# APPENDIX C
# WASTEWATER CHARACTERIZATION

# Nitrifier Growth Rate and Wastewater Characterization Study


*Submitted to*
The City of Winkler

*By*
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**15 April 2013**

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***Notice***

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# EXECUTIVE SUMMARY

## INTRODUCTION

Dr Jan Oleszkiewicz, PEng, was retained by the City of Winkler to perform the wastewater characterization and determine the nitrification rate in the City of Winkler's wastewater. The work was performed at the Environmental Engineering Laboratory of the Department of Civil Engineering, The University of Manitoba.

## APPROACH

The low F:M procedure (WERF, 2003) was used to evaluate the wastewater characteristics and nitrification kinetics of the raw sewage from Lift Station 8 (LS8) in Winkler. The low F:M protocol requires operating a bench-scale sequencing batch reactor (SBR) for several weeks to obtain a quasi-steady state, and then conducting intensive monitoring over a period of approximately two weeks. Data from the intensive testing period provide estimates of a series of wastewater fractions (e.g. unbiodegradable soluble and particulate Chemical Oxygen Demand (COD); readily biodegradable COD; unbiodegradable soluble organic nitrogen, etc.) and the nitrifiers' maximum specific growth rates.

In addition, nitrifier growth rate was determined using pure ammonia ($NH_4Cl$) to exclude any negative influence of the raw wastewater on the nitrifiers.

For the purpose of this study, one sequencing batch reactor (SBR) was set up. The SBR was a fully aerobic reactor, fed with raw sewage.

Raw sewage was collected from LS8. Grab samples were used to feed the SBR during the acclimation period for about 4 weeks and 24-h composite samples were fed to the reactor during the extensive monitoring period, which lasted 2 weeks.

The raw sewage samples were also taken from LS8 every two hours for 24 hours on three days during the extensive monitoring period. The samples were utilized for the diurnal pattern investigation.

Key information obtained from the program is presented in Figure 1 and Tables 1 to 4.

## CONCLUSIONS

Important conclusions from the study are listed below:

- Ammonia oxidizing bacteria (AOB) maximum specific growth rate was determined when the SRB were fed raw sewage and, to eliminate any potential inhibition, using $NH_4Cl$ dosing to biomass removed from the reactor. The rate was estimated at 0.95 1/d with raw sewage and 0.94 1/d was obtained with dosing $NH_4Cl$. Both of the rates are close to the typical value of 0.9 1/d, which also is BioWin™ default value.

- Nitrite oxidizing bacteria (NOB) maximum specific growth rate was determined when the SRB were fed raw sewage and, to eliminate any potential inhibition, using $NH_4Cl$. The rate was estimated at 0.74 1/d with raw sewage and 0.75 1/d was obtained with dosing $NH_4Cl$. Both of the rates are close to the typical value of 0.7 1/d, which also is the BioWin™ default value.

- The typical nitrifiers' growth rates attained from both methods and the similarity of the rates demonstrated there was no inhibition of the nitrifiers by the raw sewage from LS8.

- Analysis of influent COD indicated a higher than typical sewage fraction of readily biodegradable organic matter present in the raw sewage. Soluble biodegradable fraction of COD $f_{BS}$ = 0.36 mg COD/ mg COD; particulate biodegradable fraction $f_{BP}$ = 0.52 mg COD/ mg COD.

- The un-biodegradable portion of the total COD, was lower than typical. The soluble fractions for raw sewage was $f_{US}$ = 0.03 mg COD/ mg COD; the particulate un-biodegradable fraction was $f_{UP}$ = 0.09 mg COD/ mg COD. COD characterization of the LS8 influent is presented in Figure 1.

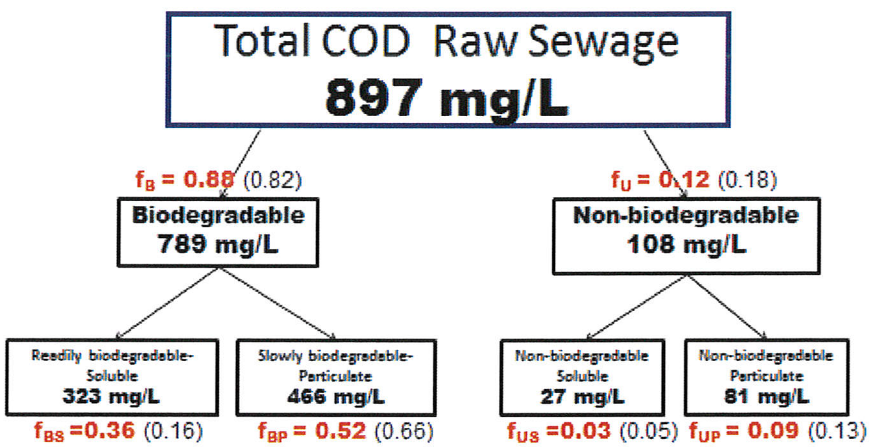



**Figure 1 COD Fractions in Raw Sewage – March 04 – 15, 2013**
**(Typical values in brackets)**

- The average total COD (TCOD), total nitrogen (TN), total phosphorus (TP) concentrations were 897 mg/L, 72 mg/L and 21.5 mg/L, respectively, during the extensive monitoring period. These concentrations of raw sewage from LS8 were higher than typical sanitary sewage.

- Influent total Kjeldahl nitrogen (TKN)/TCOD ratio was 0.08 mg TKN/mg TCOD. The lower than typical ratio is favorable for the proposed wastewater treatment plant should total nitrogen removal be required.

- Influent soluble unbiodegradable TKN fraction ($f_{NUS}$) was 0.02 mg N/mg N, which is a typical value and is beneficial if an effluent TN limit was imposed on the upgraded wastewater treatment plant because this portion of the TKN cannot be removed, regardless of the plant process configuration.

- The diurnal change of concentrations of TSS, VSS, TN, and TP followed the same pattern as those of TCOD. The pollutants' concentrations were fairly constant during the period except at the peak hours: between 10 am to 12 pm in all three days and between 2 am to 4 am in two out of the three days. The solids concentrations showed a larger variation than the other parameters.

## RECOMMENDATIONS

The following recommendations were made as a result of this investigation:

- The design of the wastewater treatment plant should adopt the values of
  $\mu_{max, AOB} = 0.9$ 1/d
  $\mu_{max, NOB} = 0.7$ 1/d

**Table 1 Summary of Average Concentrations of Main Influent Quality Parameters**

| Parameter | Average Concentration and standard deviation (mg/L) | | | |
|---|---|---|---|---|
| | | City of Winkler | Example: Combined sewage City of Winnipeg[1] | |
| | | | Winter | Spring |
| TCOD | Average | **897** | 711 | 621 |
| | Std. Dev. | **235** | 72 | 177 |
| TN | Average | **72** | 53.1 | 41 |
| | Std. Dev. | **12** | 2.5 | 13.8 |
| TP | Average | **21.5** | 7.58 | 6.35 |
| | Std. Dev. | **5.5** | 0.56 | 2.39 |
| TSS | Average | **265** | 365 | 466 |
| | Std. Dev. | **94** | 69 | 204 |
| VSS | Average | **194** | 257 | 224 |
| | Std. Dev. | **64** | 39 | 78 |

[1] from "Final Report on NEWPCC influent and nitrification and denitrification kinetics characterization for City of Winnipeg" 2012

