute Polymer Charge to Determine Maximum Allowable Storage Time Before Use 74

Objective 8d: Full-Scale Evaluation of Centrifuge Machines at Lower Dilute Polymer Strength 74

Objective 8e: Evaluation of Centrifuge Feed Characteristics (Historic Data Review) 82

Phase III Conclusions and Recommendations 89

Conclusions 90

Recommendations 90

References 91

APPENDICES

An Hourly Data Sheet for Centrifuge Machine Number 4 for February 19, 2011, Hourly Data AI

Method for Percent Active Solids Determination AII

Approved Work Plans AIII

Preventive Maintenance Schedule for the Centrifuge Machines at the Post-Centrifuge Facility at the Stickney Water Reclamation Plant AIV

LIST OF TABLES

Table No.		Page
1	Average Polymer Use Versus Recommended Polymer Dose from Procurement Testing at the Stickney Water Reclamation Plant (2007 Through 2010)	3
2	Dimensions of the Polymer Storage Tanks, Mixing Tanks, and Aging Tanks for the Pre- and Post-Centrifuge Facilities at the Stickney Water Reclamation Plant	5
3	Percent Total and Percent Active Solids of Raw Polymer Samples and Percent Total Solids of Dilute Polymer Samples Collected from the Post-Centrifuge Facility During June 8 Through 14, 2011	13
4	Regression Analysis Results of the North-End Means with Respect to the South-End Means of the Raw Polymer Percent Total Solids, Raw Polymer Percent Active Solids, and Dilute Polymer Percent Total Solids Observed During June 8 Through 14, 2011	15
5	Analysis of Variance Results of Testing a Null Hypothesis That the Means of the Raw Polymer Percent Total Solids, Percent Active Solids, and Dilute Polymer Percent Total Solids Are Equal During the Three Shifts for the Data Observed During June 8 Through 14, 2011	16
6	Characteristics of Machine Operating Parameters During Baseline Period of January 1, 2011, Through April 30, 2011	18
7	Operating Time of Centrifuge Machines During Baseline Period of January 1, 2011, Through April 30, 2011	19
8	Performance of Centrifuge Machines Measured in Terms of Percent Total Solids of Centrifuge Cake and Percent Solids Capture in Centrate During Baseline Period of January 1, 2011, Through April 30, 2011	20
9	Sludge Throughput per Machine During Baseline Period of January 1, 2011, Through April 30, 2011	21
10	Average Characteristics of Centrifuge Feed and Digester Draw Sludge During Baseline Period of January 1, 2011, Through April 30, 2011	23
11	Average Characteristics of Raw and Dilute Polymer During Baseline Period of January 1, 2011, Through April 30, 2011	25

LIST OF TABLES (Continued)

Table No.		Page
12	Average Polymer Consumption and Sludge Processing During Baseline Period of January 1, 2011, Through April 30, 2011	26
13	Ranking of Centrifuge Machines with Respect to Volume of Polymer Consumption per Unit Volume of Sludge Processed and Polymer Dose Observed During Baseline Period of January 1, 2011, Through April 30, 2011	28
14	Average Performance and Operations Data of the Post-Centrifuge Machines Observed on November 8 and 9, 2011	33
15	Laboratory-Scale Experimental Results of the Surface Tension Measurements of Decant, Tap Water, and Dilute Polymer Samples Containing Varying Amounts of Polymer	40
16	Polymer Costs for Dewatering Digested Sludge at the Stickney Water Reclamation Plant (September 15, 1999, to October 9, 2011)	45
17	Maintenance and Operations Department- and Monitoring and Research Department-Operated Machine Pairs for Side-by-Side Performance Evaluation	46
18	Comparison of Means of Hourly Data Collected During Entire Side-by-Side Testing Period Between All Maintenance and Operations Department- and Monitoring and Research Department-Run Machines	50
19	Side-by-Side Machine and Operation Settings and Performance Comparison of Monitoring and Research Department- Versus Maintenance and Operations Department-Operated Machines During the Side-by-Side Testing Period of January 1, 2012, Through February 2, 2012	52
20	Side-by-Side Comparison of Percent Hourly Variations in Torque with Respect to the Five-Hour Average Values Observed During the Side-by-Side Testing Period of January 1, 2012, Through February 2, 2012, Between Monitoring and Research Department- and Maintenance and Operations Department-Run Machines	54

LIST OF TABLES (Continued)

Table No.		Page
21	Side-by-Side Comparison of Percent Hourly Variations in Dilute Polymer to Sludge Flow Ratios with Respect to the Five-Hour Average Values Observed During the Side-by-Side Testing Period of January 1, 2012, Through February 2, 2012, Between Monitoring and Research Department- Versus Maintenance and Operations Department-Run Machines	58
22	Comparison of Average Machine Performance and Operating Data Collected from Maintenance and Operations Department-Run Machines During the Five-Hour Testing Period Versus Routine Maintenance and Operations Department Operation During the Non-Testing Hours on the Same Days	61
23	Comparison of Average Machine Performance and Operating Data Collected from Monitoring and Research Department-Run Machines During the Five-Hour Testing Versus Routine Maintenance and Operations Department Operation During Non-Testing Hours on the Same Days	63
24	A Comparative Summary of Average Machine Performance and Operating Data Collected from Monitoring and Research Department- and Maintenance and Operations Department-Run Machines During the Testing and Non-Testing Hours on the Same Days	66
25	Use of Seasonal Polymers and Their Switch Dates	73
26	Summary of Correlation Coefficients Based on the Relationships Between Volatile Solids Content in Centrifuge Feed Versus Polymer Dose, Percent Total Solids in Centrate, Percent Solids Capture, and Percent Cake Solids Data Obtained from the Stickney Water Reclamation Plant Post-Centrifuge Facility from January 15, 2002, Through December 31, 2009, Expressed by Use of an Individual Polymer and All Polymers Combined	85

LIST OF FIGURES

Figure No.		Page
1	Torque of Post-Centrifuge Machine Numbers 18 and 21 at Fixed Sludge and Polymer Flow Rates Relative to Cake Solids on July 14, 2011, Between 10:35 AM and 12:20 PM	31
2	Torque of Post-Centrifuge Machine Numbers 3 and 9 at Fixed Sludge and Polymer Flow Rates Relative to Cake Solids on October 5, 2011, Between 9:15 AM and 11:45 AM	32
3	Evaluation of City Water Versus Plant Effluent Based Dilute Polymer Doses on Dewatering Performance Expressed as Capillary Suction Time: Experimental Results from October 19, 2011, Tests	35
4	Evaluation of City Water Versus Plant Effluent Based Dilute Polymer Doses on Dewatering Performance Expressed as Capillary Suction Time: Experimental Results from October 31, 2011, Tests	36
5	Evaluation of City Water Versus Plant Effluent Based Dilute Polymer Doses on Dewatering Performance Expressed as Capillary Suction Time: Experimental Results from November 2, 2011, Tests	37
6	Evaluation of City Water Versus Plant Effluent Based Dilute Polymer Doses on Dewatering Performance Expressed as Capillary Suction Time: Experimental Results from November 7, 2011, Tests	38
7	Laboratory-Scale Experimental Surface Tension Measurements of Samples Containing Various Amounts of Polymer in Deionized Water, Tap Water, and Plant Effluent	39
8	Evaluation of City Water Versus Plant Effluent Based Dilute Polymers on Dewatering Performance Expressed as Capillary Suction Time: Experimental Results from May 7, 2012, Tests	75
9	Evaluation of City Water Versus Plant Effluent Based Dilute Polymers on Dewatering Performance Expressed as Capillary Suction Time: Experimental Results from May 8, 2012, Tests	76

LIST OF FIGURES (Continued)

Figure No.		Page
10	Evaluation of City Water Versus Plant Effluent Based Dilute Polymers on Dewatering Performance Expressed as Capillary Suction Time: Experimental Results from May 9, 2012, Tests	77
11	Evaluation of Charge Density of a Dilute Polymer with Respect to Storage Time (January 8 Through 14, 2013)	78
12	Evaluation of Charge Density of a Dilute Polymer with Respect to Storage Time (January 23 Through 28, 2013)	79
13	Laboratory-Scale Evaluation of Percent Polymer Dilution on Optimum Polymer Dose Conducted During May 10 Through 12, 2012: Sludge = 3.23 Percent Total Solids and Volume = 200 Milliliters	80
14	Laboratory-Scale Evaluation of Percent Polymer Dilution on Optimum Polymer Dose Conducted During June 12 Through 14, 2012: Sludge = 3.07 Percent Total Solids and Volume = 200 Milliliters	81
15	Laboratory-Scale Evaluation of Percent Polymer Dilution on Minimal Polymer Dose Conducted During May 10 Through 12, 2012, and June 12 Through 14, 2012	83
16	Time Series Trend Between Volatile Solids Content in Centrifuge Feed and Polymer Dosage for the Period January 1, 2000, Through December 15, 2009	84
17	Time Series Trend Between Volatile Solids Content in Centrifuge Feed and Percent Total Solids in Centrate for the Period January 1, 2000, Through December 15, 2009	86
18	Time Series Trend Between Volatile Solids Content in Centrifuge Feed and Percent Solids Capture for the Period January 1, 2000, Through December 15, 2009	87
19	Time Series Trend Between Volatile Solids Content in Centrifuge Feed and Percent Cake Solids for the Period January 1, 2000, Through December 15, 2009	88

LIST OF ABBREVIATIONS

%AS	percent active solids
%CK	percent CK
%CP	percent solids capture
%TS	percent total solids
%VS	percent volatile solids
$CaCO_3$	calcium carbonate
$CH_3CO_2^-$	acetate
CK	cake solids
CO_2	carbon dioxide
CST	capillary suction time
CV	coefficients of variation
DDPM	1,5-dimethyl-1,5-diazaundecamethylene polymethobromide
District	Metropolitan Water Reclamation District of Greater Chicago
DT	dry ton
ED	Executive Director
EM&R	Environmental Monitoring and Research
$FeCl_3$	ferric chloride
LIMS	Laboratory Information Management System
M&O	Maintenance and Operations
M&O-run	run by M&O Department OEs
M&R	Monitoring and Research
M&R-run	run by the M&R Department
MBM	Metropolitan Biosolids Management
mL	milliliter
No.	number
OE	operating engineer
Post-Centrifuge	post-digester centrifuge
Pre-Centrifuge	pre-digester centrifuge
PVSK	polyvinyl sulfate potassium salt
r	correlation coefficient
RO	reverse osmosis
rpm	revolutions per minute
SAL	Stickney Analytical Laboratory
SOP	standard operating procedure
TBO	Toluidine Blue O
TS	total solids
VA	volatile acid
WRP	Water Reclamation Plant

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DISCLAIMER

Mention of proprietary equipment and chemicals in this report does not constitute endorsement by the Metropolitan Water Reclamation District of Greater Chicago.

EXECUTIVE SUMMARY

The Executive Director (ED) of the Metropolitan Water Reclamation District of Greater Chicago (District) directed the Monitoring and Research (M&R) Department to identify and prioritize value-added research projects that can potentially save money for plant operations. In response to the ED's directive, the M&R Department identified and initiated a polymer use reduction study in summer 2011 with a goal to potentially reduce polymer consumption and optimize sludge dewatering operations at the Post-Centrifuge facility of the Stickney Water Reclamation Plant (WRP) due to increasing polymer costs and unavailability of a commercial technology for polymer usage control.

This report consolidates three phases of the study which examined and investigated the ways and means by which polymer consumption can be pragmatically reduced through a wide spectrum of initiatives, such as evaluation and adjustment of the existing centrifuge operations, polymer handling and dilute polymer preparation, review of unintended polymer wastage through the purchase and consumption records, operating and historical data review, and laboratory- and full-scale testing and verification.

Phase I

The existing dilute polymer preparation and centrifuge operations are based on a common verbal understanding among the operating engineers (OEs), as no formal written procedures or protocols for such operation exist with the Maintenance and Operations (M&O) Department. As such, the M&R Department formalized and documented the daily procedures through discussions with the OEs and the Engineer-in-Charge of this facility. The M&R Department also collected and analyzed pertinent operations and analytical data for the period of January 1 through April 30, 2011, to document the polymer consumption and the typical operations along with sludge characteristics, polymer characteristics, and the centrifuge machines' operating parameters, as a baseline.

The analysis indicated that in this period the average torque values for centrifuge machines ranged from 720 lbs-in to 768 lbs-in; the average bowl speeds were from 2,589 revolutions per minute (rpm) to 2,797 rpm; the average pinion speeds were from 2,379 rpm to 2,616 rpm; and the average differentials varied from 131 rpm to 262 rpm. The in-service machines were operated between 15 to 21 hours per day on average, and the machine working days ranged from 18 to 91 days in the four-month period. Actual usage of centrifuge machines Nos. 2 through 21 with respect to the maximum possible 2,400 machine days and 57,600 machine hours during the baseline period were 38 and 30 percent, respectively. This indicates that excess unused operating machine capacity exists even with the needed maintenance down time.

The average sludge throughput ranged from 17 to 32 dry tons (DT)/day. The average percent total solids (%TS) in cake ranged from 22 percent to 25 percent with respect to a goal of 25 percent, and average percent solids capture (%CP) in the centrate stream ranged from 91 to 95 percent with respect to a goal of 95 %CP.

The average sludge flow rates ranged from 167 to 223 gpm, and the average dilute polymer flow rates ranged from 9.7 to 11.1 gpm. The average polymer dose by weight ranged from 438 to 695 lbs/DT for all machines; 11 of 18 machines had an average of 500 to 600 lbs/DT. Volumetric ratios of dilute polymer to sludge flows ranged from 0.044 to 0.064 gpm/gpm for these machines, indicating an approximately 45 percent difference in polymer consumption between the least and the most polymer-consuming machines. About 11.83 million gallons of dilute polymer was consumed to dewater 230 million gallons of digested sludge during the baseline period by all operating machines.

Each machine consumed a different volume of polymer per unit volume of sludge processed. The polymer consumption did not vary by more than 23 percent in 12 of the 21 machines. The least productive machines with respect to sludge throughput happened to be among the highest polymer-consuming machines, and vice versa. However, machine maintenance did not directly attribute to either better-performing machines or low polymer consumption.

During the baseline period, significant variations occurred in centrifuge feed characteristics; %TS ranged from 1.97 to 3.41 percent with an average of 2.55 percent, and percent volatile solids (%VS) ranged from 45 to 59 percent with an average of 54 percent. The digester draw %TS and %VS were reviewed as a check, and were in agreement with the centrifuge feed data. The centrifuge feed pH was not routinely measured. However, evaluation of digester draw pH, as a surrogate characteristic for centrifuge feed, indicated the pH variations ranged from 7.16 to 7.51 with an average of 7.30. This pH level at or slightly above neutral is not considered to cause a negative impact on polymer demand, considering mannich polymer demand is known to increase above 7.60 pH values. The centrifuge feed had average alkalinity and volatile acid (VA) concentrations of 3,610 mg/L as calcium carbonate ($CaCO_3$) and 101 mg/L as acetate ($CH_3CO_2^-$), respectively. Both parameters at these levels are not expected to affect polymer demand; however, literature suggests that these parameters have potential to interfere with mannich polymer efficacy at higher concentrations.

The M&R Department performed intensive sampling, data review, and statistical analysis of raw and dilute polymer total and active solids characteristics from both the North- and South-end of the facility from June 8 through 14, 2011. It was observed that some daily average raw polymer %TS were different between both ends on some days. However, the dilute polymers were statistically similar and overall polymer quality from both ends as well as among the three shifts were similar during the week of testing. A further review of independently collected polymer quality control data by the M&R Department for June 2011 as well as routine plant data collected by the M&O Department and truck polymer quality control data for this same week did not show large variations in polymer characteristics that could impact machine performance or polymer consumption during the baseline period.

With regard to polymer characteristics for the baseline period, the average raw polymer %TS for South-end machines Nos. 1 through 12 was 3.69, and the average %TS of raw polymer for the North-end machines Nos. 13 through 21 was 3.67 percent. The average %TS of dilute polymer for the South- and North-end of the facility was 0.50 percent and 0.52 percent, respectively. The %TS of dilute polymer is indicative of the consistent preparation procedure and consistent strength of dilute polymer. The polymer characteristics observed during the baseline period supported the independently verified conclusions on raw polymer quality and dilute polymer preparation at the North- and South-end of the facility during June 8 through 14, 2011.

Despite a lack of formal operating procedure, the OEs exhibited a coordinated team effort to achieve consistent dilute polymer preparation at both the North- and South-end of the facility and centrifuge operations. However, improvements in polymer preparation and optimization of current centrifuge operations may be able to achieve polymer savings. Results from the M&R Department's evaluation suggested the following steps for optimization operations for achieving polymer savings: (1) consistent 14 percent dilute polymer preparation; and (2) centrifuge operations at a fixed torque of 725 lbs-in or 30 percent load factor with a sludge flow rate of 200 gpm and a polymer flow rate of 9.2 to 10.4 gpm could meet the current performance goals of 25 %TS centrifuge cake and 95 %CP, thereby leading to a reduction of polymer consumption for the baseline period. All machines can achieve these performance goals. However, some machines cannot be operated at the suggested settings and may need more machine-specific settings and attention to achieve the performance goals.

The existing practice at the Stickney WRP is to use secondary treated plant effluent for preparing dilute polymer instead of city water formerly used at the Calumet WRP for its post-digestion centrifuges. Laboratory-scale capillary suction time (CST) tests in October and November 2011 using city water did not provide enough evidence for achieving polymer savings but appeared to be promising. Additional confirmatory tests were conducted in May 2012 during the Phase III experiments.

Surface tension measurements were also made on centrate samples and indicated a slight decrease in surface tension in relation to increasing polymer dosage as anticipated. However, using surface tension as a process control parameter to indicate excess polymer use in centrifuge operations was not considered, as the trend was very weak.

Phase II

Through full-scale side-by-side testing operating centrifuges at the optimized settings established in Phase I, reduction in polymer consumption was evaluated relative to machines running under the routine M&O Department operational settings. These side-by-side tests were run for five hours during the day shift, twice per week from January 10 through February 2, 2012.

Overall comparison based on hourly data indicated that machines run by M&O Department OEs (M&O-run) had an average hourly sludge flow of 216 gpm, compared to 212 gpm for the machines run by the M&R Department (M&R-run). The M&R-run machines used an average polymer flow of 8.17 gpm, compared to 8.69 by the M&O-run machines. It should be noted that average dilute polymer flows of the M&O-run machines were much lower compared to the average dilute polymer flows of 9.7 to 11.1 gpm observed during the Phase I baseline period. The hourly average dilute polymer consumption by volume was 0.038 gpm/gpm for the M&R-run machines versus 0.041 gpm/gpm for the M&O-run machines, and hourly average polymer consumption by weight was 334.11 lbs/DT for the M&R-run machines and 362.78 lbs/DT for the M&O-run machines. Hourly average torque was 687.44 lbs-in for the M&R-run

machines versus 675.71 lbs-in for the M&O-run machines. In terms of performance, the M&R-run machines had an hourly average of 24.90 %TS in cake and 94.16 %CP compared to 25.53 %TS in cake and 93.86 %CP for the M&O-run machines. The Phase II study confirmed that the performance and polymer consumption differences in the M&O- and M&R-run machines during the side-by-side testing period may have been attributable to different operational settings mainly dilute polymer flow settings in relation to sludge flows. Additionally, this phase of the study demonstrated that centrifuges could be operated by fixing the torque, followed by maintaining the lowest possible volumetric ratios of dilute polymer flow to sludge flow as suggested in Phase I.

Phase III

The M&R Department examined polymer purchase and consumption data in light of determining whether excess polymer purchased for the Post-Centrifuge operations would reflect unintended wastage. Considering the M&O Department's zero-wastage policy, it was determined that excess polymer was not wasted due to either its shelf life or any other reasons; excess raw and dilute polymer is customarily stored in the storage tanks and used the following day.

Often, dilute polymer is prepared in excess of immediate need and stored before use. Laboratory-scale charge density tests conducted in January 2013 concluded that the efficacy of dilute polymer gradually decays due to decreasing charge density with its storage time. Thus, a higher quantity of aged dilute polymer would be needed to achieve the same dewatering performance as a freshly prepared dilute polymer. However, polymer consumption due to loss of charge density can be minimized by reducing the time between dilute polymer preparation and use. Recognizing that loss in charge density over time is inevitable and unavoidable to some extent in full-scale operations, the M&R Department suggests that dilute polymer preparation should be planned during each shift such that dilute polymer quantity in the North- and South-end aging tanks of the Post-Centrifuge facility should not exceed 7,000 and 8,000 gallons, respectively.

As discovered in Phases I and II, polymer may be unintentionally wasted in the Post-Centrifuge dewatering operations if its flow rate is not proportionately adjusted in relation to the feed sludge flow rate. This wastage tends to become more pronounced with stronger dilute polymer strength. With this kind of polymer wastage reduction in mind, laboratory-scale CST tests conducted in May and June 2012 indicated that significant polymer savings may not be realized by either diluting or concentrating the polymer solution with respect to the existing practice of 14 percent dilution, i.e. the M&O Department should continue to prepare 14 percent dilute polymer.

Historical centrifuge feed characteristics with the emphasis on VS content of the centrifuge feed were evaluated by determining correlation coefficients (r-values) and plotting time series trends with respect to polymer consumption reduction and impact on dewatering process performance. The r-values and time series trends for polymer dose, %TS in centrate, solids capture, and cake dryness versus VS content in centrifuge feed for 2000 through 2009 were examined for the entire ten-year period and for each polymer used during this period.

A relatively good correlation for polymer dose and feed VS content was observed for the combined data from January 2, 2000, through December 31, 2009, and for individual polymers, meaning a lower polymer dose is needed when a feed’s VS content is lower. Of the three performance variables examined, feed VS and cake solids (CK) had the strongest relationship for the entire period; decreased %TS in CK correlated with an increase in feed VS content. The historic data analysis concluded that VS content in centrifuge feed plays an important role regarding polymer consumption as well as dewatering performance, but other variables such as polymer flow to sludge flow ratios also play a role.

Additional confirmatory laboratory-scale tests in May 2012 as suggested from Phase I indicated that the use of city water had no distinct advantage for dilute polymer preparation relative to secondary treated plant effluent. Therefore, the current practice of using secondary effluent for polymer dilution is recommended.

EVALUATION FOR POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT – PHASE I

Introduction

The ED of the District requested that the M&R Department identify and prioritize value-added research projects which can potentially save money for plant operations. In response to the ED's directive, the M&R Department identified and initiated this project to optimize polymer consumption at the post-digester centrifuge (Post-Centrifuge) facility at the Stickney WRP.

Sludge conditioning is an important step in sludge thickening and dewatering operations to improve dewatering characteristics. Chemical sludge conditioning is the most commonly used method, which includes use of organic and/or inorganic chemicals such as organic polymers, ferric chloride ($FeCl_3$), lime, and alum. Cationic polymers having high molecular weight are preferred for centrifugal dewatering of anaerobically digested sludge. Dual conditioning is also practiced in centrifugal dewatering operations by applying two separate organic polymers or a mix of organic and inorganic conditioner to the same sludge.

Chemical conditioners must be adequately and optimally used. Underuse results in poor efficiency, and overuse results in waste of costly conditioners. Variations of sludge flow rate and quality, polymer flow rate and quality, and centrifuge machine settings make it difficult to effectively optimize dynamic polymer demand. At this time, no in-line technology is available that can continuously adjust polymer dose relative to incoming sludge flow rate and quality and centrifuge operations, thereby helping conserve the use of polymers. However, proper conditioning using the optimal polymer dose and diligent centrifuge operation can be practiced to efficiently use these costly polymers with minimum wastage. Efficient polymer use can also be enhanced by identifying and operating the better-performing machines more than the poorer-performing machines.

Background

Overview of Solids Processes. The solids processes at the Stickney WRP produced 126,442 DTs of biosolids in 2011. Approximately 88,239 and 38,203 DTs of biosolids were produced from the Post-Centrifuge dewatering operations (high solids process train) and lagoon stabilization operations (low solids process train), respectively. The Metropolitan Biosolids Management (MBM) facility utilized 37,589 DTs of centrifuge cake produced from the dewatering operations to manufacture pellets. The stabilized solids from lagoons and remaining centrifuge cake were dried and utilized for beneficial land applications.

At the Stickney WRP, North Side WRP sludge, and North and South preliminary sludge, along with waste activated sludge are mixed/equalized in a mixing chamber, fine screened, concentrated in concentration tanks, and transferred into pre-digester centrifuge (Pre-Centrifuge) feed holding tanks for centrifuge thickening. Thickened sludge from pre-centrifuge operations and Imhoff sludge are mixed in digester holding tanks and fed to the 24 Stickney anaerobic digesters. Imhoff sludge is pumped only during the day shift, whereas pre-centrifuge sludge is pumped during all three shifts. Digester holding tanks provide consistent feed characteristics to the digesters.

Upon digestion, the digested sludge is transferred to holding tanks on the draw side to serve a similar purpose of homogenizing the draw before it is sparged with carbon dioxide (CO_2) at a rate of approximately 15 lbs per 1,000 gallons of sludge and pumped to the Post-Centrifuge facility for dewatering. Consistent sludge feed characteristics and flow rate are crucial for proper dewatering operations and performance at optimal polymer consumption. An interruption in any one of the preceding processes can impact the performance of the post-centrifuge operations and polymer consumption.

Polymer Conditioning in the Post-Centrifuge Operations. Cationic mannich polymer is used to condition approximately 2.2 million gallons of digested sludge per day with approximately 3.5 to 4 %TS prior to dewatering at the Post-Centrifuge facility. A total of 21 machines are operated for dewatering sludge; machine numbers (Nos.) 1 through 12 (old machines) and machine Nos. 13 through 21 (new machines) are located in the South- and North-end of the facility, respectively. The original machine No. 1 was replaced with the latest version of respective machine and is operated under pilot-testing at twice the sludge and polymer flow rates of the other 20 machines. Polymer consumption varies from machine to machine at any given time, which in turn causes variations in total daily polymer consumption. The polymer consumption also varies seasonally in response to changes in sludge characteristics. The actual polymer usage during post-procurement was much higher than determined during procurement activities during 2007 through 2010 (Table 1). Average polymer consumption was 10 to 163 percent higher with respect to the respective recommended dosages. Bid polymers are pre-qualified based on full-scale testing, and subsequently the lowest cost polymer is purchased from all pre-qualified polymers using a competitive bid procedure (M&R Department Report No. 00-13).

Polymer costs represent the single largest cost for sludge dewatering at the District. At the Stickney WRP, polymer costs were approximately $5,000,000 per year according to the 2011 contract. This amount does not include the polymer usage at the John E. Egan WRP, which is lumped into the Stickney WRP contract. Approximately 20 to 25 percent of polymer is used at the Pre-Centrifuge facility for thickening, and the remainder is used for dewatering at the Post-Centrifuge facility.

Current Operations at the Post-Centrifuge Facility. The M&O Department staff in the Post-Centrifuge facility has no formal procedure or protocol in place to prepare dilute polymer or to operate the centrifuge machines. However, upon the M&R Department’s discussions with the OEs and Engineer-in-charge of this facility, these procedures have been formalized as documented below.

Existing Procedure for Preparation of Dilute Polymer. The North- and South-end of the facility have separate raw polymer receiving and storage tanks. There are six raw polymer storage tanks in the Post-Centrifuge facility, which have a combined total storage capacity of 72,777 gallons. Raw polymer storage tank Nos. 1 through 4 are located in the South-end of the facility, and tank Nos. 5 and 6 are located in the North-end of the facility. Raw polymer supplied by an outside vendor is hauled by tanker truck and pumped into these raw polymer storage tanks.

TABLE 1: AVERAGE POLYMER USE VERSUS RECOMMENDED POLYMER DOSE FROM PROCUREMENT TESTING AT THE STICKNEY WATER RECLAMATION PLANT (2007 THROUGH 2010)

Date	Switched to	Name of Polymer	Recommended Dose* lbs/DT	Actually Used, lbs/DT			% Higher Average Usage with Regard to Recommended Dose
				Avg	Min	Max	
05/16/07–10/31/07	Summer	CE-770	283.2	432	326	579	53
11/01/07–04/30/08	Winter	CE-659	354.5	640	542	791	81
05/01/08–08/31/08	Summer	CE-770	283.2	429	294	740	51
09/01/08–11/15/08	Summer (new contract)	CE-1100	158	410	307	877	159
11/16/08–04/30/09	Winter	CE-1142	430.2	611	455	1,211	42
05/01/09–10/31/09	Summer	CE-1100	158	416	330	552	163
11/01/09–06/14/10	Winter	CE-1142	430.2	610	389	1,163	42
06/15/10–08/31/10	Summer	CE-1100	158	398	319	506	152
09/01/10–10/31/10	Winter	CE-1142	430.2	474	380	595	10

*Dose recommended by M&R staff resulting from polymer tests conducted during the bidding process for a new polymer contract.

Each tanker carries a load of approximately 43,000 to 45,500 lbs (or 5,120 to 5,420 gallons, respectively). The details on these and the other tanks are shown in Table 2.

The dilute polymer is prepared separately in both the North- and South-end of the facility based on consistent guidelines. The secondary treated plant effluent is used as dilution water to prepare a working solution of dilute polymer. The dilution water is added to the required level (75 to 107 inches depending upon tank dimensions) in a given mixing tank and then propeller mixers are initiated. A predetermined quantity of raw polymer (11 to 14 inches or 11.6 to 12.8 percent of tank volume depending upon tank dimensions) is then proportionately added to the mixing tank such that it produces approximately a 13 to 14.5 percent working solution for use. Dilute polymer preparation is not based on the volume of water or raw polymer in gallons but is based on height in tanks. Upon addition of both water and raw polymer, the tank is mixed for approximately 30 minutes using propellers; the well-mixed dilute polymer is pumped into the aging tanks where it is stored until use. A redundant batch is prepared at all times to ensure that dilute polymer is always available. The maximum capacity of the mixing tanks and aging tanks is 21,624 and 84,108 gallons, respectively (Table 2).

Generally, the South-end aging tanks feed centrifuge machine Nos. 1 through 12, and the North-end aging tanks feed centrifuge machine Nos. 13 through 21. However, the dilute polymer is occasionally pumped from the North-end aging tanks to machine Nos. 1 through 12, but pumping from the South-end aging tanks to machine Nos. 13 through 21 is not usually practiced though it is possible, i.e. pumping from the South-end to the North-end machines is inefficient and impractical because of the labor-intensive operation of transfer pumps and valves.

Separate sets of dilute and raw polymer grab samples are collected daily from both the North- and South-end of the facility for %TS analysis during routine operation for process control.

Existing Procedure for Centrifuge Operation. As mentioned earlier, no formal written procedures or protocols exist for the operation of centrifuge machines either. However, through discussion with M&O Department personnel and the OEs, the centrifuge machines are consistently operated at a fixed torque value in auto torque mode for as much time as possible. Generally, the torque, sludge and polymer flow rates are manipulated on the centrifuge machines to conserve polymer and to achieve the performance goals of approximately 25 %TS in CK and 95 %CP. These performance goals were originally established and adopted for the M&R Department's polymer bid tests to evaluate bid test polymer performance. As such, the M&O Department has not formally defined the performance goals or the acceptable thresholds for routine operation, but it routinely operates the machines to achieve these performance goals. However, lower machine performance in terms of solids captures greater than 90 percent and %TS of CK greater than 20 percent are generally considered within the acceptable thresholds. Therefore, the results of this phase were evaluated and qualified with respect to these performance goals and the acceptable thresholds. Each machine is synchronized with Rockwell Automation System software, which displays pre-set values of torque, sludge and polymer flow rates and continuous measurements of bowl speed, pinion speed, torque, sludge and polymer flow rates, vibration of machine, motor amperage and bearing temperatures for the proper operation and maintenance.

TABLE 2: DIMENSIONS OF THE POLYMER STORAGE TANKS, MIXING TANKS, AND AGING TANKS FOR THE PRE- AND POST-CENTRIFUGE FACILITIES AT THE STICKNEY WATER RECLAMATION PLANT

Tank No./ID	Location	Length, ft	Width or Diameter, ft	Height, ft	Volume, cft	Volume, gal
Raw Polymer Storage Tanks						
1	South-end	9' 6"	9' 6"	14' 4"	1,290	9,650
2	South-end	9' 6"	9' 6"	14' 4"	1,290	9,650
3	South-end	9' 5"	8' 10"	14' 4"	1,190	8,900
4	South-end	9' 5"	9' 0"	14' 4"	1,210	9,065
5[1]	North-end	N/A	12' 0"	21' 0"	2,374	17,756
6[1]	North-end	N/A	12' 0"	21' 0"	2,374	17,756
Mixing Tanks						
1[1]	South-end	N/A	8' 4"	13' 0"	703	5,258[2]
2[1]	South-end	N/A	8' 4"	13' 0"	703	5,258[2]
3[1]	South-end	N/A	10' 0"	8' 0"	628	4,697 [3]
4[1]	North-end	N/A	6' 0"	13' 0"	367	2,748
5[1]	North-end	N/A	6' 0"	13' 0"	367	2,748
6[1]	North-end	N/A	6' 0"	13' 0"	367	2,748
Aging Tanks						
East Tank	South-end	17' 0"	17' 0"	10' 0"	2,890	21,617
West Tank	South-end	17' 0"	17' 0"	10' 0"	2,890	21,617
Pre-Centrifuge Facility Aging Tank	South-end	16' 0"	15' 6"	9' 0"	2,232	16,700
4[1]	North-end	N/A	14' 0"	7' 0"	1,077	8,058
5[1]	North-end	N/A	14' 0"	7' 0"	1,077	8,058
6[1]	North-end	N/A	14' 0"	7' 0"	1,077	8,058

N/A = Not applicable.

[1] Tank is cylindrical in shape.

[2] The top 20" of mixing tank are not used.

[3] The top 10" of mixing tank are not used. A batch of 4,210 gallons is used for the Post-Centrifuge Building aging tanks; otherwise a batch of 3,034 gallons is used when supplying the Pre-Centrifuge Building pumps directly. The bottom 24" of the tank is not pumped to the Pre-Centrifuge Building.

Typically, the day-shift OE determines the torque setting based on experience and the manufacturer's suggested range and adjusts operational parameters such as sludge and polymer flow rates to meet the above-mentioned performance goals. Sludge flow rate is determined from a number of factors such as number of available (functioning) machines, sludge quantity to be processed during a given shift and day, weather conditions during winter months, upsets in the conveyor belt system in the Post-Centrifuge facility or upsets in upstream or downstream solids treatment operations, MBM feedback on cake dryness, etc. Polymer flow rate is proportionately adjusted based on the performance of the machine. The personnel on the following two shifts maintain and/or fine-tune the set torque value and sludge and polymer flow rates as per need upon hourly inspections. Usually such adjustments are made in response to varying centrate clarity, change in production due to a disturbance in the upstream or downstream process train or a request from MBM to adjust dryness of centrifuge cake. Each OE, however, may operate the machines during his shift differently, if he prefers. On average, approximately 10 machines are operated at any given time to maintain the routine sludge processing with the performance goals outlined above.

During daily operation, the referenced machine operations data are manually recorded hourly by M&O Department staff from the machine display screen (Appendix AI). Centrifuge cake and centrate samples are collected during each shift from each machine and composited before analyzing for %TS in order to ensure that the operation performance standards are met. Similarly, centrifuge feed is composited and analyzed for %TS and %VS. A select portion of the data such as daily sludge and polymer flows for each operating machine is compiled from the daily log sheets (Appendix AI) and added up to determine total daily sludge and polymer flows for all machines in operation for preparing the monthly operating report. Daily polymer dose for the MORs is calculated using daily sludge and polymer flows and monthly average %TS of raw and dilute polymer samples. In lieu of %TS of centrifuge feed, the weighted average of digester draw %TS is used to determine polymer dose and solids capture. Based on individual digester draw volume and %TS information, the total DTs of sludge withdrawn is calculated, and this total DTs of sludge is divided by the total sludge volume to determine the weighted average based %TS of digester draw. There is no formal procedure to review the recorded data and monitor polymer consumption on a daily basis. Polymer consumption, however, is monitored based on the product receipts and bills of lading. Dilute polymer volume consumed daily by each machine is measured and recorded in daily log sheets presented in Appendix AI, but the purchased raw polymer quantity and the daily dilute polymer used are not tallied.

Objectives

The core objective of this phase is to optimize centrifuge operation with respect to polymer usage without compromising the sludge throughput or the solids recovery and consistency of solids in centrifuge cake. The specific goals of this phase are listed below, of which goal Nos. 1 through 3, 5, 6, 8a, and 8b have been accomplished, and the results are presented in this section. The research work in progress to pursue goal Nos. 4, 7, 8c, 8d, and 8e will be presented in the subsequent phases.

