Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

# MONITORING AND RESEARCH DEPARTMENT

REPORT NO. 17-01

## CALUMET PHOSPHORUS TASK FORCE

## TECHNICAL MEMORANDUM NO. 4

## SEQUENCE BATCH REACTOR STUDY AT CALUMET

May 2017

**Metropolitan Water Reclamation District of Greater Chicago**

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**May 2017**

## FOREWORD

The Metropolitan Water Reclamation District of Greater Chicago (MWRD) recognizes the value of phosphorus as a non-renewable resource. In an effort to optimize the sustainable removal of phosphorus from its wastewater influents and the subsequent recover of phosphorus in various forms suitable for use as an agronomic fertilizer, the MWRD initiated a Phosphorus Removal and Recovery Task Force in 2012. The Task Force initiated a study phase at several of the MWRD's Water Reclamation Plants to evaluate the feasibility of implementing enhanced biological phosphorus removal and to develop operational guidelines for optimizing its effectiveness. The Task Force has created WRP specific study workgroups that are focused on each of the WRP's that have been identified to participate in this initiative. As the workgroups complete various phases of their studies and evaluations they are documenting their findings and recommendations in technical memoranda. These memoranda are written by the WRP specific workgroups and vetted by the Task Force before being published. Their purpose is to capture the state of knowledge and study findings and to make recommendations for implementation of enhanced biological phosphorus recovery as they are understood at the time the memoranda are published.

## DISCLAIMER

The contents of this technical memoranda constitute the state of knowledge and recommendations developed by the MWRD's Phosphorus Task Force at the time of publication, and are subject to change as additional studies are completed and experience is attained, and as the full context of the MWRD's operating environment is considered.

# Sequence Batch Reactor Study at Calumet

## Technical Memorandum 4

**Date:** June 22, 2015

**To:** Phosphorus Task Force & Advisory Committee

**From:** Phosphorus Study/Planning Team

**Subject:** Technical Report of Enhanced Biological Phosphorus Removal Pilot Test at Calumet Water Reclamation Plant Using a Sequence Batch Reactor

Battery A at the Calumet Water Reclamation Plant (Calumet WRP) was converted to the enhanced biological phosphorus (P) removal (EBPR) process using an anoxic/anaerobic/aerobic (AAnO) zone set-up in February 2013 within the existing infrastructure. Poor P removal has been observed since conversion. Data analysis results suggested this poor performance would be due to insufficient influent biodegradable carbon to the EBPR process. As remedying these low carbon conditions for the full-scale demonstration is costly and time consuming, a smaller-scale biological sequencing batch reactor (SBR) was selected for pre-evaluation in order to determine how to successfully implement the EBPR process at the Calumet WRP.

An SBR is a batch process which depends on a cyclic repetition of reactor phases (filling, mixing, aerating, settling, and decanting) to achieve the desired treatment efficiency. The operation of an SBR can be optimized by controlling variables such as the phase times, dissolved oxygen (DO) concentration, and removal of sludge from the system. The operation mode of an SBR process is usually ruled by a fixed cycle and reaction period duration.

The SBR study was started at the Calumet WRP on February 24, 2014. The study was executed in an effort: (1) to verify whether EBPR can be established with current Calumet WRP primary effluent and optimization of the anoxic/anaerobic (AN) and aerobic phases; (2) to investigate the need for supplemental carbon to the Calumet WRP primary effluent to promote EBPR; (3) to find the optimum design and process control criteria such as hydraulic retention times (HRTs) and carbon requirements for the EBPR process at the Calumet WRP; and (4) to examine if EBPR and nitrification can occur within the existing tankage at the Calumet WRP.

The SBR status and limited preliminary results were reported in an SBR status report after two months of operation (see Appendix I). This status report included results from Stage 1 of the study (February 24, 2014, through June 10, 2014). The report concluded that no sign of EBPR was observed when no external carbon was added, with or without extending the AN zone.

This report will be focused on verifying objectives 2, 3, and 4, and data from the MicroC addition startup and steady operation periods (Stage 2 and 3: June 12, 2014, through August 16, 2014) relative to Stage 1. Originally, acetate addition as a carbon source was to be examined first. However, it was determined to use MicroC (a glycerol-based byproduct), as this product was planned for use in full-scale tests at the Calumet WRP.

After poor performance in Stage 1 without carbon addition, the SBR was reseeded with new mixed liquor (ML) on June 12, 2014. The ML was collected from the mixing channel of Battery A, which is currently operating in the EBPR process configuration. The SBR was operated with an average solids retention time (SRT) and ML suspended solids (MLSS) concentrations of 8 days and 2,170 mg/L, respectively, during Stage 2 and 3. These parameters are in close agreement to the targeted SRT (10 days) and MLSS (2,200 mg/L) values as discussed in the work plan outline (see Appendix 2), more so for the MLSS.

Figure 1 shows the ortho-P concentration of the SBR effluent during the entire study period:

1. Stage 1: No carbon addition as discussed in the status report from February 24, 2014, through June 10, 2014, in which no sign of EBPR performance was observed with different AN phases (1.5 hours versus original 1 hour) and aerobic phases (5.75 hours versus original 6.25 hours).

2. Stage 2: With 15 mg/L as chemical oxygen demand (COD) MicroC addition from June 12, 2014, through July 6, 2014, in which no P removal performance was observed, but higher P release and better nitrate reduction were observed in the AN phase;

3. Stage 3: With 30 mg/L as COD MicroC addition from July 7 through August 16 in which EBPR was established and operated steadily for a month.

In stages 2 and 3, anaerobic phase and aerobic phase were set for 1.5 hours and 5.75 hours, respectively. The average, minimum and maximum ortho-P concentrations of SBR effluent during Stage 3 were 0.296, 0.04, and 0.795 mg/L, respectively. These ortho-P results are relatively low compared to the forthcoming National Pollutant Discharge Elimination System permit limit of a monthly average of 1 mg/L total P (TP); based on full-plant monitoring data, ortho-P is 90 percent of the effluent TP. The average, minimum, and maximum ortho-P concentrations of the EBPR Battery A effluent during the same time period were 2.97, 2.13, and 3.51 mg/L, respectively.

Figure 2 shows the nitrite plus nitrate nitrogen ([$NO_2$+$NO_3$]-N) concentrations at the end of the SBR AN phase during the study stages. It can be seen that ($NO_2$+$NO_3$)-N was not depleted when no carbon was added in Stage 1, and ($NO_2$+$NO_3$)-N was brought to a low level in five (5) out of eight (8) sampling days when 15 mg/L as COD MircoC was injected in Stage 2, meaning true anaerobic conditions were not established during the first two stages of the SBR study, especially during Stage 1. Beyond carbon needs for the EBPR process, enough carbon is needed by the denitrifying biomass to denitrify the nitrate and nitrite in the return activated sludge. Or in the case of the SBR, the residual biomass nitrate and nitrite remaining after the previous aerobic cycle and decant.

With 30 mg/L COD of MicroC added in Stage 3, $(NO_2+NO_3)$-N was completely eliminated by the end of AN phase. As such, adding sufficient carbon adequately supports the denitrification in the AN phase.