## Table 2 Summary of Key Raw Influent Characteristics

| Parameter | City of Winkler | City of Winnipeg[1] | Typical Raw Influent Range[2] | Units |
|---|---|---|---|---|
| $f_{BS}$ - Fraction of total influent COD that is soluble readily biodegradable | **0.36** | 0.18 | 0.05 - 0.25 | mg COD/ mg COD |
| $f_{US}$ - Fraction of total influent COD that is soluble unbiodegradable | **0.03** | 0.06 | 0.04 - 0.10 | mg COD/mg COD |
| $f_{UP}$ - Fraction of total influent COD that is particulate unbiodegradable | **0.09** | 0.11 | 0.07 - 0.22 | mg COD/mg COD |
| $f_{BP}$ - Fraction of total influent COD that is particulate biodegradable | **0.52** | 0.65 | 0.40 - 0.80 | mg COD/mg COD |
| $f_{NA}$ - Fraction of influent TKN that is ammonia | **0.54** | 0.62 | 0.50 - 0.75 | mg N/mg N |
| $f_{NUS}$ - Fraction of influent TKN that is soluble unbiodegradable | **0.02** | 0.02 | 0.0 - 0.04 | mg N/mg N |
| $f_{Org.\,N}$ - Fraction of influent TKN that is organic | **0.46** | 0.38 | 0.25 – 0.5 | mg N/mg N |
| $f_{PO4}$ - Fraction of influent TP that is soluble phosphate | **0.61** | 0.37 | 0.4 - 0.6 | mg P/mg P |
| $f_{N,ML}$ - Nitrogen content of sludge | **0.09** | 0.09 | 0.07 - 0.10 | mg N/mg VSS |
| $f_{CV,XS}$ - Particulate biodegradable COD/VSS ratio | **1.9** | 1.9 | 1.4 - 1.6 | mg COD/mg VSS |
| $f_{CV,XI}$ - Particulate inert COD/VSS ratio | **1.9** | 1.9 | 1.4 - 1.6 | mg COD/mg VSS |

[1] Adapted from "Final Report on NEWPCC influent and nitrification and denitrification kinetics characterization for City of Winnipeg" University of Manitoba, 2012

[2] Adapted from WERF report "Methods for wastewater characterization in activated sludge modeling" WERF 2003

**Table 3 Summary of Estimated Nitrifiers Maximum Specific Growth Rate**

| Parameter | City of Winkler | | Reference example: City of Winnipeg[1] | | BioWin™ default | Units |
|---|---|---|---|---|---|---|
| | Raw Influent | $NH_4Cl$ | Raw Influent | $NH_4Cl$ | | |
| $\mu_{max,AOB,20}$ Maximum specific growth rate of AOB | **0.95** | **0.94** | 0.83 | 0.81 | 0.9 | 1/d |
| $\mu_{max,NOB,20}$ Maximum specific growth rate of NOB | **0.74** | **0.75** | 0.73 | 0.74 | 0.7 | 1/d |

[1] Adapted from "Final Report on NEWPCC influent and nitrification and denitrification kinetics characterization for City of Winnipeg" 2012

**Table 4 Summary of Assumed Nitrifiers Kinetic Parameters**

| Parameter | Value | Unit | Parameter | Value | Unit |
|---|---|---|---|---|---|
| $b_{AOB,20}$ Anaerobic/anoxic decay rate of AOB | **0.08** | 1/d | $b_{NOB,20}$ Anaerobic/anoxic decay rate of NOB | **0.08** | 1/d |
| $b_{AOB,20}$ Aerobic decay rate of AOB | **0.17** | 1/d | $b_{NOB,20}$ Aerobic decay rate of NOB | **0.17** | 1/d |
| $K_{S,AOB,NH4,20}$ Bacteria substrate half-saturation constant of AOB | **0.7** | mg N/L | $K_{S,NOB,NO2,20}$ Bacteria substrate half-saturation constant of NOB | **0.1** | mg N/L |
| $\theta_{\mu AOB}$ Arrhenius temperature coefficient of AOB growth rate | **1.072** | - | $\theta_{\mu NOB}$ Arrhenius temperature coefficient of NOB growth rate | **1.06** | - |
| $\theta_{bAOB}$ Arrhenius temperature coefficient of AOB decay rate | **1.029** | - | $\theta_{bNOB}$ Arrhenius temperature coefficient of NOB decay rate | **1.029** | - |
| DO half saturation of AOB | **0.4** | mg $O_2$/L | DO half saturation of NOB | **0.5** | mg $O_2$/L |
| Anaerobic DO half saturation of AOB | **0.01** | mg $O_2$/L | | | |

# CHAPTER 1 INTRODUCTION

## 1.1 Background

Dr Jan Oleszkiewicz, PEng, was retained by the City of Winkler to perform the wastewater characterization and nitrification kinetics determination program. The work was performed at the Environmental Engineering Laboratory of the Department of Civil Engineering, The University of Manitoba.

Kinetics of the nitrification process is a critical factor in wastewater treatment plant design when biological nutrient removal (BNR) is required. The nitrifiers' maximum specific growth rates ($\mu_{max,AOB}$ and $\mu_{max,NOB}$) are the key parameters affecting the solids retention time (SRT) required for nitrification and, thus, the reactor's size. Wastewater characterization is essential in determining the success of the BNR process in achieving the desired level of nitrate and phosphorus removal. Constituent concentration variations may change significantly during the course of a day and affect instantaneous effluent concentration. The information about the diurnal pattern of flow and major constituents is essential for predicting the time-change of effluent concentrations discharged from the future plant. Information may also be used in the future for adjustment of operation to comply with the provincial license limits.

The main objectives of the program were to obtain the nitrifier maximum specific growth rate, detailed influent characteristics, and to investigate the diurnal patterns of major pollutants the city of Winkler MB.

The influent particulate unbiodegradable chemical oxygen demand (COD) fraction $f_{UP}$, as well as the inorganic suspended solids fraction, has significant implications for treatment plant's solids inventory and sludge production. The influent unbiodegradable soluble portion of nitrogen is important to effluent TN as it cannot be removed by any biological processes. A larger fraction of nitrogen indicates that a higher reduction of biologically removable nitrogen should be achieved through the plant to meet the total nitrogen discharge limit.

The program for the City of Winkler started on February 1$^{st}$, 2013 and ended on March 15$^{th}$, 2013.

## 1.2 Objectives

The objectives of the program were:

1. Obtain detailed influent characteristics information of raw sewage to the proposed wastewater treatment plant.

2. Evaluate the nitrifier maximum specific growth rates with the raw sewage.

3. Investigate the diurnal patterns of major constituents.

## 1.3 Approach

The low F:M procedure presented in the Water Environment Research Foundation report (WERF, 2003) was used to evaluate the wastewater characteristics and nitrification kinetics of the raw wastewater from Winkler. The low F:M protocol requires operating a bench-scale sequencing batch reactor (SBR) for several weeks to obtain a quasi-steady state, and then conducting intensive monitoring over a period of approximately two weeks. Data from the intensive testing period provided estimates of a series of wastewater fractions (e.g. unbiodegradable soluble and particulate COD; readily biodegradable COD; unbiodegradable soluble organic nitrogen, etc.) and the nitrifier maximum specific growth rates.

For the purpose of this study, one sequencing batch reactor (SBR) was set up. The SBR was a fully aerobic reactor, fed with raw sewage.