1. Review and document existing procedures for current dilute polymer preparation and centrifuge operation.

2. Evaluate variations in raw and aged dilute polymer during different shifts at both the North- and South-end of the Post-Centrifuge facility.

3. Evaluate baseline centrifuge operation for each machine and polymer consumption during a four-month observation period.

4. Compare monthly measured dilute polymer consumption versus monthly polymer purchase records.

5. Identify the machines that consume less polymer relative to sludge throughput.

6. Adjust machine and/or operational settings such that the polymer demand is optimized for select machines as part of a trial evaluation.

7. Demonstrate through side-by-side testing that the centrifuge operation with optimized settings can potentially save polymer.

8. Perform the following tests to evaluate potential polymer savings:

    a. Conduct laboratory-scale and/or full-scale experiments to evaluate a switch in dilution water from secondary treated plant effluent to city water for dilute polymer preparation.

    b. Conduct laboratory-scale tests to evaluate surface tension as an indicator for excess polymer use.

    c. Conduct laboratory-scale tests to evaluate variations in dilute polymer charge to determine the maximum allowable storage time before use.

    d. Conduct full-scale tests to evaluate centrifuge machine performance at lower dilute polymer strength.

    e. Examine historic operations data and evaluate the role of %VS.

Materials and Methods

Review and Document Current Operations. The existing procedures and protocols for dilute polymer preparation and centrifuge operation were reviewed. Additionally, the OEs and Engineer-in-charge of operations and maintenance were interviewed to collect pertinent information and insight. These procedures are summarized above in the Background Section.

Quality Control for Sample Handling and Data Analysis. Before any sample collection, sample lines were flushed to obtain representative samples of centrifuge feed, raw and dilute polymer, dilution water, and centrate. Additionally, the containers were rinsed with sample contents before collecting samples. Cake samples were collected directly from the chute of the hopper in order to prevent contamination with upstream cake from other machines. All sample bottles were tagged with appropriate identification labels indicating sample type, name of sampler, time and date of sample collection, etc. Upon collection, the raw and diluted polymer, dilution water, centrifuge feed sludge, centrate, and cake samples were submitted to the Stickney Analytical Laboratory (SAL) section under a signed chain of custody within the appropriate holding times throughout study. These samples were analyzed by SAL within these permissible time periods; otherwise, SAL qualified analytical results. All analytical results were reviewed and accepted unless found to be objectionable; the samples were analyzed again in such events, and re-run analytical results were accepted. The results were considered objectionable if the results did not make physical sense or were obviously incorrect for analysis under review. For example, 1.2 %TS for a clean centrate sample is unacceptable, because clean centrate %TS is expected to be approximately 0.10 percent.

In order to base conclusions on quality assured data, plant operational and analytical data were compiled and reviewed before subjecting to data analysis. As far as possible, data integrity was maintained. An appropriate data treatment was considered including but not limited to data exclusion of outliers for the affected time period if variations in data quality were found to be substantial. The results were considered outliers if the values exceeded three times the standard deviation. All abnormal operational and Laboratory Information Management System (LIMS) data were verified for possible data logging errors by the OEs and the laboratory technicians, respectively, and data entry errors by the support staff in the Environmental Monitoring and Research (EM&R) Division. In such instances, either the abnormal values were corrected based on outcome or rejected before data analysis.

Verification of Polymer Quality. In order to verify that a consistent polymer is being used in the centrifuge operations, one raw polymer sample and one dilute polymer sample was collected per shift from the North- and South-end of the Post-Centrifuge facility for a period of one week from June 8 through 14, 2011.

The raw and dilute polymer samples were analyzed for %TS. The raw polymer samples were also analyzed for percent active solids (%AS). Active solids (or active polymer solids) represent the actual polymer solids and are considered a measure of polymer activity. Determination of active polymer solids, therefore, aims at removal of non-polymeric organic solids using organic solvent (acetone). *Standard Methods for the Examination of Water and Wastewater* does not provide a laboratory procedure for determination of %AS. The method used at the District laboratories is documented in Appendix AII.

The %TS and %AS results were compiled and appropriate statistical analyses were performed to determine: (1) whether the raw, active, and dilute polymers on the North- and South-end of the facility are similar to each other, and (2) if there exists significant differences in quality of raw polymer, dilute polymer, and active polymer solids between different shifts at both sites. The quality and consistency of polymers were evaluated based on %TS and %AS during the study period.

The EM&R Division currently operates a polymer quality assurance and quality control program for the Post-Centrifuge operations. The data from this program was reviewed to ensure that polymer quality was consistent over the study period.

Baseline Centrifuge Operations and Polymer Consumption. A baseline period was defined from January 1, 2011, through April 30, 2011. During this time, the centrifuge machines were routinely operated by OEs per the procedures outlined above. In order to determine the baseline centrifuge operation and polymer consumption, the following data were collected from M&O Department operations record sheets and the LIMS database for each machine:

- Analytical parameters analyzed daily: %TS and %VS of centrifuge feed, %TS of cake, %TS of centrate, %TS of raw polymer and diluted polymer, pH, %TS, and %VS of digester draw.

- Analytical parameters analyzed weekly: total alkalinity and total VAs of digester draw.

- Machine and operational parameters collected hourly: centrifuge feed and dilute polymer flow rates, pinion speed, bowl speed, torque, and daily hours of operation of the machine.

The above centrifuge feed and polymer characteristics, analytical data, and centrifuge operational parameters were organized, and average daily values were calculated and compared for each parameter for each machine. Average daily values normalized over hours of operation for each machine's performance parameters and polymer consumption were calculated to determine baseline performance and polymer consumption. The calculated performance parameters included the volumetric ratio of polymer to sludge flow rate, percent dilute polymer strength, polymer dose per unit dry solids, solids recovery in centrate, and sludge throughput per day.

Identification of Better-Performing Machines. The baseline centrifuge operating data and baseline polymer consumption for each machine were obtained from the above mentioned step and evaluated to identify which machines performed the best and worst with respect to polymer consumption. The average sludge throughput, and polymer consumption expressed as a ratio of polymer to sludge volume and polymer dose for all operating machines were calculated. The machines were then sorted according to performance based on volume of polymer consumption per unit volume of sludge processed and polymer dose to identify machine performance rankings.

Optimization of Polymer Demand by Adjusting Machine/Operational Settings. In order to optimize polymer consumption for each machine, optimal centrifuge operation is essential. For this phase, optimization in the existing operations involved determining the lowest fixed torque value for each machine along with the lowest practical polymer flow rate at which the machines can be operated at a minimum sludge flow rate of 200 gpm in auto-torque mode without compromising machine performance. This was accomplished in several steps as described below.

1. The machine and operational settings on 14 of the 21 centrifuges were monitored, sampled, and documented on select days after the baseline period: machine Nos. 3, 6, 7 and 12 on June 9, 2011; machine Nos. 2, 5, 9, 10 and 11 on June 20, 2011; and machine Nos. 8, 14, 18, 20 and 21 on June 21, 2011. Machine No. 1 was not included in this phase because it is a

different kind of machine compared to the other existing machines as described above. The six remaining machines, Nos. 4, 13, 15, 16, 17, and 19, could not be sampled, because they were often out of operation for maintenance.

During this step, the OE-adjusted machine settings representing normal operation (such as sludge flow rate, polymer flow rate, set torque value, bowl speed and pinion speed) were documented every fifteen minutes, and centrate and cake samples were simultaneously collected at the time of documentation for %TS analysis. Centrifuge feed sample was collected once or twice each sampling day event and analyzed for pH, %TS, %VS, alkalinity and VAs; one raw polymer and at least two dilute polymer samples were collected and analyzed for %TS. The sludge throughput, polymer consumption, and solids capture were calculated using collected analytical and operational information. All data was collected in order to represent the normal operation of each available machine.

2. Four machines were then randomly selected and operated as usual. However, the torque was decreased in each machine to evaluate whether this operational change would proportionally decrease CK firmness below the 25 %TS performance goal. Torque settings were gradually decreased in an increment of 25 lbs-in from an initial set value without disturbing the operators' polymer and sludge flow rate settings on July 14, 2011, for machine Nos. 18 and 21, and on October 5, 2011, for machine Nos. 3 and 9. The initial torque for these four machines ranged from 725 to 870 lbs-in and was gradually reduced to approximately 600 lbs-in. At each decreased torque level, cake and centrate samples were collected and analyzed for %TS. Additionally, centrifuge feed, raw polymer, and dilute polymer samples were collected once per day and analyzed for similar parameters as described above. The machine performance parameters as mentioned in the above step were calculated to evaluate a relationship between CK and torque.

3. Based on the relationship between torque and %TS in CK, conservative torque values were selected for the following step in this phase of the study such that a performance goal of 25 %TS in CK can be met at all times without deteriorating centrate clarity.

4. The available machine Nos. 3, 9, 12 and 20 on November 8, 2011, and machine Nos. 14 and 16 on November 9, 2011, were operated at these selected torque settings. During the operation of each machine, polymer flow rate was decreased by five percent until CK were judged to be lower than 25 percent. During each polymer flow rate adjustment, all other variables were maintained constant, and appropriate samples as described in the above steps were collected. The data from this step were used to determine the lowest practical polymer flow rate at which the machines can be operated at a minimum sludge flow rate of 200 gpm in auto-torque mode

at an optimum torque setting without compromising machine performance goals of approximately 95 %CP in centrate and 25 percent CK (%CK).

Laboratory-Scale Tests for Potential Polymer Savings. The following laboratory-scale tests were performed for the evaluation of polymer savings. Each experiment is separately described below.

Evaluation of Switch in Dilution Water. The existing practice at the Stickney WRP uses secondary treated plant effluent for preparing dilute polymer solution. The alternative is to use city water instead. City water is used as dilution water at the Calumet WRP for its post-digestion centrifuges when they are in operation. The objective for this test was to evaluate if the use of city water could potentially save polymer consumption compared to the secondary treated plant effluent and, if so, determine whether the polymer savings are significant enough to offset the cost of water.

A house polymer sample was collected during October and November 2011 and diluted to prepare two 10 percent working solutions using the secondary treated plant effluent and the city water as dilution waters, respectively. Varying amounts of dilute polymer from these respective working solutions were added to freshly collected centrifuge feed samples (200 milliliters [mL]) and mixed following the established mixing protocols outlined in M&R Department Report No. 00-13. CST tests were performed in duplicate on these samples. The CSTs were measured and recorded. The CSTs from sludges dosed with normalized doses of city water dilute polymer and effluent dilute polymer were compared. Lower CSTs were indicative of better dewaterability.

Evaluation of Surface Tension as an Indicator of Excess Polymer Use. Experiments were performed during July 2011 to determine whether increased polymer content in centrate would lower surface tension. The surface tension measurements in centrate could be used to develop an indicator of excess polymer use for a possible process control parameter for dewatering operations at the District facilities.

Three different working solutions of 10 percent strength from Stickney raw polymer were prepared using deionized water, tap water, and Stickney plant effluent. Serial dilution of each working solution was prepared by adding 40, 30, 20, 10, and 5 mL working solutions to 100 mL of deionized water, tap water, and Stickney WRP final effluent, respectively. The surface tension was measured using a precision Cenco DuNouy Tensiometer on all of the above samples, deionized water, tap water, and Stickney WRP final effluent.

Laboratory experiments were also conducted to measure surface tension in centrate samples collected from full-scale operations and laboratory-scale testing from July through October 2011. In order to obtain the centrate samples in the laboratory, varying amounts of working solution of dilute polymer (deionized water based) were added to 200 mL of Stickney centrifuge feed. The sludge and polymer mixture was thoroughly mixed and allowed to settle. Post-settling, decant (centrate) samples were obtained for surface tension measurements. All of the above samples were measured in duplicate for surface tension and temperature, and the average values of these parameters were used to test the above hypothesis.

Results and Discussion

Verification of Polymer Quality. A total of 42 raw and 42 dilute polymer samples were collected from both the North- and South-end of the facility from June 8 through 14, 2011. Daily mean values were calculated from three shift values for each sampling day for both sites for three parameters; %TS of raw polymer, %TS of dilute polymer and %AS of raw polymer and are presented in Table 3. A total of seven daily mean values for each parameter were calculated for both sites for seven days of study. Discrepancies in daily average raw polymer %TS between the North- and South-end occurred such as on June 11, 2011, as shown in Table 3. However, dilute polymer between both ends remained fairly uniform during the study period. In order to compare the similarity between North-end mean values and South-end mean values, the North-end mean values were regressed with respect to the South-end mean values for all three parameters to test whether the slope of the regression model is equal to 1 and thus statistically similar. The regression analyses results are shown in Table 4. The slope values close to 1 for all three parameters indicate that polymer quality on both ends were similar during the week of testing. The p-value for each parameter is greater than 0.05, which indicates similarity between two data sets as corroborative evidence.

The shift mean values were also calculated using values from each shift for the above three parameters for both sites and are also presented in Table 3. There are seven data points in each shift over the seven study days, which resulted in three different means for three different shifts (shift average) for the North- and South-ends for each parameter. The equality of means for each parameter among the three shifts for both sites was tested using Analysis of Variance (ANOVA). As a pre-requisite to ANOVA, the equality of variances among the three shifts for each parameter for both sites was tested using Cochran’s method. Variances were found to be equal for all parameters for both ends. All assumptions necessary for ANOVA were satisfied since all shift parameter data were found to have come from a normal population per the Kolmogorov-Smirnov method. Cochran’s method was used, because the sample size (n) and the number of levels (shifts) are equal. The ANOVA results are presented in Table 5. The p-values greater than 0.05 indicate that there is no significant difference among three shifts for all three parameters for both ends.

A review of independently collected polymer quality control data by the EM&R Division as well as routine plant data collected by the M&O Department and truck polymer quality control data for the June 8 through 14, 2011, period did not show large variations in polymer characteristics that could impact machine performance or polymer consumption during the baseline centrifuge operation period. Because the EM&RD-compiled quality control data showed that sampling occurred only twice during June 8 through 14, 2011, data collected during the entire month of June 2011 was reviewed; average %TS and %AS of raw polymer for June 2011 were observed to be 3.69 and 3.32, respectively. Variations measured by standard deviations were found to be 0.56 percent for TS and 0.41 percent for AS for June 2011.

The results of routine M&O Department plant samples collected during June 8 through 14, 2011, showed average %TS of raw polymer for the North- and South-end to be 3.64 and 3.60, respectively, with respective median values of 3.72 and 3.79. The results on truck raw polymer samples collected during the same week period showed average %TS of 3.72 and median of 3.65. Dilute polymer %TS on the North- and South-end were found to be 0.48 and 0.46, respectively with respective median values of 0.46 and 0.45.

TABLE 3: PERCENT TOTAL AND PERCENT ACTIVE SOLIDS OF RAW POLYMER SAMPLES AND PERCENT TOTAL SOLIDS OF DILUTE POLYMER SAMPLES COLLECTED FROM THE POST-CENTRIFUGE FACILITY DURING JUNE 8 THROUGH 14, 2011

Parameter	Shift	6/8/11	6/9/11	6/10/11	6/11/11	6/12/11	6/13/11	6/14/11	Shift Average	Standard Deviation
%TS of Raw Polymer – North-end	Shift 1	3.55	3.65	3.84	3.61	3.57	3.60	3.61	3.63	0.10
	Shift 2	3.61	3.69	3.61	3.65	3.59	3.55	3.64	3.62	0.05
	Shift 3	3.60	3.66	3.66	3.58	3.49	3.61	3.61	3.60	0.06
	Daily Average	3.59	3.67	3.70	3.61	3.55	3.59	3.62		
	Standard Deviation	0.03	0.02	0.12	0.04	0.05	0.03	0.02		
%TS of Raw Polymer – South-end	Shift 1	3.79	3.82	3.94	2.95	3.67	3.96	3.65	3.68	0.34
	Shift 2	3.57	3.61	3.91	2.89	3.76	3.93	3.66	3.62	0.35
	Shift 3	3.49	3.94	2.87	3.39	3.74	3.88	3.59	3.56	0.36
	Daily Average	3.62	3.79	3.57	3.08	3.72	3.92	3.63		
	Standard Deviation	0.16	0.17	0.61	0.27	0.05	0.04	0.04		
% AS of Raw Polymer – North-end	Shift 1	3.10	3.37	3.50	3.30	3.48	3.48	3.45	3.38	0.14
	Shift 2	3.09	3.46	3.20	3.35	3.48	3.39	3.60	3.37	0.17
	Shift 3	3.01	3.50	3.49	3.40	3.40	3.50	3.50	3.40	0.18
	Daily Average	3.07	3.44	3.40	3.35	3.45	3.46	3.52		
	Standard Deviation	0.05	0.07	0.17	0.05	0.05	0.06	0.08		
%AS of Raw Polymer – South-end	Shift 1	3.18	3.47	3.81	2.52	3.48	3.69	3.35	3.36	0.42
	Shift 2	2.95	3.52	3.73	2.50	3.64	3.61	3.51	3.35	0.45
	Shift 3	3.13	3.59	2.73	3.15	3.56	3.44	3.54	3.31	0.32
	Daily Average	3.09	3.53	3.42	2.72	3.56	3.58	3.47		
	Standard Deviation	0.12	0.06	0.60	0.37	0.08	0.13	0.10		
%TS of Dilute	Shift 1	0.46	0.56	0.48	0.47	0.50	0.48	0.44	0.48	0.04

TABLE 3 (Continued): PERCENT TOTAL AND PERCENT ACTIVE SOLIDS OF RAW POLYMER SAMPLES AND PERCENT TOTAL SOLIDS OF DILUTE POLYMER SAMPLES COLLECTED FROM THE POST-CENTRIFUGE FACILITY DURING JUNE 8 THROUGH 14, 2011

Parameter	Shift	6/8/11	6/9/11	6/10/11	6/11/11	6/12/11	6/13/11	6/14/11	Shift Average	Standard Deviation
Polymer – North-end	Shift 2	0.43	0.53	0.45	0.44	0.50	0.47	0.41	0.46	0.04
	Shift 3	0.43	0.59	0.46	0.45	0.52	0.51	0.40	0.48	0.06
	Daily Average	0.44	0.56	0.46	0.45	0.51	0.49	0.42		
	Standard Deviation	0.02	0.03	0.02	0.02	0.01	0.02	0.02		
%TS of Dilute Polymer – South-end	Shift 1	0.38	0.61	0.45	0.46	0.51	0.44	0.37	0.46	0.08
	Shift 2	0.42	0.53	0.41	0.46	0.54	0.46	0.39	0.46	0.06
	Shift 3	0.51	0.61	0.44	0.52	0.42	0.48	0.44	0.49	0.07
	Daily Average	0.44	0.58	0.43	0.48	0.49	0.46	0.40		
	Standard Deviation	0.07	0.05	0.02	0.03	0.06	0.02	0.04		

TABLE 4: REGRESSION ANALYSIS RESULTS OF THE NORTH-END MEANS WITH RESPECT TO THE SOUTH-END MEANS OF THE RAW POLYMER PERCENT TOTAL SOLIDS, RAW POLYMER PERCENT ACTIVE SOLIDS, AND DILUTE POLYMER PERCENT TOTAL SOLIDS OBSERVED DURING JUNE 8 THROUGH 14, 2011

	Parameter	Slope	Variance of Slope	Student's t-Test Value	p-Value	Adjusted r^2*
1	%TS of Raw Polymer	0.99130	0.000430421	0.41945	0.679	0.99088
2	%AS of Raw Polymer	1.00292	0.000543437	0.12515	0.902	0.98878
3	%TS of Dilute Polymer	1.00357	0.000480245	0.16276	0.872	0.99008

*Adjusted r^2 due to regression of the North-end means on the South-end means.

TABLE 5: ANALYSIS OF VARIANCE RESULTS OF TESTING A NULL HYPOTHESIS THAT THE MEANS OF THE RAW POLYMER PERCENT TOTAL SOLIDS, PERCENT ACTIVE SOLIDS, AND DILUTE POLYMER PERCENT TOTAL SOLIDS ARE EQUAL DURING THE THREE SHIFTS FOR THE DATA OBSERVED DURING JUNE 8 THROUGH 14, 2011

Parameter	Polymer Site	DF	SS	EDF	SSE	p-Value
%TS of Raw Polymer	North	2	0.003495	18	0.08823	0.70493
%TS of Raw Polymer	South	2	0.055324	18	2.23837	0.80273
%AS of Raw Polymer	North	2	0.003781	18	0.49549	0.93387
%AS of Raw Polymer	South	2	0.011124	18	2.91400	0.96629
%TS of Dilute Polymer	North	2	0.002067	18	0.04406	0.66194
%TS of Dilute Polymer	South	2	0.004010	18	0.08597	0.66349

Where

DF = degree of freedom
SS = sum of squares due to three shifts
EDF = error degrees of freedom
SSE = sum of squares due to error
p-Value = significance of probability for testing that $\mu1 = \mu2 = \mu3$

Baseline Centrifuge Operations and Polymer Consumption. This section presents the baseline centrifuge operations and polymer consumption for the period of January 1, 2011, through April 30, 2011, with due consideration of the machine and operational settings and sludge and polymer characteristics, such as sludge and polymer flow rates and number of hours of operation per day, etc. Consideration of these factors is imperative, as they have potential to influence the polymer consumption.

Baseline Centrifuge Operation. A summary of key statistical machine characteristics for the baseline period is presented in Table 6 by individual machine. All parameters shown in Table 6 were recorded hourly for each machine, and daily averages were calculated from hourly data and actual number of hours of operation per day. The daily averages for the study period were used to determine averages for the baseline period. An average torque setting was determined to be in the range of 720 lbs-in to 768 lbs-in in different machines with a range of median values of 720 lbs-in to 776 lbs-in. The highest and lowest daily average torque values among the machines were observed to be 1,002 lbs-in and 422 lbs-in, respectively. These extreme torque values are never preset by the OE, but these kinds of torque values are occasionally observed during hourly data recording likely due to accumulation of cake in the bowl. In order to remove the accumulated cake, higher torque has to be exerted by scroll until the cake is cleared. Such extreme values are also observed due to a very few hours of operation at low or high torque settings. The average and median torque values indicate that the centrifuges were operated with consistent torque settings in a narrow range. The standard deviations for all machines ranged from 5 to 52, with half the machines having a standard deviation of 15 to 30.

The average bowl speed ranged from 2,589 rpm to 2,797 rpm in all machines. The variation in bowl speed from machine to machine is not uncommon, because it is preset at the factory. The operator has no control over manipulating bowl speed. The pinion speed is self-adjusting in auto-torque mode of operation in tandem with respect to the given bowl speed and torque setting. The pinion speed is indirectly dependent on the torque value selected by the operator and to some extent on the set value of polymer flow rate.

The difference between these two speeds (commonly known as differential or delta) determines %CP in centrate. The larger the differential value, the better the capture, but the differential value beyond a certain threshold (approximately 150 rpm to 350 rpm depending upon machine) produces a softer cake. The differential value if not well maintained in a certain range can thus impact the expected performance such as %CP and dryness of CK. The pinion speeds ranged from 2,379 rpm to 2,616 rpm, and the differential values ranged from 131 rpm to 262 rpm. Based on operator experience, this range of observed differential values is determined to be conducive to accomplish the performance goal of 25 %CK with 95 %CP.

A summary of the average performance of each machine during the baseline period is presented in Tables 7 through 9. Table 7 presents the information on the average use of each centrifuge machine per day during the baseline period. All machines were very uniformly operated between 15 and 21 hours per day on an average basis with a median range of 16 to 22 hours per day. Machine Nos. 15 and 18 were not operated at all. Each of the operating machines was operated a maximum of 24 hours per day at least once during the baseline period. Many machines were operated in both extremes, from 1 hour to 24 hours in a day. No machine, however, was operated every day during the entire baseline period. Cumulative daily operation from the machines ranged between 18 and 91 days out of a maximum possible 120 days. The

TABLE 6: CHARACTERISTICS OF MACHINE OPERATING PARAMETERS DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

Machine No.*	Torque, in-lb				Average** Bowl Speed rpm	Average** Pinion Speed rpm	Average*** Differential rpm
	Average**	Std. Dev.	Range	Median			
2	727	17	701–808	724	2,632	2,407	225
3	734	27	683–885	732	2,797	2,609	188
4	727	19	619–761	727	2,644	2,458	186
5	751	26	705–826	745	2,636	2,481	155
6	734	17	701–760	733	2,781	2,616	165
7	720	14	689–757	720	2,626	2,432	194
8	725	13	663–745	727	2,647	2,480	167
9	724	44	570–1,002	726	2,777	2,616	161
10	727	6	716–742	727	2,627	2,456	171
11	731	5	719–738	731	2,641	2,379	262
12	728	23	557–771	730	2,655	2,443	212
13	743	28	654–860	743	2,589	2,458	131
14	760	11	734–785	760	2,645	2,428	217
15	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	759	52	422–787	769	2,632	2,418	214
17	743	14	699–769	744	2,606	2,412	194
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19	760	20	723–814	760	2,631	2,462	169
20	767	25	711–827	766	2,610	2,442	168
21	768	36	655–848	776	2,590	2,385	205
Max	768	52	—	776	2,797	2,616	262
Min	720	5	—	720	2,589	2,379	131

N/A = Not available or not included.

*Machine No. 1 is not included in this study because it is a different kind of machine.

**These are daily average values and were calculated by adding up all hourly values divided by actual number of hourly values per day.

***Average differential values were calculated by subtracting average pinion speed values from average bowl speed values.

TABLE 7: OPERATING TIME OF CENTRIFUGE MACHINES DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

Machine	Hours of Operation per Day					No. of Days of	Cumulative Hours of
No.*	Average	Std. Dev.	Median	Minimum	Maximum	Operation	Operation
2	19.6	5.8	22.0	2.0	24.0	68	1,335
3	19.3	5.8	22.0	1.0	24.0	63	1,215
4	20.3	5.0	22.0	2.0	24.0	91	1,848
5	18.5	6.2	21.0	2.0	24.0	55	1,018
6	15.4	7.4	16.0	1.0	24.0	34	525
7	19.1	5.6	21.0	4.0	24.0	31	591
8	18.9	5.7	21.5	4.0	24.0	42	792
9	19.1	5.6	21.0	3.0	24.0	81	1,551
10	20.8	4.3	22.0	9.0	24.0	18	374
11	21.2	3.4	22.0	7.0	24.0	31	657
12	19.9	5.1	22.0	2.0	24.0	83	1,652
13	18.7	6.7	22.0	2.0	24.0	42	785
14	20.1	5.6	22.0	3.0	24.0	49	985
15	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	20.1	5.4	22.0	2.0	24.0	47	945
17	18.3	6.4	22.0	4.0	24.0	19	347
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19	18.6	6.1	21.0	4.0	24.0	48	891
20	20.1	4.8	21.0	4.0	24.0	41	826
21	18.6	6.2	22.0	2.0	24.0	62	1,156
Max	21.2	7.4	22.0	9.0	24.0	91	1,848
Min	15.4	3.4	16.0	0.0	24.0	18	347

N/A = Not available or not included.

*Machine No. 1 is not included in this study because it is a different kind of machine.

TABLE 8: PERFORMANCE OF CENTRIFUGE MACHINES MEASURED IN TERMS OF PERCENT TOTAL SOLIDS OF CENTRIFUGE CAKE AND PERCENT SOLIDS CAPTURE IN CENTRATE DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

Machine	%TS of Centrifuge Cake					%Solids Capture				
No.	Average	Std. Dev.	Median	Minimum	Maximum	Average	Std. Dev.	Median	Minimum	Maximum
2	24	2	24	18	29	92	3	93	78	98
3	24	2	24	18	35	93	3	93	75	99
4	24	2	24	17	31	92	7	93	45	98
5	23	4	23	13	28	93	2	94	85	96
6	22	3	21	16	27	94	2	94	85	97
7	25	2	25	17	28	93	4	94	77	98
8	23	2	22	20	29	91	6	92	59	95
9	24	2	24	20	31	92	7	93	52	97
10	25	1	25	24	26	95	1	95	94	98
11	25	1	25	21	28	94	1	94	93	96
12	24	2	24	19	28	92	5	93	63	99
13	25	1	25	23	28	93	3	94	78	96
14	24	2	24	18	29	94	2	94	89	97
15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	23	2	23	20	27	93	8	94	38	97
17	24	1	24	20	26	94	1	94	91	96
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19	22	3	23	14	27	92	8	94	44	99
20	25	2	25	20	28	94	1	94	92	96
21	23	2	23	18	27	91	9	93	32	97
Max	25	4	25	24	35	95	9	95	94	99
Min	22	1	21	13	26	91	1	92	32	95

N/A = Not available or not included.

Percent solids capture is the percent total solids in cake with respect to the total solids content in centrifuge feed.

*Machine No. 1 is not included in this study because it is a different kind of machine.

TABLE 9: SLUDGE THROUGHPUT PER MACHINE DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

	Daily Sludge Throughput (Dry Tons/Day)					Cumulative Sludge Throughput (Dry Tons)
Machine No.*	Average	Std. Dev.	Median	Minimum	Maximum	
2	27.1	9.0	30.8	2.8	40.5	1,818
3	24.9	8.1	27.1	1.1	39.9	1,566
4	27.6	7.0	29.6	2.4	39.6	2,459
5	19.5	6.7	21.0	2.5	29.8	1,050
6	17.3	7.8	17.3	1.3	29.8	571
7	28.4	9.2	30.9	5.4	38.1	879
8	24.7	8.2	25.8	6.1	40.1	988
9	26.2	8.0	28.5	4.7	45.8	2,073
10	31.4	6.9	33.0	13.3	37.8	566
11	32.0	5.8	32.6	9.5	39.9	993
12	26.9	7.1	29.0	2.5	36.3	2,182
13	23.4	8.6	27.5	2.3	33.6	984
14	27.7	8.0	29.8	3.8	37.9	1,356
15	N/A	N/A	N/A	N/A	N/A	N/A
16	26.5	7.6	28.6	2.6	35.7	1,245
17	23.4	8.5	27.3	4.9	33.6	444
18	N/A	N/A	N/A	N/A	N/A	N/A
19	20.8	6.6	22.7	4.6	31.1	959
20	27.1	7.4	28.4	4.9	40.0	1,111
21	22.0	7.4	24.6	2.3	33.3	1,342
Max	32.0	9.2	33.0	13.3	45.8	2,459
Min	17.3	5.8	17.3	1.1	29.8	444

N/A = Not available or not included.
*Machine No. 1 is not included in this study because it is a different kind of machine.

cumulative hours of operation during the baseline period ranged from 347 hours (machine No. 17) to 1,848 hours (machine No. 4). The highest hours of operation of 1,848 hours indicates approximately 65 percent of usage of machine No. 4 with respect to the maximum possible hours of 2,880. If machine Nos. 2 through 21 were continuously operated during the baseline period then maximum possible machine days and machine hours would have been 2,400 and 57,600, respectively. Actual usage of these machines with respect to the machine days and machine hours were 38 and 30 percent, respectively.

Table 8 provides performance of the machines as measured in terms of %TS of centrifuge cake and %CP. Average %TS of centrifuge cake ranged from 22 to 25 percent with a median range of 21 to 25 %TS. Average solids capture ranged from 91 to 95 percent with a median range of 92 to 95 percent. These results indicate that the performance goals were reasonably met. However, %TS of cake ranged 13 to 35 percent and solids capture ranged from 32 to 99 percent during the baseline period. However, occasional skewed results may not be representative as normal operation and may simply be an artifact of grab sampling.

Average daily sludge throughput (solids processed on a dry basis) was found to be in a wide range from 17.3 to 32.0 DT/day amongst all machines with a median ranging from 17.3 to 33.0 DT/day (Table 9). Variations in sludge throughput were due to many reasons such as practical limitations in daily operations, operators' personal preference of choosing certain machines more frequently than others, diurnal variations in %TS in centrifuge feed, and daily goal of sludge volume to be processed. Despite low sludge throughputs from a few machines, most machines produced relatively similar sludge throughput on a daily average basis. Significant variations in daily operation among the machines caused daily sludge throughput variations from as low as 1.1 DT to as high as 45.8 DT per machine. The highest cumulative sludge throughput of 2,459 DT during the baseline period was found in machine No. 4, with 1,848 hours of operation, and the least sludge throughput of 444 DT in machine No. 17, with 347 hours of operation.

The average centrifuge feed characteristics for the baseline period is presented in Table 10. Significant variations in %TS in feed were observed to range from 1.97 to 3.41 percent with an average of 2.55 percent and a median of 2.51 percent. Similar proportionate variations were found in %VS as well, which ranged from 45 to 59 percent with an average of 54 percent and a median of 54 percent. The separate measurements made daily by the M&O Department for its routine process control on digester draw %TS and %VS were compared against centrifuge feed %TS and %VS, respectively, and found both separate measurements to be very similar but not identical. Average digester draw %TS during the baseline period was found to be 2.66 percent with a range of 2.17 to 3.30 percent and a median of 2.66 percent. Similarly, average digester draw %VS during the baseline period was found to be 55 percent with a range of 50 to 58 percent and a median of 56 percent. Compared to centrifuge feed, digester draw shows much tighter ranges of %TS and %VS. This might be due to diurnal variations in sludge quality in draw tanks from where centrifuge feed is obtained. Generally, larger variations take place when centrifuge feed is obtained from the bottom two feet in the draw tanks due to stratification of solids in draw tanks.

A slight decrease is anticipated in centrifuge feed pH upon CO_2 injection into the digester draw. A drop in centrifuge pH could not be verified, because pH of centrifuge feed is not routinely measured. However, digester draw pH, VAs, and alkalinity concentrations were

TABLE 10: AVERAGE CHARACTERISTICS OF CENTRIFUGE FEED AND DIGESTER DRAW SLUDGE DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

Parameter	Centrifuge Feed % TS	Centrifuge Feed %VS	Digester Draw pH	Digester Draw %TS	Digester Draw %VS	Digester Draw Total VAs, mg/L as Acetate	Digester Draw Alkalinity, mg/L as Calcium Carbonate
Maximum	3.41	59	7.51	3.30	58	153	3,991
Minimum	1.97	45	7.16	2.17	50	45	3,025
Average	2.55	54	7.30	2.66	55	101	3,610
Std. Dev.	0.26	2	0.06	0.24	2	35	253
Median	2.51	54	7.30	2.66	56	93	3,633
No. Observations	99	100	85	120	120	17	17

evaluated as surrogate characteristics for centrifuge feed. The pH ranged from 7.16 to 7.51 with an average of 7.30. This pH at or slightly above neutral range was not likely to cause material impact on polymer demand, because mannich polymer demand is known to increase above 7.6 pH values. The alkalinity concentration averaging 3,610 mg/L as $CaCO_3$ and VA concentrations averaging 101 mg/L as $CH_3CO_2^-$ were observed. Both parameters at these levels were not expected to affect polymer demand. As such, no threshold limits have been set for these parameters that can suggest the effects on polymer demand. The literature suggests, however, that these parameters have potential to interfere with polymer efficacy at higher concentrations.

A slight decrease is anticipated in centrifuge feed pH upon CO_2 injection into the digester draw. A drop in centrifuge pH could not be verified, because pH of centrifuge feed is not routinely measured. However, digester draw pH, VAs, and alkalinity concentrations were evaluated as surrogate characteristics for centrifuge feed. The pH ranged from 7.16 to 7.51 with an average of 7.30. This pH at or slightly above neutral range was not likely to cause material impact on polymer demand, because mannich polymer demand is known to increase above 7.6 pH values. The alkalinity concentration averaging 3,610 mg/L as $CaCO_3$ and VA concentrations averaging 101 mg/L as $CH_3CO_2^-$ were observed. Both parameters at these levels were not expected to affect polymer demand. As such, no threshold limits have been set for these parameters that can suggest the effects on polymer demand. The literature suggests, however, that these parameters have potential to interfere with polymer efficacy at higher concentrations.

Basic statistics on the average polymer characteristics for the baseline period are presented in Table 11. The average %TS of raw polymer for machine Nos. 1 through 12 were observed to be 3.69 percent with a median of 3.67 percent; the average %TS of raw polymer for machine Nos. 13 through 21 were observed to be 3.67 percent with a median of 3.64 percent. The polymer activity is measured from %AS, but it is not routinely analyzed and therefore not included in this analysis. The average %TS of dilute polymer for machine Nos. 1 through 12 were observed to be 0.50 percent with a median of 0.51 percent; the average %TS of dilute polymer for machines Nos. 13 through 21 were observed to be 0.52 percent with a median of 0.52 percent. The %TS of dilute polymer is indicative of the consistent preparation procedure and consistent strength of dilute polymer. Variations in raw and dilute polymers were 8 percent and 16 percent, respectively, according to the coefficients of variation (CVs). The polymer characteristics observed during the baseline period supports the independently verified and previously discussed conclusions on raw polymer quality and dilute polymer preparation at the North- and South-end of the facility.