Figure 3 indicates significant improvement on P removal efficiency occurring after the MicroC addition was increased from 15 mg/L to 30 mg/L as COD in Stage 3. The P removal was negative in Stage 2 when 15 mg/L MicroC was being added, meaning P uptake was much less effective than P release during this insufficient carbon addition. An increase of ortho-P release in the anaerobic phase was observed during Stage 2, but the P uptake in the aerobic phase did not reach the levels expected; this caused ortho-P removal efficiencies of less than 0 percent. It is unknown why this happened. Expected typical P release and uptake was observed with the 30 mg/L COD of MicroC addition during Stage 3 as shown in Figure 4, especially after a two-week startup period (July 21, 2014, and beyond).

Figure 5 shows the percent TP (%TP) in the SBR activated sludge. It can be seen that the %TP with respect to suspended solids in the activated sludge after SBR decanting were fluctuating in the range of 1 percent to 3 percent when no EBPR was observed. However, the %TP in the activated sludge was elevated up to 3 percent to 4 percent after about two to three SRTs of steady EBPR performance in Stage 3. The average %TP in the activated sludge in Stages 1, 2, and 3 are 1.71 percent, 2.09 percent and 2.68 percent, respectively. Limited data are presented in this report, because we conducted a starved carbon study in late August, and the %TP in the activated sludge started fluctuating again.

In the EBPR process, the growth of phosphate-accumulating organisms (PAOs) is encouraged by cycling them between anaerobic and aerobic conditions. Under anaerobic conditions, PAOs take up volatile fatty acids and store them as polyhydroxy alkanoate (PHA) compounds such as poly-β-hydroxybutyrate (PHB). Under aerobic conditions, PAOs oxidize the stored PHAs and as a result P uptake occurs. PAOs can be visualized by conventional microscopy after staining. In the anaerobic zone, PHB, a lipid-like polymeric ester is stored in the PAO cell as discrete inclusions or granules. PHB can be identified using the Sudan Black staining procedure. In the aerobic zone where P uptake occurs, P is stored in the PAO cell as polyphosphate (poly-P) granules, which serve as reserves for high energy phosphate. Stored polyphosphate granules can be identified using the Neisser microscopic staining procedure. Figure 6 shows the abundance of phosphate accumulating organisms (PAOs) responsible for EBPR with respect to PHB and poly-P and corresponding effluent ortho-P concentrations during the whole study period in the Calumet SBR ML samples. An increase in PHB count was observed late in Stage 1 when no carbon was added. However, no poly-P was found in any of the aerobic cycle samples, and no ortho-P removal was observed. The SBR was restarted with new ML when MicroC was added on June 12, 2014, at 15 mg/L in Stage 2. Although P removal was not observed during the Stage 2 (June 23, 2014, sampling), an improvement in PHB count was observed. However, poly-P remained low and effluent ortho-P was high, which indicates no EBPR at this 15 mg/L MicroC addition. Effluent ortho-P decreased significantly along with increases in both PHB and poly-P abundance after the MicroC addition was increased to 30 mg/L as COD in Stage 3, as shown in Figure 6.

Table 1 shows a summary of steady performance profile data with 30 mg/L as COD MicroC addition July 14, 2014, to August 16, 2014. It can be seen that the ortho-P removal can be up to 98 percent and the P release in the anaerobic phase can be up to 674 percent. The results show that the typical P release and efficient P uptake expected for good performing EBPR occurred in the SBR reactor as a result of sufficient supplemental carbon added.

Table 2 summarizes the ammonia-nitrogen removal performance in SBR during the whole study period. It shows that average effluent ammonia-nitrogen ($NH_3$-N) concentration was less than 0.12 mg/L, which indicates complete nitrification can likely occur within the existing SBR tankage with an aerobic HRT of 5.75 hours.

In conclusion, the SBR achieved over 85 percent average TP removal and very low effluent $NH_3$-N (<0.12 mg/L) with 30 mg/L as COD MicroC addition and performed steadily with consistent sufficient carbon addition.

TABLE 1: SUMMARY OF PROFILE DATA OF SEQUENCING BATCH REACTOR STUDY
DURING CARBON ADDITION STEADY PERFORMANCE
(STAGE 3 STEADY PERFORMANCE PERIOD: 7/14/14–8/16/14)

| | % Ortho-P Removal in SBR | solCOD/ ortho-P | % P Release in anaerobic phase | MLSS (mg/L) | SRT (days) |
|---|---|---|---|---|---|
| No. of samples | 11 | 11 | 11 | 11 | 11 |
| Average | 87 | 35 | 265 | 2,073 | 8 |
| Minimum | 56 | 21 | -24 | 1,320 | 6 |
| Maximum | 98 | 49 | 674 | 2,804 | 13 |
| Stdev. | 13 | 10 | 231 | 373 | 2 |

TABLE 2: SUMMARY OF AMMONIA-NITROGEN REMOVAL
IN SEQUENCING BATCH REACTOR DURING STUDY PERIOD
(STAGES 1 THROUGH 3: 2/24/14–8/16/14)

| | $NH_3$-N (mg/L) | |
|---|---|---|
| | SBR Influent | SBR Effluent |
| No. of samples | 41 | P102 |
| Average | 8.74 | <0.12 |
| Minimum | 3.25 | P0.10 |
| Maximum | 15.37 | P1.38 |
| Stdev. | 2.99 | P0.13 |

*SBR effluent samples were collected 4 days per week by Maintenance and Operations Department staff; SBR influent samples were collected by Monitoring and Research Department staff 1–2 times per week.