Raw sewage was collected from the LS8. Grab samples were used to feed the SBR during the acclimation period for about 4 weeks and 24-h composite samples were fed to the reactor during the extensive monitoring period, which lasted 2 weeks.

The raw sewage samples were also taken from LS8 every two hours for 24 hours on three days during the extensive monitoring period. The samples were utilized for the diurnal pattern investigation.

# CHAPTER 2 METHODOLOGY

## 2.1 Preamble

This chapter of the report provides the equipment used for the program, the analytical equipment used during the intensive testing period, and the protocols used during both the acclimatization and the intensive testing periods.

## 2.2 Required Equipment

A variety of equipment used in the influent characteristics study is listed in Table 2.1.

**Table 2.1 Equipment Used in the Influent Characteristics Study**

| | |
|---|---|
| One incubator | Programmable sampler, sump pump, funnels, and 20L plastic carboys for sample collecting, transportation, and storage |
| DO controller with DO concentration and Temperature Logger | Supplies commonly used in wastewater laboratory, such as beakers, graduated cylinders, flasks, DI water etc. |
| One DO probe | Thermometer |
| One reactor with 5L working volume | Filtration apparatus and vacuum pump |
| One magnetic mixer with stirring bar | HACH DBR 200 digestion block and DR 2000 spectrophotometer |
| Three aquarium air pumps with flexible tubing and air diffusers to provide aeration | QuikChem 8500 Flow Injection Analyzer |
| Tubing for decant by siphoning and plastic pales for collecting effluent | Filter papers |
| Portable pH probe and meter | Phipps & Bird mixer for coagulation |
| Auto-sampler with refrigerated storage | Tubing for auto-sampler |

## 2.2 Location of the SBR Reactor

The reactor was set up in the incubator, which was placed in the Environmental Engineering Lab of the University of Manitoba. The photos of the SBR reactor are presented in Figure 2.1.

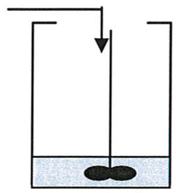
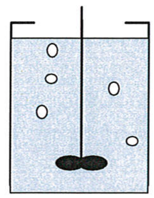
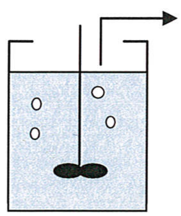
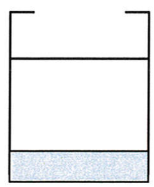
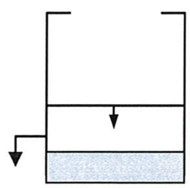
**Figure 2.1 SBR Reactor before start on the left Reactor during program on the right**

## 2.3 Description of Daily SBR Cycle

One cycle of SBR operation, stated in the protocol for wastewater characterization, consists of five operating periods. The periods are to fill, react, waste, settle, and decant in sequence. The SBR was operated on the basis of a 24-hour cycle, with a selected maximum volume ($V_P$). The volume of decant (effluent) withdrawn after the settling period was equal to the volume of wastewater added at each cycle ($V_{WW}$), less the volume wasted ($q_W$).

At the beginning, the SBR reactor was seeded with the mixed liquor from the West End Water Pollution Control Centre in Winnipeg. Following start up, quasi-steady state condition was achieved by operating the 24-hour cycles, shown in Table 2.2, for about four weeks. The reactor had the working volume of 5L ($V_P$). For the purpose of this study, one sequencing batch reactors (SBR) was set up. The SBR was a fully aerobic reactor, fed with raw sewage.

Table 2.2 Sequencing Batch Reactor Operating Conditions

| Stage | Time | Reactor cycle | Operation |
|---|---|---|---|
| Fill | T=0<br>(Instantaneous fill) |  | Add $V_{ww}$ of wastewater to reactor containing $V_P$ -$V_{ww}$ of mixed liquor, i.e. filling reactor to the volume of $V_P$ |
| React | T=0-23h |  | Reactor volume constant ($V_P$)<br>Air on<br>Mixing on<br>DO = 2 ± 0.5 mg/L |
| Waste | T=22.9-23h |  | Air on<br>Mixing on<br>Waste 1/15 of mixed liquor ($q_W$) |
| Settle | T=23-23.75h |  | Air off<br>Mixing off<br>Allow sludge to settle |
| Draw | T=23.75-24h |  | Air off<br>Mixing off<br>Decant supernatant with volume of $V_{ww}$-$q_W$, leaving reactor with liquid volume of $V_P$-$V_{ww}$ |
| Parameters for this study: $V_P$=5L, $V_{ww}$=4L, SRT=15d, $q_W$=5L/15=333.3mL | | | |

## 2.4 Daily Maintenance of the SBR

The daily procedure for the care and feeding of the SBR throughout the acclimation and intensive monitoring periods was as follows:

1. **Sample Collection and Storage:** Grab samples of raw sewage from List Station 8 were taken by the City staff and delivered to the Lab twice per week during the acclimation period. 24-h composite samples were collected by the City staff during the extensive monitoring period and delivered five times. The samples were stored at 4 °C in a cold chamber.

2. **Warming up of Influent:** Before each cycle, the feed was taken out of the cold chamber and warmed up to 20 °C to avoid a temperature shock to the biomass.

3. **Re-Suspension of Wall Growths:** Biomass accumulated on the walls of the SBR, the tubing in the reactor, and the DO probe etc. The biomass was scraped off and re-suspended into the mixed liquor.

4. **Topping-Up the SBR:** Distilled water was used to top-up the SBR to 5L to compensate for the liquid loss through evaporation due to constant mixing and aeration.

5. **Collection of Waste Activated Sludge (WAS) Sample:** A beaker was used to withdraw wastage from the SBR. A 1L graduated cylinder was used to obtain the correct WAS volume.

6. **Mixed Liquor Settling Phase:** After collecting the WAS sample, the mixer and the air pumps were shut off and the mixed liquor was allowed to settle for a period of 45 minutes.

7. **Treated Effluent Decanting:** After settling, supernatant was siphoned out as effluent. It was collected in a pail for analysis.

8. **Re-Filling the SBR:** After decanting the effluent, the SBR was refilled to 5L with a well-mixed feed. The mixer and the air pumps were re-started.

## 2.5 Sampling and Analytical Schedules

The program started on February 1$^{st}$, 2013 and ended on March 15$^{th}$, 2013. From the beginning to March 3$^{rd}$, 2013 was the acclimation period, which lasted for 31 days (2 SRTs). The extensive monitoring period for the program commenced on March 4$^{th}$, 2013 and ended on March 15$^{th}$, 2013. During this period, the 24-h composite samples were collected five times on March 4$^{th}$, 6$^{th}$, 8$^{th}$, 11$^{th}$, and 13$^{th}$, respectively. The diurnal samples were collected on March 4$^{th}$, 6$^{th}$, and 8$^{th}$.

During the acclimation period, the sewage samples from Lift Station 5 were delivered twice on February 7th and 15th, 2013. Septage samples from Reinfeld and Schanzenfeld were delivered on February 12th, 2013. During the extensive monitoring period, wastewater from Lift Station 5 was delivered five times with the raw sewage from Schanzenfeld. The wastewater from Saputo was delivered twice on March 5th and 9th, 2013.

Analyses were conducted on samples of influent, waste mixed liquor, and decant during the acclimation and extensive monitoring periods. The sampling and analysis schedules are presented in Tables 2.3 and 2.4. An auto-sampler with refrigerated storage was used to collect samples for diurnal investigation. The samples were collected every two hours during this period. Major parameters were analyzed on the diurnal samples, including TCOD, TSS, VSS, TN, TP, $NH_3$-N, and pH.