Baseline Polymer Consumption. Polymer consumption was evaluated in conjunction with the amount of sludge processed. A summary of polymer consumption and sludge processed per machine is presented in Table 12 in terms of average daily sludge and polymer flow rates, average volumetric ratio of daily polymer consumption flow rate to daily sludge flow rate, average polymer dose, and contribution of each machine towards total polymer consumption, and total sludge processed during the baseline period. It was previously noted that machine No. 1 is not included in this phase as it is operated differently than the other 20 machines. However, throughout this phase summary, total polymer consumption and total sludge processed by all machines includes contribution of machine No. 1 unless specifically mentioned due to the fact that percent contribution of each machine is based on total polymer consumption and sludge processed during the baseline period. Approximately 230 million gallons of sludge was

TABLE 11: AVERAGE CHARACTERISTICS OF RAW AND DILUTE POLYMER DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

Site	Parameter	Raw Polymer % TS	Diluted Polymer % TS
South-end Machines No. 1 to 12	Maximum	4.58	0.75
	Minimum	2.12	0.27
	Average	3.69	0.50
	Median	3.67	0.51
	Std. Dev.	0.31	0.08
	No. Observations	99	98
North-end Machines No. 13 to 21	Maximum	4.74	0.71
	Minimum	2.40	0.19
	Average	3.67	0.52
	Median	3.64	0.52
	Std. Dev.	0.29	0.08
	No. Observations	97	95

TABLE 12: AVERAGE POLYMER CONSUMPTION AND SLUDGE PROCESSING DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

Machine No.	Sludge Flow, gpm	Polymer Flow, gpm	Polymer Flow/ Sludge Flow, gpm/gpm	Cumulative Sludge Processed, gal	Cumulative Polymer Consumed, gal	Polymer Dose, lbs/DT
1	380	22.8	0.060	15,114,060	908,137	647
2	216	10.2	0.047	17,267,604	817,805	511
3	206	10.3	0.050	15,074,520	753,022	539
4	214	10.4	0.049	23,671,560	1,156,748	530
5	167	10.6	0.064	10,143,360	648,400	695
6	177	10.6	0.060	5,514,240	331,230	644
7	218	10.0	0.046	7,737,480	352,458	454
8	212	10.6	0.050	10,123,200	503,496	557
9	211	10.8	0.051	19,689,060	996,944	553
10	213	9.8	0.046	4,772,100	219,918	438
11	223	10.0	0.045	8,796,540	396,126	446
12	211	10.4	0.049	20,931,480	1,030,489	531
13	204	10.6	0.052	9,657,360	501,098	599
14	218	9.7	0.044	12,878,280	567,816	516
15	N/A	N/A	N/A	N/A	N/A	N/A
16	206	10.8	0.052	11,708,700	612,679	596
17	201	10.4	0.052	4,171,560	215,028	573
18	N/A	N/A	N/A	N/A	N/A	N/A
19	183	9.8	0.054	9,709,680	525,240	657
20	206	10.4	0.051	10,244,280	515,868	550
21	186	11.1	0.060	12,913,920	772,884	690
			N/A			
Max*	223	11.1	0.064	23,671,560	1,156,748	695
Min*	167	9.7	0.044	4,171,560	215,028	438
Sum*	N/A	N/A	N/A	230,118,984	11,825,388	N/A

N/A = Not applicable.

*Machine No. 1 is included to determine cumulative sludge processed and cumulative polymer consumption by all machines, but is not included to determine “max” and “min” quantities.

processed by all operating machines during the baseline period, and 11.83 million gallons of dilute polymer was consumed.

The average sludge flow rate was observed to range from 167 to 223 gpm, and the average polymer flow rate was observed to range from 9.7 to 11.1 gpm excluding machine No. 1. Operations predominantly occurred at a median sludge flow rate range of 200 to 225 gpm except for machine Nos. 5, 6, 19, and 21, and a median polymer flow rate range of 9.6 to 10.7 gpm except for machine Nos. 16 and 21. Variations in polymer consumption expressed in terms of average ratio of polymer to sludge flow rates ranged from 0.044 to 0.064 gpm/gpm. Inherent assumption for comparisons based on volumetric flow rates is that sludge and polymer quality is similar during the observed period. It is clear that each machine consumed different volume of polymer per unit volume of sludge processed. The polymer consumption did not vary more than 23 percent in 12 of 21 machines (machine Nos. 1, 5, 6, 13, 15, 16, 18, 19, and 21 excluded). Machine No. 14 consumed the least polymer and machine No. 5 consumed the most polymer based on per unit volume. This amounts to approximately 45 percent difference in polymer consumption between the least polymer-consuming and the most polymer-consuming machines.

The average polymer dose was observed to vary from 438 to 695 lbs/DT among all machines; 11 of 18 (except for machine Nos. 1, 15, and 18) machines consumed an average of 500 to 600 lbs/DT. Large variations in polymer dose mainly came from wide variations in polymer and sludge flows and daily variations in sludge characteristics (such as %TS of centrifuge feed) during the baseline period. The volumetric comparison does not depend upon analytical results and hence, such results may be more valuable for this evaluation.

The individual machine contribution in terms of gallons of sludge processed and polymer consumed during the baseline period is also shown in Table 12. Machine No. 4 processed the largest amount of sludge of almost 24 million gallons, and consumed the largest amount of dilute polymer of 1.16 million gallons. In contrast, of the operating centrifuges, machine No. 17 processed only 4.17 million gallons of sludge, and consumed 0.22 million gallons of polymer.

Identification of Better-Performing Machines. The baseline centrifuge operation and polymer consumption data were evaluated to identify the best- and worst-performing machines. Table 13 presents machines in ascending order with respect to their polymer consumption expressed as a ratio of polymer to sludge volume and polymer dose. The five lowest polymer consuming machines by volume ratio in ascending order were machine Nos. 14, 11, 7, 10, and 2. In contrast, the five machines that consumed the most polymer volume in descending order were machine Nos. 5, 6, 21, 19, and 16. With respect to polymer dose, the five lowest polymer consuming machines in ascending order were machine Nos. 10, 11, 7, 2, and 14, and the five highest polymer consuming machines in descending order were machine Nos. 5, 21, 19, 6, and 13. The polymer volume based ranking is considered better than the polymer dose based ranking as there is more likelihood of potential measurement and analytical errors in the polymer dose based ranking.

The productivity in terms of sludge throughput is important, but such ranking is not included in Table 13, because this quantity depends upon operating hours and sludge flow. The five most productive machines with respect to sludge throughput were machine Nos. 11, 10, 7, 14, and 4, and the five least productive machines were machine Nos. 6, 5, 19, 21, and 17. A review of data presented in Table 13 reveals that the least productive machines happened to be

TABLE 13: RANKING OF CENTRIFUGE MACHINES WITH RESPECT TO VOLUME OF POLYMER CONSUMPTION PER UNIT VOLUME OF SLUDGE PROCESSED AND POLYMER DOSE OBSERVED DURING BASELINE PERIOD OF JANUARY 1, 2011, THROUGH APRIL 30, 2011

Machine No.*	Polymer Flow/Sludge Flow, gpm/gpm	Machine No.*	Polymer Dose, lbs/DT
14	0.044	10	438
11	0.045	11	446
7	0.046	7	454
10	0.046	2	511
2	0.047	14	516
4	0.049	4	530
12	0.049	12	531
8	0.050	3	539
3	0.050	20	550
20	0.051	9	553
9	0.051	8	557
17	0.052	17	573
13	0.052	16	596
16	0.052	13	599
19	0.054	6	644
21	0.060	19	657
6	0.060	21	690
5	0.064	5	695
18	N/A	15	N/A
15	N/A	18	N/A

N/A = Not available.

*Machine No. 1 is not included in this study because it is a different kind of machine.

the most polymer-consuming machines by volume and vice versa. Daily observation of machine performance by M&O Department personnel may have played a role in their preference for choosing the better-performing machines with the intent to maintain reliable production. It is also likely that the least productive machines consumed more polymer because operators routinely set polymer flow in a normal range, but these machines could not process 200 gpm or higher sludge flow. This may be due to the operators' desire to prioritize maintenance of reliable production over polymer savings.

Optimization of Polymer Demand by Adjusting Machine/Operational Settings. The baseline centrifuge operations and baseline polymer consumption discussed in the preceding section suggests that despite consistency in operating guidelines, the machines were operated differently in terms of different sludge, polymer flow rates, and torque settings. These machine-specific idiosyncrasies translate into different performance and polymer consumption. Ideally this should be addressed by formulating unique/custom machine settings for each machine, but this is highly impractical because the operator is expected to operate many machines in addition to other duties. Custom adjustments on many machines may consume the operator's productivity. One possibility is to formulate and recommend a uniform operational strategy for all machines based on intensive evaluations of a few select machines that can represent the whole. The operational strategies from this evaluation can be applied to each machine. It is also recognized that centrifuge operation at a set torque value is a practical and desirable operating strategy at the Stickney WRP, because it allows fewer operators to operate the machines on a continuous basis.

As mentioned above, a few select machines (as a representation of all machines) were operated with a goal to optimize polymer demand for each machine. The optimal polymer demand was determined in a few select machines in several steps as described below. These steps included determining the lowest fixed torque value for each select machine along with the lowest practical polymer flow rate at which the machines can be operated at a minimum sludge flow rate of 200 gpm in auto-torque mode without compromising machine performance.

1. During the post-baseline period from June 9 through 21, 2011, the observations on each of 14 machines were made twice every 15 minutes and compiled. This compiled data was evaluated to ensure that the post-baseline operation was similar to the baseline operation and is representative of normal operation. This was essential before undertaking optimization of select machine and operational settings. A review of compiled data (not shown) revealed that all machines were operated similarly during the post-baseline period with respect to the baseline period in auto-torque mode at a fixed torque setting in a range of 723 to 870 lbs-in with an average and median torque values of 756 and 750 lbs-in, respectively. The average sludge flow rate was 194 gpm with a median of 200 gpm and a range of 160 to 210 gpm, and the average polymer flow rate was 11.3 gpm with a median of 11.4 gpm and a range of 8 to 13.8 gpm. Average CK were 27.1 percent with a median of 27.6 percent and a range of 20.8 to 31.4 percent, and average solids capture was 95 percent with a median of 96 percent and a range of 78 to 97 percent.

The average %TS of 2.55 in centrifuge feed during the baseline period increased to 3.77 during this post-baseline study period. Such changes are not uncommon. Likewise, some differences in sludge and polymer flow rates were observed, but machine performance was not impacted due to the consistent guidelines of operating the machines in auto-torque mode.

2. Four machines were randomly selected and operated at incrementally decreased pre-set torque values to evaluate the relationship between decreasing torque and %TS of CK. The cake %TS results were plotted against torque observations in Figures 1 and 2. No trend was found between %TS of CK and decreasing torque values with constant sludge and polymer flow rates. Figure 2 shows one data point for machine No. 9 (corresponding to an 800 torque value) and two data points for machine No. 3 as outliers (corresponding to 675 and 775 torque values). These outliers may occur as previously explained, i.e. the machines' torque tends to vacillate upon cake purging and accumulation durations. The figures indicate however, that 25 %CK were achieved by setting a torque value in the broad range from 650 to 800 lbs-in. The other machines were operated by OEs in a normal pre-set torque value range of approximately 712 to 750 lbs-in.

3. A conservative torque value of 725 lbs-in was selected as an assurance of 25 %CK for machine Nos. 2 through 12 based on the work performed in the above step. An equivalent setting at 30 percent load factor was selected for machine Nos. 13 through 21 as these machines are operated/monitored with different control system.

4. Average performance of the different machines that were operated on November 8 and 9, 2011, is shown in Table 14. All machines were operated in auto-torque mode at a sludge flow rate of 200 gpm and a pre-selected torque value of 725 lbs-in for machine Nos. 3, 9, and 12, or 30 percent load factor for machine Nos. 14, 16, and 20. The polymer flow was reduced to the lowest possible rate with an attempt to maintain centrate clarity and 25% CK. Machine No. 16 produced much lower than 25% CK because of the lower torque setting. The lower torque setting generally increases differential (delta), causing softer cake but superior centrate clarity. Prior to commencing tests on this machine, machine No. 16 was operating at a fixed torque of 791 lbs-in with very dark centrate and firmer cake. Machine Nos. 9 and 12 produced lower solids capture due to too much reduction in polymer flow. This sort of uniqueness of machine performance due to adjustments in machine settings such as machine Nos. 16, 9, and 12, is referred to as "machine idiosyncrasy," which affects performance. Machine settings for such idiosyncratic machines need increased effort on the operator's part and attention.

   Machine Nos. 14 and 16 were rated in top five and bottom five performing machines, respectively, with respect to polymer consumption (Table 13). The final average polymer flow rate ranged from 9.2 to 10.4 gpm for the various machines resulting in polymer dose of 282 to 326 lbs/DT. Average

FIGURE 1: TORQUE OF POST-CENTRIFUGE MACHINE NUMBERS 18 AND 21 AT FIXED SLUDGE AND POLYMER FLOW RATES RELATIVE TO CAKE SOLIDS ON JULY 14, 2011, BETWEEN 10:35 AM AND 12:20 PM

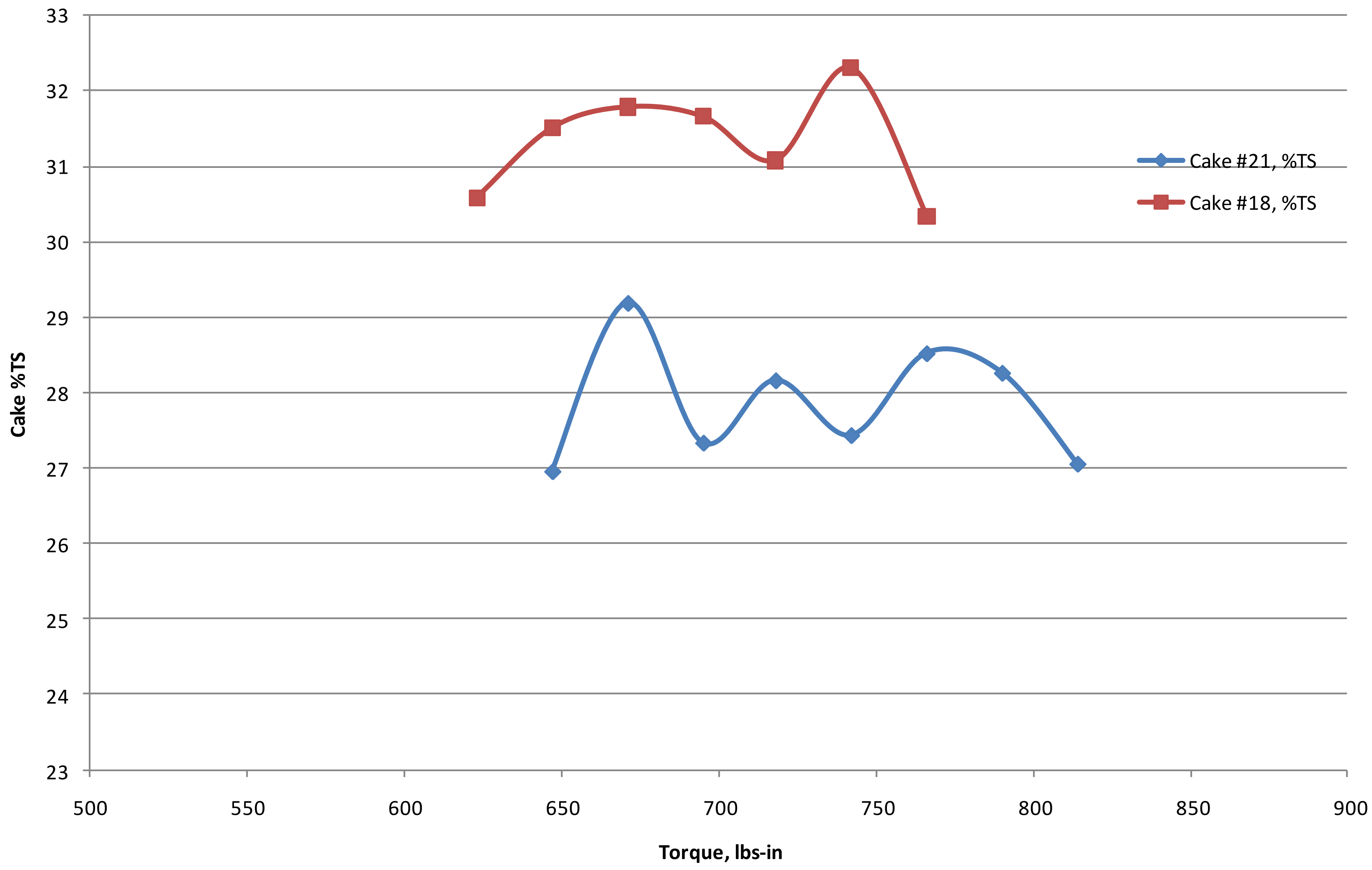


FIGURE 2: TORQUE OF POST-CENTRIFUGE MACHINE NUMBERS 3 AND 9 AT FIXED SLUDGE AND POLYMER FLOW RATES RELATIVE TO CAKE SOLIDS ON OCTOBER 5, 2011, BETWEEN 9:15 AM AND 11:45 AM

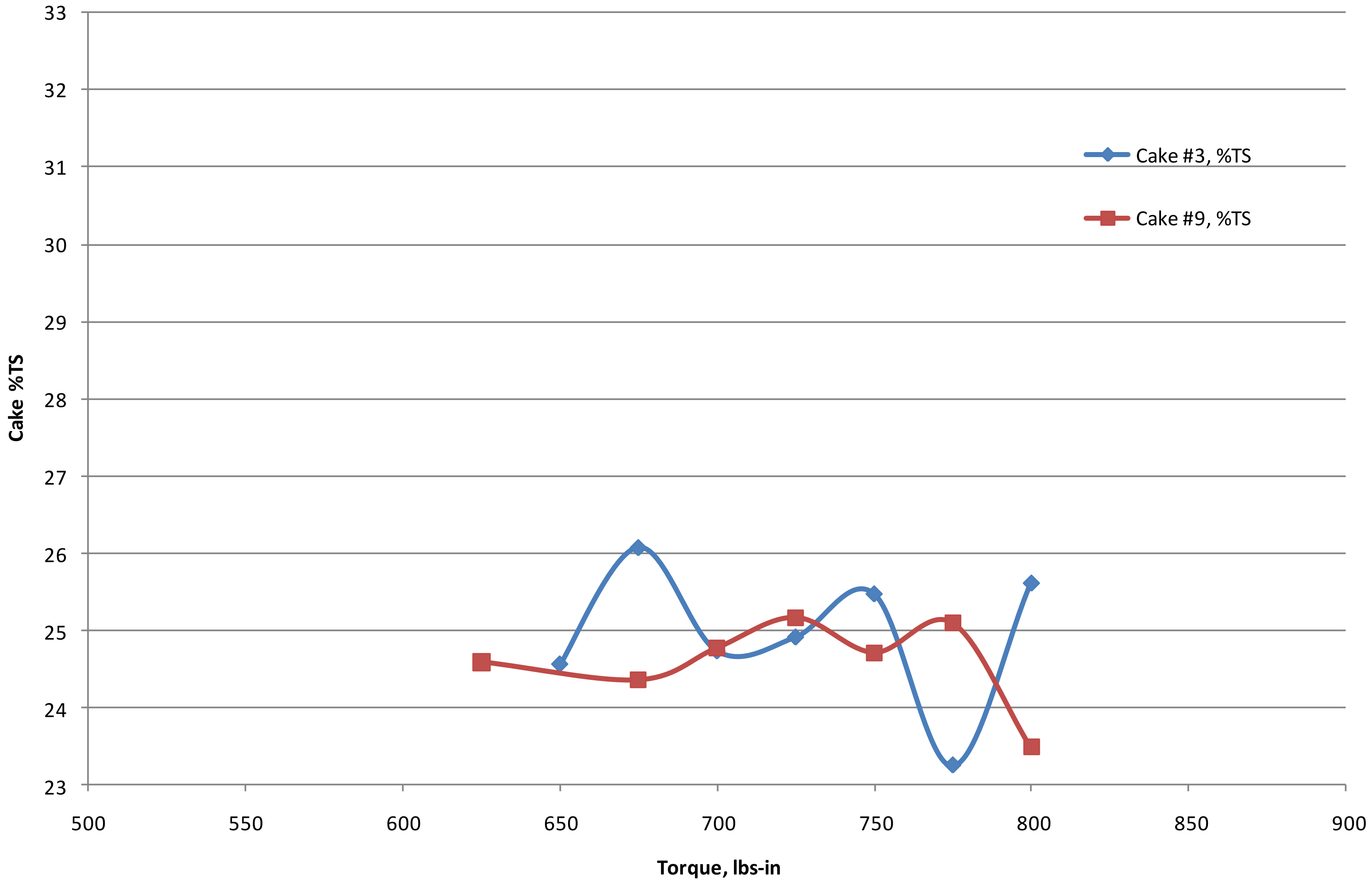


TABLE 14: AVERAGE PERFORMANCE AND OPERATIONS DATA OF THE POST-CENTRIFUGE MACHINES OBSERVED ON NOVEMBER 8 AND 9, 2011

Date of Operation	Machine No.	Sludge Flow Rate, gpm	Polymer Flow Rate, gpm	% Solids Capture	%TS of Cake	Polymer Dose, lbs/DT
11/08/11	3	200	10.4	95	25	287
	9	200	10.3	91	26	283
	12	200	10.2	91	25	282
	20	200	10.3	95	27	326
11/09/11	14	200	9.2	96	25	286
	16	200	10.4	97	19	321

All machines were operated in auto-torque mode at sludge flow rate of 200 gpm and selected torque of 725 lbs-in for machine Nos. 2 through 12 and 30% load factor for machine Nos. 13 through 21. The polymer flow rate was reduced by 5% until the machines were judged to meet the performance goals of 25% TS of centrifuge cake and 95% solids capture.

CK ranged from 19 to 27 percent and the solids capture ranged from 91 to 97 percent. All machines, however, can meet the performance goals at different polymer consumption rate.

Laboratory-Scale Tests for Potential Polymer Savings.

Evaluation of Switch in Dilution Water. Varying amounts of dilute polymer prepared from the secondary treated plant effluent and city water with a 10 percent strength were added to the freshly collected centrifuge feed samples (200 mL) and mixed following the established mixing protocols (500 rpm for 120 seconds followed by hand mixing for a few seconds). Upon conditioning the sludge samples with the different polymer dilutions, CST tests were performed. The results of CST tests are shown in Figures 3 through 6. Figures 3 and 6 indicate improved dewatering with city water based polymer solution at a lower polymer dose. Figures 4 and 5 do not show significant improvement in dewatering with the city water based polymer solution, indicating that the city water based optimum polymer dose may not be significantly different compared to the optimum dose with the plant effluent based polymer. The laboratory-scale test results appear to be promising but inconclusive. These test results do not provide enough evidence to be able to determine whether the polymer savings will offset the cost of water.

Evaluation of Surface Tension as an Indicator of Excess Polymer Use. Deionized water, tap water, and secondary effluent were dosed with varying amounts (0 to 50 mL) of dilute polymer to determine the effects on surface tension. Surface tension in centrate samples is expected to decrease with increased polymer and may be an indicator of excess polymer use in centrifuge operations. The surface tension was measured in the above samples, and the results are presented in Figure 7. All the measured values ranged between 66 and 73 dynes/cm. These results are consistent with our anticipated hypothesis, i.e. decreasing surface tension with increased polymer, but the results show a very weak trend. The varying amounts of polymers cannot be clearly distinguished in the range tested except in the samples prepared from deionized water.

Centrifuge feed samples were also dosed with varying doses of dilute polymer (0 to 90 mL). The conditioned sludge was mixed, allowed to settle, and the supernatant was decanted for surface tension analysis. Table 15 presents the measured values of surface tension in decant samples collected from full-scale and laboratory-scale operations. For the decant samples, values ranged from 69.8 dynes/cm to 70.9 dynes/cm, but no visible trend could be observed with increasing polymer dosage.

Phase I Conclusions and Recommendations

Based on the findings of this phase, the following conclusions are drawn and recommendations are made for potential implementation with due consideration. Certain recommendations are not solely based on this phase but on previous experience with operations:

Conclusions.

1. No formal written procedures or protocols for dilute polymer preparation and centrifuge operations exist with M&O Department staff. However, the

FIGURE 3: EVALUATION OF CITY WATER VERSUS PLANT EFFLUENT BASED DILUTE POLYMER DOSES ON DEWATERING PERFORMANCE EXPRESSED AS CAPILLARY SUCTION TIME: EXPERIMENTAL RESULTS FROM OCTOBER 19, 2011, TESTS

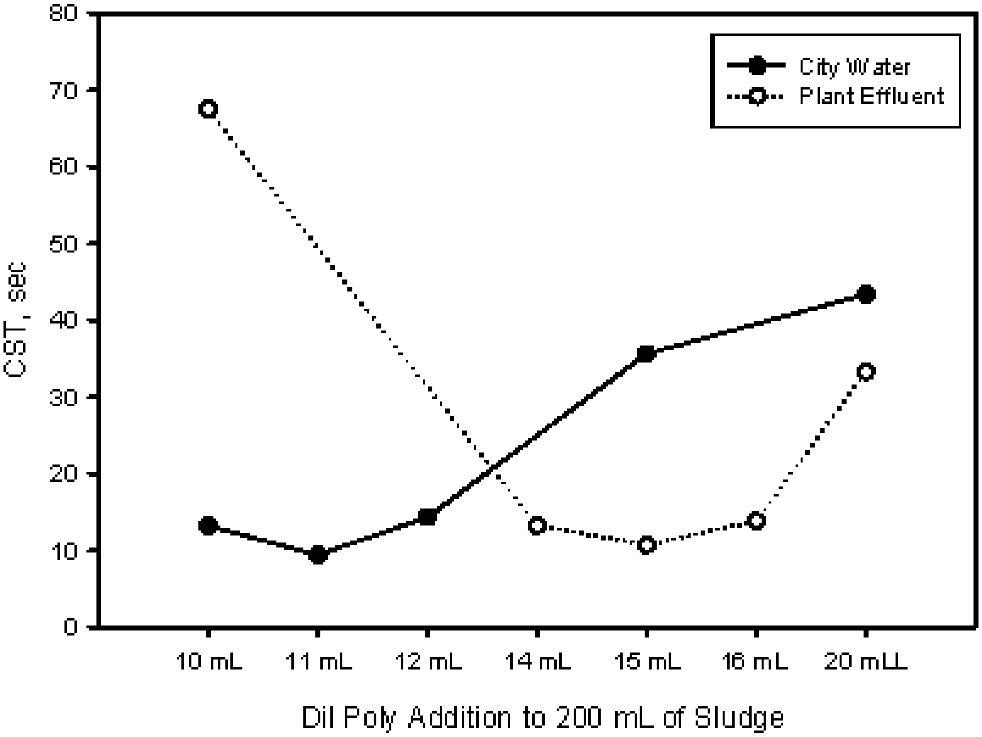


FIGURE 4: EVALUATION OF CITY WATER VERSUS PLANT EFFLUENT BASED DILUTE POLYMER DOSES ON DEWATERING PERFORMANCE EXPRESSED AS CAPILLARY SUCTION TIME:
EXPERIMENTAL RESULTS FROM OCTOBER 31, 2011, TESTS

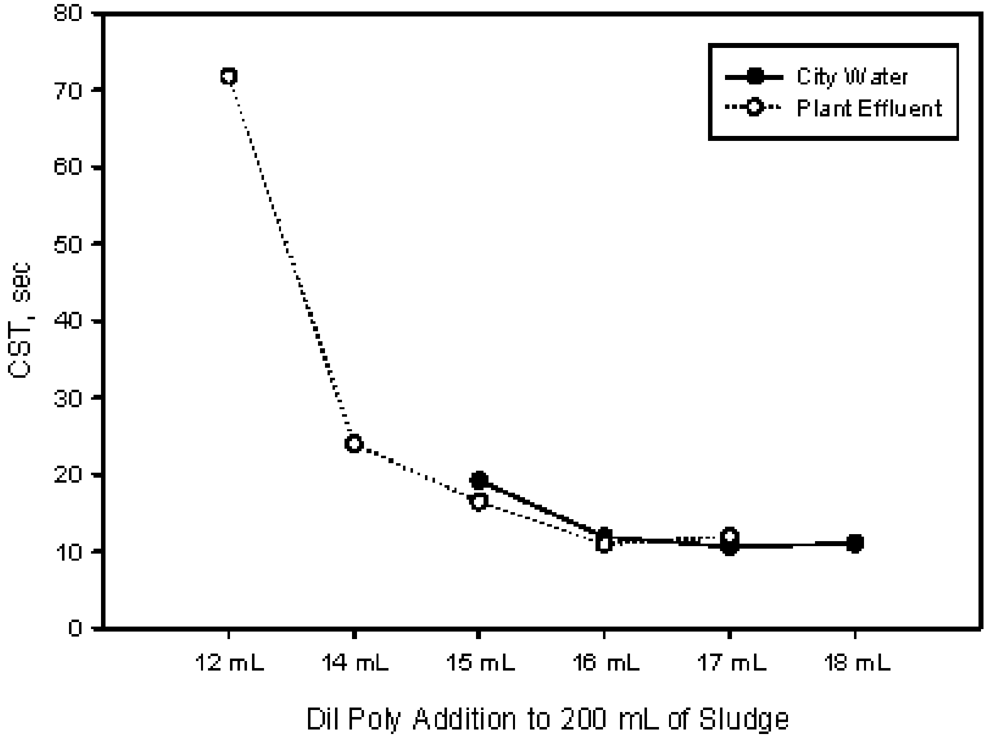


FIGURE 5: EVALUATION OF CITY WATER VERSUS PLANT EFFLUENT BASED DILUTE POLYMER DOSES ON DEWATERING PERFORMANCE EXPRESSED AS CAPILLARY SUCTION TIME: EXPERIMENTAL RESULTS FROM NOVEMBER 2, 2011, TESTS

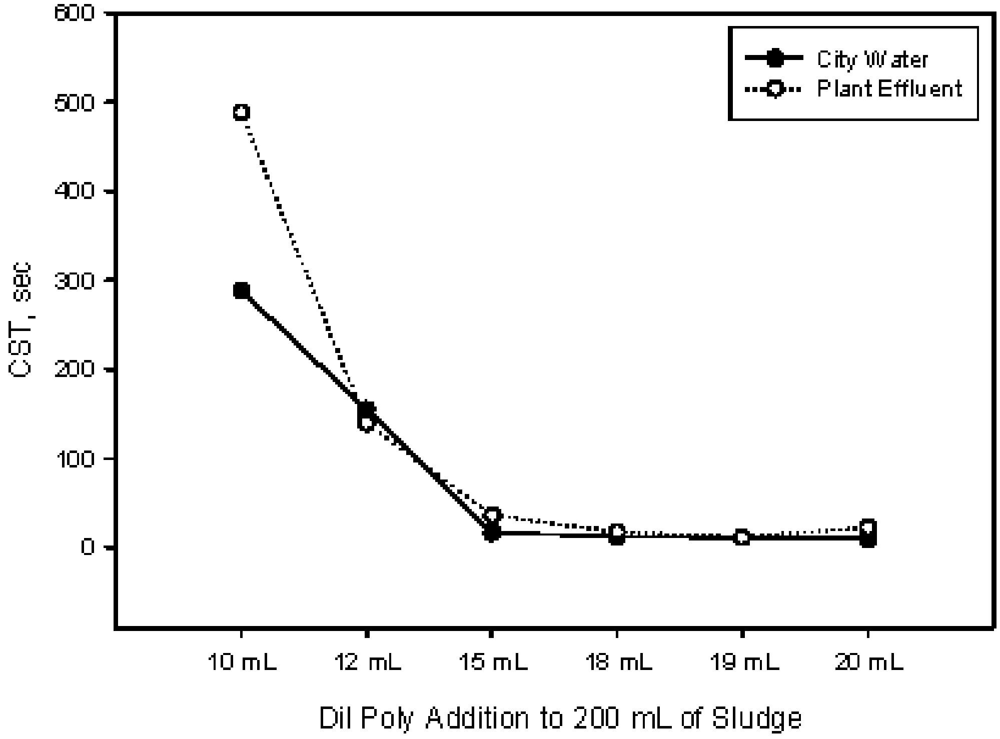


FIGURE 6: EVALUATION OF CITY WATER VERSUS PLANT EFFLUENT BASED DILUTE POLYMER DOSES ON DEWATERING PERFORMANCE EXPRESSED AS CAPILLARY SUCTION TIME: EXPERIMENTAL RESULTS FROM NOVEMBER 7, 2011, TESTS

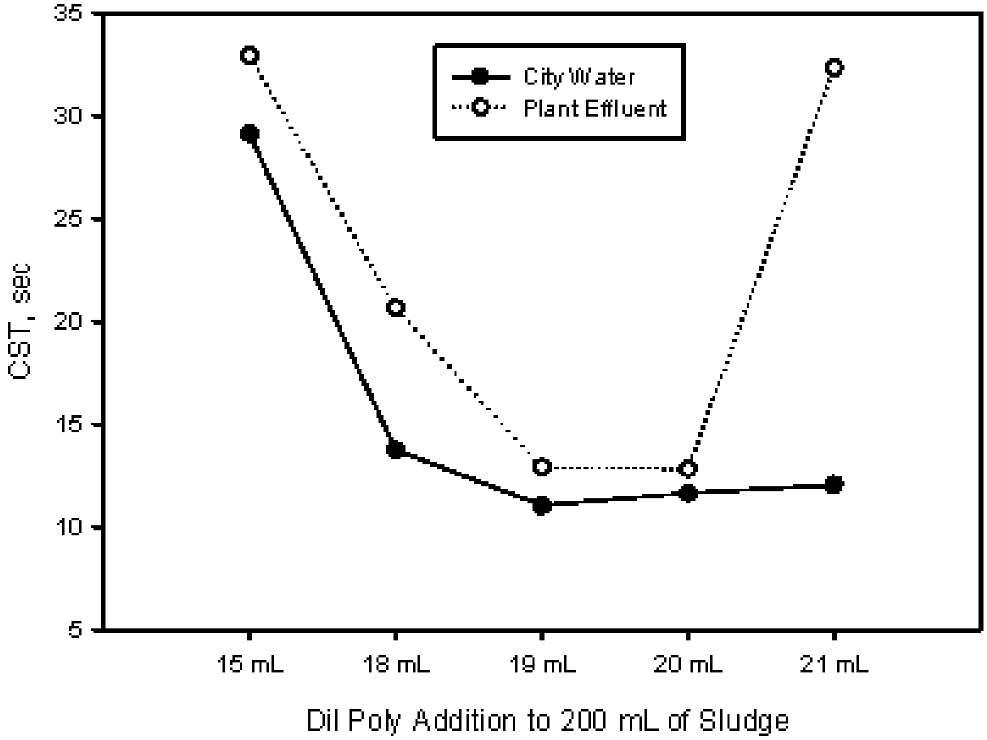


FIGURE 7: LABORATORY-SCALE EXPERIMENTAL SURFACE TENSION MEASUREMENTS OF SAMPLES CONTAINING VARIOUS AMOUNTS OF POLYMER IN DEIONIZED WATER, TAP WATER, AND PLANT EFFLUENT

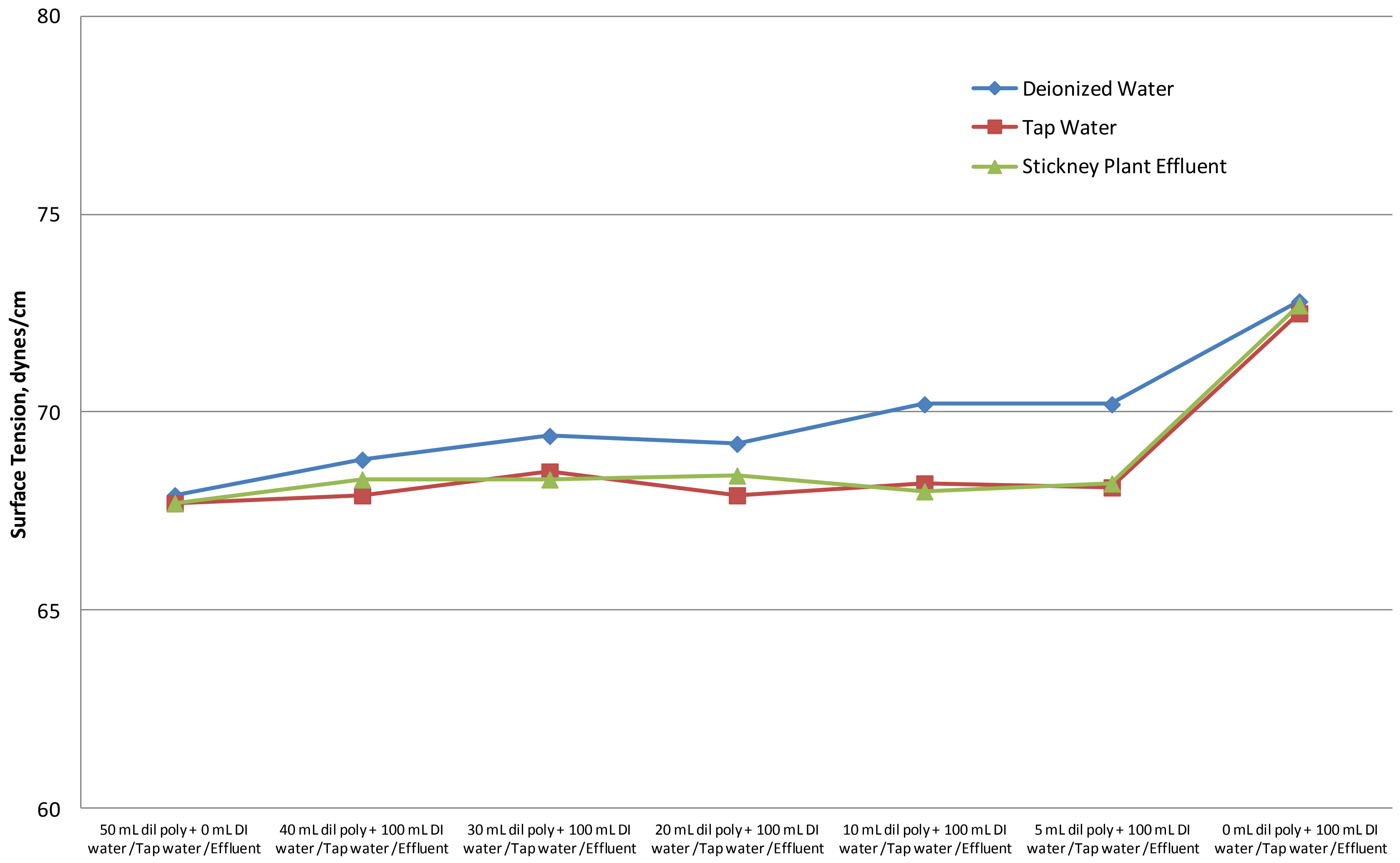


TABLE 15: LABORATORY-SCALE EXPERIMENTAL RESULTS OF THE SURFACE TENSION MEASUREMENTS OF DECANT, TAP WATER, AND DILUTE POLYMER SAMPLES CONTAINING VARYING AMOUNTS OF POLYMER

Sample Name	Surface Tension, dynes/cm	Temp, °C
Tap water	72.8	20
Decant from 5 mL polymer	70.9	22
Decant from 15 mL polymer	70.4	22
Decant from 25 mL polymer	69.8	22
Decant from 30 mL polymer	70.8	22
Decant from 40 mL polymer	70.9	22
Decant from 60 mL polymer	70.8	22
Decant from 90 mL polymer	70.4	22
Working solution of dilute polymer (10%)	71.9	22

Note:

1. A house raw polymer (CE 1509) was diluted to 10 percent working solution and different amounts of the dilute polymer were added to 200 mL sludge samples. Decant was collected from these samples post-mixing for the measurement of surface tension.
2. All measurements were made after calibrating with tap water; 72.8 dynes/cm @ 20°C.

operators do exhibit a coordinated team effort to achieve: (1) consistency in dilute polymer at both dilute polymer production sites in the Post-Centrifuge facility and (2) a consistent operation of the centrifuges at a fixed torque of approximately 750 ± 22 lbs-in.