FIGURE 1: SEQUENCING BATCH REACTOR EFFLUENT ORTHO-P CONCENTRATION DURING THE STUDY

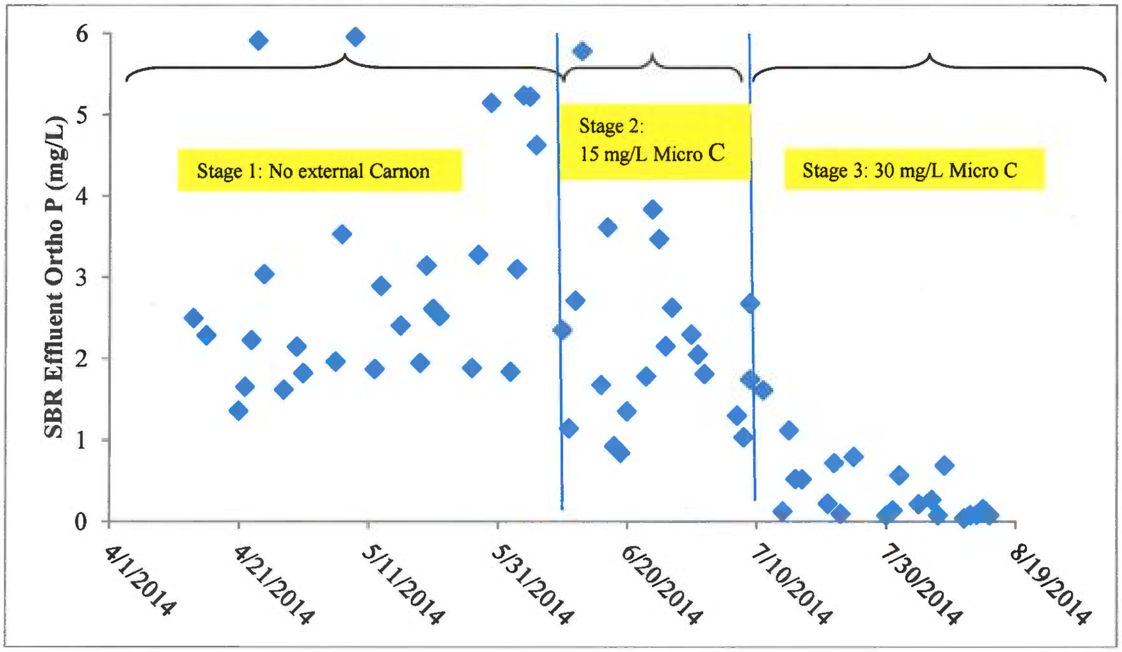



FIGURE 2: $(NO_2+NO_3)$-N CONCENTRATION BY THE END OF SEQUENCING BATCH REACTOR ANOXIC/ANAEROBIC PHASE

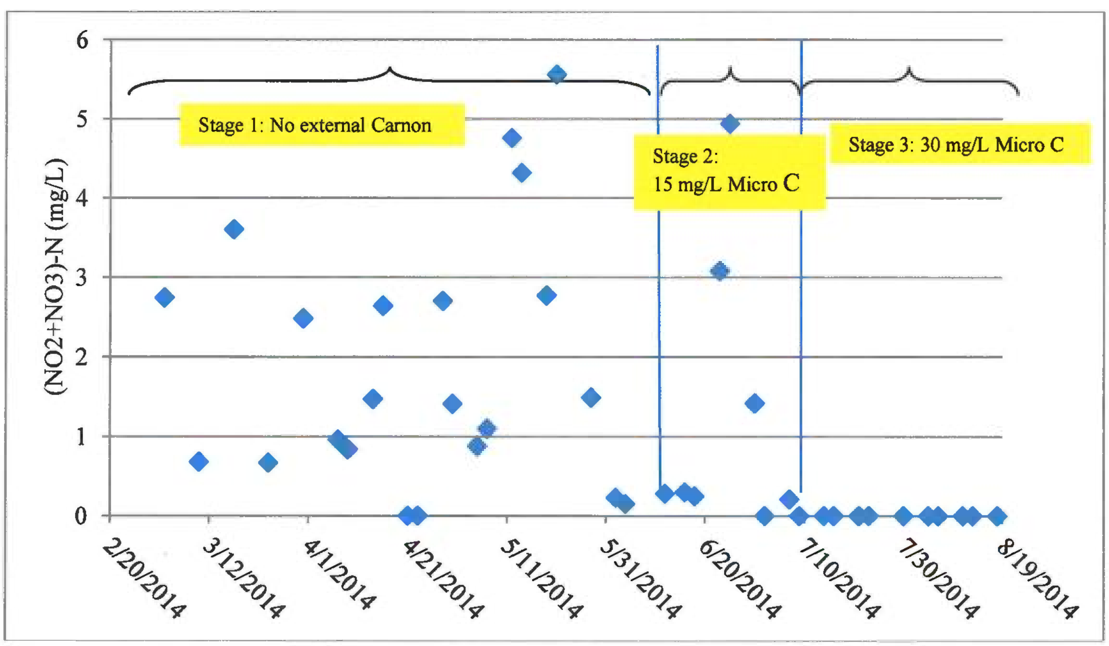


FIGURE 3: PERCENT PHOSPHORUS REMOVAL OF SEQUENCING BATCH REACTOR DURING MICROC ADDITION PERIOD

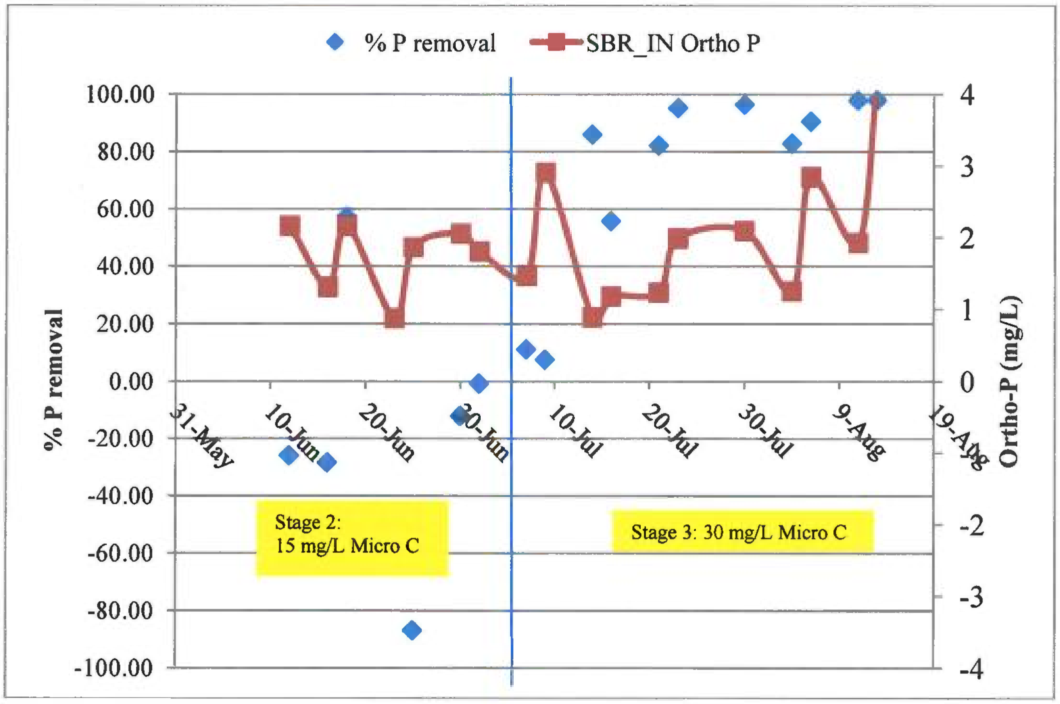



FIGURE 4: ORTHOPHOSPHATE PROFILE DURING 30 MG/L MICROC ADDITION (STAGE 3: JULY 7/14–8/16/14)