**Table 2.3 Sampling and Analysis Schedule during the Acclimation Period**

| Parameter | LS 8 | LS 5 | Septage | Effluent | Mixed Liquor |
|---|---|---|---|---|---|
| TSS, VSS & TDS (duplicate) | X | X | X | X | X |
| TCOD, sCOD | X | X | X | X | |
| TN | X | X | X | | |
| $NH_3$-N & $NO_x$-N | X | X | X | X | |
| TP & $PO_4$-P | X | X | X | | |
| pH | X | X | X | | |
| Alkalinity | X | X | X | | |
| Conductivity | X | X | X | | |
| Ca | X | X | X | | |
| Mg | X | X | X | | |

**Table 2.4 Sampling and Analysis Schedule during the Extensive Monitoring Period**

| Parameter | LS 8 | LS 5 | Saputo | Effluent | Mixed Liquor |
|---|---|---|---|---|---|
| TSS&VSS (duplicate) | X | | X | X | X |
| TCOD (triplicate) | X | X | X | X | X |
| sCOD (triplicate) | X | X | X | X | |
| ffCOD (triplicate) | X | | X | X | |
| TN (triplicate) | X | | X | | X |
| sTN (triplicate) | | | | X | |
| $NH_3$-N & $NO_x$-N | X | | X | X | |
| TP (triplicate) | X | | X | | |
| $PO_4$-N | X | | X | | |

**Note:** **TSS** stands for **T**otal **S**uspended **S**olids
**VSS** stands for **V**olatile **S**uspended **S**olids
**TCOD** stands for **T**otal **C**hemical **O**xygen **D**emand
**sCOD** stands for **s**oluble **COD**
**ffCOD** stands for **f**locculation **f**iltration **COD**
**TN** sands for **T**otal **N**itrogen
**sTN** stands for **s**oluble **TN**
**$NH_3$-N** stands for ammonia nitrogen
**$NO_x$-N** stands for sum of nitrite nitrogen and nitrate nitrogen
**TP** stands for **T**otal **P**hosphorous
**$PO_4$-P** stands for Phosphate Phosphorous

In addition to the above testing schedule, on five days during the extensive monitoring period, profiles of ammonia and nitrite/nitrate concentration were measured over the first 12 hours of the react period. Analyses were performed on small sample volumes (10 mL) withdrawn from the reactor at intervals of approximately 30 min. This provided the data for estimating nitrifier maximum specific growth rates of the ammonia and nitrite oxidizing bacteria.

One additional batch test was conducted in parallel with the afore-mentioned SBR by dosing Ammonium Chloride into the wasted sludge from the SBR as substrate for the nitrifiers. Samples (10 mL each) were taken every 30 min and analyzed for ammonia, nitrite, and nitrate. The potential inhibitory effects of raw influent on the nitrifiers were eliminated and the nitrifier specific growth rates obtained from this additional batch test were compared with those attained from the main SBR.

## 2.6 Analysis of Results

Results collected during the extensive monitoring period were used to obtain a range of influent wastewater characteristic parameters and to estimate the nitrifier maximum specific growth rates. Certain wastewater characteristics can be calculated from direct measurements. These include:

**Influent soluble unbiodegradable COD fraction ($f_{US}$):**

The influent soluble unbiodegradable COD fraction is obtained directly from measured data as follows:

$$f_{US} = \frac{\text{Effluent ffCOD}}{\text{Unfiltered Influent COD}}$$

**Influent readily biodegradable COD fraction ($f_{BS}$):**

The readily biodegradable COD fraction is obtained directly from measured flocculated and filtered COD (ffCOD) data as follows:

$$f_{BS} = \frac{\text{Influent ffCOD} - \text{Effluent ffCOD}}{\text{Unfiltered Influent COD}}$$

**Ammonia fraction of the influent TKN ($f_{NA}$):**

The fraction of the total influent TKN that is free and saline ammonia is:

$$f_{NA} = \frac{\text{Influent NH3} - \text{N}}{\text{Unfiltered Influent TN} - \text{Influent NO3} - \text{N}}$$

**Soluble unbiodegradable fraction of the influent TKN ($f_{NUS}$):**

The soluble unbiodegradable fraction of the influent TKN can only be estimated based on the filtered effluent TKN (or TN) and ammonia concentrations from a fully-nitrifying activated sludge system. In the case of the SBRs for this study, the filtered effluent TN is comprised of nitrate ($NO_3$-N), nitrite ($NO_2$-N), residual ammonia ($NH_3$-N), residual soluble biodegradable organic nitrogen ($N_{OS}$), and any soluble unbiodegradable organic nitrogen ($N_{US}$) from the influent:

$$\text{Filtered effluent TN} = NO_2\text{-N} + NO_3\text{-N} + NH_3\text{-N} + N_{OS} + N_{US}$$

The difference between the filtered TN and the sum of ammonia, nitrite, and nitrate concentrations will be the sum of soluble biodegradable ($N_{OS}$) and unbiodegradable organic nitrogen ($N_{US}$). For a fully-nitrifying system, usually the ammonia concentration will be low, say 0.1 mg N/L. Model applications indicate that the residual concentration of biodegradable organic in the effluent typically is about 0.5 mg N/L. Based on these assumptions, the unbiodegradable soluble nitrogen can be estimated as follows:

$$f_{NUS} = \frac{\text{Filtered effluent TN} - \text{NO2} - \text{NO3} - \text{NH3} - 0.5\ \text{mgN/L}}{\text{influent TKN}}$$

**Phosphate fraction of the influent TP ($f_{PO4}$):**

The fraction of the influent TP that is phosphate is:

$$f_{PO4} = \frac{\text{Influent PO4−P}}{\text{Unfiltered Influent TP}}$$

The parameters listed above are characteristics of the influent wastewater that are specifically required as model input information for applying the BioWin™ simulator. It is useful to calculate a number of other parameters based on the monitored data as a means of assessing data quality; these include:

**Mixed liquor inorganic suspended solids concentration (ISS):**

The concentration of inorganic suspended solids (ISS) in the mixed liquor is the difference between the total and volatile suspended solids concentrations:

$$ISS_{ML} = TSS - VSS$$

**Mixed liquor COD/VSS ratio ($f_{CV,ML}$):**

The mixed liquor COD/VSS ratio is a composite determined by the COD/VSS ratios of the biomass, unbiodegradable solids from the influent, *etc.* Typically, the observed value is approximately 1.48 mg COD / mg VSS for sludge withdrawn from a system treating municipal wastewater:

$$COD/VSS = \frac{\text{ML TCOD−ML sCOD}}{\text{MLVSS}}$$

The mixed liquor filtered COD should be closely equal to the effluent filtered COD, so that the ratio can also be calculated as follows:

$$COD/VSS = \frac{\text{ML TCOD−Effluent sCOD}}{\text{MLVSS}}$$

**Mixed liquor nitrogen content ($f_{N, ML}$):**

$$N/VSS = \frac{\text{ML TN−Effluent sTN}}{\text{MLVSS}}$$

**Influent TKN/COD ratio:**

$$TKN/COD = \frac{\text{Influent TN−Influent NO3}}{\text{Influent TCOD}}$$

**Influent glass fiber filtrate COD/ total COD fraction:**

$$gfCOD/TCOD = \frac{\text{Influent sTCOD}}{\text{Influent TCOD}}$$

**Influent ffCOD/ total COD fraction:**

$$ffCOD/COD = \frac{\text{Influent ffCOD}}{\text{Influent TCOD}}$$

**Influent TSS/COD ratio:**

$$TSS/COD = \frac{\text{Influent TSS}}{\text{Influent TCOD}}$$

**Influent ISS/TSS ratio:**

$$ISS/TSS = \frac{\text{Influent ISS}}{\text{Influent TSS}}$$

**Influent ISS/COD ratio:**

$$ISS/COD = \frac{\text{Influent ISS}}{\text{Influent TCOD}}$$

**Influent VSS/TSS ratio:**

$$VSS/TSS = \frac{\text{Influent VSS}}{\text{Influent TSS}}$$

**Influent TP/COD ratio:**

$$TP/COD = \frac{\text{Influent TP}}{\text{Influent TCOD}}$$

Some influent wastewater characteristics and the maximum specific growth rates of the nitrifiers cannot be determined by direct measurement, or the estimates calculated from direct measurements are not accurate. These include the fraction of the influent COD which is particulate unbiodegradable ($f_{UP}$). This parameter is particularly important with respect to estimating sludge production. This study estimated this fraction through BioWin™ simulations. The simulation approach also provides a basis for confirming estimates of certain parameters such as the fraction of the influent TKN which is soluble unbiodegradable ($f_{NUS}$).

The simulation study of SBR behaviour was conducted to model system response for the SBR over the whole study period. The simulated response was compared to the actual measured values during the extensive monitoring period. Figure 2.2 illustrates the BioWin™ modeling interface. Operating conditions such as the influent volume and the various periods in the SBR cycle time are set up in the simulator. The influent COD, TKN, and ISS concentrations for each day are specified in the influent element, together with the fractional characteristics determined from the direct measurements. A number of simulation runs are performed, iteratively varying the values of the parameter to be estimated, $f_{UP}$. The objective is to obtain a reasonable fit of simulated to observed response over the intensive period using a single value for the parameter. In the case of $f_{UP}$, the primary parameter response to match is TCOD concentration in the SBR.

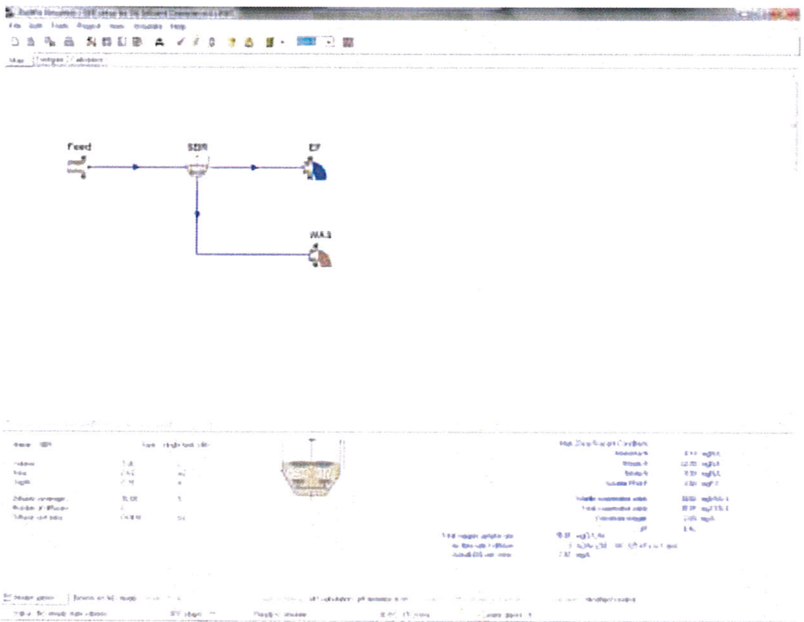



**Figure 2.2 Screen View of the SBR Model Setup in BioWin™**

The maximum specific growth rates of the nitrifiers are determined in a similar fashion. However, in this case, the data to be matched are the responses of ammonia, nitrite, and nitrate over the first 10 – 12 hours of the days of SBR operation when these profiles were collected.

## 2.7 Data Validation

Verifying the experimental data as best as possible is an important quality control check. Several checks can be applied to the data obtained during the intensive monitoring period, such as:

**Consistency of fractions/ratios:** The SBRs are not at a perfect steady state, and influent concentrations may vary from day to day. Therefore, the values of measured parameters also will vary; for example, changing influent TKN results in changing effluent nitrate from day to day. This makes it difficult to assess the reasonableness of many of the measured parameters. A useful approach for data validation is to review the daily fractions/ratios calculated from the measured data. Typically these should not vary substantially from day to day. For example, although influent COD and TKN may increase on a given day, one would expect the TKN/COD ratio to remain relatively constant. Examining data fractions and ratios is useful for identifying suspect data, screening outliers, and identifying unusual data.

**Nitrogen mass balance:** A mass balance on nitrogen (*i.e.* output N / input N) can be calculated for each day of operation, and over the whole period of intensive monitoring. This provides an overall validation of the experimental nitrogen data (*e.g.* TKN, TN, $NO_3$). Typically the daily balances may show some variability due to daily loading changes. The basis for calculating the balances was as follows:

Daily Input = $V_{WW}$ * Influent TN

Daily Output = $V_{WW}$ * Decant Nitrate N
+ $V_{WW}$ * Decant Nitrite N
+ $V_{WW}$ * Decant Ammonia N
+ $V_{WW}$ * Decant Soluble N (org. + unbio.)
+ ($V_{WW}$ - $q_W$) * Decant VSS * N content of VSS
+ $q_W$ * SBR VSS * N content of VSS

**Comparison of fractions/ratios to typical/expected values:** A database of information exists on wastewater characteristic fractions/ratios for many different municipal wastewaters (WERF, 2003), and these typically show reasonable consistency from plant to plant. This can be used as a reference for evaluating the new data. Any significant deviations from "typical" values should be justifiable.

All of these techniques for data validation were applied during and at the end of the intensive monitoring period.

# CHAPTER 3 RESULTS FROM THE SBR ACCLIMATION PERIOD

## 3.1 Preamble

This chapter of the report describes the general performance of the bench-scale SBRs during the acclimation period of the study. Results from the routine daily sampling program (see Table 2.3) are plotted and reviewed.

## 3.2 COD, TSS, and VSS of Raw Sewage from LS8

Figure 3.1 shows the variability of the TSS, VSS, and TCOD concentrations of the raw sewage during the acclimation period.

In general, the TCOD concentration in the raw sewage was about 1000 mg/L, with some days displaying very high TCOD values, as high as 2314 mg/L. The TSS and VSS showed less variability than TCOD, but the concentrations still varied in the large range from 79 to 538 mg TSS/L, and 71 to 474 mg VSS/L. Generally, increases in the total COD concentration were coupled with increases in solids concentration, as verified by the plot of the ratio of TCOD to VSS shown in Figure 3.2, except on days of February 15$^{th}$ and 19$^{th}$, 2013, when TCOD and TSS changed disproportionately. On both days, the TCOD/VSS ratio was much higher than normal, which indicated that there was a significant input of soluble organics to the SBR on this day. The high TCOD and TSS concentrations indicate this is a high strength wastewater.

Figure 3.2 also demonstrates the VSS/TSS ratio of the raw sewage, which was between 0.69 and 0.92 with a mean value of 0.84. The ratio was typical for domestic wastewater.