2. The averages of raw polymer %TS and %AS content collected from the North- and South-end of the facility were observed to be identical during the one-week test period. The dilute polymer preparation procedure was found to be consistent and both ends yielded identical dilute polymer. Also, some hourly variation was found in raw polymer %TS and %AS or dilute polymer %TS from the samples collected during the three shifts at both sites.

3. Machine Nos. 15 and 18 were not operated during the baseline period, but the remaining machines were operated between 15 to 21 hours per day on average, and the machine working days ranged from 18 to 91. Actual usage of the machines was 30 percent with respect to machine hours during the baseline period, indicating excess unused machine capacity. The average CK from these working machines ranged from 22 to 25 percent, and average solids capture ranged from 91 to 95 percent. The average sludge throughput and flow per machine were found to be in a range from 17 to 32 DT/day and 167 to 223 gpm, respectively.

4. Average consumption of polymer expressed in terms of the ratio of polymer to sludge flow rates for each machine was found to be in a range of 0.044 to 0.064 gpm/gpm. Both extreme values in this range represent 45 percent variation in polymer consumption. Polymer consumption did not vary more than 23 percent among the 15 lowest polymer-consuming machines based on volumetric ratios of polymer to sludge flow rates.

5. With respect to the ratio of polymer to sludge volume, the five lowest polymer-consuming machines in ascending order were machine Nos. 14, 11, 7, 10, and 2, and the five highest polymer-consuming machines in descending order were machine Nos. 5, 6, 21, 19, and 16 during the baseline period.

6. Based on previous centrifuge operational experiences and insights gained during this phase, it is believed that the auto-torque mode of operations at a set torque value is the optimal centrifuge operating strategy at the Stickney WRP, enabling fewer operators to operate the required number of machines continuously.

7. Optimization of current centrifuge operations may be possible by adjusting machine and/or operational settings to achieve polymer savings. Results from the optimization evaluation indicate that centrifuge operations at a fixed torque of 725 lbs-in or 30 percent load factor with sludge flow rate of 200 gpm and polymer flow rate to 9.2 to 10.4 gpm can meet the current performance goals of 25 %TS in centrifuge cake and 95 %CP. All machines

can achieve the performance goals. However, some machines cannot be operated at the suggested settings, or may need more attention to setting up the proper settings, to achieve the performance goals. Regardless, this operation strategy appears to be promising for reducing polymer consumption.

8. Use of city water for preparing dilute polymer solution indicated marginally better dewaterability in laboratory-scale experiments compared to the existing practice of using plant effluent. The results appeared to be promising but inconclusive.

9. It was hypothesized that residual excess polymer may end up in the centrate and such measurements may be used as a process control parameter for polymer use reduction. However, the laboratory-scale experimental results did not provide a strong relationship between the polymer content of centrate and surface tension measurements. Further investigation in this area will not be pursued.

Recommendations.

1. The M&R Department recommends continuing to maintain similar polymer handling operations including use of existing procedure for dilute polymer preparation. However, it is suggested that written standard operating procedures (SOPs) for polymer preparation and centrifuge operation be prepared and kept on file in centrifuge control room at all times for proper and consistent implementation as well as for training purposes. It is also suggested that a committee of M&R Department and M&O Department staff at the Stickney plant be formed to develop the written SOPs and protocols. This committee should also review and update the written documentation biannually.

2. The M&R Department recommends continuing centrifuge operations in auto-torque mode. It is suggested that the post-digestion centrifuges be operated using the following settings: sludge flow rate at 200 gpm; polymer flow rate at 9.2 to 10.4 gpm; torque setting at 725 lbs-in for machine Nos. 2 through 12 and 30 percent load factor for machine Nos. 13 through 21, with a few exceptions. These settings should be maintained in auto-torque mode operation except for operating constraints and practical difficulties. Some machines, however, might need extra efforts and/or different settings than the ones suggested above. As such, if this method of operation is adopted, individual machine performance should be tracked. If performance suffers for a machine, further testing to define the proper settings should be performed.

3. Fewer machines should be operated at the maximum possible sludge flow rate as opposed to operating many machines at lower sludge flow rates. The polymer flow rate should be reduced in proportion to the sludge flow rate such that the ratio of the polymer flow rate to the sludge flow rate remains

in a range of 0.044 to 0.050 when the characteristics of the feed sludge and raw polymer are similar to those identified in the baseline period of January 1 to April 30, 2011, or a new range if new conditions necessitate.

4. It is recommended that city water as dilution water should be evaluated by conducting additional laboratory-scale tests. If results show conclusive evidence, then further evaluation at full scale will be recommended for a one-week period. This will allow the M&R Department to collect tangible information to determine the magnitude of polymer savings after offsetting the cost of water.

5. It is also proposed that a full-scale trial experiment be conducted for a one-week period to determine whether centrifuge performance can be maintained at lower dilute polymer strength. The existing procedure for preparing dilute polymer should be continued, but dilute polymer concentrations should be gradually decreased from a goal of 15 percent to 10 to 13 percent range.

6. At present, CO_2 is used at a rate of 15 lbs/1,000 gallons of sludge to lower the pH of centrifuge feed to prevent struvite build-up in the system. Digester draw pH is measured before CO_2 addition but not after the addition of the CO_2. It is suggested that the pH in centrifuge feed after CO_2 addition be measured and monitored, as mannich polymers work most efficiently at a pH slightly lower than 7. At pH levels above 7.6, mannich polymer consumption is known to increase. This may contribute to polymer savings while preventing struvite formation. However, cost effectiveness can be evaluated only after sufficient monitoring data is collected.

7. The M&R Department suggests that the switch in seasonal polymer be based on change in sludge characteristics as opposed to the availability of funds in winter and/or summer polymer cost line items.

References

Standard Methods for the Examination of Water and Wastewater, APHA, AWWA, WEF, 19th Edition, 1995.

Test Procedures for the Selection and Procurement of Polymers for Centrifugal Dewatering of Anaerobically Digested Sludge, M&R Department Report No. 2000-13, October 2000.

EVALUATION FOR POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT – PHASE II: SIDE-BY-SIDE TESTS

Background

Recently, the cost of polymer used for sludge dewatering operations at the Post-Centrifuge facility at the Stickney WRP has increased significantly (Table 16). In order to reduce the polymer usage at the Post-Centrifuge facility, the EM&R Division of the M&R Department proposed and initiated a study during summer 2011. That phase of the study (Phase I) primarily focused on evaluating the current centrifuge operations and dilute polymer preparation, optimizing operations by adjusting machine settings with respect to reducing polymer consumption, and verifying that polymer savings could be achieved under optimal centrifuge operations in full-scale side-by-side tests.

As indicated in the Phase I section, the current dilute polymer preparation and centrifuge operation were reviewed, the baseline operation and polymer consumption was documented, and the optimal operations and machine settings were determined and suggested for the reduction of polymer consumption without compromising desired performance as prerequisite steps for side-by-side tests. However, it is still unknown whether the suggested settings can truly be applied for all 21 centrifuges to meet the performance goals due to machine idiosyncrasies. Therefore, a demonstration through side-by-side testing that operating centrifuges at optimized settings can reduce polymer consumption was proposed as a Phase II study. The method and results of this phase are described below.

Materials and Methods

In order to determine polymer savings due to adjustment and optimization in the current centrifuge operations and machine settings, the polymer consumptions were simultaneously monitored and compared between (M&O-run) machines representing routine operations and M&R-run machines representing optimal operations. The side-by-side tests were conducted twice per week for four weeks: available machines from machine Nos. 1–12 in the South-end of the facility were evaluated on Tuesdays, and available machines from machine Nos. 13–21 in the North-end were evaluated on Thursdays. On these respective days, half of the machines in operation were M&R-run for five hours, and the other half of the machines were M&O-run for similar period for a side-by-side comparison. Each M&O-run machine was paired with an M&R-run machine for comparative evaluation before testing began. These pairs were determined by OEs based on the availability of machines and are presented in Table 17. No previous performance or any other set of criteria were used to pair the machines. These machines were operated for five hours during the M&O Department's day shift (testing period). For the remaining 19 hours of the day (non-testing period), the M&O Department operated all machines.

M&R Department and M&O Department staff both operated each of their respective test centrifuges in auto-torque mode during the entire testing period. M&O Department staff operated their machines based on their experience as documented in the Phase I summary in order to meet the performance goals of 25 %TS in the cake and 95 %CP as adopted from the polymer bid

TABLE 16: POLYMER COSTS FOR DEWATERING DIGESTED SLUDGE AT THE STICKNEY WATER RECLAMATION PLANT (SEPTEMBER 15, 1999, TO OCTOBER 9, 2011)

Duration of Contract	Contract No.	Amount
08/25/08–10/09/11	08-633-11	$14,965,551.46
07/29/06–08/24/08	06-633-11	$6,574,210.03
05/01/04–07/28/06	03-658-11	$5,674,909.95
01/15/02–04/30/04	01-658-11	$5,693,360.02
09/15/1999–01/14/02	99-661-11	$4,292,264.66

TABLE 17: MAINTENANCE AND OPERATIONS DEPARTMENT- AND MONITORING AND RESEARCH DEPARTMENT-OPERATED MACHINE PAIRS FOR SIDE-BY-SIDE PERFORMANCE EVALUATION

Date of Operation	M&O Machine No.	M&R Machine No.
01/10/12	5	10
01/10/12	6	11
01/17/12	2	3
01/17/12	12	10
01/19/12	20	18
01/24/12	10	2
01/24/12	12	6
01/26/12	18	19
01/31/12	11	3
01/31/12	12	5
02/02/12	19	14

testing. However, lower machine performance of solids captures down to 90 percent and %TS of cake down to 20 percent are generally considered within the acceptable levels by OEs during routine operations.

During this phase, M&R Department staff took over their respective machines from the M&O Department, M&R Department staff gradually changed the torque setting per need at first and then fine-tuned sludge and polymer flows to adjust to the optimized settings range. Torque was set at approximately 725 lbs-in or lower for machine Nos. 2 through 12 or at a 27 to 30 percent load factor for machine Nos. 13 through 21 with a minimum sludge flow rate of 200 gpm and the lowest practical polymer flow rate (optimized range determined was from 9.2 to 10.4 gpm during the baseline study) that could consistently meet the above machine performance benchmarks.

Centrate clarity was monitored a few times per hour by the M&R Department staff, similar to the oversight by M&O Department staff, as a measure of desired performance. Cake firmness was judged based on instantaneous torque values displayed on the machine screen. If necessary, operational setting of the M&R-run machines were adjusted accordingly by M&R Department staff if either indicator was considered substandard (i.e. need-based adjustment). Similarly, M&O-run machines were adjusted by M&O Department staff. M&R Department staff, however, made no adjustments to M&O-run machines and vice versa during the test period.

The operational conditions and machine settings were recorded hourly for both the M&R- and M&O-run machines. The parameters recorded were sludge flow rate, dilute polymer flow rate, set torque value, bowl speed, and pinion speed. The latter two parameters were recorded for operational setting, but were not included in further evaluation.

Grab samples were manually collected from both the M&O- and M&R-run machines during testing days and analyzed for the comparative performance evaluation. A raw polymer, dilute polymer, centrifuge feed, and dilution water sample were collected twice each day of testing, once at the beginning and once at the end of the test. A centrifuge cake and centrate sample were collected from each test machine approximately five times per day (once per hour per machine during the test period). All samples were collected, preserved accordingly, and submitted to SAL within the appropriate holding times with a signed chain of custody. The raw polymer, dilute polymer, and dilution water samples were analyzed for %TS. Centrifuge feed samples were analyzed for pH, %TS, and %VS. Cake and centrate samples were analyzed for %TS.

All collected analytical and operating data were reviewed prior to data analysis for validity and to remove outliers before data use. The raw polymer and centrifuge feed characterization (%TS and %TVS) were examined with respect to the baseline centrifuge operating data collected from January 1, 2011, through April 30, 2011 (baseline period), to ensure that the post-digester centrifuges were operating under normal conditions during the side-by-side study. The M&O Department digester draw operating data on available parameters (%TS, %TVS, alkalinity, pH and VAs) were compared between the testing and baseline periods as well.

Hourly data compiled for the side-by-side testing period beginning January 10, 2012, through February 2, 2012, were collectively evaluated, because the M&O- and M&R-run machines were randomly paired. The means of the above-mentioned hourly parameters collected during the entire testing period were determined and compared between M&O- and M&R-run machines in order to perform an overall evaluation regardless of machine pairs. The equality of means for each parameter was tested using ANOVA. The z-test was used in preference to the paired t-test, because there were greater than 50 observations.

Based on the hourly data, the average values over the five-hour testing period were calculated for both the M&R- and M&O-run centrifuges for the following parameters: torque, sludge flow, polymer flow, volumetric ratio of polymer to sludge flow rates, polymer dose, solids capture, %TS in the cake, and sludge throughput per machine. Side-by-side pair-wise comparison of these hourly and average values for each pair of machines were performed against each other in order to examine how centrifuge performance compared between M&O- and M&R-run machines for torque, sludge and polymer flows, ratio of dilute polymer to sludge flows, %CP, and %TS in the cake. The comparative evaluation of M&R-run machines in each pair was performed with respect to the average values of M&O-run machines.

Side-by-side comparison of percent hourly variations in torque settings with respect to the five-hour average values observed during the testing periods was performed for the M&O- and M&R-run machines to determine the relative stability of machine operation. A similar analysis for the ratios of polymer to sludge flow rates was performed for both the M&O- and M&R-run machines to determine the variability in polymer flow adjustments relative to variations in sludge flow. Correlations between hourly polymer and sludge flows were also examined to further evaluate the relative polymer flow adjustments made in the M&O- and M&R-run machines in response to variations in sludge flows.

In addition, the above-mentioned parameters were calculated for both the M&R- and M&O-run machines for 19 hours of non-testing operation during testing days (non-testing period). Similar 19-hour average values mentioned above were determined using actual operating data collected during the remaining 19 hours of the non-testing period and analytical data obtained from daily composite samples. Analytical results used for these 19 hours of operation were from daily composite samples collected by the M&O Department over three shifts; this data does include operation during the testing and non-testing periods. Comparison of average operational setting parameters such as torque and sludge and polymer flows between testing and non-testing periods was performed for both the M&O- and M&R-run machines. Similarly, polymer usage along with centrifuge performance (%TS in cake and %CP) was compared between the testing and the non-testing periods for a given test machine to determine whether the machine settings set by M&R Department or M&O Department staff was maintained during the following shifts of the day and whether polymer consumption changed.

Results

Comparison of Centrifuge Feed, Digester Draw, and Polymer Characteristics Between the Baseline and Testing Periods. Average torque settings, sludge and polymer flow rates ranged from 720 to 768 lbs-in, 167 to 223 gpm, and 9.7 to 11.1 gpm, respectively, during the baseline period. All machines during the baseline period were routinely operated by the

M&O Department. Average centrifuge feed %TS and VS were 2.55 percent and 53.70 percent, respectively, during this baseline period.

During the testing period, the five-hour average values from seven monitoring days for %TS and %TVS of centrifuge feed ranged from 2.53 to 3.05 percent with an average of 2.85 percent and from 48.06 to 51.05 percent with an average of 49.41 percent, respectively. This overall average of 2.85 %TS was approximately 12 percent higher than the baseline period average of 2.55 percent, and 49.41 percent TVS was approximately 9 percent lower than the baseline period average of 53.70 percent. Both %TS and %TVS of the centrifuge feed were statistically significantly different between the baseline and testing periods.

Based on M&O Department operating data, the average %TS, %TVS, alkalinity, pH and VAs of digester draw during the baseline period were observed to be 2.66 percent, 54.81 percent, 3,610 mg/L as $CaCO_3$, 7.30 pH units, and 101 mg/L, respectively and 3.18 percent, 49.65 percent, 3,313 mg/L as $CaCO_3$, 7.31 pH units, and 83 mg/L, respectively, during the testing period. The M&O Department digester draw operating data comparison between the testing and baseline periods indicated that draw %TS, %TVS, and alkalinity were significantly different, but pH and VAs were not statistically different.

Average %TS of raw and dilute polymer for the South-end were 3.81 percent and 0.48 percent, respectively, during the side-by-side testing period; average %TS of raw and dilute polymer for the North-end were 3.92 percent and 0.50 percent, respectively, during the side-by-side testing period. During the baseline period, %TS of raw and dilute polymer for the South-end was 3.69 percent and 0.50 percent, respectively, and 3.67 percent and 0.52 percent, respectively, for the North-end. The differences in %TS of raw and dilute polymer between two periods were within 4 percent with respect to the baseline period values except for raw polymer for the North-end, which had a 6.8 percent difference. A statistical comparison indicated that raw and dilute polymer for the North-end versus the North-end and the South-end versus the South-end between the testing period and baseline period were similar.

Based on the above, any performance differences during the side-by-side testing period in relation to the baseline period is assumed to be attributed to the adjustments in machine and operational settings in response to the variations in sludge characteristics.

Overall Comparison Between Maintenance and Operations Department- Versus Monitoring and Research Department-Run Machines Based on Hourly Data Collected During the Testing Period. The overall comparison based on hourly data included testing of equality of means for hourly sludge and polymer flows, %CP, %CK, and torque data for M&O- and M&R-run machines. The test results are presented in Table 18, which indicate that hourly polymer flow, %CK, torque, and polymer dose on weight and volumetric basis were significantly different between M&O- and M&R-run machines. It should be noted that the M&R Department processed higher sludge flow on average and produced slightly better %CP, but these differences were not significant. The M&R Department processed average hourly sludge flow of 216 gpm compared to 212 gpm by the M&O Department. The M&R Department used an average polymer flow of 8.17 gpm compared to 8.69 gpm by the M&O Department. The hourly average polymer consumption by volume was 0.038 gpm/gpm for the M&R Department versus 0.041 gpm/gpm for the M&O Department, and hourly average polymer consumption by weight was 334.11 lbs/DT for the M&R Department and 362.78 lbs/DT for the M&O Department. Hourly average

TABLE 18: COMPARISON OF MEANS OF HOURLY DATA COLLECTED DURING ENTIRE SIDE-BY-SIDE TESTING PERIOD BETWEEN ALL MAINTENANCE AND OPERATIONS DEPARTMENT- AND MONITORING AND RESEARCH DEPARTMENT-RUN MACHINES

Parameter	No. of Observations		Mean		Standard Deviation		p-value
	M&R	M&O	M&R	M&O	M&R	M&O	
Hourly Sludge Flow, gpm	55	55	215.98	212.04	14.08	18.49	0.208
Hourly Polymer Flow, gpm	55	55	8.17	8.69	0.45	0.68	0.000
Solids Capture, %	55	55	94.16	93.86	2.00	2.51	0.476
Cake Solids, %	55	55	24.90	25.53	1.42	1.25	0.014
Torque, lbs-in	55	55	687.44	675.71	24.52	22.49	0.009
Polymer Dose, lbs/DT	55	55	334.11	362.78	33.87	46.24	0.000
Hourly Ratio of Polymer to Sludge Flows, gpm/gpm	55	55	0.038	0.041	0.004	0.005	0.000

Means are not statistically different if p-value is >0.05.

torque was 687.44 lbs-in for the M&R Department versus 675.71 lbs-in for the M&O Department. In terms of hourly performance, the M&R Department had an hourly average of 24.90 %TS in cake and 94.16 %CP compared to 25.53 %TS in cake and 93.86 %CP for the M&O Department.

Pair-wise Comparison Between Maintenance and Operations Department- Versus Monitoring and Research Department-Run Machines During the Testing Period.

Torque. Data compiled and analyzed for the side-by-side testing period beginning January 10, 2012, through February 2, 2012, were also evaluated in pairs of machines as presented in Table 17. Table 19 provides average pair-wise operating and performance comparison between the M&R- and the M&O-run machines. Average set torque values varied from 647 lbs-in to 721 lbs-in for the M&R-run machines and from 642 lbs-in to 689 lbs-in for the M&O-run machines. The comparison indicates that set torque values did not exceed 4.8 percent between paired machines. Six of the eleven pairs indicated significant difference in torque between the M&O- and M&R-run machines, and the remaining five pairs did not. The torque settings by the M&O Department during the side-by-side testing period ranging from 642 lbs-in to 689 lbs-in were much lower than the average torque values of 720 to 768 lbs-in during the baseline period.

Table 20 presents percent hourly variations in torque settings with respect to the five-hour testing period average values, the five-hour testing period average, standard deviation and percent CV values for the machines evaluated during the side-by-side testing period. Hourly torque variations for the M&O-run machines were observed to be within ±4 percent except for machine No. 18 on January 26, 2011, which had an hourly variation of 7 percent. The M&R-run machines had hourly torque variations within ±5 percent. The standard deviations representing variability in the hourly data set ranged from four to 33 lbs-in for the M&O-run machines, and from four to 22 lbs-in for the M&R-run machines. Similarly, CVs were observed in the range of 0.6 to 4.8 percent for the M&O-run machines and 0.8 to 3.1 percent for the M&R-run machines. The hourly percent variations of torque with respect to the average torque during the testing period, standard deviations and CVs indicate that the M&O- and M&R-run machines were operated consistently with slightly greater stability in M&R-run machines during the side-by-side testing period.

Sludge Flow. M&R-run machines had average hourly sludge flows in the range of 200 to 240 gpm, and M&O-run machines had average hourly sludge flows in the range of 180 to 236 gpm (Table 19). Average hourly sludge flow was typically 200 gpm or higher during the entire side-by-side testing period except for M&O-run machines No. 12 on January 17, 2012, and No. 19 on February 2, 2012. This could be due to the operator’s operating preference, rather than machine limitations. Percent difference in sludge flows between different pairs of M&O- and M&R-run machines was as high as 13.9 percent. Higher sludge flows were observed in the M&R-run machines in six of 11 pairs (5.6 percent on an average basis), but 2 percent lower sludge flows were observed in the remaining five pairs. Two of three pairs indicated significantly higher sludge flows in M&O-run machines and one pair indicated significantly higher flow in M&R-run machine. One of 11 pairs did not indicate significant difference, and the remaining seven pairs could not be compared due to zero variance. Overall, average sludge flow during the side-by-side testing period ranged from 180 to 240 gpm for all machines compared to the average sludge flows of 167 to 223 gpm observed during the baseline period operation.

TABLE 19: SIDE-BY-SIDE MACHINE AND OPERATION SETTINGS AND PERFORMANCE COMPARISON OF MONITORING AND RESEARCH DEPARTMENT- VERSUS MAINTENANCE AND OPERATIONS DEPARTMENT-OPERATED MACHINES DURING THE SIDE-BY-SIDE TESTING PERIOD OF JANUARY 1, 2012, THROUGH FEBRUARY 2, 2012

Date of Operation	Operated by	Machine No.	Torque, in-lbs	Sludge Flow, gpm	Dilute Polymer Flow, gpm	Dilute Polymer Flow/Sludge Flow, gpm/gpm	Polymer Dose, lbs/DT	Solids Capture, %	%TS of Cake
01/10/12	M&O	5	663	204	9.7	0.04739	407	96	28
		6	682	205	8.4	0.04083	353	96	26
	M&R	10	683	200	9.0	0.04500	385	96	25
		11	669	220	8.3	0.03764	323	96	26
% Difference 5:10			3.1	-1.8	-7.0	-5.0	-5.4	-0.1	-10.7
% Difference 6:11			-1.8	7.7	-1.2	-7.8	-8.3	0.1	0.0
01/17/12	M&O	2	689	212	9.2	0.04319	347	92	26
		12	688	186	8.7	0.04623	371	95	25
	M&R	3	705	202	8.5	0.04211	337	95	25
		10	721	200	8.1	0.04050	321	94	26
% Difference 2:3			2.4	-4.7	-7.4	-2.5	-2.9	2.9	-3.8
% Difference 12:10			4.8	7.4	-6.9	-12.4	-13.5	-0.9	4.0
01/19/12	M&O	20	646	205	8.7	0.04256	325	94	27
	M&R	18	666	206	8.5	0.04090	316	95	27
% Difference 20:18			3.2	0.2	-2.5	-3.9	-2.7	1.3	0.0
01/24/12	M&O	10	689	217	9.2	0.04217	382	92	25
		12	681	228	8.7	0.03777	344	94	26
	M&R	2	702	215	8.7	0.04023	363	94	25
		6	705	223	7.8	0.03498	316	94	26

TABLE 19 (Continued): SIDE-BY-SIDE MACHINE AND OPERATION SETTINGS AND PERFORMANCE COMPARISON OF MONITORING AND RESEARCH DEPARTMENT- VERSUS MAINTENANCE AND OPERATIONS DEPARTMENT-OPERATED MACHINES DURING THE SIDE-BY-SIDE TESTING PERIOD OF JANUARY 1, 2012, THROUGH FEBRUARY 2, 2012

Date of Operation	Operated by	Machine No.	Torque, in-lbs	Sludge Flow, gpm	Dilute Polymer Flow, gpm	Dilute Polymer Flow/Sludge Flow, gpm/gpm	Polymer Dose, lbs/DT	Solids Capture, %	%TS of Cake
% Difference 10:2			1.9	-0.7	-5.7	-4.6	-5.0	1.4	0.0
% Difference 12:6			3.6	-2.2	-9.9	-7.4	-7.9	0.4	0.0
01/26/12	M&O	18	689	225	9.6	0.04256	380	94	26
	M&R	19	666	230	7.7	0.03337	298	95	23
% Difference 18:19			-3.3	2.2	-19.8	-21.6	-21.6	0.1	-11.5
01/31/12	M&O	11	684	235	7.9	0.03340	224	94	25
		12	680	236	7.8	0.03302	221	92	25
	M&R	3	700	240	7.9	0.03306	220	93	24
		5	696	235	7.8	0.03319	222	90	24
% Difference 11:3			2.3	2.0	0.5	-1.0	-1.5	-0.2	-4.0
% Difference 12:5			2.4	-0.5	0.0	0.5	0.5	-1.6	-4.0
02/02/12	M&O	19	642	180	7.7	0.04264	468	94	25
	M&R	14	647	205	7.6	0.03707	404	94	24
% Difference 19:14			0.7	13.9	-1.8	-13.1	-13.8	-0.3	-4.0

Note: Performance and operating data represent average values from hourly data collected during the five-hour testing period.

TABLE 20: SIDE-BY-SIDE COMPARISON OF PERCENT HOURLY VARIATIONS IN TORQUE WITH RESPECT TO THE FIVE-HOUR AVERAGE VALUES OBSERVED DURING THE SIDE-BY-SIDE TESTING PERIOD OF JANUARY 1, 2012, THROUGH FEBRUARY 2, 2012, BETWEEN MONITORING AND RESEARCH DEPARTMENT- AND MAINTENANCE AND OPERATIONS DEPARTMENT-RUN MACHINES

Date of Operation	Operated by	Machine No.	Percent Variation in Torque with Respect to 5-Hour Average					Five-Hour Average	Standard Deviation	Percent Coefficient of Variation
			Hour 1	Hour 2	Hour 3	Hour 4	Hour 5			
01/10/12	M&O	5	-2	-3	3	2	1	663	17	2.6
		6	0	0	0	0	1	682	4	0.6
	M&R	10	0	0	0	1	0	683	5	0.8
		11	2	-1	-4	2	2	669	16	2.4
01/17/12	M&O	2	-2	-1	-2	2	3	689	16	2.4
		12	-1	-2	-1	0	3	688	12	1.7
	M&R	3	4	-4	-2	1	1	705	22	3.1
		10	-2	3	1	0	-1	721	14	1.9
01/19/12	M&O	20	3	-1	0	-1	-2	646	13	2.0
	M&R	18	-1	5	-1	-2	-2	666	19	2.8
01/24/12	M&O	10	2	-3	0	2	-1	689	13	1.9
		12	-3	-1	1	4	0	681	17	2.5
	M&R	2	-2	2	1	-1	-1	702	11	1.6
		6	0	-1	1	1	0	705	7	1.0
01/26/12	M&O	18	-7	6	0	3	-1	689	33	4.8
	M&R	19	0	0	-2	0	0	666	6	0.9

TABLE 20 (Continued): SIDE-BY-SIDE COMPARISON OF PERCENT HOURLY VARIATIONS IN TORQUE WITH RESPECT TO THE FIVE-HOUR AVERAGE VALUES OBSERVED DURING THE SIDE-BY-SIDE TESTING PERIOD OF JANUARY 1, 2012, THROUGH FEBRUARY 2, 2012, BETWEEN MONITORING AND RESEARCH DEPARTMENT- AND MAINTENANCE AND OPERATIONS DEPARTMENT-RUN MACHINES

Date of Operation	Operated by	Machine No.	Percent Variation in Torque with Respect to 5-Hour Average					Five-Hour Average	Standard Deviation	Percent Coefficient of Variation
			Hour 1	Hour 2	Hour 3	Hour 4	Hour 5			
01/31/12	M&O	11	1	3	0	-1	-2	684	14	2.0
		12	1	1	-3	1	0	680	11	1.6
	M&R	3	1	-1	0	0	0	700	4	0.5
		5	0	1	0	1	-2	696	9	1.3
02/02/12	M&O	19	-4	3	1	1	-1	642	18	2.7
	M&R	14	1	2	-3	1	0	647	12	1.9

Polymer Flow. M&R-run machines had average dilute polymer flows in the range of 7.6 to 9.0 gpm, and M&O-run machines had average dilute polymer flows in the range of 7.7 to 9.7 gpm (Table 19). The highest difference between the M&O- and M&R-run machine pair was 19.8 percent on January 26, 2012. Nine of the 11 test pairs indicated higher polymer usage by the M&O-run machines (6.9 percent on an average basis); the other two pairs performed on January 31, 2012, indicated that M&O-run machines had similar polymer flows compared to the respective M&R-run machines. Seven of the eleven pairs indicated significant difference, and one pair did not; significant difference could not be determined in the remaining three pairs due to either similar means or standard deviations.

Compared to the polymer flow range of 9.7 to 11.1 gpm observed during the baseline period, polymer flow range of 7.7 to 9.7 gpm for the M&O-run machines was much lower during the side-by-side testing period. This is indicative of OEs' increased diligence during the side-by-side testing period. Analysis of data collected from January 1 through 9, 2012, immediately before commencing the side-by-side tests, indicate polymer flows in a range of 7.7 to 13.5 gpm with an average of 9.6 gpm. This indicates that polymer savings may be possible in a routine operation if OEs closely monitor polymer flows.

Polymer to Sludge Flow Ratios. The testing period average ratios of dilute polymer flow per unit sludge flow resulted in a range of 0.03302 to 0.04739 gpm/gpm for M&O-run machines and 0.03306 to 0.04500 gpm/gpm for M&R-run machines (Table 19). Each pair-wise comparison shows lower polymer use by M&R-run machines except for one pair, machine Nos. 12 and 5 on January 31, 2012, where the M&O-run machine had a 0.5 percent lower volumetric polymer dose than the M&R-run machine. Polymer savings in M&R-run machines on January 26, 2012, peaked at 21.6 percent due to major difference in polymer flow, which caused similar solids capture and 11.5 percent lower CK relative to the M&O-run machine. Cake solids did not meet 25 percent on this date for the M&R-run machine, but 23 %TS of CK was within the acceptable threshold.

M&R-run machines showed average savings in polymer ranging from 1.0 to 21.6 percent with respect to the ratios of dilute polymer flows to sludge flows, and from 1.5 to 21.6 percent with respect to polymer dose relative to M&O-run machines (Table 19) with the exception of January 31, 2012, where one M&O-run machine showed a slight savings (0.5 percent) relative to the associated M&R-run machine. Average polymer savings in M&R-run machines in the 10 of 11 pairs was 7.9 percent with respect to the polymer to sludge flow ratios and 8.2 percent with respect to polymer dose.

The polymer savings in M&R-run machines did slightly compromise performance goals (Table 19). Average solids capture ranged from 90 to 96 percent and 92 to 96 percent for M&R- and M&O-run machines, respectively. Average solids captures between the M&R- and M&O-run centrifuge pairs were very similar as well with a maximum difference of 2.9 percent. Considering 95 %CP as the performance goal for this phase, five M&R-run machines produced 95 %CP or higher, four M&R-run machines produced 94 %CP, and two other M&R-run machines showed capture as low as 93 and 90 %CP on January 31, 2012. Three M&O-run machines produced 95 %CP, five M&O-run machines produced 94 %CP, and the three remaining M&O-run machines produced 92 %CP, respectively. Average %TS of cake ranged from 23 to 27 percent and 25 to 28 percent for M&R- and M&O-run machines, respectively (Table 19). Differences in average %TS of CK indicate that M&R-run machines produced either equal %TS in cake or 3.8 to 11.5 percent lower TS in cake relative to M&O-run machines. With respect to 25 %CK solids as the performance goal for this phase, four M&R-run machines did not meet the goal; three of these four machines had 24 %TS and one had 23 %TS. Despite the instances during which the performance goals were not met for M&R-run machines, the slightly lower performance of solids capture and CK are considered to be within the acceptance thresholds of the M&O Department as mentioned above.