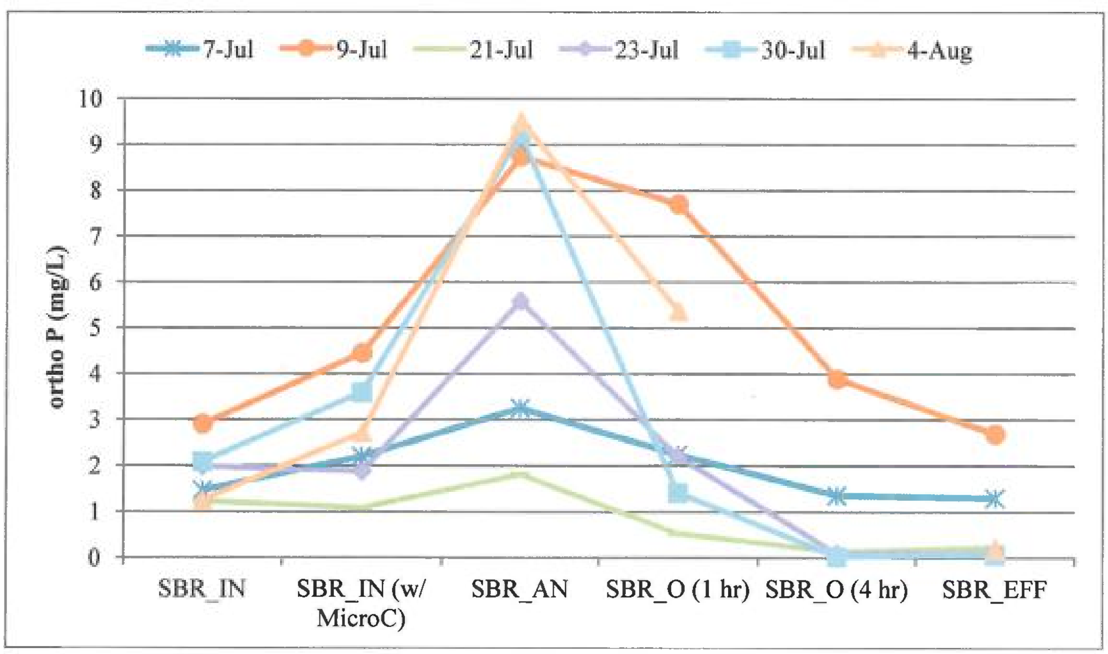


FIGURE 5: PERCENT TOTAL PHOSPHORUS PER TOTAL SUSPENDED SOLIDS IN SEQUENCING BATCH REACTOR RETURN ACTIVATED SLUDGE

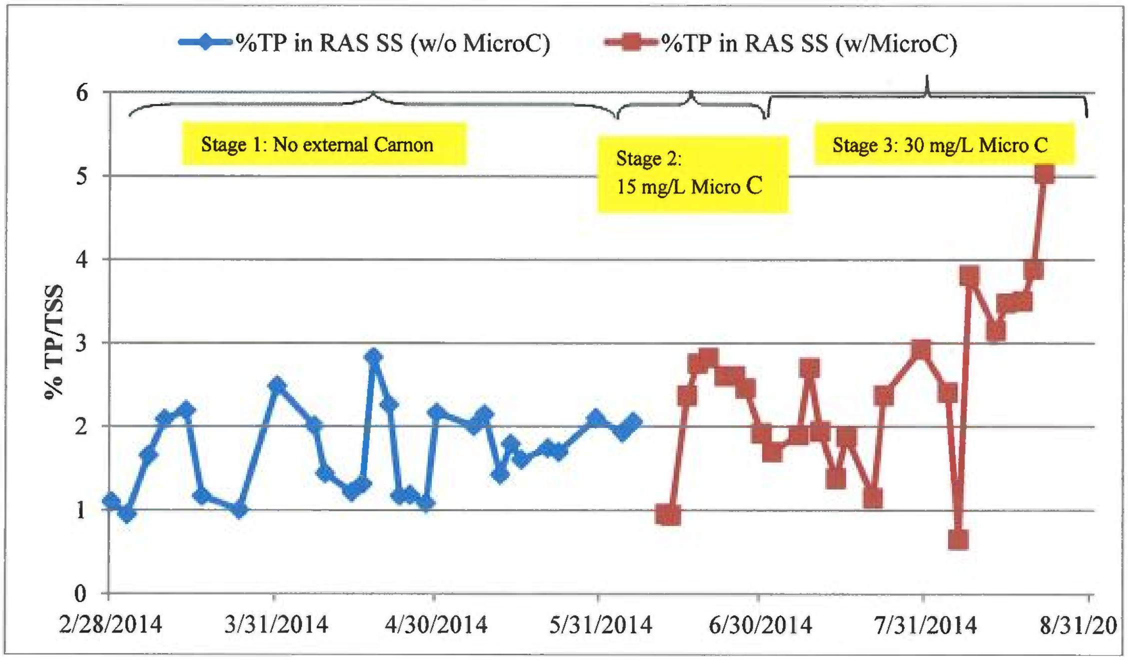
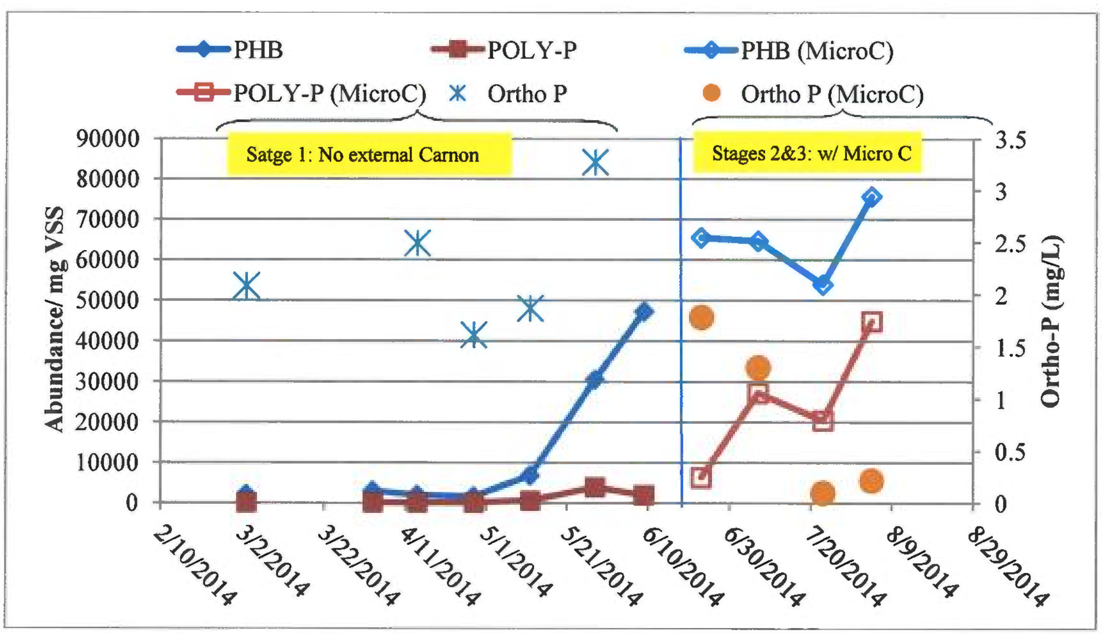



FIGURE 6: ABUNDANCE OF PHOSPHATE-ACCUMULATING ORGANISMS IN CALUMET WATER RECLAMATION PLANT SEQUENCING BATCH REACTOR MIXED LIQUOR SAMPLES



# APPENDIX I

## STATUS REPORT OF ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL PILOT TEST AT CALUMET WATER RECLAMATION PLANT USING SEQUENCE BATCH REACTOR

# STATUS REPORT OF ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL PILOT TEST AT CALUMET WATER RECLAMATION PLANT USING SEQUENCE BATCH REACTOR

A 30-gallon anaerobic-aerobic sequence batch reactor (SBR) was started in the Calumet WRP on February 24, 2014, and would be operated for approximately 6 months. An experimental work plan outline (see attached) was developed and is being executed in an effort: (1) to verify whether enhanced biological phosphorus (P) removal (EBPR) can be established with current Calumet primary effluent and optimizing the anaerobic and aerobic phases; (2) to investigate the needs of supplemental carbon to primary effluent to promote EBPR at the Calumet WRP; (3) to find the optimum design and process control criteria such as hydraulic retention times (HRTs) and carbon requirements for the EBPR process at the Calumet WRP; and (4) to examine if EBPR and nitrification can occur within the design, using the existing tankage. Currently, we are in the process of addressing the first objective and examining the EBPR potential without carbon addition.