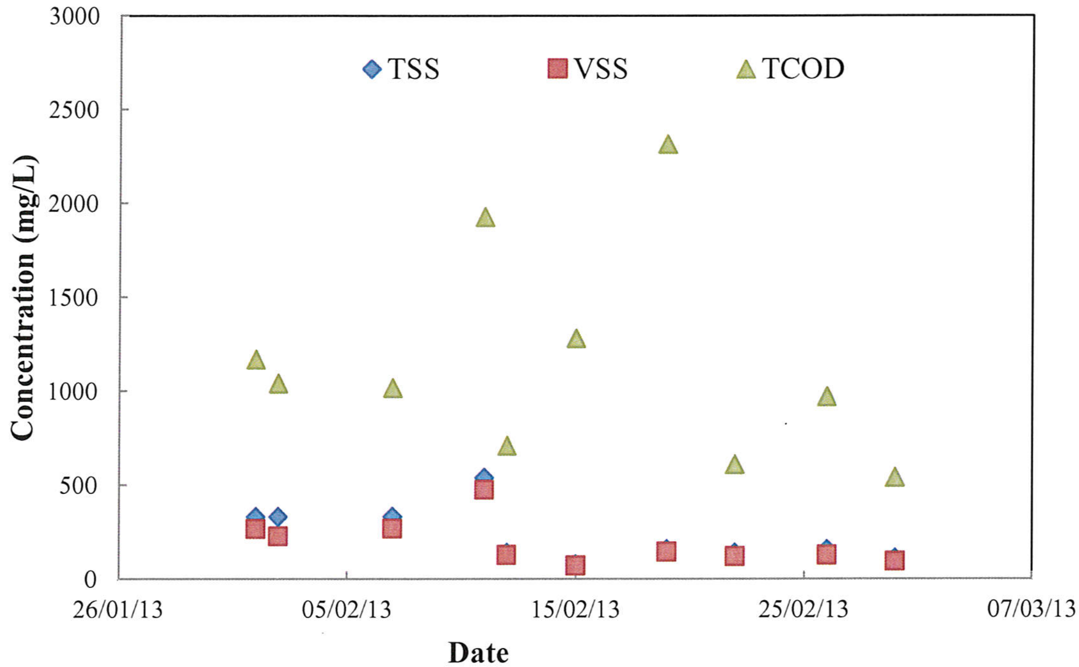



**Figure 3.1 Raw Sewage TCOD, TSS, and VSS**

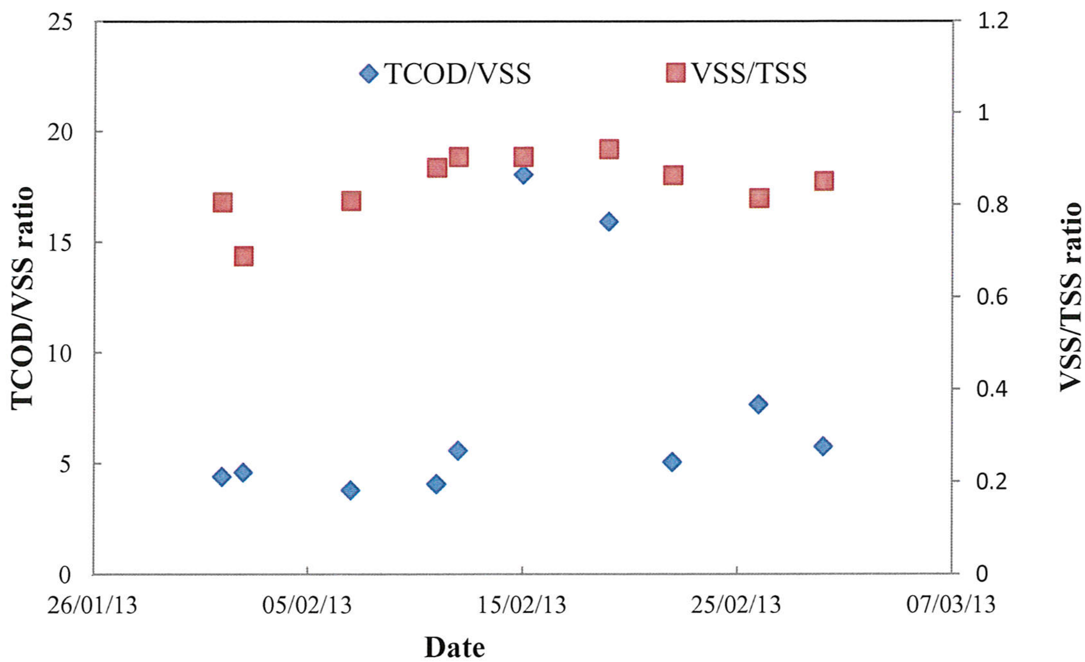



**Figure 3.2 Raw Sewage COD/VSS and VSS/TSS**

## 3.3 TN and Ammonia in Raw Sewage from LS8

Figure 3.3 shows the variability of the TN and ammonia concentrations of the raw sewage during the acclimation period. The TN concentration of the raw sewage ranged from 59.5 to 105.2 mg/L with a mean value of 85.4 mg/L. The ammonia concentration in the raw sewage was between 28.7 and 62.6 mg/L and the average ammonia concentration was 41.2 mg/L. The concentrations show the sewage from LS8 is a high strength wastewater.

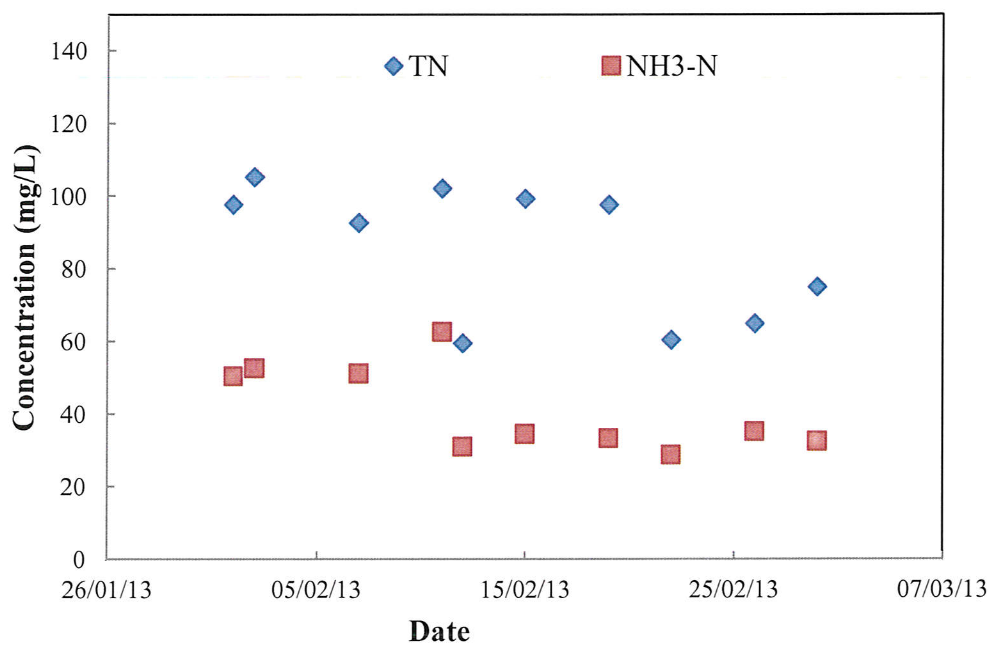



**Figure 3.3 TN and Ammonia Concentrations of Raw Sewage**

## 3.4 TP and $PO_4$-P in Raw Sewage from LS8

Figure 3.4 shows the variability of the TP and $PO_4$-P concentrations of the raw sewage during the acclimation period. The TP concentration of the raw sewage ranged from 15.6 to 28.8 mg/L with a mean value of 22.9 mg/L. The $PO_4$-P concentration in the raw sewage was between 10.6 and 22.3 mg/L and the average $PO_4$-P concentration was 17.1 mg/L. The concentrations also demonstrate the sewage from LS8 is a high strength wastewater. The TP concentration of 22.9 mg/L is significantly higher than typical municipal wastewater, but pretty much matches the data (21.4 mg/L) obtained on 15 February 2012.