Different ratios of polymer to sludge flow rates for the same machine can occur on different days (e.g. machine No. 10 on January 10, 17, and 24, 2012). This can be mainly due to how the OE operates the machines. Generally, an operator initially adjusts the machines and operational settings for given sludge characteristics to achieve the desired performance and subsequently re-adjusts the machines and operational settings in response to the need-based (performance deterioration) or non need-based situations (such as an operating constraint like limited sludge quantity for a few hours or diurnal variations in sludge characteristics) to maintain the desired performance. All these adjustments and re-adjustments call for periodic visual observations of centrate and cake quality as well as judgment and intuitive but experienced guess work regarding sustained performance. As judgment differs from OE to OE, these ratios and performance may vary for the same machine on different days.

Seven of the eleven pairs of volumetric ratios of polymer to sludge flows indicated significant difference and two pairs did not; significant difference could not be determined in the remaining two pairs due to zero variance in at least one set of data. This comparative analysis in conjunction with the similar analyses on sludge and polymer flow rates indicate that polymer flows were not similar in relation to sludge flows between M&R- and M&O-run machines during the side-by-side testing period. This was due to lack of proportionate increase/decrease in polymer flows when sludge flows were altered in M&O-run machines.

Percent variations in the hourly ratios of polymer to sludge flows with respect to the five-hour averages are presented in Table 21 along with the testing period average, standard deviation, and CV values. Percent hourly variations in these ratios varied within ±6 percent for M&O-run machines and ±2 percent for M&R-run machines. Lower variation for M&R-run machines indicate that the M&R Department adjusted their machines according to changes in sludge and polymer flow more often than M&O-run machines, e.g. when sludge flows decreased, the M&R Department decreased polymer flows. Percent CVs for five-hour operations ranged from 0.7 to 4.6 percent and 0.0 to 2.3 percent for M&O- and M&R-run machines, respectively, corroborating this slightly higher variability in M&O-run machines. It should be noted that during centrifuge operation, some periodic need-based adjustments might be necessary in response to poor centrate clarity or too soft or dry cake.

Overall and Pair-Wise Comparison Between Testing and Non-Testing Periods for Maintenance and Operations Department- and Monitoring and Research Department-Run Machines. Hourly data collected during testing and non-testing periods indicate that sludge flows were similar between the two periods for both M&O- and M&R-run machines, but polymer to sludge flow ratios were significantly different between the two periods for both M&O- and M&R-run machines. Polymer flows were significantly different between the two periods for M&R-run machines, but not for M&O-run machines. Torque values were significantly different between the two periods for M&O-run machines, but not for M&R-run machines. This suggests that polymer flows were re-adjusted in M&R-run machines and torque

TABLE 21: SIDE-BY-SIDE COMPARISON OF PERCENT HOURLY VARIATIONS IN DILUTE POLYMER TO SLUDGE FLOW RATIOS WITH RESPECT TO THE FIVE-HOUR AVERAGE VALUES OBSERVED DURING THE SIDE-BY-SIDE TESTING PERIOD OF JANUARY 1, 2012, THROUGH FEBRUARY 2, 2012, BETWEEN MONITORING AND RESEARCH DEPARTMENT- VERSUS MAINTENANCE AND OPERATIONS DEPARTMENT-RUN MACHINES

Date of Operation	Operated by	Machine No.	Percent Variation in Ratio of Dilute Polymer to Sludge Flows, gpm/gpm					Five-Hour Average	Standard Deviation	Percent Coefficient of Variation
			Hour 1	Hour 2	Hour 3	Hour 4	Hour 5			
01/10/12	M&O	5	1	-3	1	0	1	0.04755	0.00076	1.6
		6	3	0	0	0	-2	0.04116	0.00079	1.9
	M&R	10	0	0	0	0	0	0.04500	0.00000	0.0
		11	1	0	0	0	-1	0.03775	0.00028	0.7
01/17/12	M&O	2	3	4	-6	-1	-1	0.04355	0.00181	4.2
		12	3	2	2	-3	-3	0.04659	0.00147	3.1
	M&R	3	2	2	1	-2	-2	0.04229	0.00078	1.8
		10	-2	-1	-1	2	2	0.04030	0.00067	1.7
01/19/12	M&O	20	-1	-1	0	0	2	0.04245	0.00058	1.4
	M&R	18	4	-1	-1	-1	0	0.04130	0.00093	2.3
01/24/12	M&O	10	2	1	-1	-1	-1	0.04238	0.00063	1.5
		12	4	1	-1	-2	-2	0.03811	0.00090	2.4
	M&R	2	0	0	0	-1	-1	0.04028	0.00025	0.6
		6	1	1	0	-1	-1	0.03510	0.00046	1.3
01/26/12	M&O	18	0	-1	-1	0	1	0.04258	0.00037	0.9
	M&R	19	0	0	-1	0	0	0.03339	0.00019	0.6

TABLE 21 (Continued): SIDE-BY-SIDE COMPARISON OF PERCENT HOURLY VARIATIONS IN DILUTE POLYMER TO SLUDGE FLOW RATIOS WITH RESPECT TO THE FIVE-HOUR AVERAGE VALUES OBSERVED DURING THE SIDE-BY-SIDE TESTING PERIOD OF JANUARY 1, 2012, THROUGH FEBRUARY 2, 2012, BETWEEN MONITORING AND RESEARCH DEPARTMENT- VERSUS MAINTENANCE AND OPERATIONS DEPARTMENT-RUN MACHINES

Date of Operation	Operated by	Machine No.	Percent Variation in Ratio of Dilute Polymer to Sludge Flows, gpm/gpm					Five-Hour Average	Standard Deviation	Percent Coefficient of Variation
			Hour 1	Hour 2	Hour 3	Hour 4	Hour 5			
01/31/12	M&O	11	1	1	1	-1	-1	0.03345	0.00023	0.7
		12	1	-1	2	1	-2	0.03311	0.00052	1.6
	M&R	3	-1	2	-1	0	1	0.03295	0.00047	1.4
		5	1	1	1	-2	-2	0.03328	0.00047	1.4
02/02/12	M&O	19	3	3	3	-4	-6	0.04300	0.00199	4.6
	M&R	14	0	0	0	0	0	0.03707	0.00000	0.0

values in M&O-run machines during the non-testing period. It is unclear if these re-adjustments were need-based or not during the non-testing period.

Table 22 presents pair-wise comparison of average machine and operation settings adjusted by the OEs during the five-hour side-by-side testing periods with average machine performance versus average machine and operation settings adjusted by the OEs during non-testing periods with average machine performance. This average comparison provides insight as to whether variations in day-shift M&O Department settings occurred during other shifts and what the impacts of such variations on daily polymer savings were. The maximum difference in torque settings was 5.1 percent, which, indicates little change in torque made by the OEs during the non-testing period. Likewise, average differences in sludge flows were also within 5 percent except for three machines on January 17 and 19, 2012, and February 2, 2012, during which the differences were 9.6, 6.5 and 17.2 percent, respectively, between the two periods. The day-shift OEs set the sludge flow rates at 186, 205, and 180 gpm, respectively, on these three days. On two of these occasions, the non-testing period shift OEs increased sludge flows to conserve the polymer consumption and reduced sludge flow once without a clear objective; the January 17, 2012 sludge flow increase had no effect on the performance while the similar adjustment in sludge flow on February 2, 2012 deteriorated performance, because the OEs did not incorporate proportionate adjustment in polymer flow. During the January 19, 2012 adjustments, the reduction in sludge flow did not accompany proportionate adjustment in polymer flow, thereby consuming more polymer. Dilute polymer flows changed within ±1.2 percent if the highest three variations were not considered. The three highest adjustments showed a 7 percent decrease, 5.1 percent increase and 3.2 percent increase on January 10, 17, and 19, 2012, respectively, during non-testing hours.

Whenever the sludge and polymer flows were changed regardless if they were need-based or not, these adjustments resulted in assorted ratios of polymer to sludge flows; such assortment in the ratios caused variations in polymer consumption and impact on performance in some instances. In four out of 11 machine pairs, polymer savings of 0.6 to 14.1 percent by volumetric ratio of polymer to sludge flows were observed; in the remaining seven pairs, polymer consumption increased in a range of 1.2 to 10.9 percent. The non-proportional adjustment of polymer flow on January 19, 2012, in relation to the decrease in sludge flow resulted in 10.9 percent higher polymer consumption during the non-testing period. Solids captures during the non-testing relative to the testing period remained within ±3 percent. %TS of CK increased in two pairs by 7.5 percent on an average basis; decreased in four pairs by 5.9 percent, and remained unchanged in five pairs.

Like Table 22, Table 23 presents a similar comparison between the M&R Department operation during the testing periods versus M&O Department operation during the non-testing hours on the same days. Much like the M&O-run machines, no significant changes in machine and operational settings were made in M&R-run machines during non-testing hours. Differences in average torque were within 1.6 percent during all testing days except for January 31, 2012, for machine No. 3 with a 15.7 percent increase during the non-testing period operation. Changes in average sludge flows were within ±2.5 percent except for January 31, 2012, and February 2, 2012. On January 31, 2012, sludge flows were reduced for machine Nos. 3 and 5, but proportionate reduction in respective polymer flows was not made; this increased polymer consumption on a volumetric basis by 12 and 6.5 percent, respectively. On the other hand, on February 2, 2012, an

TABLE 22: COMPARISON OF AVERAGE MACHINE PERFORMANCE AND OPERATING DATA COLLECTED FROM MAINTENANCE AND OPERATIONS DEPARTMENT-RUN MACHINES DURING THE FIVE-HOUR TESTING PERIOD VERSUS ROUTINE MAINTENANCE AND OPERATIONS DEPARTMENT OPERATION DURING THE NON-TESTING HOURS ON THE SAME DAYS

Date of Operation	Operated by	Duration	Machine No.	Torque, in-lbs	Sludge Flow, gpm	Dilute Polymer Flow, gpm	Dilute Polymer Flow/ Sludge Flow, gpm/gpm	Polymer Dose, lbs/DT	Solids Capture, %	%TS of Cake
01/10/12	M&O	Testing	5	663	204	9.7	0.04739	407	96	28
		Testing	6	682	205	8.4	0.04083	353	96	26
	M&O	Non-testing	5	680	199	9.0	0.04520	387	96	28
		Non-testing	6	680	199	8.3	0.04187	359	95	28
	% Difference 5:5			2.6	-2.3	-7.0	-4.6	-5.0	-0.1	0.0
	% Difference 6:6			-0.3	-2.7	-1.2	2.6	1.8	-0.7	7.7
01/17/12	M&O	Testing	2	689	212	9.2	0.04319	347	92	26
		Testing	12	688	186	8.7	0.04623	371	95	25
	M&O	Non-testing	2	699	206	9.2	0.04459	355	95	25
		Non-testing	12	697	204	9.1	0.04468	356	95	25
	% Difference 2:2			1.5	-2.8	-0.2	3.2	2.3	2.9	-3.8
	% Difference 12:12			1.4	9.6	5.1	-3.4	-4.1	-0.3	0.0
01/19/12	M&O	Testing	20	646	205	8.7	0.04256	325	94	27
	M&O	Non-testing	20	679	192	9.0	0.04721	362	95	29
	% Difference 20:20			5.1	-6.5	3.2	10.9	11.3	1.3	7.4

TABLE 22 (Continued): COMPARISON OF AVERAGE MACHINE PERFORMANCE AND OPERATING DATA COLLECTED FROM MAINTENANCE AND OPERATIONS DEPARTMENT-RUN MACHINES DURING THE FIVE-HOUR TESTING PERIOD VERSUS ROUTINE MAINTENANCE AND OPERATIONS DEPARTMENT OPERATION DURING THE NON-TESTING HOURS ON THE SAME DAYS

Date of Operation	Operated by	Duration	Machine No.	Torque, in-lbs	Sludge Flow, gpm	Dilute Polymer Flow, gpm	Dilute Polymer Flow/ Sludge Flow, gpm/gpm	Polymer Dose, lbs/DT	Solids Capture, %	%TS of Cake
01/24/12	M&O	Testing	10	689	217	9.2	0.04217	382	92	25
		Testing	12	681	228	8.7	0.03777	344	94	26
	M&O	Non-testing	10	701	215	9.2	0.04275	385	92	25
		Non-testing	12	688	221	8.7	0.03950	356	93	25
	% Difference 10:10			1.8	-0.7	0.2	1.4	0.8	-0.3	0.0
	% Difference 12:12			1.0	-3.0	0.2	4.6	3.6	-0.7	-3.8
01/26/12	M&O	Testing	18	689	225	9.6	0.04256	380	94	26
	M&O	Non-testing	18	714	223	9.6	0.04307	385	94	26
	% Difference 18:18			3.6	-0.9	0.2	1.2	1.2	-0.5	0.0
01/31/12	M&O	Testing	11	684	235	7.9	0.03340	224	94	25
		Testing	12	680	236	7.8	0.03302	221	92	25
	M&O	Non-testing	11	690	235	7.8	0.03320	222	94	25
		Non-testing	12	688	225	7.8	0.03464	232	92	24
	% Difference 11:11			0.8	0.0	-0.8	-0.6	-0.7	0.5	0.0
	% Difference 12:12			1.1	-4.7	0.0	4.9	4.8	0.3	-4.0
02/02/12	M&O	Testing	19	642	180	7.7	0.04264	468	94	25
	M&O	Non-testing	19	655	211	7.7	0.03663	399	94	22
	% Difference 19:19			2.0	17.2	-0.5	-14.1	-14.7	0.3	-12.0

TABLE 23: COMPARISON OF AVERAGE MACHINE PERFORMANCE AND OPERATING DATA COLLECTED FROM MONITORING AND RESEARCH DEPARTMENT-RUN MACHINES DURING THE FIVE-HOUR TESTING VERSUS ROUTINE MAINTENANCE AND OPERATIONS DEPARTMENT OPERATION DURING NON-TESTING HOURS ON THE SAME DAYS

Date of Operation	Operated by	Duration	Machine No.	Torque, in-lbs	Sludge Flow, gpm	Dilute Polymer Flow, gpm	Dilute Polymer Flow/ Sludge Flow, gpm/gpm	Polymer Dose, lbs/DT	Solids Capture, %	%TS of Cake
01/10/12	M&R	Testing	10	683	200	9.0	0.04500	385	96	25
		Testing	11	669	220	8.3	0.03764	323	96	26
	M&O	Non-testing	10	692	202	9.4	0.04652	398	96	28
		Non-testing	11	671	216	8.6	0.04002	343	96	25
	% Difference 10:10			1.3	1.0	4.4	3.4	3.3	0.0	12.0
	% Difference 6:11			0.2	-2.0	3.4	6.3	6.1	0.0	-3.8
01/17/12	M&R	Testing	3	705	202	8.5	0.04211	337	95	25
		Testing	10	721	200	8.1	0.04050	321	94	26
	M&O	Non-testing	3	709	197	8.6	0.04378	349	95	26
		Non-testing	10	713	197	8.4	0.04239	338	94	25
	% Difference 3:3			0.5	-2.5	0.7	4.0	3.5	0.0	4.0
	% Difference 10:10			-1.1	-1.5	4.2	4.7	5.2	0.0	-3.8
01/19/12	M&R	Testing	18	666	206	8.5	0.04090	316	95	27
	M&O	Non-testing	18	666	206	8.5	0.04090	316	95	27
	% Difference 18:18			0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 23 (Continued): COMPARISON OF AVERAGE MACHINE PERFORMANCE AND OPERATING DATA COLLECTED FROM MONITORING AND RESEARCH DEPARTMENT-RUN MACHINES DURING THE FIVE-HOUR TESTING VERSUS ROUTINE MAINTENANCE AND OPERATIONS DEPARTMENT OPERATION DURING NON-TESTING HOURS ON THE SAME DAYS

Date of Operation	Operated by	Duration	Machine No.	Torque, in-lbs	Sludge Flow, gpm	Dilute Polymer Flow, gpm	Dilute Polymer Flow/ Sludge Flow, gpm/gpm	Polymer Dose, lbs/DT	Solids Capture, %	%TS of Cake
01/24/12	M&R	Testing	2	702	215	8.7	0.04023	363	94	25
		Testing	6	705	223	7.8	0.03498	316	94	26
	M&O	Non-testing	2	691	218	8.9	0.04088	368	94	25
		Non-testing	6	704	228	8.3	0.03651	329	94	26
	% Difference 2:2			-1.6	1.4	2.8	1.6	1.4	0.0	0.0
	% Difference 6:6			-0.2	2.3	6.1	4.4	4.0	0.0	0.0
01/26/12	M&R	Testing	19	666	230	7.7	0.03337	298	95	23
	M&O	Non-testing	19	664	227	8.6	0.03796	339	94	27
	% Difference 19:19			-0.4	-1.3	12.0	13.8	13.6	-0.6	17.4
01/31/12	M&R	Testing	3	700	240	7.9	0.03306	220	93	24
		Testing	5	696	235	7.8	0.03319	222	90	24
	M&O	Non-testing	3	810	217	8.0	0.03701	247	94	25
		Non-testing	5	695	223	7.9	0.03536	236	91	26
	% Difference 3:3			15.7	-9.5	1.3	12.0	12.2	0.6	4.2
	% Difference 5:5			-0.2	-5.1	1.0	6.5	6.1	0.9	8.3
02/02/12	M&R	Testing	14	647	205	7.6	0.03707	404	94	24
	M&O	Non-testing	14	652	219	7.6	0.03458	376	94	19
	% Difference 14:14			0.8	6.8	0.0	-6.7	-6.8	0.6	-20.8

increase in sludge flow without increasing polymer flow resulted in polymer savings by 6.7 percent based on the volumetric ratio of polymer to sludge flow. On January 31, 2012, excess polymer use based on the volumetric ratios marginally improved solids capture (0.6 and 0.9 percent) for Machine Nos. 3 and 5 and increased %TS of cake by 4.2 and 8.3 percent, respectively. On February 2, 2012, the adjustments increased solids capture by 0.6 percent but decreased %TS of CK by 20.8 percent. In general, average polymer consumption on a volumetric basis increased by approximately 6.3 percent during the non-testing period with a maximum increase of 13.8 percent and only one decrease of 6.7 percent. The solids captures remained relatively unchanged. The %TS of cake increased in five instances by approximately 9.2 percent on an average basis with a maximum increase of 17.4 percent; %TS of cake decreased in three times by approximately 9.5 percent on an average basis with a maximum of 20.8 percent decrease; and three pairs did not show a difference in %TS.

Table 24 presents the average percent increases, decreases, or no change for all parameters presented in Tables 22 and 23. Table 24 indicates that regardless of the machines run by the M&O Department or the M&R Department, torque was increased at a higher frequency (15 out of 22) during the non-testing period, but percent increase averaged only 3.7 percent for M&R-run machines and 2.1 percent for M&O-run machines. Sludge flows were reduced 14 times for both M&R- and M&O-run machines at approximately 3 to 3.6 percent on an average basis. In contrast, polymer flows were increased 14 times by approximately 1.8 to 4 percent on an average basis. These adjustments in sludge and polymer flows caused polymer consumptions to vary within ±6.8 percent on a volumetric or weight basis; solids capture varied within ±1.1 percent, and %TS of cake varied within ±9.5 percent.

Based on the above, the polymer savings or overages in M&O- and M&R-run machines during the testing and non-testing periods were mainly due to the need-based or non need-based adjustments in sludge or polymer flows, and those adjustments caused variations in polymer consumption and impact on performance in some instances.

Phase II Conclusions and Recommendations

Conclusions.

1. Unlike polymer characteristics, digester draw and centrifuge feed characteristics were significantly different between the side-by-side testing (Phase II) and baseline (Phase I) periods. Performance differences between these two periods could be attributed to the machine and operational settings adjustments made in response to different sludge characteristics and to the increased oversight of side-by-side operating performance evaluation during the testing period.

2. Overall hourly data analysis for the entire testing period between collective M&O- and M&R-run machines indicated statistically lower dilute polymer flow, slightly higher torque, and lower polymer dose on weight and volumetric bases in M&R-run machines. Both the M&O Department and the M&R Department were generally able to achieve the machine performance goals with respect to %CK and %CP.

TABLE 24: A COMPARATIVE SUMMARY OF AVERAGE MACHINE PERFORMANCE AND OPERATING DATA COLLECTED FROM MONITORING AND RESEARCH DEPARTMENT- AND MAINTENANCE AND OPERATIONS DEPARTMENT-RUN MACHINES DURING THE TESTING AND NON-TESTING HOURS ON THE SAME DAYS

Determinant	Torque, in-lbs	Sludge Flow, gpm	Dilute Polymer Flow, gpm	Dilute Polymer Flow/ Sludge Flow, gpm/gpm	Polymer Dose, lbs/DT	Solids Capture, %	%TS of Cake
———M&R 5-Hour Operation Versus 19-Hour M&O Operation of 11 Pairs of Machines———							
Average increase (%)	3.7	2.9	4.0	6.3	6.2	0.7	9.2
No. of times increased	5	4	9	9	9	3	5
Average decrease (%)	-0.7	-3.6	N/A	-6.7	-6.8	-0.6	-9.5
No. of times decreased	5	6	0	1	1	1	3
No. of times no change	1	1	2	1	1	7	3
———M&O 5-Hour Operation Versus 19-Hour M&O Operation of 11 Pairs of Machines———							
Average increase (%)	2.1	13.4	1.8	4.1	3.7	1.1	7.5
No. of times increased	10	2	5	7	7	5	2
Average decrease (%)	-0.3	-3.0	-1.9	-5.7	-6.1	-0.4	-5.9
No. of times decreased	1	8	5	4	4	6	4
No. of times no change	0	1	1	0	0	0	5

3. Overall comparison based on hourly data indicated that hourly polymer flow, %CK, torque, and polymer dose on weight and volumetric bases were significantly different between M&O- and M&R-run machines during the testing period, but hourly sludge flow and %CP were not significantly different. The M&R Department processed an average hourly sludge flow of 216 gpm compared to 212 gpm by the M&O Department. The M&R Department used an average polymer flow of 8.17 gpm compared to 8.69 gpm by the M&O Department. The hourly average polymer consumption by volume was 0.038 gpm/gpm for the M&R Department versus 0.041 gpm/gpm for the M&O Department, and hourly average polymer consumption by weight was 334.11 lbs/DT for the M&R Department and 362.78 lbs/DT for the M&O Department. Hourly average torque was 687.44 lbs-in for the M&R Department versus 675.71 lbs-in for the M&O Department. In terms of hourly performance, the M&R Department had an hourly average of 24.90 %TS in cake and 94.16 %CP compared to 25.53 %TS in cake and 93.86 %CP for the M&O Department.

4. All the pair-wise analyses indicated average set torque values varied from 647 lbs-in to 721 lbs-in for the M&R-run machines and from 642 lbs-in to 689 lbs-in for the M&O-run machines. The pair-wise differences did not exceed 4.8 percent. Six of the eleven pairs had significantly different torque, and the remaining five pairs did not. However, the collective M&O-run versus M&R-run machines evaluation based on hourly data indicated that the hourly average torque of 687.44 lbs-in in the M&R-run machines was statistically higher compared to 675.71 lbs-in in M&O-run machines.

   The hourly percent variations with respect to the testing period average values, standard deviations, and CV of torque values indicated that the M&O- and M&R-run machines were operated consistently with slightly greater stability in M&R-run machines during the side-by-side testing period.

   The torque settings by the M&O Department during the side-by-side testing period ranging from 642 lbs-in to 689 lbs-in were much lower than the average torque values of 720 to 768 lbs-in during the baseline period.

5. M&R-run machines had average sludge flows in the range of 200 to 240 gpm, and M&O-run machines had average sludge flows in the range of 180 to 236 gpm. Generally, average sludge flows between the M&R- and M&O-run machine pairs varied within ±8 percent except for one pair that had a difference of 13.9 percent. There was no observable statistical difference in hourly sludge flows between M&R- and M&O-run machines with average sludge flows of 215.98 gpm and 212.04 gpm, respectively.

6. M&R-run machines had average dilute polymer flows in the range of 7.6 to 9.0 gpm during the testing period, and M&O-run machines had average dilute polymer flows in the range of 7.7 to 9.7 gpm. The highest pair-wise difference between a M&O- and M&R-run machine pair was 19.8 percent.

Nine of the 11 test pairs indicated higher polymer usage by the M&O-run machines (6.9 percent on an average basis); the other two pairs indicated that M&O-run machines had similar polymer flows compared to the respective M&R-run machines.

Average dilute polymer flows of M&O-run machines during the side-by-side testing period was much lower compared to the average dilute polymer flows of 9.7 to 11.1 gpm observed during the baseline period.

7. The five-hour testing period average volumetric ratios of dilute polymer flow per unit sludge flow for M&O- and M&R-run machines was in the range of 0.03302 to 0.04739 gpm/gpm and 0.03306 to 0.04500 gpm/gpm, respectively. The average hourly volumetric ratios for M&R- and M&O-run machines were 0.0381 and 0.041 gpm/gpm, respectively.

8. Side-by-side testing demonstrated that operating centrifuges at optimized settings can reduce polymer consumption. Average polymer consumption in M&R-run machines relative to M&O-run machines ranged from 0.5 to -21.6 percent with respect to the volumetric ratio of dilute polymer flow to sludge flow, and from 0.5 to -21.6 percent with respect to polymer dose. Average polymer savings in M&R-run machines were 7.9 percent and 8.2 percent with respect to the volumetric and weight based consumptions, respectively, in 10 of 11 pairs. Considering 25 %CK as a performance goal for this phase, all 11 M&O-run machines met the goal while four M&R-run machines did not meet the goal; three of these four M&R-run machines had 24 %CK, and one had 23 %CK. Similarly with respect to 95 %CP as a performance goal for this phase, four M&R- and five M&O-run machines produced 94 percent, one M&R-run machine produced 93 percent, three M&O-run machines produced 92 percent, and one M&R-run machine produced 90 percent. Despite the instances during which the performance goals were not met, all of the lower performances were within generally acceptance thresholds of the M&O Department, i.e. >20 %TS in CK and >90 %CP.

9. The performance and polymer consumption differences in M&O- and M&R-run machines during the side-by-side testing period may have been attributed to different operational settings mainly dilute polymer flow settings in relation to sludge flows.

10. The M&R Department demonstrated during the side-by-side testing that the optimal centrifuge operation can be achieved by fixing the torque value followed by maintaining the lowest possible volumetric ratio of dilute polymer flow to sludge flow. As a general rule of thumb, a torque of 650 to 725 lbs-in for machine Nos. 2 through 12 and 27 to 30 percent load factor for machine Nos. 13 through 21 should be set with a minimum sludge flow of 200 gpm with the lowest possible polymer flow to maintain the volumetric ratio of polymer flow to sludge flow in a range of 0.0331 to

0.0450 gpm/gpm with a target of achieving centrifuge performance goals of 25 %CK and 95 %CP.

11. It appeared that the OEs during the non-day shifts are more likely to maintain similar torque settings to what was set during the day shift, but less so for sludge and polymer flow settings. This indicates that polymer savings during all shifts through optimal machine operation settings could be possible if a unified coordination in operating strategy to maintain the volumetric ratios of polymer to sludge flow is effectively administered.

Recommendations.

1. If properly trained and challenged to achieve a goal of polymer savings, OEs should be requested to operate the machines similar to the optimal operation settings practiced during the side-by-side testing periods. Should this strategy be employed, machine performance and polymer volumetric ratios (polymer flow to sludge flow) should be recorded on a log sheet each shift and tracked. Daily polymer dosages (volumetric and weight basis) should be calculated, periodically evaluated and used as a guiding tool.

2. A reduction in polymer flow should generally follow proportionate reduction in sludge flow. Likewise, an increase in polymer flow should follow an increase in sludge flow to the extent that the performance goals are achieved via visual inspections.

3. Fewer machines should be operated at higher sludge flows (a minimum of 200 gpm or higher), if possible, rather than operating more machines at lower sludge flows.

4. The M&O Department should establish desired machine performance goals in terms of %CP and %CK in order to evaluate polymer usage. The polymer usage and machine performance should be used as the OE’s job performance criteria.

EVALUATION FOR POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT – PHASE III: LABORATORY TESTS AND HISTORIC DATA REVIEW

Background

In previous phases, the study focused on evaluating the current centrifuge operations and dilute polymer preparation, optimizing operations by adjusting machine settings with respect to reducing polymer consumption, and verifying that polymer savings could be achieved under optimal centrifuge operations in full-scale side-by-side tests. This phase considered and examined a wide spectrum of initiatives to reduce polymer use, which included: (1) review of polymer purchase and consumption data to determine unintended polymer wastage, (2) evaluation of a switch in dilution water from secondary treated plant effluent to city water for dilute polymer preparation, (3) evaluation of surface tension as an indicator for excess polymer use, (4) evaluation of variations in dilute polymer's charge density with storage time to determine the maximum practical storage time before use, (5) evaluation of centrifuge machine performance at lower dilute polymer strength compared to a strength of 15 percent, and (6) evaluation of historic data with respect to the relationships between centrifuge machine performance and polymer use with sludge characteristics with an added emphasis on %VS.

The previous portion of the report included two phases of this study. The overall objectives of this phase are given in the Phase I section. This phase, which is considered to be Phase III, concludes the study by summarizing the results, conclusions, and recommendations on the above-mentioned initiatives that have not been previously addressed. These initiatives are identified and presented as Objective Nos. 4, 8a, 8c, 8d, and 8e on page 6 of this report. The experimental test details and preliminary results for Objective No. 8a, i.e. the use of city water as dilution water for preparing dilute polymer solution in lieu of the current practice of using Stickney secondary treated plant effluent, were provided in the Phase I summary. However, the preliminary results warranted further evaluation, because they were inconclusive.

Materials and Methods

Objective 4: Compare Monthly Measured Dilute Polymer Consumption Versus Monthly Polymer Purchase Records. The M&R Department acquired polymer purchase and consumption data in light of determining whether excess polymer was purchased for the Post-Centrifuge operations, which would reflect wastage.

Laboratory-Scale Tests for Potential Polymer Savings (Objective Numbers 8a, 8c, 8d, and 8e). The following laboratory-scale tests were performed for the evaluation of polymer savings. Each experiment is separately described below.

Objective 8a: Comparison of City Water Versus Stickney Secondary Treated Effluent for Dilute Polymer Preparation – Additional Tests. The first phase summary provided the experimental test details and preliminary results on the use of city water as dilution water for preparing dilute polymer solution in lieu of the current practice of using Stickney secondary treated plant effluent. The preliminary results warranted further evaluation, because the test results were inconclusive. Therefore, additional tests were performed during May 2012, to evaluate possible improvement in dewaterability and polymer savings.

A house polymer sample was collected during May 2012, and diluted to prepare two 10 percent working solutions using secondary treated plant effluent and city water as dilution water, respectively. Varying doses from 10 to 20 mL of dilute polymer from these respective working solutions were added to freshly collected centrifuge feed samples (200 mL) and mixed for 120 seconds at 500 rpm. CST tests were performed in duplicate on these treated sludge samples. The CSTs were measured and recorded. The duplicate CSTs were then averaged. The average CSTs from sludges treated with normalized doses of city water dilute polymer and effluent dilute polymer were compared to evaluate better dewaterability as indicated by lower CSTs.

Objective 8c: Laboratory-Scale Evaluation of Variations in Dilute Polymer Charge to Determine Maximum Allowable Storage Time Before Use. The effect of aging on the quality of dilute polymer was evaluated as the charge density on the polymer chains that aid in dewatering were expected to decay with time. A house polymer sample, a cationic mannich polymer, was collected on January 8 and 23, 2013, and diluted to prepare 5 percent working solutions using reverse osmosis (RO) water as dilution water. In lieu of secondary treated effluent for dilution water, RO water was used, because it provides a much better controlled test condition to evaluate the concept of diminishing charge density with storage time; additionally, a 5 percent solution was selected to avoid using costly titrant and to ensure reliable color changes at the endpoints. An aliquot from these dilute polymer solutions was titrated in duplicate with a standard anionic solution of polyvinyl sulfate potassium salt (PVSK) using a Toluidine Blue O (TBO) indicator to determine charge density at different time intervals spanning one hour to six days.

The PVSK solution's charge density was first determined by titrating with a cationic 1,5-dimethyl-1,5-diazaundecamethylene polymethobromide (DDPM) or polybrene standard. The PVSK was then added to the cationic polymer aliquots until charge neutralization was observed, as indicated by a color change of the TBO indicator from blue to light purplish pink. A pH buffer was added during this titration of the polymer solutions since some polymers vary in charge with pH. Duplicate charge density analyses were performed at each time interval and averaged; time intervals were calculated as the time between dilute polymer preparation and charge density analysis. The average charge density results were plotted against the elapsed time to determine the rate of decrease; charge density was expected to decrease with time, which would impact dewatering performance. It is conventionally known that charge neutralization is one of the well-established mechanisms by which sludge particles are destabilized. Polymer with a lower charge density may be consumed in higher quantities to achieve the same dewatering performance compared with the polymer with a higher charge density.

Objective 8d: Full-Scale Evaluation of Centrifuge Machines at Lower Dilute Polymer Strength. As noted in the first and second phase summaries, polymer may be wasted in the Post-Centrifuge dewatering operations if its flow rate is not proportionately adjusted in relation to the feed sludge flow rate. If no efforts are made to adjust polymer flow rate in relation to the feed sludge flow rate and routine operations are maintained, the only way polymer wastage can theoretically be minimized is by using lower strength dilute polymer. With this in mind, full-scale tests were designed to evaluate the polymer dilution effects (using assorted dilute polymer strengths) on optimum polymer dose and polymer savings with respect to operations currently using 15 percent dilute polymer strength; this dilution has produced satisfactory performance for the Stickney dewatering operations. However, full-scale operation of centrifuge machines using different dilute polymer strength solutions can disrupt the routine Pre- and Post-Centrifuge operations. To avoid disruption and practical difficulties in preparing the different dilute polymer strength solutions as well as isolating test machines for full-scale test evaluation, bench-scale tests were conducted during May and June 2012 as a preliminary investigation.

For these bench scale tests, a house polymer sample was collected and diluted using secondary treated Stickney plant effluent as dilution water to prepare working dilute polymer solutions of different strengths ranging from 8 to 19 percent. This broader range of strength was chosen during preliminary testing in May 2012, but refined range during follow up testing in June 2012. Varying doses from 5 to 21 mL of these working solutions were added to centrifuge feed samples (200 mL) and mixed for 120 seconds at 500 rpm. CST tests were then performed in duplicate on each treated sludge as a test of dewaterability. The CSTs were measured and recorded. The duplicate CSTs were then averaged. Volumetric polymer consumptions and the average CSTs were plotted for each dilute polymer solution. The volumetric polymer doses corresponding to the lowest measured CSTs are considered the optimum volumetric polymer doses. These volumetric optimum polymer doses at each dilution were then converted into the traditional expression routinely used by the plant (lbs of polymer used per DT of sludge processed) and plotted against different dilutions to determine impact of polymer dilution on optimum polymer dose.

Objective 8e: Evaluation of Centrifuge Feed Characteristics (Historic Data Review). The centrifuge feed characteristics with the emphasis on VS content in centrifuge feed was evaluated with respect to polymer savings and impact on dewatering process performance. In order to accomplish these objectives, the time series trends for polymer dose, TS in centrate, solids capture, and cake dryness with VS content in centrifuge feed for calendar years 2000 through 2009 were plotted. These time series trends included use of multiple polymers selected from different polymer procurement contracts during the ten years (Table 25). Therefore, the effect of feed VS content was further examined for each individual polymer used in different contracts as well as for entire ten-year period by determining r-values and trends from the plots. Due to lack of information on polymer switch dates between two seasons, the data from January 2, 2000, through January 14, 2002, were excluded. Further evaluation based on the winter and summer seasons was not pursued as the season-specific designated polymer was not used consistently.

Based on the above analyses of individual polymer and combined polymer use over ten years, the relationship between VS and polymer dose, TS in centrate, solids capture, and cake dryness was evaluated.