The SBR status and limited preliminary results reported here are from two months of operation. The SBR was seeded using biomass collected at the mixing channel of aeration Battery A of the Calumet WRP, which is currently converted to the EBPR process configuration. The SBR has a working volume of 30 gallon and is being operated with eight-hour cycles. In standard operation, each cycle consisted of an influent phase of 0.25 hour, an anoxic/anaerobic (AN) mixing phase of 1 hour, an aerobic phase of 6.25 hour, and a settling and decant phase of 0.5 hour. The average solids retention time (SRT) and mixed liquor suspended solids (MLSS) in the first month of SBR operation are 10 days and 1,960 mg/L respectively. These are in the range of targeted SRT (10 days) and MLSS (2,200 mg/L) values as discussed in the work plan outline (see attached).

Twenty-six (26) SBR effluent and six (6) SBR waste activated sludge (WAS) samples were collected by Calumet Maintenance and Operations (M&O) Department staff. Nine (9) profile sampling events were completed by Environmental Monitoring and Research Division staff during the time period. Three (3) microbial samples were collected on March 3, 2014, March 17, 2014, and April 9, 2014, respectively. The study is on schedule according to the work plan outline.

<u>Table 1</u> summarizes the profile data in the first two months of the SBR study. <u>Figure 1</u> shows the percent ortho-P removal between SBR influent and effluent, percent P release in the AN phase, soluble chemical oxygen demand (solCOD) to ortho-P ratios, and MLSS during the profile sampling events. An increase of ortho-P release in the AN phase was observed during the first two months of the study. The P uptake in the aerobic phase, however, has not reached or exceeded the same levels as P release as expect; this has caused occasional ortho-P removal efficiencies of less than 0 percent. Profiles in <u>Figure 2a</u> show no P release over 100 percent in the AN phase in SBR except on one day, April 21, 2014. <u>Figures 2b</u> and <u>2c</u> show that ammonia was being nitrified in the AN phase likely leading to nitrate nitrogen concentration not reaching 0 mg/L by the end of the anaerobic phase. As seen in <u>Figure 3</u>, dissolved oxygen (DO) levels have been in an appropriate range for the AN phase (less than 0.2 mg/L) and the aerobic phase (greater

than 1 mg/L). Reasons for this partial nitrification in the AN phase may be due to the high DO level in the first 5 minutes or so of the AN phase as shown in Figure 3.

The M&O Department collected SBR effluent samples only Tuesday though Friday as a grab sample. Because the SBR influent is measured as a daily composite of Calumet primary effluent (CAPREF), percent ortho-P removals were not calculated due to the different type of samples.

Table 2 lists the observation/problems and solutions suggested after two months of SBR operation. We will reach out to an Assistant Chief Operation Engineer (ACOE) in the M&O department to improve the SBR's working consistency and reliability. Despite the problems, we are still on schedule for SBR Stage 1 study (see work plan outline). Since the preliminary results with limited data points have shown some indications of EBPR potential with Calumet primary effluent without carbon addition, we would like to extend the Stage 1 baseline study without carbon addition to collect more profile data to add to Figure 1. Profile sampling will be increased to twice a week. Field sampling from the converted Battery A will also be performed at the same time as SBR profile sampling. Ortho-P percent removal will be compared between the converted EBPR battery and the SBR. Next steps for Stage 1 study are running for 4 weeks with a longer SRT (15–20 days) and for an additional 4 weeks with a longer anaerobic phase (2 hours *vs* current 1 hour) and longer aerobic phase (7.25 hours *vs* current 6.25 hours) with a total SBR cycle of 10 hours. This will extend Stage 1 study to 16 weeks instead of the 8 weeks originally allocated in the work plan outline.

TABLE 1: SUMMARY OF PROFILE DATA IN THE FIRST TWO MONTHS OF THE SEQUENCING BATCH REACTOR STUDY

| | % Ortho-P Removal in SBR | solCOD/ ortho-P | % P Release in AN Phase | MLSS (mg/L) | SRT (days) |
|---|---|---|---|---|---|
| No. of Samples | 9 | 8 | 8 | 8 | 9 |
| Average | 26 | 42 | 39 | 1,960 | 10 |
| Minimum | -19 | 33 | 2 | 1,660 | 6 |
| Maximum | 72 | 57 | 109 | 2,380 | 13 |
| Stdev. | 32 | 8 | 37 | 231 | 2 |

FIGURE 1: SEQUENCING BATCH REACTOR PROFILE DATA FROM THE FIRST TWO MONTHS OF STUDY

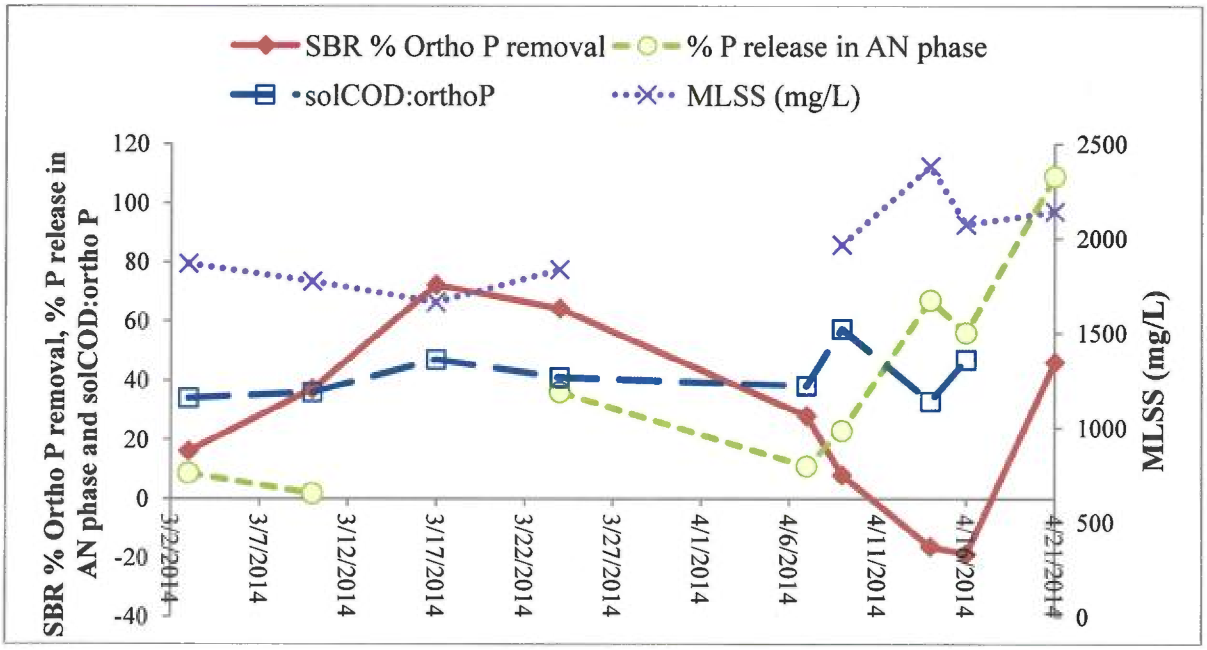


FIGURE 2: SEQUENCING BATCH REACTOR PROFILES OF (a) ORTHOPHOSPHATE, (b) AMMONIA NITROGEN, AND (c) NITRATE PLUS NITRITE NITROGEN