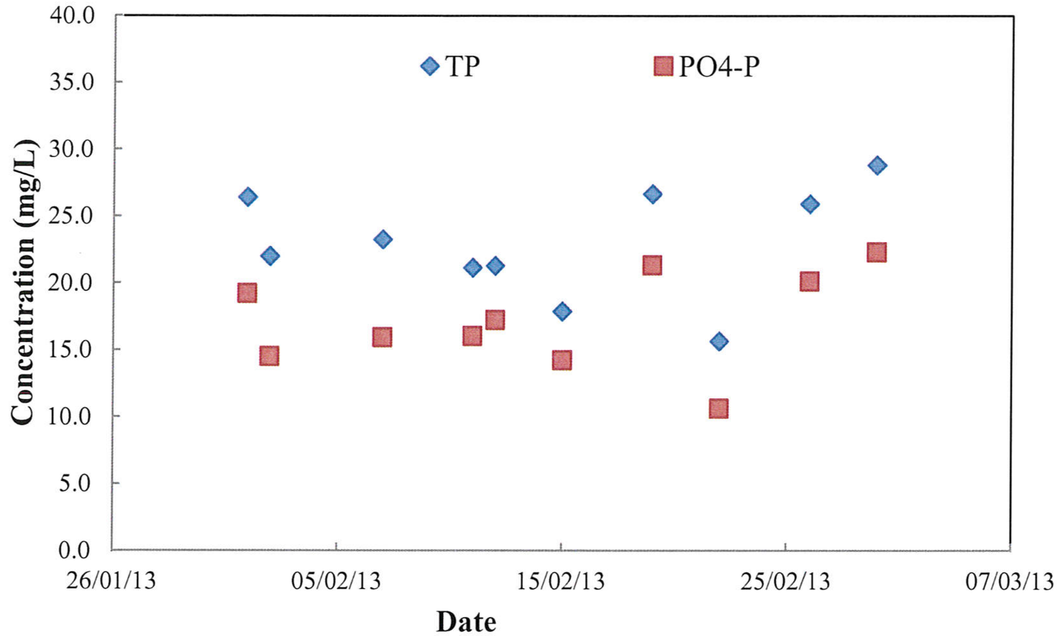



**Figure 3.4 TP and $PO_4$-P Concentrations of Raw Sewage**

## 3.5 TN and TP Ratios of Raw Sewage from LS8

Figures 3.5 and 3.6 show the ratios of TN/TCOD and $NH_3$-N/TN of the raw sewage and TP/TCOD and $PO_4$-P/TN ratios of the raw sewage during the acclimation period. The TN/TCOD ratio of raw sewage was fairly consistent with a mean of about 0.08 mg N / mg COD, which is lower than typical for a domestic wastewater. The TN/TCOD ratio is an indicator of a plant's denitrification potential; a lower than typical TN/COD ratio indicates there may be a sufficient carbon in the influent wastewater to drive denitrification. $NH_3$-N/TN ratio had an average value of 0.48 mg N/ mg N, which is lower than the typical value for a domestic wastewater.

The TP/TCOD ratio of raw sewage was also consistent with a mean of about 0.02 mg P / mg COD, which is higher than typical for domestic wastewater. The average $PO_4$-P/TN ratio was 0.75 mg P/ mg P, which is much higher than the typical value for domestic wastewater.