Results and Discussion

Objective 4: Compare Monthly Measured Dilute Polymer Consumption Versus Monthly Polymer Purchase Records. The Stickney polymer is purchased and received in a combined load for both the Pre-Centrifuge thickening and Post-Centrifuge dewatering operations and is documented accordingly in the bills of lading, i.e. the purchased amounts include polymer needs for both the Pre- and Post-Centrifuge operations. Any excess purchased polymer dedicated

TABLE 25: USE OF SEASONAL POLYMERS AND THEIR SWITCH DATES

Contract #	Season	Polymer Name	Switch Date
11-633-11	Winter	CE-1520	10/10/11
08-633-11	Winter	CE-1142	09/01/10
	Summer	CE-1100	06/15/10
	Winter	CE-1142	11/01/09
	Summer	CE-1100	05/01/09
	Winter	CE-1142	11/16/08
	Summer	CE-1100	08/25/08
06-633-11	Summer	CE-770	05/01/08
	Winter	CE-659	11/01/07
	Summer	CE-770	05/16/07
	Winter	CE-659	11/16/06
	Summer	CE-770	07/29/06
03-658-11	Summer	CE-386	05/16/06
	Winter	CE-347	12/16/05
	Summer	CE-386	05/16/05
	Winter	CE-347	01/16/05
	Summer	CE-386	05/01/04
01-658-11	Winter	NW-198	02/14/04
	Summer	CE-045	06/01/03
	Winter	NW-198	12/16/02
	Summer	CE-045	05/01/02
	Winter	NW-198	01/15/02

for the Post-Centrifuge operations is maintained in the storage tanks and used the following day. As such, purchased polymer is not wasted due to either its shelf life or any other reasons. Considering the zero-wastage policy, excess polymer purchase cannot be related to wastage.

Laboratory-Scale Tests for Potential Polymer Savings (Objective Numbers 8a, 8c, 8d, and 8e). The following laboratory-scale tests were performed for the evaluation of polymer savings. Each experiment is separately described below.

Objective 8a: Comparison of City Water Versus Stickney Secondary Treated Effluent for Dilute Polymer Preparation – Additional Tests. The results of additional tests performed during May 2012, to evaluate improvement in dewaterability and polymer savings are presented in Figures 8 through 10. Like the previous test results in the first report, additional tests conducted during May 2012 indicated no distinct advantage of using city water for dilute polymer preparation relative to secondary effluent.

Objective 8c: Laboratory-Scale Evaluation of Variations in Dilute Polymer Charge to Determine Maximum Allowable Storage Time Before Use. The average charge density results at different time intervals are depicted in Figures 11 and 12, respectively, for January 8 to 14, 2013, and January 23 to 28, 2013, experiments. Both figures indicate a common trend of gradual decrease in charge density with increasing storage time; decrease began soon after the dilute polymer was prepared. Figure 11 indicates loss of charge density at a rate of approximately 2.2 percent per hour during the first five hours of storage time, 0.5 percent per hour during the next 72 hours of storage time, and 0.2 percent per hour during the next 72 hours of storage time. With reference to the initial charge density of 5.82 meq/g, 5, 11, 20, 33, 41, and 51 percent loss in charge density occurred at 1, 5, 24, 48, 73, and 142 hours of storage time, respectively. Figure 12 indicates loss of charge density at a rate of approximately 1.3 percent per hour during first five hours of storage time and 0.8 percent per hour during next 72 hours of storage time. With reference to the initial charge density of 5.01 meq/g, 6, 7, 21, 37, and 54 percent loss in charge density occurred at 1, 5, 25, 48, and 73 hours of storage time, respectively. The first test results (Figure 11) indicate an exponential to linear deterioration of charge density with accelerated rate of deterioration in early hours of aging; the second set of results (Figure 12) indicate a more linear rate of deterioration of charge density between five and 72 hours, but this could be an artifact of lack of data in the first five hours of aging. These results suggest that loss in charge density over time is inevitable and unavoidable to some extent in full-scale operations, for example five to six percent loss in charge density is unavoidable due to the typical one hour of aging time. However, charge density loss can be minimized by reducing the time between dilute polymer preparation and use. The dilute polymer with higher charge density will deliver higher active polymer content per unit sludge mass treated compared to aged dilute polymer. It is believed this will help save polymer consumption since higher charge per unit polymer mass will more effectively destabilize and dewater the sludge by charge neutralization (Mangravite et al., 1978; Tiravanti et al., 1985).

Objective 8d: Full-Scale Evaluation of Centrifuge Machines at Lower Dilute Polymer Strength. Volumetric raw polymer consumptions and the average CSTs were plotted for each dilute polymer solution ranging from 8 to 19 percent as shown in Figures 13 and 14. The volumetric polymer doses corresponding to the lowest measured CSTs are considered the optimum volumetric polymer doses. These volumetric optimum polymer doses at each dilution

FIGURE 8: EVALUATION OF CITY WATER VERSUS PLANT EFFLUENT BASED DILUTE POLYMERS ON DEWATERING PERFORMANCE EXPRESSED AS CAPILLARY SUCTION TIME: EXPERIMENTAL RESULTS FROM MAY 7, 2012, TESTS

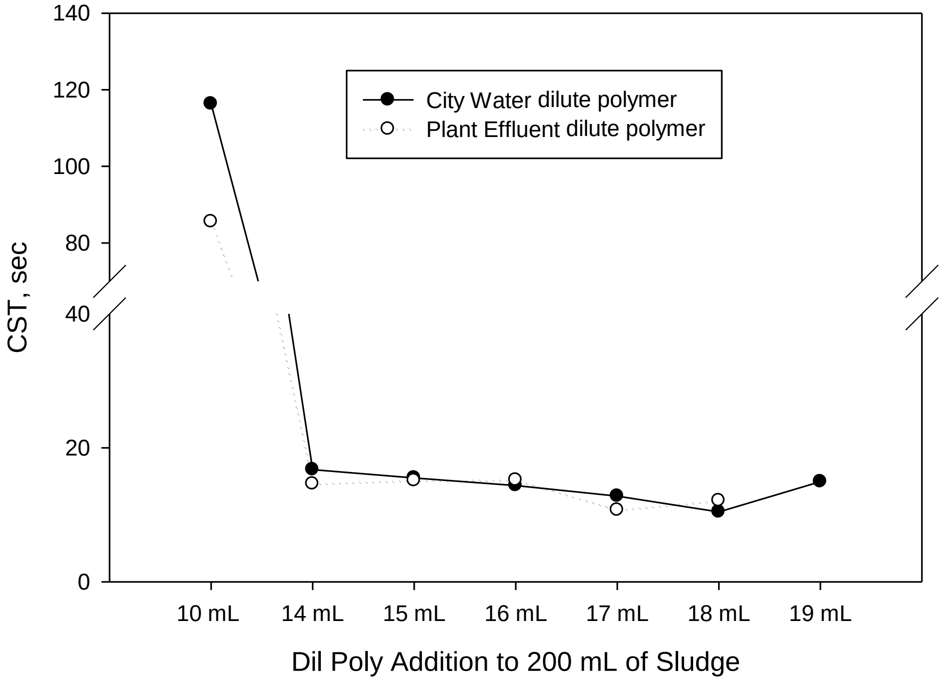


FIGURE 9: EVALUATION OF CITY WATER VERSUS PLANT EFFLUENT BASED DILUTE POLYMERS ON DEWATERING PERFORMANCE EXPRESSED AS CAPILLARY SUCTION TIME: EXPERIMENTAL RESULTS FROM MAY 8, 2012, TESTS

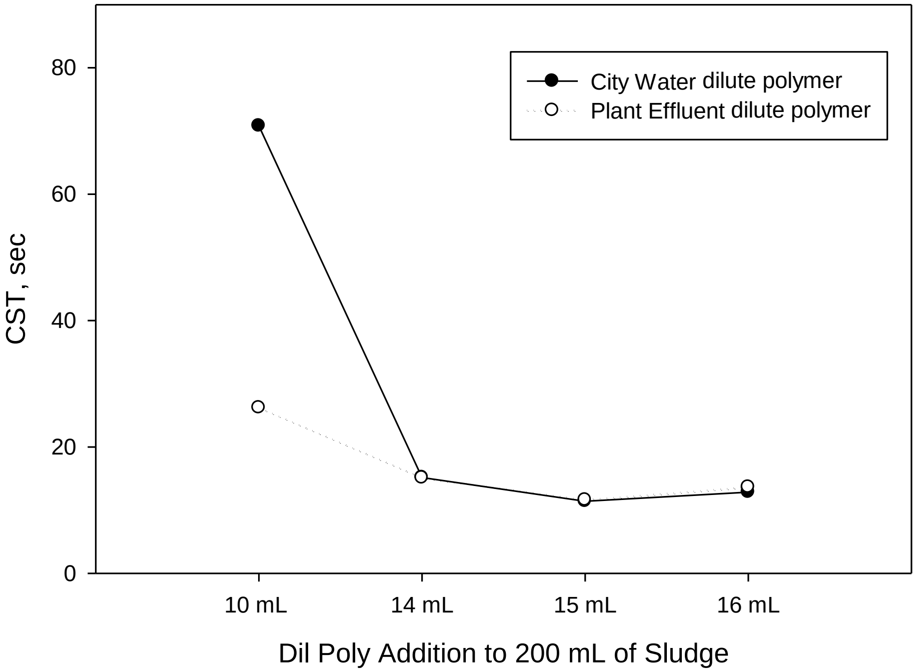


FIGURE 10: EVALUATION OF CITY WATER VERSUS PLANT EFFLUENT BASED DILUTE POLYMERS ON DEWATERING PERFORMANCE EXPRESSED AS CAPILLARY SUCTION TIME: EXPERIMENTAL RESULTS FROM MAY 9, 2012, TESTS

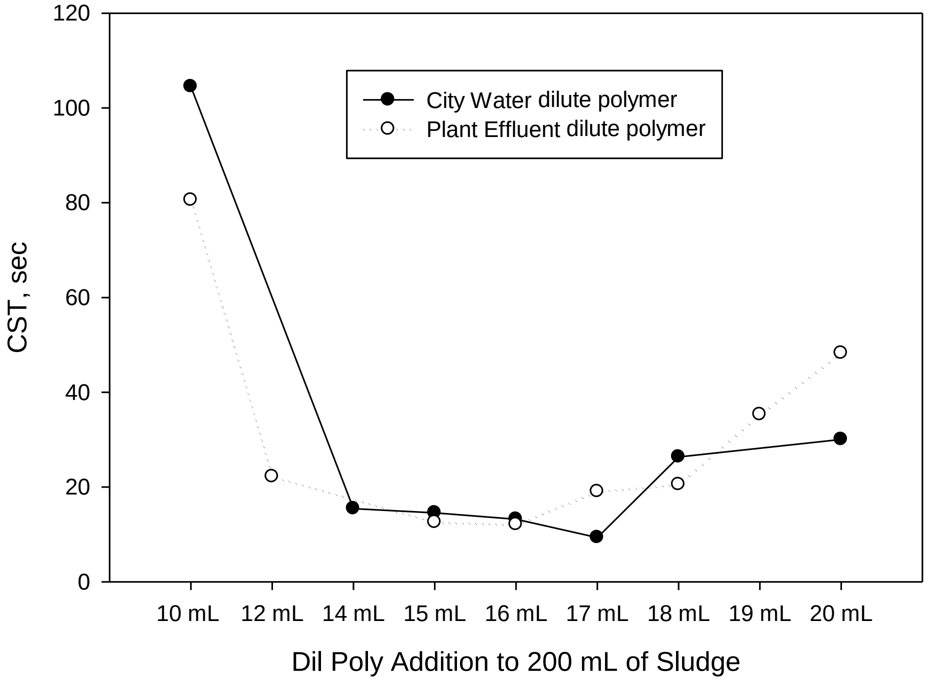


FIGURE 11: EVALUATION OF CHARGE DENSITY OF A DILUTE POLYMER WITH RESPECT TO STORAGE TIME
(JANUARY 8 THROUGH 14, 2013)

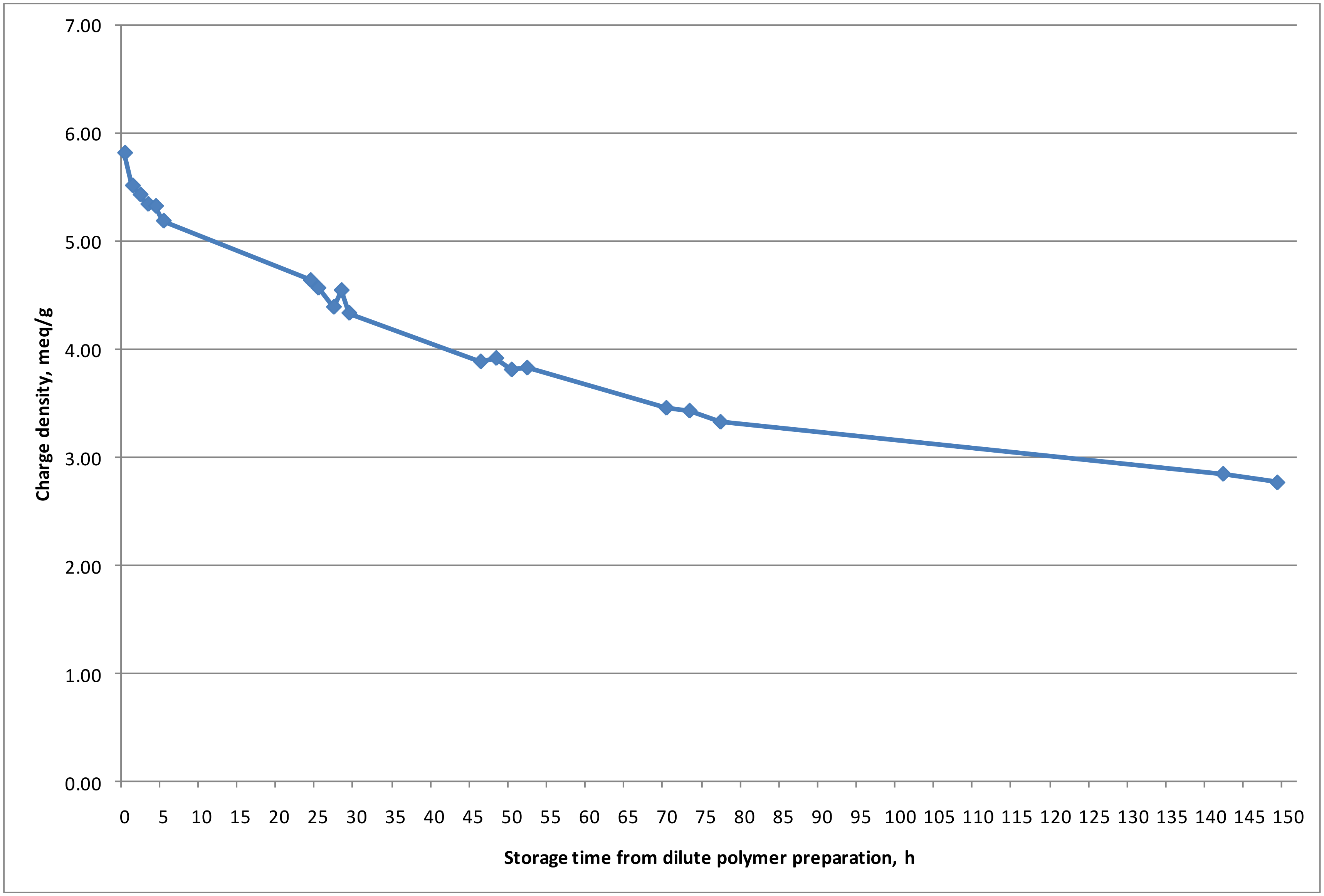


FIGURE 12: EVALUATION OF CHARGE DENSITY OF A DILUTE POLYMER WITH RESPECT TO STORAGE TIME
(JANUARY 23 THROUGH 28, 2013)

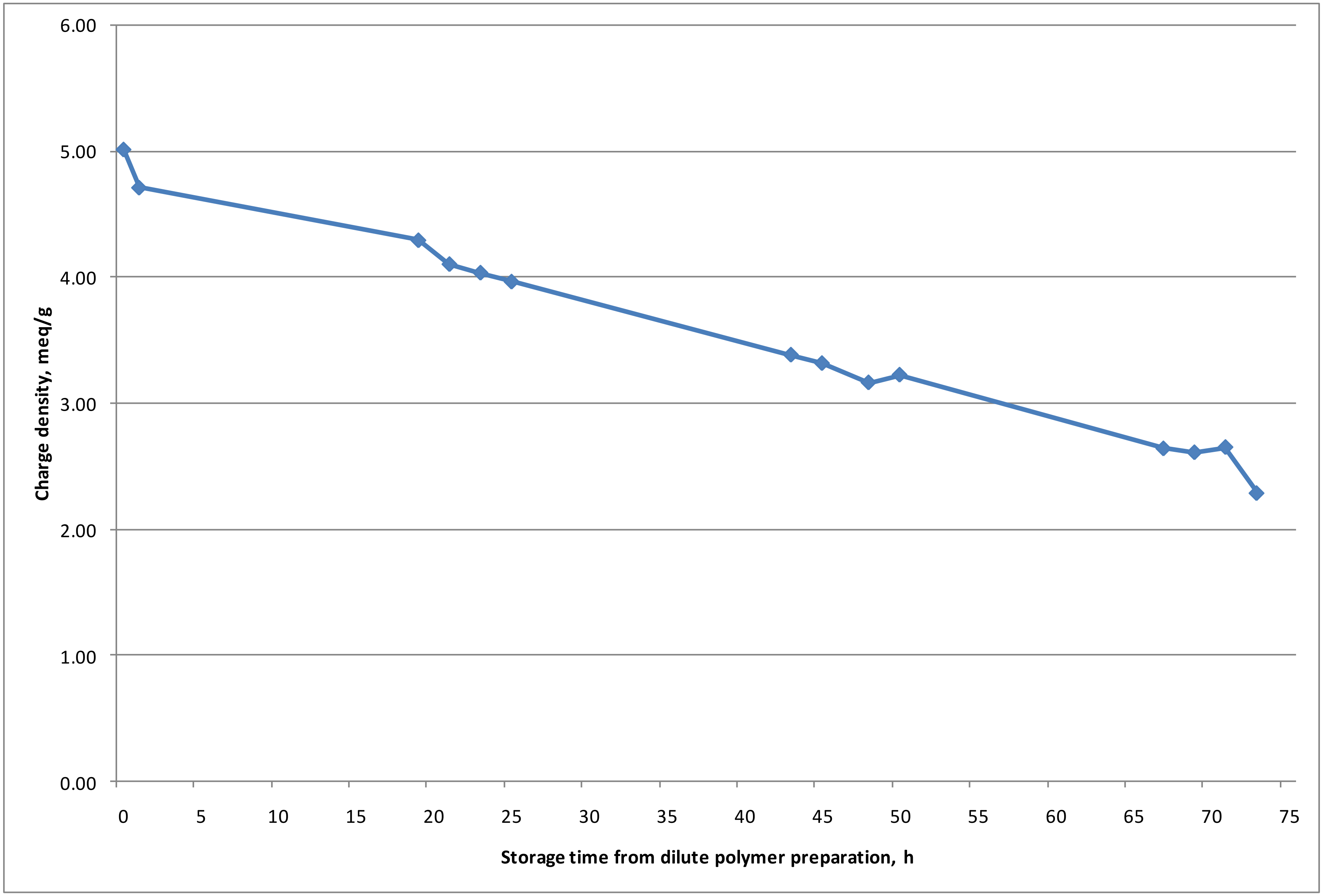


FIGURE 13: LABORATORY-SCALE EVALUATION OF PERCENT POLYMER DILUTION ON OPTIMUM POLYMER DOSE CONDUCTED DURING MAY 10 THROUGH 12, 2012: SLUDGE = 3.23 PERCENT TOTAL SOLIDS AND VOLUME = 200 MILLILITERS

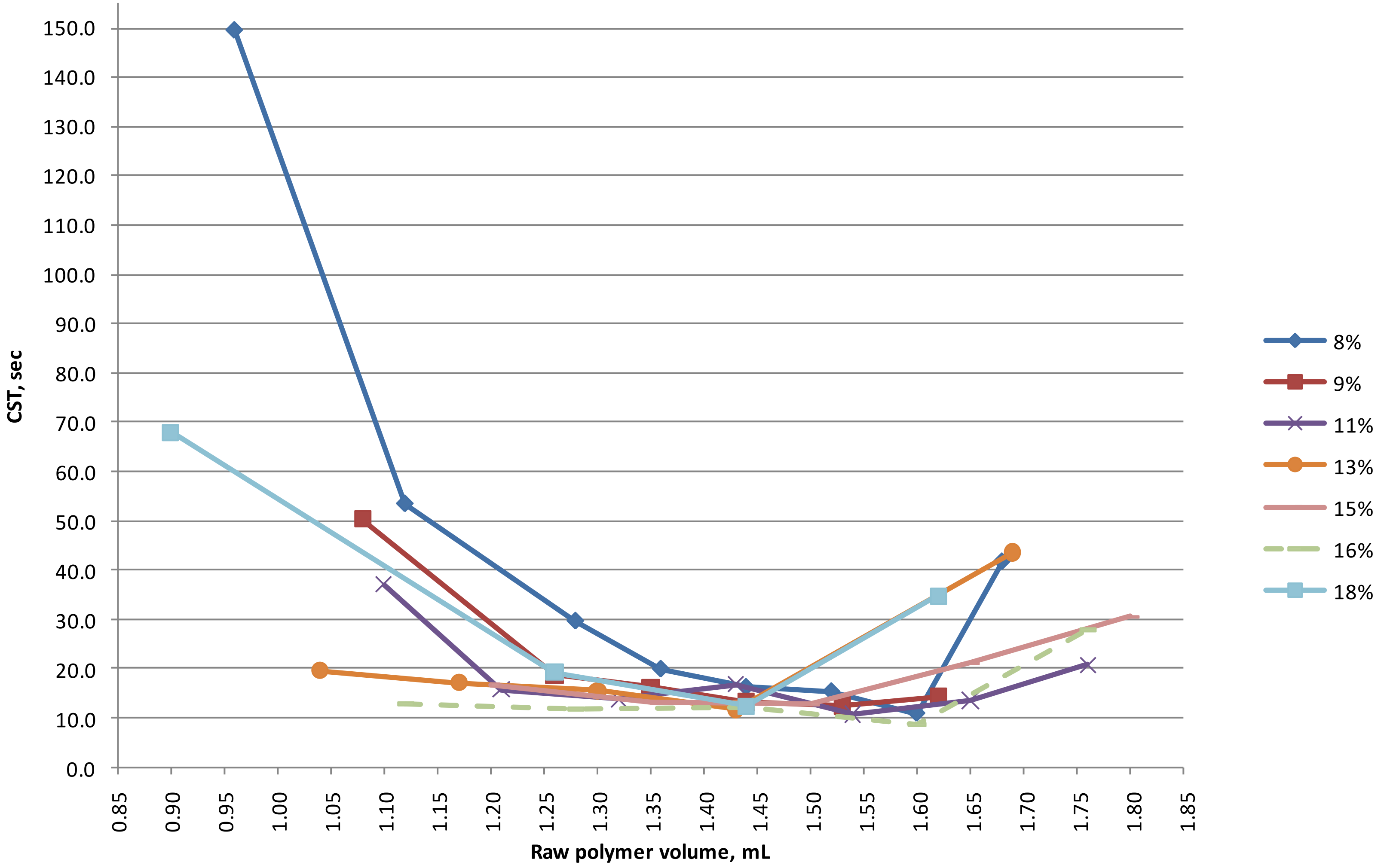
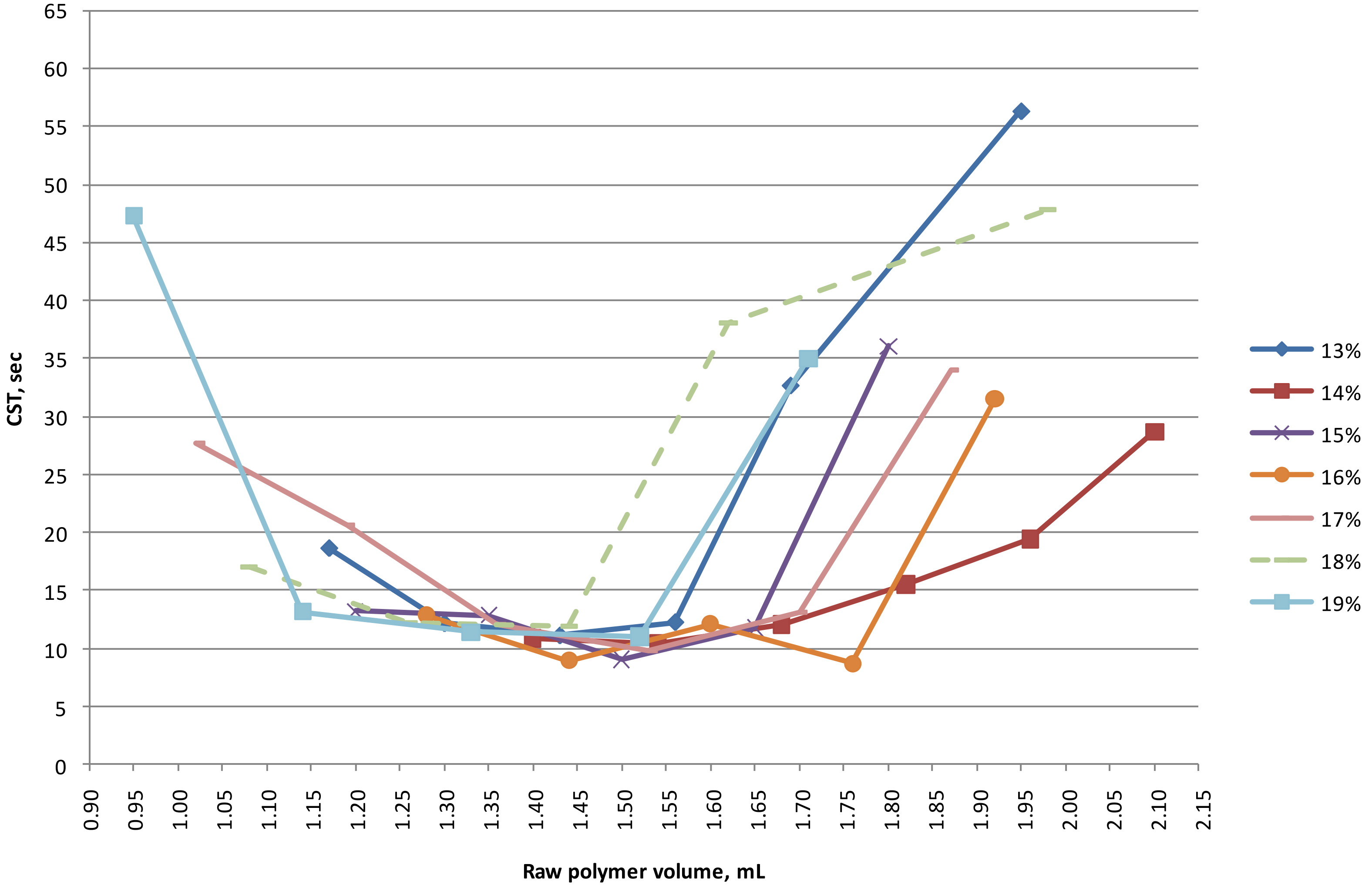


FIGURE 14: LABORATORY-SCALE EVALUATION OF PERCENT POLYMER DILUTION ON OPTIMUM POLYMER DOSE CONDUCTED DURING JUNE 12 THROUGH 14, 2012: SLUDGE = 3.07 PERCENT TOTAL SOLIDS AND VOLUME = 200 MILLILITERS



were then converted into the traditional expression routinely used by the plant (lbs of polymer used per DT of sludge processed) and are illustrated in Figure 15.

The test results presented in Figures 13, 14 and 15 indicate that polymer savings may not be realized by either diluting or concentrating the polymer solution with respect to the existing practice of 15 percent dilution. The polymer doses remained in a range of approximately 450 and 500 lbs/DT at all dilutions in both tests.

Objective 8e: Evaluation of Centrifuge Feed Characteristics (Historic Data Review). The centrifuge feed characteristics with the emphasis on VS content in centrifuge feed were evaluated with respect to polymer savings and impact on dewatering process performance. Figure 16 depicts the time series trends for polymer dose and VS content in centrifuge feed for calendar years 2000 through 2009. This figure generally indicates that polymer dose decreased when VS content in feed sludge decreased. These time series trends include use of multiple polymers selected from different polymer procurement contracts during the ten years (Table 25). A relatively good r-value of 0.6602 for polymer dose and VS content was determined for the combined data from January 2, 2000, through December 31, 2009 (Table 26). The closer the r-value is to either 1 or -1, the stronger the relationship; the closer the r is to zero, the weaker the relationship.

The effect of feed VS content was further examined for each individual polymer used in different contracts through these r-values as summarized in Table 26. (Please note that due to lack of information on polymer switch dates, the data from January 2, 2000, through January 14, 2002, were excluded). Based on the individual polymer analyses, it is evident that the relationship between VS and polymer dose were much stronger for CE-770 (r = 0.7298) and CE-659 (r = 0.7028) relative to the six other polymers whose r-values ranged from 0.1071 to 0.4695. However, all eight polymers showed a similar relationship of decreasing polymer dose with decreasing VS content of the feed. Even though the r-values of the individual polymers were not consistently as strong as the polymers combined, this analysis does indicate that polymer dose is dependent on VS content of feed sludge, but not univariate, i.e. it is also dependent on other unknown or known variables such as polymer to sludge flow rate ratios as expressed in the Phase I and II summaries.

The effect of feed VS content was further examined to evaluate its impact on dewatering process performance. Figures 17, 18, and 19 represent similar time series trends for TS in centrate, solids capture, and cake dryness, respectively, in relation to VS content in centrifuge feed. Figure 17 suggests that for the entire period of 2000 through 2009, lower VS content led to lower TS in the centrate. Similar plots were generated for each polymer, and this same trend was generally observed for all polymers with the exception of CE-386 and CE-1100. To support the visual trends identified, r-values were determined for the entire period including all polymers and for each individual polymer. The resulting r-values are summarized in Table 26. An r-value of 0.3602 for centrate TS and feed VS content was determined for the combined data from January 2, 2000, through December 31, 2009. Low r-values were observed for all polymers (<|0.4450|), and the highest r-value from individual polymers was determined to be 0.4449 for NW-198. Based on the individual polymer analyses, it is evident that the relationships between VS and centrate TS were slightly stronger (r > 0.3175) for NW-198, CE-770, CE-659, and CE-1142 relative to the four other polymers whose r-values ranged from -0.1113 to 0.1453. Of these polymers, CE-386 and CE-1100 had r-value of -0.0002 and -0.1113, respectively. The negative

FIGURE 15: LABORATORY-SCALE EVALUATION OF PERCENT POLYMER DILUTION ON MINIMAL POLYMER DOSE CONDUCTED DURING MAY 10 THROUGH 12, 2012, AND JUNE 12 THROUGH 14, 2012

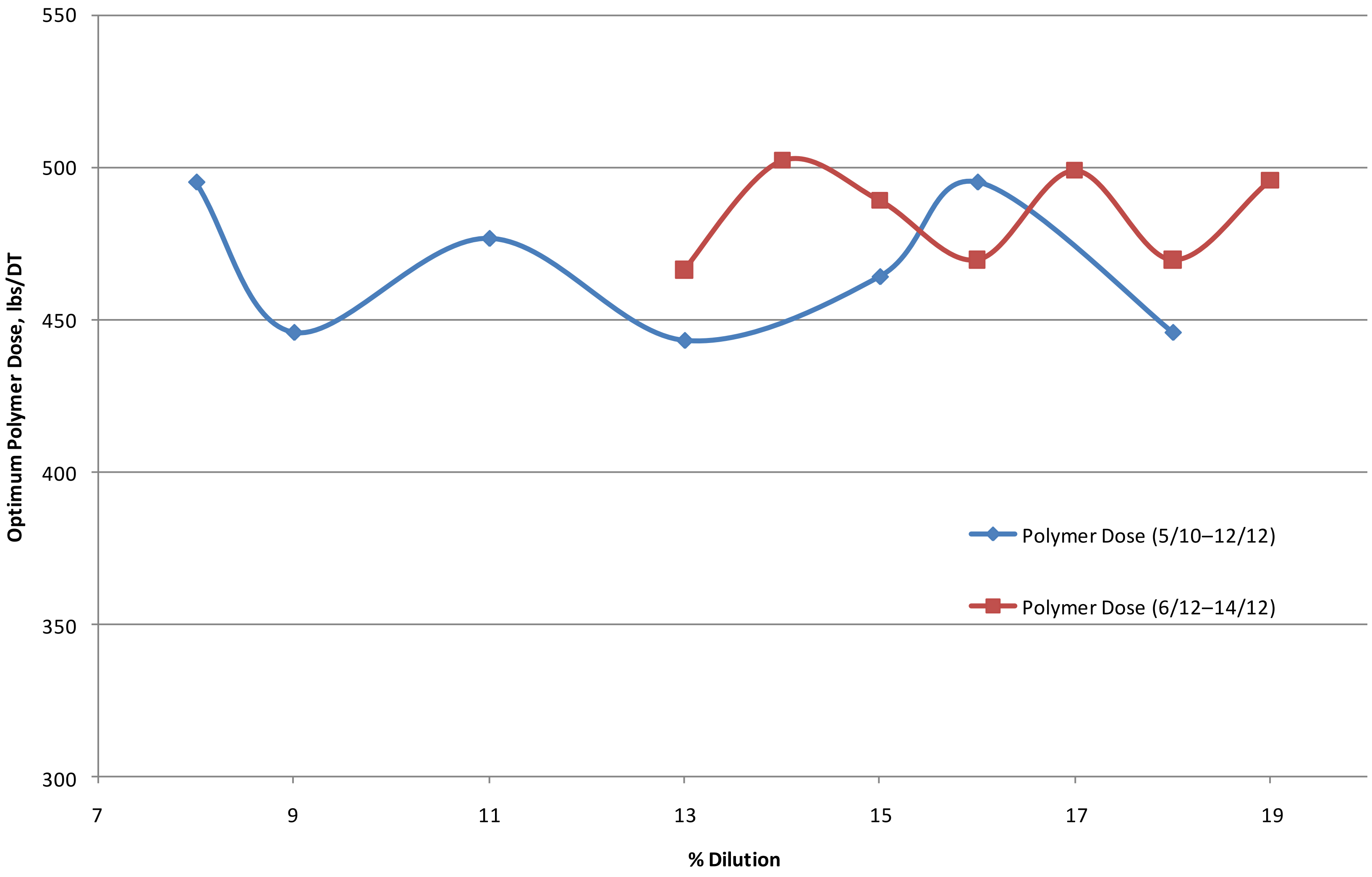


FIGURE 16: TIME SERIES TREND BETWEEN VOLATILE SOLIDS CONTENT IN CENTRIFUGE FEED AND POLYMER DOSAGE FOR THE PERIOD JANUARY 1, 2000, THROUGH DECEMBER 15, 2009

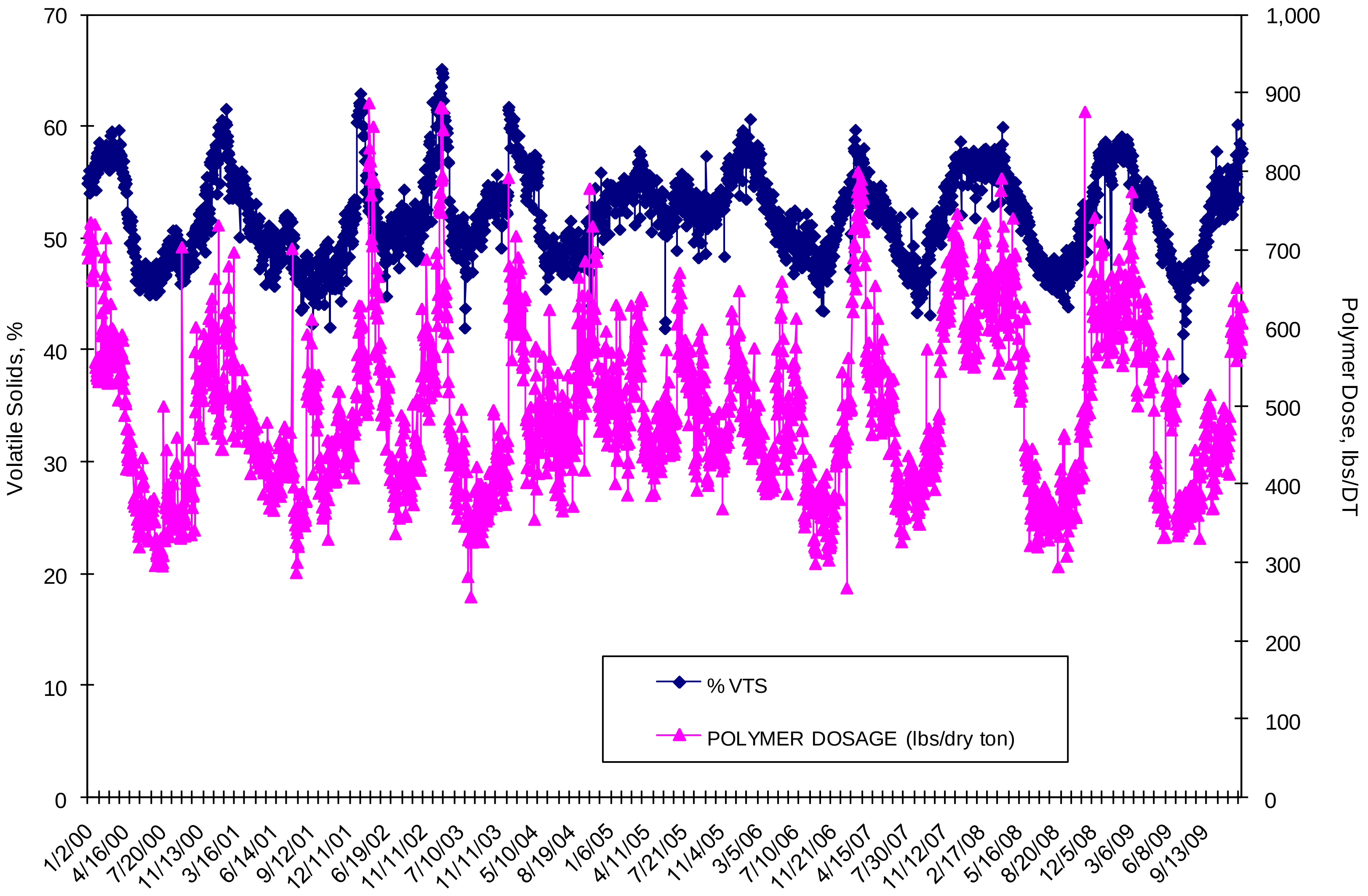


TABLE 26: SUMMARY OF CORRELATION COEFFICIENTS BASED ON THE RELATIONSHIPS BETWEEN VOLATILE SOLIDS CONTENT IN CENTRIFUGE FEED VERSUS POLYMER DOSE, PERCENT TOTAL SOLIDS IN CENTRATE, PERCENT SOLIDS CAPTURE, AND PERCENT CAKE SOLIDS DATA OBTAINED FROM THE STICKNEY WATER RECLAMATION PLANT POST-CENTRIFUGE FACILITY FROM JANUARY 15, 2002, THROUGH DECEMBER 31, 2009, EXPRESSED BY USE OF AN INDIVIDUAL POLYMER AND ALL POLYMERS COMBINED

Polymer Name	Time Period Used	Correlation Coefficient (r)*			
		VS vs. Polymer Dose	VS vs. Centrate %TS	VS vs. % Solids Capture	VS vs. Cake %TS
Combined	01/02/00–12/31/09	0.6602	0.3602	-0.4952	-0.7374
Combined	01/15/02–12/31/09	0.6410	0.3455	-0.4826	-0.6942
NW-198	01/15–04/30/02, 12/16/02–05/31/03, 02/14/04–04/30/04	0.4695	0.4449	-0.6827	-0.8332
CE-045	05/01–12/15/02, 06/01/03–02/13/04	0.1613	0.0060	-0.1447	-0.2760
CE-386	05/01/04–01/15/05, 05/16/05–12/15/05, 05/16/06–07/28/06	0.1071	-0.0002	-0.2124	-0.5465
CE-347	01/16/05–05/15/05, 12/16/05–05/15/06	0.2695	0.1453	-0.3273	-0.6315
CE-770	07/29/06–11/15/06, 05/16/07–10/31/07, 05/01/08–08/24/08	0.7298	0.3176	-0.4328	-0.5657
CE-659	11/16/06–05/15/07, 11/01/07–04/30/08	0.7028	0.3851	-0.4348	-0.5139
CE-1100	08/25/08–11/15/08, 05/01/09–10/31/09	0.3231	-0.1113	-0.1058	-0.5815
CE-1142	11/16/08–04/30/09, 11/01/09–12/31/09	0.4646	0.3581	-0.4264	-0.4490

*Negative correlation coefficients indicate parameter decrease with increase in VS values.