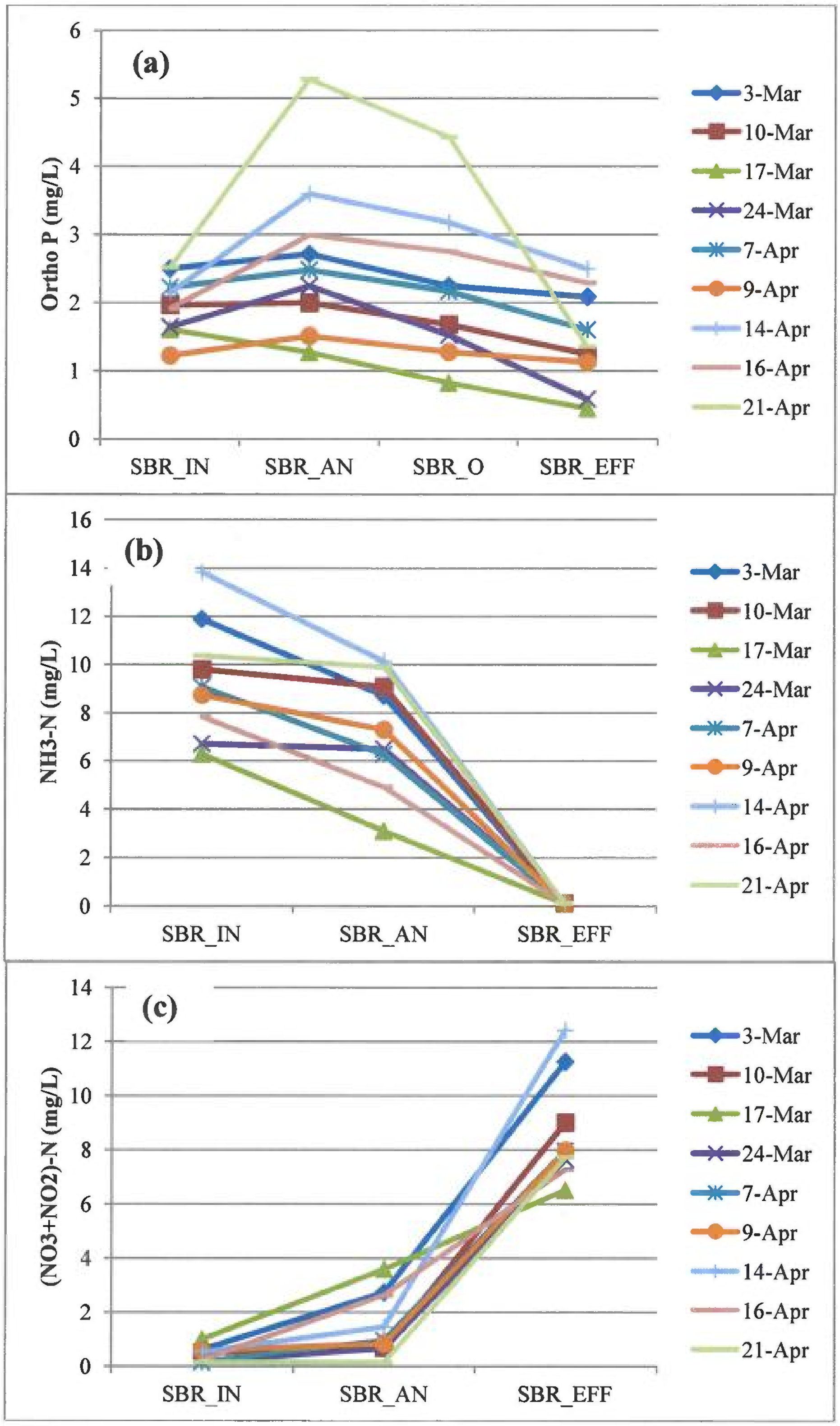


FIGURE 3: DISSOLVED OXYGEN PROFILE OF A SEQUENCING BATCH REACTOR WORKING CYCLE

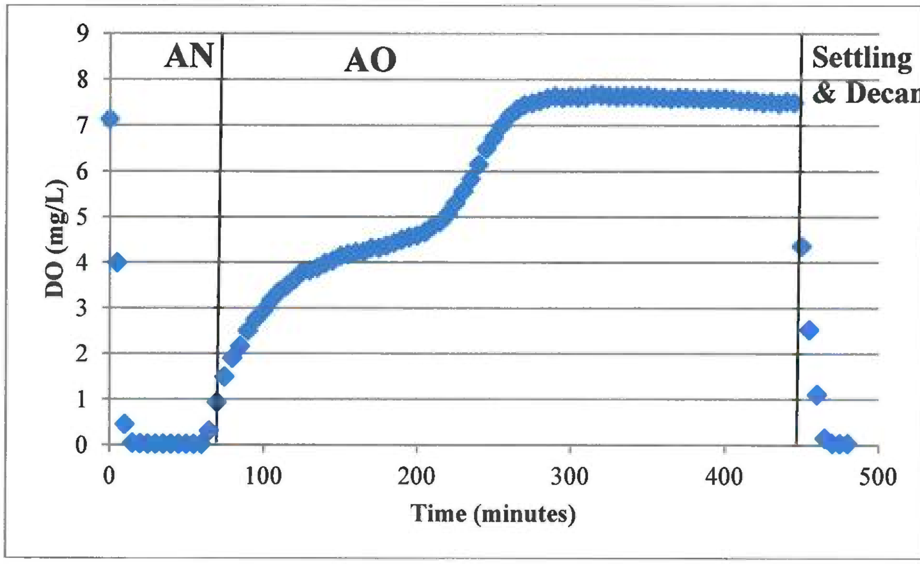


TABLE 2: PROBLEMS AND TROUBLESHOOTING AFTER ONE MONTH OF SEQUENCING BATCH REACTOR OPERATION

| Date | Observations | Probable Cause | Check or Monitor | SolutionS |
|---|---|---|---|---|
| 3/3 | Floatables and foam were found. | Overhead heater blew extra heat on the reactor. | AERS checked log sheet and found average temperature of 22.5°C. AERS visited site and turned off the heater with the help of M&O. | After the adjustment, the average temperature inside the reactor was reduced to 17°C and foam inside was reduced at the same time. The heater will remain off. |
| 3/17 | SBR cycle stopped during weekend. | Dirty sensors. | EMRD technician checked the sensor line and found sludge built up in the sensor chain. | Sensors will be cleaned weekly or more frequently if needed. |
| 3/24 | Settling timer was off about 15 minutes during the profile sampling day. | Bad timer. | EMRD technician checked and reset timer accordingly. | Need to talk to ACOE to have the bad timer replaced. |
| 3/26 | Timer was off more than 1.5 hour. M&O was not able to catch the settling phase to grab SBR effluent sample. | Broken timer. | EMRD technician monitored SBR cycle closely to figure out which timer needed to be changed. | During the monitoring cycle, all timers worked. Unable to identify the broken timer. |
| 4/16 | Effluent phase not stopping. | Water drop remained at the end of copper sensor, which did not trigger SBR to the fill phase. | EMRD technician cleaned the copper sensor. | ACOE will be contacted to discuss solution of a less sensitive sensor. |

## APPENDIX 2

## WORK PLAN OUTLINE FOR ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL PILOT TEST AT CALUMET WATER RECLAMATION PLANT USING SEQUENCE BATCH REACTOR

# WORK PLAN OUTLINE FOR ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL PILOT TEST AT CALUMET WATER RECLAMATION PLANT USING SEQUENCE BATCH REACTOR

## INTRODUCTION

Enhanced biological phosphorus (P) removal (EBPR) has been used for decades to remove P from municipal wastewater. EBPR is a process during which activated sludge is cycled alternately from anaerobic conditions to aerobic conditions. EBPR in wastewater treatment is accomplished by phosphate-accumulating organisms (PAOs). PAOs are heterotrophic bacteria that occur naturally in the environment and activated sludge processes. The growth of PAOs is encouraged by cycling them between anaerobic and aerobic conditions.

Calumet Battery A was converted to EBPR using the anoxic/anaerobic/aerobic (AAnO) set-up in February 2013 using the existing infrastructure. Poor P removal has been observed since conversion, and is considered to be due to suboptimal dissolved oxygen (DO) conditions in the three zones and insufficient influent biodegradable carbon to the EBPR process. As remedying these poor conditions for the full-scale demonstration is costly and time consuming, a smaller-scale biological sequencing batch reactor (SBR) was selected for further evaluation in order to determine how to successfully implement the EBPR process at Calumet.

An SBR is a versatile system capable of chemical oxygen demand (COD) removal, nitrification, denitrification, and EBPR. The SBR is a batch process which depends on a cyclic repetition of reactor phases (filling, mixing, aerating, settling, and decanting) to achieve the desired treatment efficiency. The operation of an SBR can be optimized by controlling the phase times, DO concentration, and removal of sludge from the system. The operation mode of an SBR process is usually ruled by a fixed cycle and reaction period duration.

# BACKGROUND

Table 1 summarizes the optimal EBPR process design parameters and historic Calumet primary effluent (SBR influent) characteristics. It shows that Calumet primary effluent has a very low carbon to total P (TP) ratio compared to the recommended EBPR requirements. Therefore, the SBR study will be focused on the carbon addition using different types and dosage.

TABLE 1: OPTIMAL ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL CONDITIONS AND CALUMET PRIMARY EFFLUENT CHARACTERISTICS

| Parameter | EBPR Design Range/Target | CAPREF Characteristics |
|---|---|---|
| RAS $NO_3$-N (mg/L) | 0[1] | ~1.3 |
| Influent BOD:TP | >25 | 13.5 |
| Influent rbCOD:TP | 11–16 | 6.5 |
| SRT (days) | ~4[2] | 10 |
| MLSS (mg/L) | 3,000–4,000[2] | 2,200 |
| Temperature (°C) | 5–28[2] | 10–20 |

rbCOD = Readily biodegradable chemical oxygen demand.
[1]WEF, Nutrient Removal Task Force. 2011. *Nutrient Removal: WEF Manual of Practice No. 34.* New York: McGraw-Hill.
[2]WEF and ASCE/EWRI. 2006. *Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants, WEF Manual of Practice No. 29, ASCE/EWRI Manuals and Reports on Engineering Practice, No. 109.* New York: WEF Press, McGraw-Hill.

## OBJECTIVES

To verify whether EBPR can be established with current Calumet primary effluent by using an SBR reactor and optimizing anaerobic and aerobic phases.

To investigate the needs of supplemental carbon to Calumet influent to promote EBPR at the Calumet WRP.

To find the optimum design and process control criteria such as hydraulic retention times (HRTs) and carbon requirements for the EBPR process at Calumet WRP.

To examine if EBPR and nitrification can occur within the design, using the existing tankage.

# MATERIALS AND METHODS

## 1.0. Sequencing Batch Reactor and Operation Summary

Physically, the SBR consists of a reactor, controller, mixer, air flow piping, aeration diffusers, effluent discharge piping and a sludge removal valve. The reactor is a 60-gallon drum with 50-gallon working volume. However, we will only use a 30-gallon working volume to ensure even DO distribution by the air stone diffuser inside the reactor.

The SBR will be set up as an anoxic/anaerobic/aerobic (AAnO) process. The reactor will be operated with three eight-hour cycles per day regulated automatically through programmable timers. The SBR will be operated in five phases. In the filling phase, feeding will be done automatically through a sump pump to draw the Calumet primary effluent into the reactor until it reaches the 30-gallon working volume; this 30-gallon volume includes 10 gallons of activated sludge. This is followed by the one (1) hour anoxic/anaerobic phase, in which no aeration will be used and the mixer will be turned on to suspend the mixed liquor (ML) at 0 mg/L DO. Denitrification and P release will occur during this phase. During experiments with external carbon additions, carbon will be added to the reactor at a predetermined dosage at the beginning of this phase through a metered peristaltic pump. In the following 6.25 hours of the aerobic phase, aeration and mixing are achieved using an air stone diffuser with a constant air flow; the DO concentration will be maintained between one to two mg/L. During this phase, nitrification, P uptake, and further carbon removal will be achieved. pH will not be controlled during this study since it is within a reasonable range (7.0–7.5) based on the pre-study results. The ML will then be allowed to settle for 0.5 hour during the settling phase. Decant starts immediately after the settling phase by decanting 20 gallon of supernatant, leaving behind a predetermined recycle volume (10 gallons) of biomass in the reactor. During this time, excess waste activated sludge will also be removed. The SBR is designed to run in Garrett configuration, where biomass will be wasted after the settling phase (without being thoroughly mixed) directly from the reactor, thus achieving and maintaining a desired SRT of approximately 10 days, which is very similar to Calumet's current operation range. In summary, the cycle timings are 0.25 hours for filling, one hour for the anoxic/anaerobic phase, 6.25 hours for the aerobic phase, and 0.5 hours for the settle and decant phases. Three SBR cycles will be completed per day. However, the activated sludge will only be wasted every third cycle during the day shift.

This testing will help establish baseline information for the converted EBPR battery. In light of this, future tests can be performed upon changes in operation to determine the effect on the PAO activity and aid in process control. Additionally, this testing can provide valuable information into whether the converted battery is carbon limited.

The study will proceed in three stages as shown in Table 2.

1. Stage I: To test the possibility of establishing EBPR without addition of external carbon as a baseline; the duration of each phase (anaerobic, aerobic, etc.) will be adjusted starting in week five based on the preliminary results collected; the test period will be two months.

2. Stage II: To use acetate (70 percent) and propionic acids (30 percent) as carbon source addition through a metered peristaltic pump; the test period will last two months.

3. Stage III: To use MicroC concentrated carbon as an external carbon source; the test period will be two months as well.

Optimal EBPR parameters in Table 1 suggest that ML suspended solids (MLSS) of 3,000 to 4,000 mg/L. However, Calumet WRP has experienced low F/M ratio and bulking problems in its history. The plant is normally operated at 2,000 – 2,500 mg/L with an average of 2,200 mg/L in 2013. This SBR study will be conducted with the average MLSS of 2,200 mg/L.