FIGURE 17: TIME SERIES TREND BETWEEN VOLATILE SOLIDS CONTENT IN CENTRIFUGE FEED AND PERCENT TOTAL SOLIDS IN CENTRATE FOR THE PERIOD JANUARY 1, 2000, THROUGH DECEMBER 15, 2009

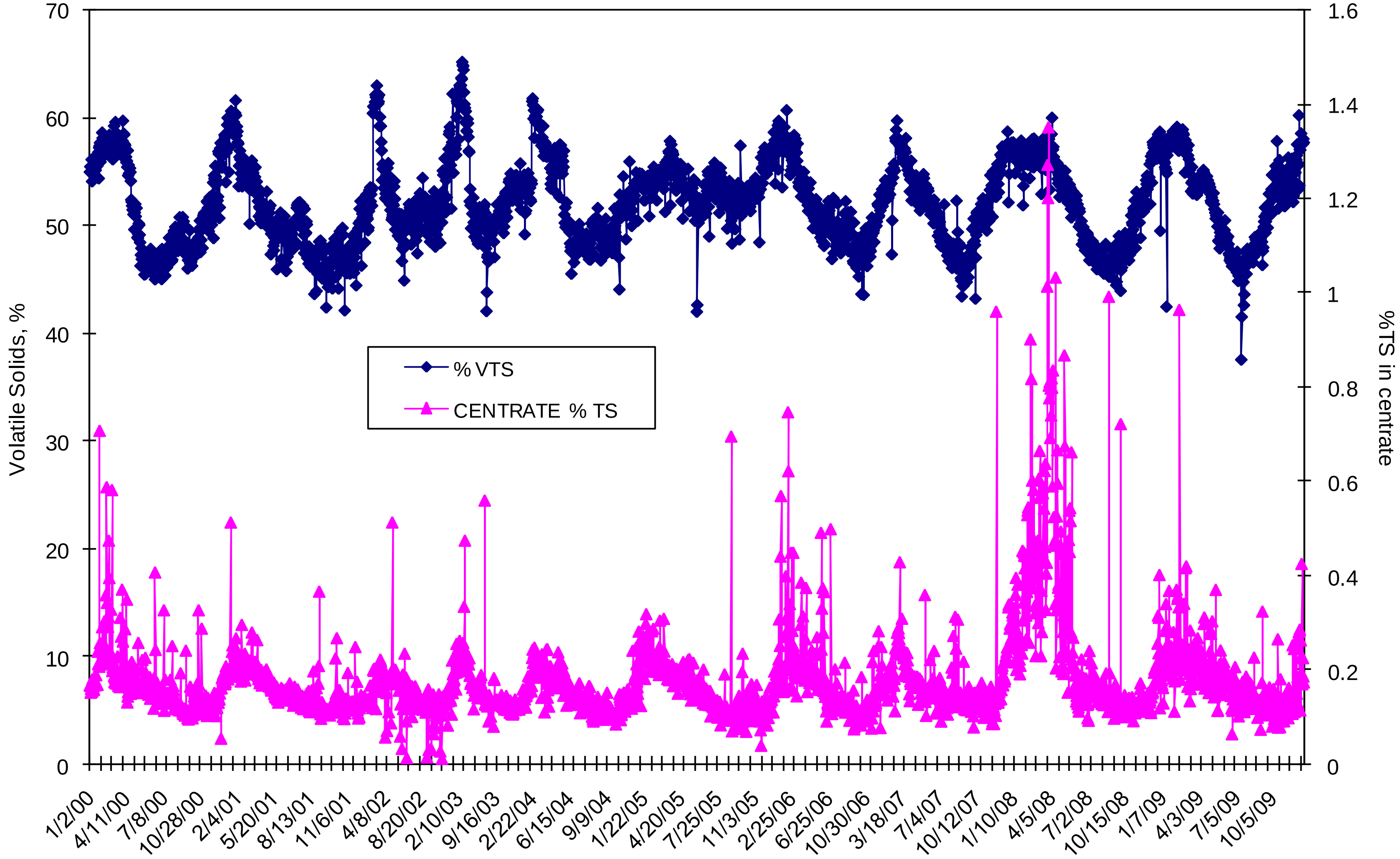


FIGURE 18: TIME SERIES TREND BETWEEN VOLATILE SOLIDS CONTENT IN CENTRIFUGE FEED AND PERCENT SOLIDS CAPTURE FOR THE PERIOD JANUARY 1, 2000, THROUGH DECEMBER 15, 2009

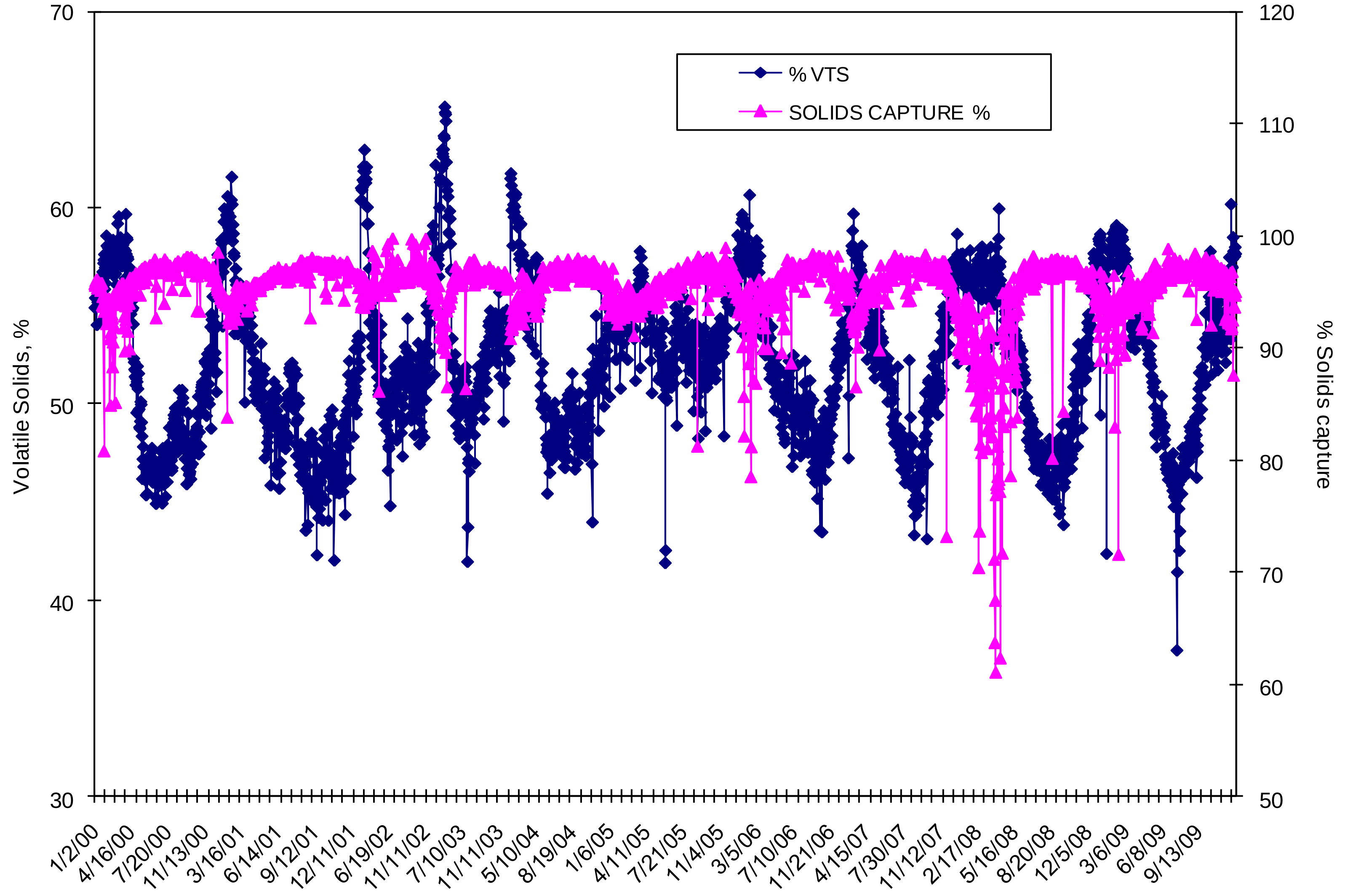
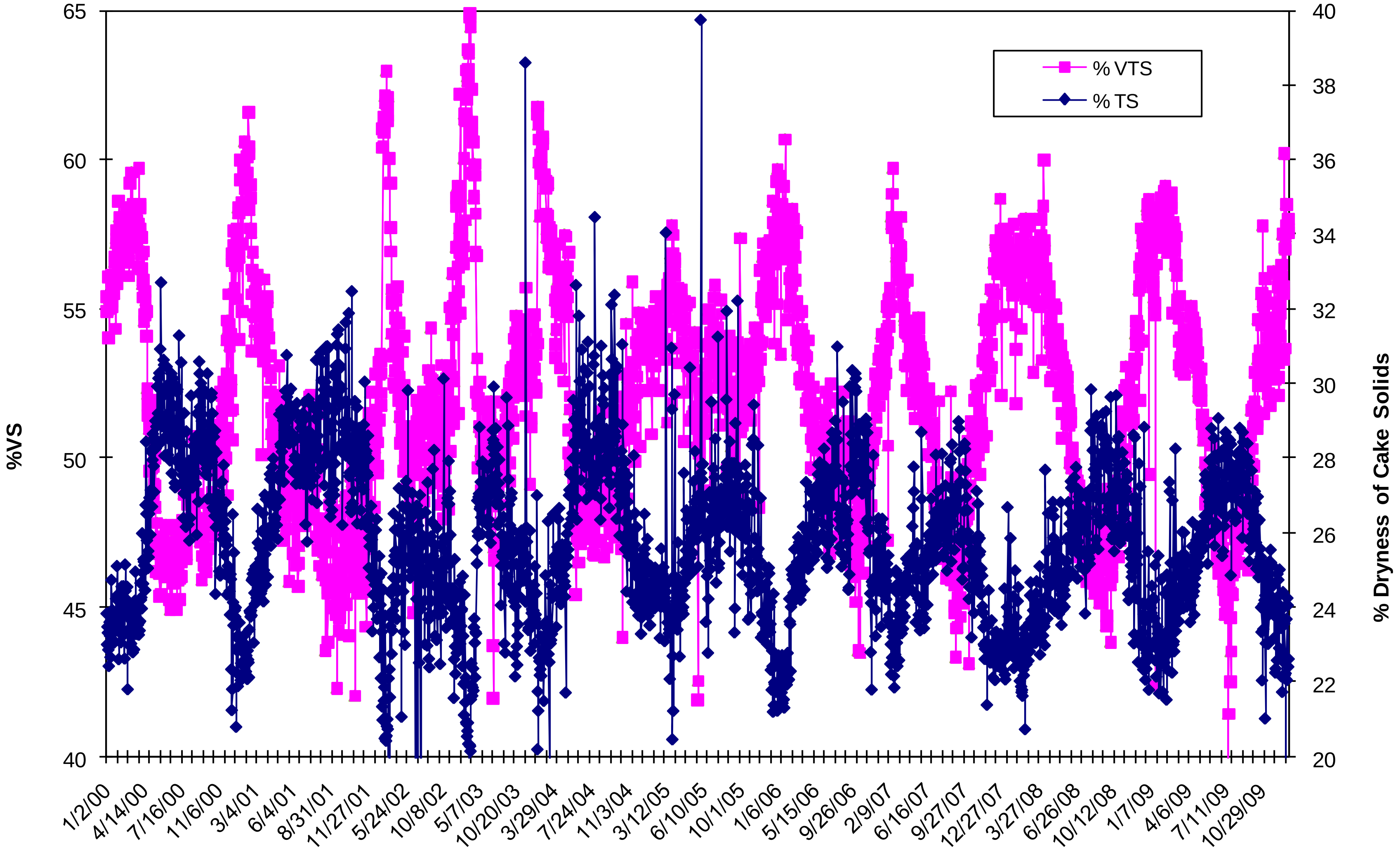


FIGURE 19: TIME SERIES TREND BETWEEN VOLATILE SOLIDS CONTENT IN CENTRIFUGE FEED AND PERCENT CAKE SOLIDS FOR THE PERIOD JANUARY 1, 2000, THROUGH DECEMBER 15, 2009



r-values indicate an opposite trend, i.e. lower VS content in feed did not lead to lower TS in the centrate; this opposite trend, however, was observed to be much weaker based on the two lower negative r-values relative to the general trend observed. While the r-value analyses did not indicate a strong relationship between feed VS content and centrate TS, the visual trends still suggest that lower feed VS concentrations is an important variable with respect to better centrifuge performance based on the lower TS concentrations in the centrate. In relation to the incoming feed solids concentration, TS content in centrate can also be expressed as solids capture or solids removal efficiency of centrifuge machines. The visual trends between solids capture and feed VS content for the entire period of 2000 through 2009 is presented in Figure 18, which indicate that lower VS content in feed sludge generally produced better solids capture. Similar plots were generated for each polymer, and this same trend was generally observed. To support the visual trends identified, r-value analyses were determined and summarized in Table 26 for the entire period of 2000 through 2009 including all polymers and for each individual polymer. An r-value of -0.4952 for solids capture and VS content was determined for the combined data from January 2, 2000, through December 31, 2009; the negative sign indicates lower solids capture with higher feed VS content. Based on the individual polymer analyses, it is evident that the relationships between feed VS and solids capture was slightly stronger for NW-198 (r = -0.6827), CE-770 (r = -0.4328), CE-659 (r = -0.4348), and CE-1142 (r = -0.4264) relative to the five other polymers whose r-values ranged between -0.1058 and -0.3273. While the r-value analyses did not indicate a strong relationship between feed VS content and solids capture, the visual trends still suggest that lower feed VS concentrations is an important variable with respect to better performance based on the higher solids capture in the centrate.

The VS content in centrifuge feed also influences cake dryness based on the visual relationship in Figure 19. It can be inferred from Figure 19 that lower VS content produced relatively dryer cake for the entire period of 2000 through 2009; dryer cake results in fewer costs due to transportation of CK. Similar plots were generated for each polymer, and this same trend was generally observed. Correlation coefficients between CK and feed VS content were determined to support the visual trends observed (Table 26). An r-value of -0.7374 for CK and VS content was determined for the combined data from January 2, 2000, through December 31, 2009; the negative sign denotes decrease in CK with increase in feed VS content. Based on the individual polymer analyses, it is clear that the relationships between feed VS and CK were relatively strong for all polymers except for CE-045 (r = -0.2760); the highest r-value of -0.8332 was observed for NW-198. Overall the r-value analyses between feed VS content and CK and the visual trends suggest that lower feed VS concentrations is an important variable with respect to better performance based on the higher solids capture in the cake. Of the three performance variables examined, feed VS and CK had the strongest relationship.

The historic data analysis indicates that VS content in centrifuge feed plays an important role with regard to polymer consumption as well as dewatering performance, but other variables such as sludge flow to polymer flow ratios also play a role.

Phase III Conclusions and Recommendations

Based on the study, the following conclusions are drawn and recommendations are made for potential implementation with due consideration.

Conclusions.

1. Based on polymer purchase and consumption records, excess polymer purchased cannot be related to wastage, because any excess purchased polymer dedicated for the Post-Centrifuge operations is maintained in the storage tanks and used the following day.

2. Additional sludge-dewaterability tests conducted during May 2012 indicated no distinct advantage of using city water for dilute polymer preparation relative to secondary effluent like previous test results.

3. Testing of change in charge density of a dilute polymer indicated that a decrease in charge density began soon after the dilute polymer was prepared and continued to occur with increasing storage time. There was approximately 20 percent loss in charge density at 24 hours of storage time, 33 to 37 percent loss in charge density at 48 hours of storage time, and approximately 41 to 48 percent loss in charge density at 72 hours of storage. At a maximum storage time of 149 hours, 52 percent loss in charge density was observed indicating much slower decay in charge density beyond 72 hours of storage time. It can be concluded that loss in charge density is inevitable and unavoidable to some extent in full-scale operations, but can be minimized by reducing the time between dilute polymer preparation and use.

4. From the testing of sludge dewaterability using different percentages of dilute polymer, the optimum polymer dose varied in a narrow range of 450 to 500 lbs/DT for a tested dilute polymer solution range of 8 to 19 percent. The test results indicate that polymer savings will not be realized by either diluting or concentrating the polymer solution with respect to the existing practice of 15 percent dilution.

5. Based on the historic data analysis of VS of the centrifuge feed relative to polymer dose and a number of performance parameters, it may be concluded that VS content in centrifuge feed plays an important role with regard to polymer consumption as well as dewatering performance, but other variables such as sludge flow to polymer flow ratios also play a role.

Recommendations.

1. Continue to use secondary effluent for polymer dilution and make 15 percent dilution to prepare dilute polymer.

2. Do not prepare dilute polymer in bulk quantity or store it well in advance in anticipation of future need. The suggested dilute polymer quantities in the North- and South-end aging tanks of the Post-Centrifuge facility are approximately 7,000 and 8,000 gallons, respectively. These suggested quantities may be adjusted to accommodate operational constraints.

3. Maximize VS destruction in anaerobic sludge digestion through different means, such as improving mixing and preventing short-circuiting.

References

Mangravite, F.J. Jr., Leitz, C. R., and Juvan, D. J. “Chemistry of Wastewater Technology,” Chapter 17, Application of Polyelectrolytes for Industrial Sludge Dewatering, Ann Arbor Science, Ann Arbor Michigan (1978), pp. 263–281.

Tiravanti, G., Lore, F., and Sonnante, G. “Influence of the Charge Density of Cationic Polyelectrolytes on Sludge Conditioning,” Water Research, Vol.19, No. 1 (1985), pp. 93–97.

APPENDIX AI

AN HOURLY DATA SHEET FOR CENTRIFUGE MACHINE NUMBER 4 FOR FEBRUARY 19, 2011, HOURLY DATA

STICKNEY WATER RECLAMATION PLANT
SHARPLES CENTRIFUGE DS706 NO. 4 DATE: 2-19-11

ITEM	MIDNIGHT to 8:00 A.M.								8:00 A.M. To 4:00 P. M.								4:00 P. M. To MIDNIGHT							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
FEED (GPM)	226	225	230	231	C		203	210	213	213	206	210	215	215	212	214	[illegible]	224	225	219	219	223	218	217
POLY (GPM)	11.1	11.0	11.1	11.4			11.0	11.2	11.3	11.3	11.4	11.4	11.2	11.2	10.9	11.0	11.0	10.9	10.8	11.0	10.6	10.5	10.7	10.6
PINION (RPM)	2515	2517	2509	2510			2470	2470	2457	2453	2470	2468	2449	2449	2458	2459	[illegible]	2494	2495	2491	2470	2472	2498	2499
TORQUE IN/LB	719	720	776	773	L		740	741	745	743	762	761	757	755	735	737	[illegible]	755	737	741	752	753	750	753
VIBRATION	2.1		1.0				2.5		2.5		2.9		2.2		.6		2.6		2.9		.7		2.2	
MOTOR (AMP)	217		219				210		208		210		213		211		216		214		214		214	
BOWL (RPM)	2644		2642		E		2641		2640		2641		2641		2641		2640		2642		2645		2642	
L BRG TEMP	131		132				131		132		132		132		132		131		131		131		131	
R BRG TEMP	146		147		A		147		147		147		147		147		146		146		146		146	
FEED (LAB)																								
mg/l (ss)																								
mg/l (ts)					N																			
SPINDOWN																								
VOLATILES %																								
ALKALINITY					I																			
CAKE (TS)					N																			
CENT. (SS)																								
CENT SPNDN																								
% RECOVERY					G																			
LUBRICATION																								
LB RTN TEMP	124		124				124		124		124		124		124		122		124		124		124	
LB OIL FLOW	1.0		1.0				1.4		1.4		1.4		1.4		1.0		1.0		1.0		1.6		1.4	
RB RTN TEMP	120		120				121		121		121		121		121		120		120		120		120	
RB OIL FLOW	1.0		1.0				1.4		1.4		1.4		1.4		1.0		1.0		1.0		1.0		1.4	
OIL FD PRESS	31		31				31		31		31		31		31		32		31		31		30	
OIL FD TEMP	94		94				96		96		96		94		94		92		96		96		96	
OIL RESV.	7		7				7		7		7		7		F		F		F		F		7	

24 HR. SLUDGE AND POLY FLOW

SLUDGE FLOW 315360
POLYMER FLOW 15984

COMMENTS:

OPERATING ENGINEERS
MID
DAYS
AFT

APPENDIX AII

METHOD FOR PERCENT ACTIVE SOLIDS DETERMINATION

Standard Operating Procedure

Standard Methods, Method 2540 G

Determination of Total and Active Solids in Polymer Products

Prepared by: ______________________ Date: 06/28/11
Natalia Solov

Reviewed by: ______________________ Date: 07/15/11
John McNamara

Approved by: ______________________ Date: 07/15/11
Joseph Calvano

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

Document: ST-Poly-TPS
Effective Date: 09/01/11
Copy Number _____
(Do Not Copy)

Stickney Analytical Laboratory
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(708) 588-4064

ST-Poly-TPS changes from Version 1.6 – 1.7
Effective Date: 09/01/11

Section	**Changes**
Table of Contents	Changed.
7.1	Section is updated.
8.2	Section is deleted, subsequent section is renumbered.
12.3	Formula is corrected.

Table of Contents

1. Scope and Application
2. Summary of Method
3. Definitions
4. Interferences
5. Health and Safety Warning
6. Equipment and Supplies
7. Reagents and Standards
8. Sample Collection, Preservation and Storage
9. Quality Control
10. Calibration and Standardization
11. Procedure
12. Data Analysis and Calculation
13. Method Performance
14. Preventive Maintenance
15. Pollution Prevention
16. Waste Management
17. References
18. Deviations from Referenced Method
19. Appendices

1.0 Scope and Application

1.1 This is a gravimetric analysis to determine the total and active solids in raw and diluted polymer products.

1.2 The procedure utilized by this laboratory is method 2540G "Total, Fixed, and Volatile Solids in Solid and Semisolid Samples" from "Standard Methods for the Examination of Water and Wastewater", 20th Edition, 1998. The method has been modified as described in Section 18 of this document.

2.0 Summary of Method

2.1 A well-mixed polymer sample (mannich raw polymer sample can not be well mixed; raw emulsion and dilute mannich and emulsion can be well mixed) is placed in a weighed dish and dried in an oven at 70°C +/- 2°C for 24 +/- 2 hrs. The increase in weight over that of the empty dish represents the total solids.

2.2 A well-mixed polymer sample is placed in a weighed dish. Acetone is added and mixed with the sample until it forms a ball. The acetone is drained and the sample is dried at 70°C +/- 2°C for 24 +/- 2 hrs. The increase in weight of the dish over that of empty dish represents the active solids in the polymer.

2.3 The active solids should be equal to or less than the total solids.

3.0 Definitions

3.1 Gravimetric analysis - technique in which an analyte determination is based on weighing.

3.2 Reagent grade water - 18 megohm/cm ultrapure water used to prepare standards. This water is obtained from a Millipore "Milli-Q" water purification system fed by a central deionization system.

3.3 Duplicate - a second aliquot taken in the laboratory from the same sample container and carried through all steps of the analytical procedures in an independent and identical manner. Sample duplicates are used to assess variance of the total method.

3.4 Quality Assurance Plan (QAP) - the written plan of operation that will ensure that the accuracy and precision as well as the overall reliability of laboratory results, meets or exceeds the needs and expectations of those for whom laboratory data is produced. Management, administrative, statistical, investigative, preventive, and corrective techniques will be employed to maximize reliability of data.

3.5 Demonstration of Capability (DOC) - the procedures performed by an analyst that ensure that an analyst does not analyze unknown samples via a new or unfamiliar method prior to obtaining the required experience.

3.6 Sample - any solution or media introduced into an analytical instrument on which an analysis is performed excluding calibration standards, initial calibration verification check standards, calibration blanks, and continuing calibration verification check standards.

3.7 AR (ACS) - The standard Mallinckrodt grade of analytical reagents; suitable for laboratory and general use. If the reagent also meets the requirements of the American Chemical Society Committee on Analytical Reagent, it is denoted as an AR (ACS) reagent (MBI trademark).

4.0 Interferences

4.1 Drying temperature must be maintained at 70°C to minimize volatilization of organic matter.

4.2 Weigh samples quickly because wet samples tend to lose weight by evaporation.

4.3 Following drying, the dishes containing the residues must stand until cool enough to handle and allowed to finish cooling at room temperature in the desiccator to balance the temperature before weighing.

4.4 Inspect desiccant for color change. If the blue indicator is pink, the desiccant must be changed immediately. Minimize opening of the desiccator.

4.5 It is important that the evaporating dishes with sample residues be brought to constant weight before recording weights. Small errors in weight can be quite significant.

5.0 Health and Safety Warning

5.1 Lab coats with proper protective clothing should be worn. Protective eye wear and rubber gloves should also be worn.

5.2 No smoking, eating, or drinking is allowed in the laboratory.

5.3 All cracked or chipped lab ware should be appropriately discarded in the glass disposal containers.

5.4 Keep work areas clean and well organized.

5.5 Care should be taken when working around the ovens and furnaces to avoid burns. Use protective gloves and tongs when putting samples into the ovens or when taking samples out.

5.6 Avoid inhaling vapor from polymer samples.

6.0 Equipment and Supplies

6.1 Porcelain evaporating dishes 70-75 mL capacity.

6.2 Drying oven, for operation at 70 +/-2°C.

6.3 Tools for transferring samples (syringes, spoons, or spatulas).

6.4 Desiccator, with a desiccant containing a color indicator.

6.5 Analytical balance, capable of weighing to 0.001 g.

6.6 Tongs and heat resistant gloves.

7.0 Reagents and Standards

7.1 Acetone, AR (ACS) grade. The solvent is kept at room temperature. The holding time is five years, or the date indicated by the manufacturer. A "Code Identification Number" is given to each Acetone bottle. The unique identification corresponds to the date received prefaced by its chemical designation - Acetone received on July 12, 2007, i.e., Acetone-071207.

7.2 Each reagent received by the laboratory is documented in the “Standard/Reagent” book and the container is labeled with the date received, date opened, and expiration date.

8.0 Sample Collection, Preservation, and Storage

8.1 Representative samples are collected by Research personnel and delivered directly to the Solids Laboratory in plastic containers.

8.2 Based on stability and shelf life of all polymer products that are in use at the District, M&R staff feel it is appropriate to extend sample holding time to 28 days.

9.0 Quality Control

9.1 Each analyst must successfully complete a DOC study before he or she will be permitted to analyze samples independently. At least four samples should be analyzed in duplicate. The Relative Percent Difference (RPD) is calculated for each duplicate. Acceptable RPD limit is 5% or less. The obtained values should be within 95-105% of the original values obtained by an experienced analyst. The DOC records are kept in the administrative files in the Laboratory Manager’s office.

9.2 Analytical balance accuracy is checked daily with 1, 10, and 100 g NIST Class 1 certified weights. These checks are recorded on a daily log sheet. Calibrate and recheck the balance if a reading is outside of the acceptance range. Refer to Appendix 19.4.

9.3 Oven and furnace temperatures are checked and recorded daily in the "Temperature Monitoring Log". The recorded value includes a correction factor. Check the reading after the temperature has stabilized. The oven's door opening will cause a drop in the temperature. Recheck the temperature within a reasonable time. If the temperature cannot stabilize within the specified range of 70°C +/- 2°C, the unit cannot be used to run analysis. Inform your supervisor.

9.4 A sample duplicate is analyzed with each analytical batch of 20 or fewer samples to evaluate precision. The precision data is used to evaluate batch acceptance. The accepted criterion is +/- 5% RPD. If this criterion is not met, rerun samples to the last RPD acceptable duplicate. Precision charts are printed out weekly and reviewed for systematic trends.

9.5 All "out of control" events must be fully documented in the "Problem Log". Such events must be investigated to determine the cause of the problem. Corrective actions should be implemented and their effectiveness evaluated.

9.6 The time/date of each step of the analysis, analyst's initials, are recorded on the coversheet of the respective batch. The batch worksheet includes the list of samples with their analytical data.

10.0 Calibration and Standardization

10.1 Analytical balances are calibrated semi-annually by a qualified service representative. The daily balance check is done following procedure in Appendix 19.3.

10.2 Weights are NIST certified annually.

10.3 The ovens' and furnaces' digital thermometers are checked annually against a NIST traceable thermometer. The correction factor is posted on each unit.

11.0 Procedure

11.1 Prepare clean evaporating dishes by heating them in the 550°C muffle furnace and ignite for at least one hour. Remove and let stand until they have cooled enough to handle. Finish cooling in the desiccator for a minimum of 30 minutes to balance temperature. Weigh the dishes and store in the desiccator until needed.

11.2 Pre-weigh the evaporating dishes and enter weights into the TS_DISH Pre-Weight Table.

11.3 Log-In each sample following the procedure in Appendix 19.1.

11.4 Determination of Total Solids in the Polymer Product

11.4.1 Mix sample well. Transfer 10 ± 2 (accurate weight of polymer is difficult, and that should be mentioned)grams of sample to a pre-weighed evaporating dish and weigh.

11.4.2 Evaporate to dryness in the 70°C drying oven for 24 +/- 2 hrs (consistent implementation is up to the lab as to use this for both active and total solids or use 70 C for active and 100 C 24±2 hrs for total solids). Put active polymers and total polymers in the oven at the same time.

11.4.3 Remove dishes from the oven and cool in the desiccator for a minimum of 30 minutes to balance temperature.

11.4.4 Weigh the dish with the dry residue and record the dry weight.

11.5 Determination of Active Solids in the Polymer Product

11.5.1 Mix sample well. Transfer approximately 2.5 ± 0.5 grams of sample to a pre-weighed dish and weigh.

11.5.2 Add 50 mL of acetone to the sample. Mix sample with acetone thoroughly using a glass rod or spatula. Continue mixing the sample with acetone until the sample forms a hard ball. Drain the acetone.

11.5.3 Dry sample at 70°C for 24 +/- 2 hrs. Put active polymers and total polymers in the oven at the same time.

11.5.4 Remove dried sample from the oven and cool in the desiccator for a minimum of 30 minutes.

11.5.5 Weigh the dry residue and record the dry weight.

12.0 Data Analysis and Calculations

12.1 % Total Solids and % Active Solids in Polymer product are calculated using the following formula:

$$\text{Solids}\,\% = \frac{(A - B) \times 100\%}{(C - B)}$$

Where:
A = weight of evaporating dish with dried residue, g
B = weight of evaporating dish, g
C = weight of wet sample and dish, g

12.2 The percentage of active solids should be equal to or less than the percentage of total solids.

12.3 The relative percent difference (RPD) is calculated as follows:

$$\text{RPD}\% = \frac{(\text{Duplicate} - \text{Sample}) \times 100\%}{1/2\ (\text{Sample} + \text{Duplicate})}$$

12.4 To review the data, refer to the procedure in Appendix 19.5.

13.0 Method Performance

13.1 Specification limits of +/- 5% are used for control limits rather than statistical limits. When specification limits are used no warning limits are required.

14.0 Preventive Maintenance

14.1 Balances are kept clean, dry, and wiped daily before use with kimwipes or with a soft brush.

14.2 Desiccant is checked daily and changed when the blue pellets turn pink. The check and change are documented in the "Desiccator Maintenance Log"

14.3 Anti-static bars are changed once per year.

14.4 Ovens and furnaces are kept clean and dry daily.

14.5 Crucibles are cleaned following the "Cleaning procedure for crucibles". Refer to Appendix 19.3.

15.0 Pollution Prevention

15.1 Drying ovens and muffle furnaces are located in exhaust hoods.

16.0 Waste Management

16.1 Sample residue and non-hazardous wastes are disposed of in non-hazardous waste receptacles.

17.0 References

17.1 Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998. Method 2540G "Total Solids Dried at 103°C to 105°C,"

17.2 Stickney Analytical Laboratory Quality Assurance Plan, current version.

18.0 Deviations from Referenced Method

18.0 Method 2540G states that the cycle of drying, cooling, desiccating, and weighing of the dish and sample should be repeated until a constant weight is obtained, or until weight change is less than 50 mg, whichever is less. The SOP does not require confirmation of a constant weight. The samples are dried in the oven for 22 to 26 hrs as recommended by the Research Department.

18.1 Samples are dried at 70 +/-2°C rather than at 104°C +/- 1°C.

18.2 Raw and diluted polymer products are shipped and stored at room temperature due to adverse effect of low temperature on samples properties. Holding time for the polymer products is 28 days comparing to maximum 7 days for environmental samples.

19.0 Appendices

19.1 Pre-weighing of Evaporating Dishes.

19.2 Samples Login for Polymers.

19.3 Crucibles Procedure.

19.4 Daily Balance Check and Calibration.

19.5 Data Review

APPENDIX 19.1

PRE-WEIGHING OF EVAPORATING DISHES

Samples are logged in background in advance and received in LIMS before analysis.