TABLE 2: SEQUENCING BATCH REACTOR TESTING STAGES WITH DIFFERENT SCENARIOS

| Stage | Date | Carbon Types | Carbon Dosage (as mg/L COD) | MLSS (mg/L) | SRT (days) |
|---|---|---|---|---|---|
| I | (2/24–4/20) | No carbon addition | 0 mg/L (8 wks) | 2,200 | Targeted at 10 days for all scenarios. However, It will be adjusted based on two weeks preliminary results after changing the operation conditions. |
| II | (4/21–6/15) | Acetate + propionic acids (70:30) | 15 mg/L (4 wks)<br>30 mg/L (4 wks) | 2,200 | |
| III | (6/16–8/10) | MicroC concentrated carbon | 15 mg/L (4 wks)<br>30 mg/L (4 wks) | 2,200 | |

[1]As shown in Table 1, SBR influent has a rbCOD:TP of 6.5. Carbon addition of 15 mg/L as COD will make rbCOD:TP of 9 (a little bit below the minimum recommended ratio of 11 for EBPR shown in Table 1)

[2]As shown in Table 1, SBR influent has a rbCOD:TP of 6.5. Carbon addition of 30 mg/L as COD will make rbCOD:TP of 12 (well above the minimum recommended ratio of 11 for EBPR shown in Table 1).

## 2.0. Sampling Schedule and Analysis

The SBR operations will be monitored for pH, DO, MLSS, ML volatile suspended solids (MLVSS), ortho-P, soluble COD (sol-COD), volatile acids (VFA), nitrate nitrogen ($NO_3$-N), ammonia nitrogen ($NH_3$-N), and TP. Weekly microbial sampling will also be collected for PAO, ammonia-oxidizing bacteria and nitrite-oxidizing bacteria analyses.

Table 3 also summarizes all the SBR sampling and test schedule.

**Maintenance and Operations Department Tasks During Sequencing Batch Reactor Study.**

1. On a daily basis, collect SBR supernatant in the settling phase as SBR effluent (SBR_Eff) sample at around 9:00 a.m. and coarse filter immediately Tuesday through Friday. Collect an SBR_WAS sample during the decant phase on Friday for analysis. Calumet primary effluent (SBR_In) information will be collected from the routine daily sample.

2. Wait until the settling phase ends at 9:10 a.m. and remove one (1) gallon of excess waste activated sludge from the reactor once per day. Sludge will not be mixed.

3. Check the SBR operation when collecting samples. Report abnormal observations to the Monitoring and Research Department.

4. Record pH, DO and temperature by using the Hach DO meter and pH meter provided by EM&RD.

5. Fill log note for SBR operation, e.g. sampling time, wasted volume and observations, etc.

6. Daily sampling and maintenance of SBR should continue for six months.

**Monitoring and Research Department Tasks During Sequencing Batch Reactor Study.**

1. Provide instructions of sampling procedure to M&O staff.

2. Provide log book for SBR operation.

3. Review laboratory data and make operational changes according to reported data.

4. Check SBR operation once per week.

5. Do the SBR profile sampling once per week. Five samples will be collected once per week on Monday as shown in Table 3.

   SBR influent (SBR_In).
   ML sample at the end of anaerobic phase (SBR_An).
   ML sample after one hour of aerobic phase (SBR_O).
   SBR effluent sample (SBR_Eff).
   Waste activated sludge sample during the decant phase (SBR_WAS). Temperature, pH and DO will be recorded at time of profile sampling.

6. Collect biweekly microbial sample and send to microbial laboratory for PAO analyses.

TABLE 3: SEQUENCING BATCH REACTOR SAMPLING AND TEST SCHEDULE

| | Sampling Points | Sampling Time | Analyses |
|---|---|---|---|
| Monday (profile sampling day, once per week) | SBR_In | 9:15 a.m. | Ortho-P, TP, ($NO_3$+$NO_2$-N), $NH_3$-N, solCOD, VFA |
| | SBR_An | 10:15 a.m. | Ortho-P, TSS_VSS, ($NO_3$+$NO_2$-N), solCOD, VFA |
| | SBR_O | 11:15 a.m. | Ortho-P |
| | SBR_Eff | 5:00 p.m. | Ortho-P, TP, ($NO_3$+$NO_2$-N), $NH_3$-N, solCOD |
| | SBR_WAS | 5:10 p.m. | TSS_VSS, TP |
| Tuesday-Thursday | SBR_Eff | 9:00 a.m. | Ortho-P, TP, ($NO_3$+$NO_2$-N), $NH_3$-N, solCOD |
| Friday | SBR_Eff | 9:00 a.m. | TP, ($NO_3$+$NO_2$-N), $NH_3$-N, solCOD |
| | SBR_WAS | 9:10 a.m. | TSS_VSS, TP |

## 3.0. Data Evaluation

Data obtained from this study and all data analyses completed will be reviewed for accuracy.

Data evaluation will be focused on:

1. P removal efficiency (percent P removed) to evaluate the treatability of Calumet influent using Calumet biomass.
2. P release ratio in the anaerobic phase and influence of carbon on the ratio.
3. sol COD/TP ratio in CAPREF (mg sol COD/mg P).
4. VFA/TP ratio in SBR_In (mg VFA/mg P).
5. Carbon consumption as mg sol COD used per mg ortho-P removal:

$$\frac{\Delta C}{\Delta P} = \frac{solCODin - solCODout}{orthoPin - orthoPout}$$

to decide the optimum carbon requirement for EBPR at CWRP.

6. $NH_3$-N concentration in SBR effluent to assure nitrification accomplished at the same time with EBPR set up.

7. Normalized P uptake in WAS (mg P/mg VSS).

## 4.0. Quality Assurance and Quality Control

A quality assurance/quality control program will be employed to ensure the evaluation is representative of the test. All field samples will be collected in a manner that will ensure analysis and evaluation will provide an accurate representation of the test. These factors include preparation of sample containers (new or cleaned bottles), sample collection techniques (rinse scooper with ML before sampling), sample preparation (coarse filter samples immediately after collection), sample storage and delivery, and laboratory analysis. The chain of custody form will be filled in and the samples stored in the ice cooler immediately after collection and during transport to the Analytical Laboratories Division (ALD) laboratory. The data quality will be evaluated as soon as possible after each study day. Extreme data values will be investigated to determine legitimacy. All instruments used in the field and/or laboratory will be calibrated weekly and checked to ensure accuracy.

## 5.0. Experiment Preparation

Prior to any sampling efforts, all parties involved in the study will review the project work plan. ALD support requests will be generated to ensure that the analytical needs of the project can be met.

Additionally, the following materials will be readied prior to experiment: (1) field log books or data log sheets for M&O; (2) a copy of sampling procedures for M&O staff performing the work; (3) blank chain of custody forms; (4) all new or washed plastic and glass containers and sample collection equipment, and chemicals used in the sampling methodology outlined above; (5) logged-in laboratory information management system (LIMS) labels; (6) calibrated Hach DO meter; (7) calibrated pH meter.

Field logs will be filled by treatment plant operators (TPOs) and laboratory technicians recording instantaneous operational data and observations. The log will be initialed by the TPOs and dated. Data retrieved from the LIMS database will be digitally converted, copied or transcribed into spreadsheets. A five percent check will be performed, whereby five percent of the sample data will be viewed individually in the LIMS platform to ensure the end document values agree and that the sample results were authorized by the LIMS administrator. Any qualified data will be noted. The data review will be random. The analytical results will be reviewed soon after they are available to ensure any necessary changes can be made in the sampling protocol before subsequent sampling.

## 6.0. Project Deliverables

Project schedule has a six (6) month testing period. The data obtained from this project will be analyzed to determine the basic strategy for implementing EBPR in Calumet WRP. Two draft status reports will be completed two weeks after the first two stages of tests. A draft final memo report will be completed by September 30, 2014.