To Pre-Weigh the Dishes:

In Sample Manager select **MWRDGC**, select **General**, select **Crucibles - Pre Weight**, select **TS_Dish**

The screen will display the list of dishes with prefix ST for Stickney. For example, dish no. 516 will be displayed as ST516 and the weight in **Container Weight** column will show the actual weight or 0.0000 if the dish has to be pre-weighed.

To pre-weigh a dish, put it on the balance. When the scale reads a stable weight, click on cell corresponding to the dish weight and push print on the balance. This will transfer the weight to LIMS. Repeat the same for all dishes to be weighed.

If the dish is not on the list, click **Insert**, type in dish ID and pre-weigh it.

When all dishes have been pre-weighed, click **Update** to store the weights.

APPENDIX 19.2

SAMPLES LOGIN FOR POLYMERS

In Sample Manager select **Sample**, select **login**,

Click on **Template**

Choose **STPOLY_TPS**

Click on **Login**

Enter the requested sample information

Click **Login** to create sample

Click **Close** to exit the login function

BATCH GENERATION FOR POLYMERS

In Sample Manger select from the main menu **Batches**, click **Create**.

Enter batch template: **ST_CENT** for total solids, or **ST_PS** for active solids

For: Collection Date >= enter "-20" and Collection Date <=
enter “1”. Click **Update**.

Click **List** in **Create Batch** window to bring samples to the screen. Visually scan the list of samples to ensure all needing analysis are present, and click **Create**. Record the batch ID.

To modify the batch select from the main menu **Batches**, click **Modify**. Enter batch ID. Enter collection dates (see above), click **Update**. Click **List** in **Modify Batch** window. To remove, highlight sample ID and click **Remove.** To add sample click **Insert** to create additional line, type in sample ID in the vacant space. Click **OK** to save changes.

To Assign Evaporating (Crucible) Dishes to the Batch Worksheet:

Select menu option **Batches - Result entry**.

Type: Batch I.D. Number (ST_CENT_XXXXXX) or (ST_PS-XXXXX) in the box.
The screen will display the Batch with the list of samples. Type in Dish ID in the designated column as STXXX, etc. When all dishes have been assigned click **Save**. Click "**Recalculate**" to enter dish weights. This will bring all weights stored in the pre-weigh file. When done, click **Save**.

<u>To Print the Batch:</u>

Select Menu option: **MWRDGC - General - Batch Processing - Print**
Enter the Batch I.D., ST_PS-XXXXX. Click **OK**.
In the pop-up window select ST_LC220 and click **Printer** to generate the report.

For more information on LIMS operations refer to "Sample Manager for Window Training" in Microsoft outlook-Public Folders-All Public Folders-Research & Development-"SMW training techs SZ 6-29-04".

APPENDIX 19.3

Crucibles Procedure

1. Wash crucibles with soapy water in a tub. Use one plunger of detergent (Liquid Nox) or sufficient amount of detergent to create soapy water. Let the crucibles soak for a minimum of 30 minutes.

2. Rinse with tap water followed by rinse with reagent water.

3. Place crucibles in the 550°C muffle furnace and ignite for or at least 60 minutes. Remove and let crucibles cool enough to be handled. Finish cooling of the crucibles for 30 minutes in desiccator to balance temperature.

4. Weigh the crucibles and enter weights into the pre-weight table using the menu option MWRDGC from the Sample Manager window. Store in appropriate desiccator according to the designation until needed.

Category	DISH ID	DISH mL	To use for:	Desiccator #
TS_Dish	ST01 - ST200	70-75	TSW: Centrates/Cakes	12
TS_Dish	ST201 - ST400	70-75	TS_V, TDS, TS_W	9; 10; 11
TS_Dish	S500 and above	70-75	TDS, reruns, special projects, back up	9; 10; 11
TS_Dish	ST900 - ST920	100	Special projects	9; 10; 11
TS_Dish	STA01-STA25	>100	Special projects	12
DIG_DISH	SD200 - SD296	40	Digesters	4; 3; 16
DIG_DISH	SD296 and above	40	IMHOFF	4; 3; 16
SS_CRUS	SS001 and above	40	TSS	5; 6; 7; 8

APPENDIX 19.4

DAILY BALANCE CHECK AND CALIBRATION

1. Make sure that the balance and the working station are clean and neat. Brush/Clean the pan and the chamber.
2. Check the level of the sitting/platform.
3. Check the desiccant.
4. Tare the balance.
5. Verify calibration with NIST traceable Mass Standards: 1g, 10g, and 100g.
6. Record the weights displayed in the maintenance book and compare to the acceptance range:

Weights (g):	1 g	10 g	100 g
Balance # 1 and # 4 Acceptance Range (g):	1.000+/-0.001	10.000+/-0.002	100.000+/-0.002

7. If any of the displayed weights is out of the acceptance range calibrate the balance.
   - Tare the balance.
   - Press CAL. The motorized calibration weight will be applied and removed automatically. Do not disturb balance during calibration.
   - 0.0000g or 0.000g on the screen indicates that the calibration is complete.
8. Verify calibration. Document all actions.
9. If the calibration cannot be verified, place a comment in the book and immediately notify the supervisor.

Appendix 19.5

Data Review

Data Review by Analyst

1. The coversheet should have the batch ID, the date the batch was analyzed and the initials of the analyst(s).
2. The analyzed samples should meet the required drying time for the oven drying.
3. Total polymer value should be higher than active polymer value; if not a second test must be assigned.
4. Abnormal results are very high or low sample results based on MLP limits or an analyst’s experience. If abnormal results are present, inspect residue and sample to ensure complete drying and that no foreign particles are present. Note abnormal observations on the batch coversheet. Check dish ID and tare dish weight against quarterly weights. Check balance calibration. Inform the supervisor. The supervisor will assign a second test.
5. Check the charts associated with the batch.
6. Failed precision: Outside RPD limits. Inform the supervisor, investigate, perform corrective action and document your corrective in the QA Log/Problem Log. Rerun the group of samples associated with the batch.
7. Record control limit event (i.e. duplicate failure) information including the time and details of the occurrence, whether a problem was discovered, any corrective action taken and any samples that may have been rerun as a consequence.
8. Inform the supervisor before assigning a second test.

Data Review by Supervisor

1. The coversheet should have the batch ID, the date the batch was analyzed and the initials of the analyst(s).
2. Samples in the oven must meet the required drying time and temperature.
3. Total polymer value should be higher than active polymer value, if not a second test must be assigned.
4. Make sure the correct sample amount (2 g to 25 g) was initially weighed. If not, assign a second test.
5. Abnormal results: Very high or very low sample results based on MLP limits or an analyst’s experience. Check the

investigation and corrective action. Check batch coversheet for notations of abnormalities.

6. Check the charts associated with the batch.
7. Failed precision: Outside RPD limits. Supervisor must check the investigation and corrective action and documentation in the QA log.
8. Check control limit event information including the time and details of the occurrence, whether a problem was discovered, any corrective action taken and any samples that may have been rerun as a consequence.
9. Remove points from the control charts which have a known cause failure (ex. bad initial crucible weight, etc.) or are greater than four sigma.

APPENDIX AIII

APPROVED WORK PLANS

INTEROFFICE MEMORANDUM

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

DEPARTMENT: Monitoring and Research DATE: July 5, 2011

TO: Thomas C. Granato
Acting Director of Monitoring and Research

FROM: Catherine O'Connor CaO'Connor
Assistant Director of M&R, EM&R Division

SUBJECT: Evaluation of Potential Reduction of Polymer Consumption at Post-Centrifuge Facility at the Stickney Water Reclamation Plant (ASN 117)

Please find attached the approved work plan with the minor revisions. Please note that corrections on page 5 and 11 have been made to reflect your suggested revisions. A concern regarding possible variations in polymer quality over the study period is addressed on page 5 under item 7. e.

CO'C:HZ:KKP:lf
Attachment
cc: Zhang
Patel

INTEROFFICE MEMORANDUM

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

DEPARTMENT: Monitoring and Research DATE: May 10, 2011

TO: Thomas C. Granato
Acting Director of Monitoring and Research

FROM: Catherine O'Connor CA O'Connor
Assistant Director of M&R, EM&R Division

SUBJECT: Evaluation of Potential Reduction of Polymer Consumption at Post-Centrifuge Facility at the Stickney Water Reclamation Plant

Please find attached a draft proposal regarding the subject for your comments and approval. This draft proposal presents a non-experimental study approach to investigate the potential overuse of polymer for dewatering.

5/6
CO'C:HZ:KKP:lf
Attachment
cc: Zhang
Patel

EVALUATION OF POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT

Kamlesh Patel
Monitoring and Research Department
Metropolitan Water Reclamation District of Greater Chicago

INTRODUCTION

Polymer costs represent the single largest cost component for the sludge dewatering processes. At the Stickney Water Reclamation Plant (WRP), polymer costs are approximately $5,000,000 per year according to the current contract. This contract amount does not include the polymer usage at the John E. Egan WRP, though its usage is a fraction of the usage at the Stickney WRP. Approximately 20 to 25 percent of polymer is used at the pre-centrifuge facility for thickening and the remainder for dewatering at the post-centrifuge facility. No formal procedure and protocols are in place to operate the centrifuge machines. However, all the machines are consistently operated at a fixed torque of approximately 750 lbs-in. Traditionally, the day shift operating engineer (OE) adjusts the machine settings and the personnel on the following two shifts maintain and fine-tune these settings. However, each OE may operate the machines differently. It is likely that polymer may be consumed in different proportion in each machine to produce ~25 percent solids in centrifuge cake. The polymer use during the last four years is shown in Table 1, which indicates that the polymer use determined for procurement purposes is not predictive of actual usage.

Each machine is tied with Rockwell Automation System (RAS) software, which displays on-line values of pertinent operational parameters for the proper operation and maintenance of each machine. At present, the on-line polymer control algorithm does not exist in RAS. The pertinent data are manually recorded from the display screen hourly (Appendix I). Dilute and raw polymer grab samples are collected once per day and analyzed for percent total solids (TS). Centrifuge cake and centrate samples are collected during each shift from each machine and composited before analyzing for TS as well. Similarly, centrifuge feed is composited and analyzed for TS and total volatile solids (TVS). A select portion of the data is used for preparing the monthly operating report and is shown in Appendix II. There is no formal procedure to review data recorded and monitor polymer consumption on a daily basis. Polymer consumption is monitored based on the product receipts.

Based on the above, we propose optimizing polymer consumption for conditioning/ dewatering post-digestion solids by evaluating and adjusting polymer demand for each machine. We also propose to monitor polymer usage in each of the 21 centrifuge machines on a daily basis and evaluate the polymer consumption with respect to the adjusted polymer dose during optimization of individual machine.

TABLE 1: AVERAGE POLYMER USE VERSUS RECOMMENDED POLYMER DOSE AT STICKNEY WATER RECLAMATION PLANT

Date	Switched to	Name of Polymer	Recommended Dose* lbs/DT	Actually Used, lbs/DT		
				Avg	Min	Max
5/16/07–10/31/07	Summer	CE-770	283.2	432	326	579
11/1/07–4/30/08	Winter	CE-659	354.5	640	542	791
5/1/08–8/31/08	Summer	CE-770	283.2	429	294	740
9/1/08–11/15/08	Summer (new contract)	CE-1100	158	410	307	877
11/16/08–4/30/09	Winter	CE-1142	430.2	611	455	1,211
5/1/09–10/31/09	Summer	CE-1100	158	416	330	552
11/1/09–6/14/10	Winter	CE-1142	430.2	610	389	1,163
6/15/10–8/31/10	Summer	CE-1100	158	398	319	506
9/1/10–10/31/10	Winter	CE-1142	430.2	474	380	595

*Dose recommended by M&R staff resulting from polymer tests conducted during the bidding process for a new polymer contract.

OBJECTIVES

This study is proposed to optimize polymer usage without compromising the sludge throughput or the solids recovery and consistency of solids in centrifuge cake. The specific goals of the study are as follows:

1. Document polymer demand and other variables for each machine. Adjust machine settings such that polymer demand is optimized for each machine.

2. Compile pertinent operating information pertaining to polymer usage for each of the 21 centrifuge machines on a daily basis and build a database with data captured since January 1, 2011. The database will include pertinent operating data before and after review of settings as described in this work plan.

3. Evaluate daily polymer consumption by machine with respect to the optimized polymer dose.

4. Identify the machines that consume more polymer and determine reasons for variability.

WORK PLAN

During the proposed six-month study period, the following study plan includes:

Document Current Operations

1. Review written procedures for dilute polymer preparation and centrifuge operation. Also, interview OEs and Engineer-in-charge of operation and maintenance to collect pertinent information and insight.

2. Collect one raw polymer sample and two dilute polymer samples per shift every day for a period of two weeks to verify consistency in preparing dilute polymer. Raw and dilute polymer samples will be analyzed for TS.

3. Document the OE-adjusted machine settings such as sludge flow rate, polymer flow rate, set value for torque, bowl speed, pinion speed, vibration values. Collect two samples of centrate and cake at these settings from each machine. Analyze cake samples for TS and TVS and centrate samples for TS. Collect two samples per day of centrifuge feed and analyze for pH, TS, TVS, alkalinity, and volatile acids (VAs). Collect one raw polymer and two dilute polymer samples and analyze all polymer samples for TS.

Process Optimization

4. Decrease torque setting from 800 to 600 lbs-in by increments of 25 lbs-in and collect two cake and two centrate samples for each torque setting. Analyze cake samples for TS and TVS and centrate samples for TS. Collect two samples per day of centrifuge feed and analyze for pH, TS, TVS, alkalinity and VAs. During each of these settings, maintain sludge and polymer flow rates, pinion speed and bowl speed constant. Determine percent solids recovery and cake solids values for each setting. Also, collect one raw polymer and two dilute polymer samples and analyze polymer samples for TS. Repeat this procedure on four random machines and develop a calibration curve. If the machine's performance varies considerably, calibrate all 21 machines.

Optimize Machine Settings

5. Based on the results from Step 4, set machine torque value corresponding to a cake solids value of 25 percent. At this torque setting, decrease polymer flow rate by 5 percent increments until cake solids fall below 23 percent. During each polymer flow rate setting, maintain all other variables constant and collect two centrate and two cake samples. Analyze cake samples for TS and

TVS and centrate samples for TS. Collect two samples per day of centrifuge feed and analyze for pH, TS, TVS, alkalinity and VAs. Collect one raw polymer and two dilute polymer samples and analyze all samples for TS. Based on solids recovery and cake solids values, determine the optimized polymer flow rate for each machine.

6. Recommend the sludge flow rate, polymer flow rate, torque, pinion speed and bowl speed for each machine obtained from Step 5 for implementation.

7. Create a database by machine which includes the following parameters:

   a. Analytical parameters: centrifuge feed percent TS and percent TVS, cake percent TS, centrate percent TS, percent TS on raw polymer and diluted polymer, digester draw pH, digester draw percent TS and percent TVS, digester draw total alkalinity, and total VAs.

   b. Operational parameters: Centrifuge feed and dilute polymer flow rates, pinion speed, bowl speed, and torque.

   c. Machine parameters: Hours - machine in service.

   d. Daily values calculated for each machine: volumetric ratio of polymer-to-sludge flow rate, dilute polymer strength, polymer dose on dry basis, solids recovery in centrate and sludge throughput per day.

   e. Polymer quality control is beyond an operator’s reach; hence, it is independently monitored under a different program because large variations could potentially impact polymer consumption and machine performance. Data collected from the polymer quality control program to date suggests that variation in polymer quality is highly unlikely. However, we plan to use data from this program to evaluate variation in polymer quality or characteristics over the study period. We plan to consider an appropriate data treatment including but not limited to data exclusion for the affected time period if variations in polymer quality are found to be substantial.

   f. Compare the data collected prior to adjustment of the recommended settings with the data compiled after recommended settings in order to assess polymer savings.

   g. Identify poorly performing machines and provide explanation, if possible.

    h. Identify the most important variables from the database that influence the polymer consumption.

8. Conduct following laboratory tests to enhance polymer savings:

    a. Conduct capillary suction time tests to determine if a change in existing practice of using plant effluent for dilute polymer preparation can potentially save polymer consumption. The alternative is to use city water instead of plant effluent.

    b. Evaluate surface tension in centrate as an indicator of excess polymer use, which may eventually be used as a control parameter.

9. Document findings and recommendations in a final report.

10. PROJECT SCHEDULE AND DELIVERABLES

Full-scale operating data will be compiled during the project schedule of approximately six months from the approval of this work plan. The data collection will be retrospectively from January 1, 2011. The final report will be completed four months after the conclusion of the study period. Interim reports will be prepared as appropriate.

STUDY COSTS

This is an investigational study which will be conducted by the District’s Environmental Monitoring and Research Division (EM&R) Wastewater Treatment Process Research (WTPR) section with the cooperation of Maintenance and Operations Department (M&O) staff at the Stickney WRP. Most of the cost comes from the staff time and that cost is covered under the current division budget. As a result, there is no additional cost to conduct this study.

The analytical laboratory support from the Analytical Laboratories Division is shown in Table 2 and is attached with “Analytical Support Request.” Because of the nature of the study, minor help might be sought to retrieve certain Laboratory Information Management System data.

TABLE 2: PROJECTION OF NUMBER OF SAMPLES AND PARAMETERS TO BE ANALYZED

Step No. of Work Plan	Sample	Samples Per Shift	Per Day	Duration	Entire Project	Parameters	Note
2	Raw polymer	1	3	10 days	30	TS	
	Dilute polymer	2	6	10 days	60	TS	
3	Cake	2 x 21	42		42	TS, TVS	Repeat once at each of 21 machines.
	Centrate	2 x 21	42		42	TS	Based on one-day work planning
	Feed	3	3		3	TS, TVS, pH, Alkalinity, Total VAs	
	Raw polymer	1	1		1	TS	
	Dilute polymer	2	2		2	TS	
4	Cake	2 x 8 x 2	32	2 days	64	TS, TVS	8 different settings of torque
	Centrate	2 x 8 x 2	32	2 days	64	TS	on 4 random machines
	Feed	2 x 8 x 2	32	2 days	64	TS, TVS, pH, Alkalinity, Total VAs	based on 2 machines per day
	Raw polymer	1	1	2 days	2	TS	
	Dilute polymer	2	2	2 days	4	TS	
5	Cake	2 x 5 x 3	30	7 days	210	TS, TVS	Approximately
	Centrate	2 x 5 x 3	30	7 days	210	TS	5 different polymer settings at each of
	Feed	2 x 5 x 3	30	7 days	210	TS, TVS, pH, Alkalinity, Total VAs	21 machines.
	Raw polymer	1	1	7 days	7	TS	Based on 3 machines per day.

TABLE 2: PROJECTION OF NUMBER OF SAMPLES AND PARAMETERS TO BE ANALYZED

Step No. of Work Plan	Sample	Samples Per Shift	Per Day	Duration	Entire Project	Parameters	Note
	Dilute polymer	2	2	7 days	14	TS	
8	Cake		<10	TBA	<30	TS, TVS	Lab-scale tests
	Centrate		<10	TBA	<30	TS	Uncertain quantity at this time
	Feed		1	TBA	<10	TS, TVS, pH, Alkalinity, Total VAs	
	Raw polymer		1	TBA	<5	TS	
	Dilute polymer		6	TBA	<30	TS	

PERSONNEL INVOLVED AND TIME COMMITMENT

The M&O personnel will continue to record data according to their routine on log sheets. A laboratory technician will pick up the log sheets daily from post-centrifuge building and enter the information in a structured database. Laboratory technicians assigned to the WTPR Section will assist in building up database as required. The estimated professional and laboratory-technician-hours required are presented below on a weekly and entire project basis.

Person-Hours

Wastewater Treatment Process Research Section	Hours
Assistance in Collection and Transport of Log Sheets	1
Entering the Data	4
Total Weekly Laboratory Technician-Person-Hours	25
Total Laboratory Technician-Person-Hours during Project	625
Senior Environmental Research Scientist Involvement	
Supervision of Database Build-Up and Overall Coordination	5
Database Maintenance	2
Preparation of Tables and Graph for Final Report	2
Preparation of Final Report	2
Total Weekly Senior Environmental Research Scientist –Hours	11
Total Senior Environmental Research Scientist –Hours during Project	300
Supervising Environmental Research Scientist Involvement	
Evaluation of Data and Results w r t Objective	1
Consultation with Senior Environmental Research Scientist	1
Consultation with Manager and Assistant Director of R&D, EM&R Division	1
Total Weekly Supervising Environmental Research Scientist –Hours	3
Total Research Scientist III –Hours during Project	80
Assistant Director, EM&R Division Involvement	
Evaluation of Data and Results w r t Objective	0.25
Consultation with Manager	0.25
Review of Deliverables	1
Total Weekly Assistant Director –Hours	1.50
Total Assistant Director –Hours during Project	36

APPENDIX I
(OF WORK PLAN)

STICKNEY WATER RECLAMATION PLANT
SHARPLES CENTRIFUGE DS706

NO. 4

DATE: 2-19-11

ITEM	MIDNIGHT to 8:00 A.M.								8:00 A.M. To 4:00 P. M.								4:00 P. M. To MIDNIGHT							
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
FEED (GPM)	226	225	230	231	C		203	210	213	213	206	210	215	215	212	214	224	224	225	219	219	223	218	217
POLY (GPM)	11.1	11.0	11.1	11.4			11.0	11.2	11.3	11.3	11.4	11.4	11.2	11.2	10.9	11.0	11.0	10.9	10.8	11.0	10.6	10.5	10.7	10.6
PINION (RPM)	2515	2517	2508	2510			2470	2470	2457	2453	2470	2468	2449	2449	2458	2459	2459	2494	2495	2491	2470	2472	2498	2499
TORQUE IN/LB	719	720	776	773			740	741	745	743	762	761	757	755	735	737	752	755	737	741	752	753	750	753
VIBRATION	2.1		1.0		L		2.5		2.5		2.9		2.2		.6		2.6		2.9		.7		2.2	
MOTOR (AMP)	217		219				210		208		210		213		211		216		214		214		214	
BOWL (RPM)	2644		2642				2641		2640		2641		2641		2641		2640		2642		2645		2642	
L BRG TEMP	131		132		E		131		132		132		132		132		131		131		131		131	
R BRG TEMP	146		147				147		147		147		147		147		146		146		146		146	
FEED (LAB)					A																			
mg/l (ss)																								
mg/l (ts)					N																			
SPINDOWN																								
VOLATILES %																								
ALKALINITY					I																			
CAKE (TS)																								
CENT. (SS)					N																			
CENT. SPNDN																								
% RECOVERY					G																			
LUBRICATION																								
LB RTN TEMP	124		124				124		124		124		124		124		122		124		124		134	
LB OIL FLOW	1.0		1.0				1.4		1.4		1.4		1.4		1.0		1.0		1.0		1.6		1.4	
RB RTN TEMP	120		120				121		121		121		121		121		120		120		120		120	
RB OIL FLOW	1.0		1.0				1.4		1.4		1.4		1.4		1.0		1.0		1.0		1.0		1.4	
OIL FD PRESS	31		31				31		31		31		31		31		32		31		31		30	
OIL FD TEMP	94		94				96		96		96		94		94		92		96		96		96	
OIL RESV.	7		7				7		7		7		7		F		F		F		F		7	

24 HR. SLUDGE AND POLY FLOW	
SLUDGE FLOW	315360
POLYMER FLOW	15984

COMMENTS:

OPERATING ENGINEERS

MID

DAYS

AFT

APPENDIX II
(OF WORK PLAN)

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO
STICKNEY WATER RECLAMATION PLANT
POST DIGESTION CENTRIFUGES

RICHARD LANYON, EXECUTIVE DIRECTOR
OSOTH JAMJUN, DIRECTOR OF M&O
BRETT GARELLI, DEPUTY DIRECTOR OF M&O

	UNITS	FEED				CENTRATE	CAKE			R.R. CARS	TRUCKS	POLYMER USAGE	POLYMER DOSAGE	SOLIDS CAPTURE
	I/S	x 10^3 gal	% TS	% VTS	DRY TONS	% TS	WET TONS	% TS	DRY TONS	LOADED	LOADED	(gal/day)	(lbs/dry ton)	%
12/1/2009	7.0	2005	3.08	53.38	258	0.11	1056	23.73	251	10	0	17611	570	96.9
12/2/2009	7.0	1614	2.93	56.15	197	0.12	824	23.16	191	5	0	14085	595	96.5
12/3/2009	6.5	1700	2.87	55.74	204	0.11	792	24.91	197	3	0	14874	609	96.5
12/4/2009	9.8	2778	2.98	53.21	345	0.25	1317	24.30	320	22	0	23711	573	92.4
12/5/2009	8.6	2385	2.88	52.11	286	0.15	1104	24.75	273	17	0	20568	599	95.2
12/6/2009	7.6	2130	2.95	52.69	262	0.11	1022	24.78	253	17	0	18426	587	96.6
12/7/2009	7.9	2301	2.99	54.07	287	0.24	1165	22.92	267	13	0	19784	576	92.8
12/8/2009	6.4	2029	2.88	55.23	244	0.12	940	25.02	235	9	0	17284	592	96.4
12/9/2009	8.0	1885	2.80	55.75	220	0.12	886	23.99	213	10	0	16765	635	96.2
12/10/2009	7.5	1785	2.93	54.87	218	0.13	875	24.05	210	8	0	14995	573	96.1
12/11/2009	11.0	2366	2.95	55.69	291	0.26	1113	24.16	269	16	0	20304	582	92.2
12/12/2009	12.7	3576	2.98	56.07	445	0.26	1719	23.95	412	31	0	31539	591	92.2
12/13/2009	11.5	2814	3.00	56.47	352	0.17	1437	23.34	335	29	0	25169	596	95.0
12/14/2009	8.5	2440	3.00	57.49	305	0.13	1314	22.38	294	17	0	21326	583	96.2
12/15/2009	8.5	2214	3.03	55.77	280	0.18	1178	22.57	266	14	0	18732	558	94.7
12/16/2009	10.8	2708	3.04	55.53	343	0.13	1357	24.42	331	17	0	26806	651	96.3
12/17/2009	11.5	2957	3.01	53.31	371	0.11	1525	23.58	360	20	0	26311	592	96.7
12/18/2009	8.0	2085	3.09	60.20	269	0.28	1091	22.73	248	5	5	18492	574	92.1
12/19/2009	9.7	2561	2.98	53.66	318	0.28	1242	23.58	293	1	23	22937	601	91.7
12/20/2009	7.8	2115	3.05	57.03	269	0.28	1118	22.19	248	10	1	19045	590	91.9
12/21/2009	9.4	2360	2.98	56.97	293	0.16	1277	21.96	280	14	0	21648	616	95.5
12/22/2009	9.6	2654	3.03	57.41	336	0.26	1400	22.24	311	22	0	22879	568	92.5
12/23/2009	11.0	2934	3.08	58.51	377	0.23	1604	22.09	354	25	0	25783	570	93.6
12/24/2009	3.8	898	3.04	57.96	114	0.22	475	22.55	107	18	0	8351	612	93.7
12/25/2009	0.0	0			0		0		0	0	0	0		
12/26/2009	0.6	88	3.02	57.80	11	0.42	41	23.70	10	39	0	762	573	87.5
12/27/2009	9.8	2543	3.01	57.60	319	0.17	1379	22.06	304	10	0	23965	627	95.1
12/28/2009	10.4	1729	3.09	57.58	223	0.17	875	24.26	212	22	0	15708	588	95.1
12/29/2009	9.6	2455	3.09	57.54	316	0.22	1234	24.07	297	29	0	22188	585	93.6
12/30/2009	9.8	2682	3.03	58.01	339	0.19	1435	22.42	322	31	0	24614	606	94.7
12/31/2009	5.3	1359	3.01	57.67	171	0.17	719	22.63	163	11	0	12866	628	95.0
TOTAL	255.3	66151	89.82	1681.47	8263	5.77	33515	702.49	7827	495	29	587529	17800	2831.0
AVERAGE	8.2	2134	2.99	56.05	267	0.19	1081	23.42	252	16	1	18953	593	94.4
MIN	0.0	0	2.80	52.11	0	0.11	0	21.96	0	0	0	0	558	87.5
MAX	12.7	3576	3.09	60.20	445	0.42	1719	25.02	412	39	23	31539	651	96.9

1/22/2010 POB

EVALUATION OF POTENTIAL REDUCTION OF POLYMER CONSUMPTION AT THE STICKNEY WATER RECLAMATION PLANT POST-CENTRIFUGE FACILITY-WORK PLAN

Recently, the cost of polymer used for sludge dewatering at the Stickney WRP has increased significantly. In order to reduce the polymer usage at the Stickney Post-Digester centrifuges, EM&RD proposed and initiated a study during 2011. The baseline centrifuge operation was established under the study initiatives. The optimal operations and machine settings were also subsequently determined for the potential reduction of polymer consumption without compromising the desired performance. Now, EM&RD is proposing a follow-up full-scale testing to verify whether the centrifuge operation under optimal settings can save polymer usage.

The polymer consumption in the Stickney Post-Digester centrifuges will be evaluated twice a week for a minimum of four weeks beginning January 10, 2012. On Tuesdays, Machine Nos. 1-12 on the south side and on Thursdays, Machine Nos. 13-21 on the north side of the centrifuge facility will be investigated independently. On the respective days, half of the machines in operation will be operated and optimized by EM&RD for approximately five hours and the other half will be operated as per usual by the M&O operating engineer for a side by side comparison. EM&RD staff will operate each centrifuge under its supervision in auto-torque mode at approximately 725 lbs-in of set torque with a sludge flow rate of approximately 200 gpm and a polymer flow rate in the range of 8.5 to 10.5 gpm with an objective of minimizing polymer usage without compromising the desired machine performance, i.e. 25% total solids (TS) in the cake and 95% solids capture. Centrate clarity and cake firmness will be frequently monitored as a measure of desired performance; should centrate quality or cake firmness suffer due to changes in feed quality, the EM&RD-operated machine and operations settings will be adjusted accordingly. No adjustment will be made to M&O-operated machines. Necessary grab samples will also be collected and analyzed as explained below for the comparison and verification of performance achievement.

The details of sample collection frequency and subsequent quality analyses during the proposed study period beginning January 10, 2012 are summarized below as well as Table 1:

Sample Type and Frequencies

The following samples will be collected from both the M&O- and EM&RD-operated machines during monitoring days.

1. A raw polymer, dilute polymer, centrifuge feed, and dilution water sample will be collected twice each day.
2. A centrifuge cake and centrate sample will be collected from each machine approximately five times per day (once an hour per machine).

Table 1. Projected of Number of Samples and Parameters to be Analyzed on the Days of Study

Sample	Samples Per Machine	Total Samples Per Day	Parameters
Raw polymer	n/a	2	%TS, % Active solids
Dilute Polymer	n/a	2	%TS
Dilution Water	n/a	2	%TS
Feed	n/a	2	%TS, %TVS, pH, Total Alkalinity, Total Volatile Acids
Cake*	5	31	%TS
Centrate*	5	31	%TS

n/a=not applicable

*Total samples per day denote maximum. Number of samples is based on the assumption that 3 machines are available in both the M&O- and EM&RD-operated groups. One random duplicate sample per day will be collected as a quality control and quality assurance measure.

Sample Analysis

All samples will be collected with the appropriate sampling equipment, preserved accordingly, and submitted to the Stickney ALD labortatory within the appropriate holding times with a signed chain of custody. The raw polymer samples will be analyzed for percent TS (%TS) and percent active solids (%AS. Dilute polymer and dilution water samples will be analyzed for %TS. Centrifuge feed samples will be analyzed for pH, %TS, %VS, total alkalinity, and volatile acids. Cake and centrate samples will be analyzed for %TS.

Machine Operations Documentation

The operations data from the EM&RD- and M&O-operated machines will be recorded every 30 minutes. The following machine settings will be recorded for each machine: sludge flow rate, polymer flow rate, set value for torque, bowl speed, and pinion speed and hours of machine in service.

Data Analysis

All analytical and operating data will be reviewed and outlying data will be removed prior to analysis. The raw polymer and centrifuge feed characterization will be examined with respect to recent baseline centrifuge operating data to ensure that the post-digester centrifuges are operating under normal conditions during the monitoring study. The average daily volumetric ratio of polymer-to-sludge flow rate, dilute polymer strength, polymer dose, solids recovery in the centrate, %TS in the cake, and sludge throughput per machine will be calculated for both the EM&RD- and M&O-operated centrifuges. These daily calculated variables for each set of machines will viewed against each other in order to verify whether centrifuge performance can be maintained at lower polymer doses.

02-12

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO
RESEARCH AND DEVELOPMENT DEPARTMENT
ANALYTICAL LABORATORIES DIVISION

Requests for analytical support must be preceded by a completed and signed support request form; this form should have approval one week before receipt of samples at the laboratory; any request with an indefinite closing date should be kept current by an annual support request.

ANALYTICAL SUPPORT REQUEST **NEW** ☒ **UPDATE** ☐

DATE 1/10/2012

PROJECT NAME Polymer reduction test at STickney WRP

PROGRAM AND PROJECT NUMBERS 4681 / NA

DURATION 1/10/2012 to 2/3/2012

SECTION REQUESTING SUPPORT Section 122

PROJECT LEADER Kamlesh Patel / Joseph Kozak 1/10/12

APPROVAL OF DIVISION HEAD Catherine O'Connor /HZ

REPORT TO BE SUBMITTED TO Kamlesh Patel

FREQUENCY OF REPORTING DESIRED Weekly

SAMPLE DISPOSAL INSTRUCTIONS Upon notification

APPROVAL OF ALD DIVISION HEAD Thomas Liston 1/10/12

SUPPORT REQUESTED:

PARAMETER	SOURCE	FREQUENCY
See attached table		

ANALYTICAL LABORATORY

☒ STICKNEY

☐ CALUMET

☐ EGAN

☐ INDUSTIAL WASTE

☐ ORGANIC COMPOUNDS

162

M&R-Support
Revision 1.3 4/7/09 smz/ed

APPENDIX AIV

PREVENTIVE MAINTENANCE SCHEDULE FOR THE CENTRIFUGE MACHINES AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT

PREVENTIVE MAINTENANCE SCHEDULE FOR THE CENTRIFUGE MACHINES AT THE POST-CENTRIFUGE FACILITY AT THE STICKNEY WATER RECLAMATION PLANT

720 hours (30 days run time) PM:

Centrifuge

1. Remove bowl cover and inspect wear saddles
2. Remove cover and inspect DC back drive flex coupling
3. Remove jackshaft, gear box, V-belt covers for lubrication
4. Retention snubbers
5. Check level of centrifuge
6. Inspect DC motor brush seating and wear
   Clean motor of all carbon dust
   Check motor (armature and field) leakage to ground
   Clean motor as necessary
   Check SCR leakage (cathode-anode)
   Change all leaky SCRs
7. Purge conveyor rear bearing
8. Purge conveyor front bearing
9. Lube chute diverter shaft bearings
10. Lube jackshaft bearings

2,160 hours (90 days run time) PM:

Centrifuge

11. Inspect/clean loose dirt from commutator and brush holders
12. Inspect commutator segments
13. Inspect connections, repair corroded terminals and lugs
14. Change memory back-up battery
15. Run motor - check commutation - check for vibration

Polymer Feed

16. Inspect/clean loose dirt from commutator and brush holders
17. Stone commutator - inspect commutator segments and brush wear
18. Replace short brushes
19. Check relays and controller
20. Spray "CORTEC 248 spray" (MM #115168) on B/D controller hardware and exposed cables and starter (except CENT0030, CENT0033, CENT0036)

4,320 hours (6 months run time) PM:

Centrifuge

21. Change conveyor gear box oil
22. Lube motor base adjustment, clean-SDC 60, lube-SDC 54, brush-on film
23. Lube belt tensioner bearing
24. Purge pulley thrust bearing

Polymer Feed

25. Change polymer feed pump oil, SDC 40, level, fill drain lubrication unit
26. Change lube system oil, SUNVIS-946, sight GLS
27. Change oil filter

Centrifuge

28. With motor running and warm, lube main motor and back drive motor bearings with SDC 73, purge, 2-hydr each. Check electrical connections, clean motors, clean out front and back cabinets

8,760 hours (1 year run time) - perform the following:

Lubrication Unit

29. Completely drain oil lubrication system
30. Remove oil filler cap assembly from reservoir
31. Clean oil cooler
32. Inspect and clean anodes
33. Clean oil strainer
34. Clean control filter on sludge feed valve, check operation
35. Check reservoir bottom for debris, remove all remaining oil with dry cloth and re-check for debris particles
36. Replace oil filler cap assembly
37. Replace oil filter
38. Replace lube system oil, SUNVIS-946, sight glass

Centrifuge

39. When PM is completed and all covers have been replaced, return centrifuge to service, report status to operations

Note: This procedure covers the centrifuge and related equipment items: centrifuge, lubrication unit, and polymer feed pump.