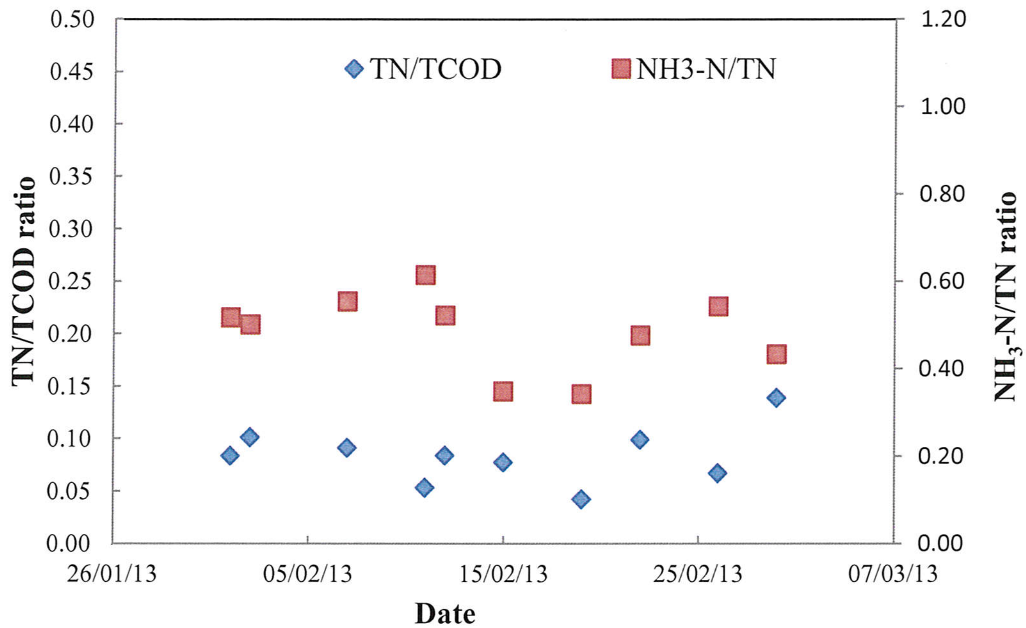



**Figure 3.5 TN/TCOD and $NH_3$-N/TN Ratios of Raw Sewage**

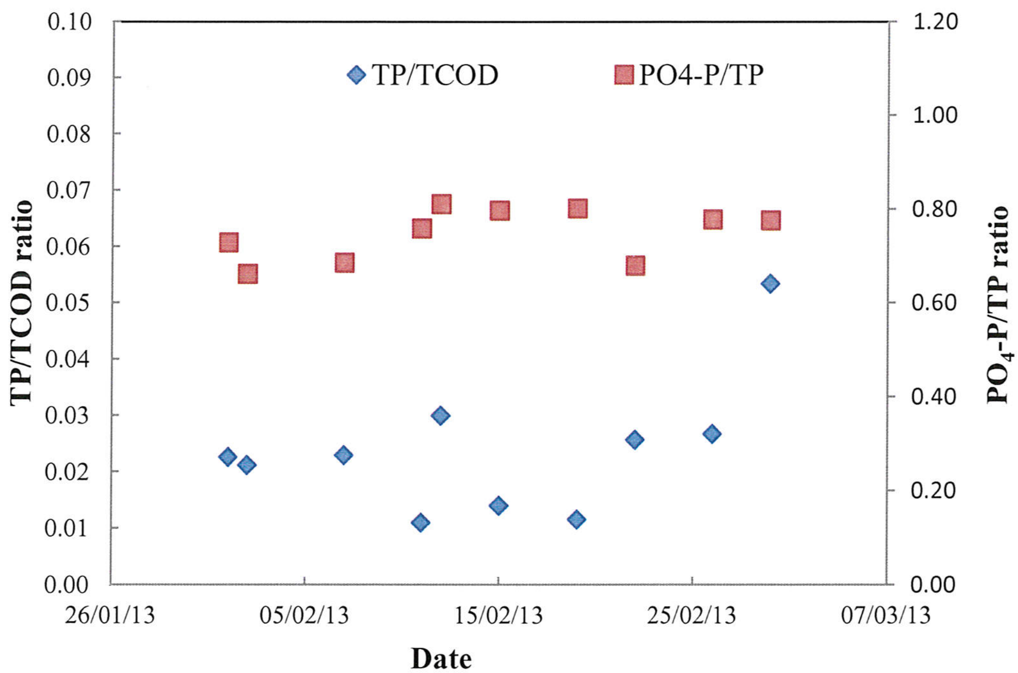



**Figure 3.6 TP/TCOD and $PO_4$-P/TP Ratios of Settled Sewage**

The key parameters of wastewater tested during the acclimation period are summarized in Tables 3.1 through 3.3.

## Table 3.1 Key Wastewater Parameters for Raw Sewage from LS8

| Date | pH | Alkalinity (mg $CaCO_3$/L) | Conductivity (mS/cm) | TSS (mg/L) | VSS (mg/L) | TDS (mg/L) | TCOD (mg/L) | sCOD (mg/L) | TP (mg/L) | $PO_4$-P (mg/L) | TN (mg/L) | $NH_3$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | Ca (mg/L) | Mg (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/02/2013 | 6.38 | 295 | 2.70 | 330 | 266 | 1680 | 1169 | 678 | 26.4 | 19.2 | 97.6 | 50.4 | 0.1 | 0.0 | 85 | 36 |
| 02/02/2013 | 6.91 | 330 | 2.51 | 330 | 227 | 1578 | 1040 | 561 | 22.0 | 14.5 | 105.2 | 52.6 | 0.1 | 0.0 | 87 | 35 |
| 07/02/2013 | 7.50 | 390 | 2.69 | 333 | 269 | 1813 | 1016 | 608 | 23.2 | 15.9 | 92.6 | 51.2 | 0.1 | 1.4 | 99 | 38 |
| 11/02/2013 | 6.64 | 355 | 2.60 | 538 | 474 | 1553 | 1926 | 590 | 21.1 | 16.0 | 102 | 62.6 | 0.1 | 0.0 | 72 | 28 |
| 12/02/2013 | 7.64 | 340 | 1.88 | 141 | 128 | 1225 | 710 | 437 | 21.2 | 17.2 | 59.5 | 31.0 | 0.6 | 5.0 | 98 | 27 |
| 15/02/2013 | 7.34 | 330 | 1.60 | 79 | 71 | 1053 | 1280 | 469 | 17.8 | 14.2 | 99.2 | 34.5 | 0.1 | 0.5 | -* | -* |
| 19/02/2013 | 7.19 | 320 | 1.91 | 158 | 146 | 2492 | 2314 | 1948 | 26.6 | 21.3 | 97.5 | 33.3 | 0.2 | 7.5 | 96 | 29 |
| 22/02/2013 | 7.28 | 270 | 1.44 | 140 | 121 | 962 | 610 | 374 | 15.6 | 10.6 | 60.3 | 28.68 | 0.1 | 1.3 | 72 | 30 |
| 26/02/2013 | 7.43 | 390 | 1.88 | 156 | 127 | 1265 | 970 | 429 | 25.9 | 20.1 | 64.8 | 35.1 | 0.4 | 4.4 | 80 | 34 |
| 01/03/2013 | 7.19 | 275 | 1.89 | 111 | 94 | 1180 | 540 | 404 | 28.8 | 22.3 | 74.9 | 32.4 | 0.0 | 0.0 | 88 | 34 |
| **Average** | **7.15** | **330** | **2.11** | **232** | **192** | **1480** | **1158** | **650** | **22.9** | **17.1** | **85.4** | **41.2** | **0.2** | **2.0** | **86** | **32** |
| **Std. Dev.** | **0.40** | **42** | **0.47** | **145** | **121** | **452** | **567** | **467** | **4.2** | **3.6** | **18.4** | **11.8** | **0.2** | **2.7** | **10** | **4** |

* No data available. Could not reach end point and no sample available for repetition.

### Table 3.2 Key Wastewater Parameters for Raw Sewage from LS5

| Date | pH | Alkalinity (mg CaCO3/L) | Conductivity (mS/cm) | TSS (mg/L) | VSS (mg/L) | TDS (mg/L) | TCOD (mg/L) | sCOD (mg/L) | TP (mg/L) | $PO_4$-P (mg/L) | TN (mg/L) | $NH_3$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | Ca (mg/L) | Mg (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **07/02/ 2013** | 7.81 | 760 | 11.2 | 132.5 | 96 | 7138 | 333 | 212 | 2.4 | 1.0 | 21.3 | 14.36 | 0.1 | 0.2 | 460 | 141 |
| **15/02/ 2013** | 7.87 | 840 | 10.7 | 34.5 | 21 | 6985 | 167 | 146 | 0.9 | 0.5 | 12.9 | 8.91 | 0.1 | 0.1 | 404 | 126 |
| **Average** | **7.84** | **800** | **11.0** | **83.5** | **59** | **7062** | **250** | **179** | **1.7** | **0.8** | **17.1** | **11.6** | **0.1** | **0.2** | **432** | **134** |
| **Std. Dev.** | **0.04** | **57** | **0.4** | **69.3** | **53** | **108** | **117** | **47** | **1.1** | **0.4** | **5.9** | **3.9** | **0.0** | **0.1** | **40** | **11** |

### Table 3.3 Key Wastewater Parameters for Raw Sewage from Septage

| Date | Sample | pH | Alka. (mg CaCO3/L) | Conductivity (mS/cm) | TSS (mg/L) | VSS (mg/L) | TDS (mg/L) | TCOD (mg/L) | sCOD (mg/L) | TP (mg/L) | $PO_4$-P (mg/L) | TN (mg/L) | $NH_3$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) | Ca (mg/L) | Mg (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **12/2/ 2013** | **Reinfeld** | 7.48 | 620 | 3.40 | 119 | 95 | 1697 | 796 | 580 | 14.2 | 10.4 | 133.7 | 89.4 | 0.0 | 0.1 | 93 | 0* |
| | **Schan-zenfeld** | 7.41 | 570 | 2.41 | 256 | 235 | 1277 | 1080 | 584 | 11.5 | 8.4 | 105.6 | 78.0 | 0.1 | 0.0 | 64 | 0* |

*For Mg measurement, no EDTA used to reach final end point

**Table 3.4 Loads of major contaminants in LS8**

| Date | TCOD (kg/d) | TP (kg/d) | TN (kg/d) | $NH_3$-N (kg/d) |
|---|---|---|---|---|
| 07-Feb-13 | 2638.6 | 60.3 | 240.5 | 133.0 |
| 12-Feb-13 | 1982.3 | 59.2 | 166.1 | 86.6 |
| 15-Feb-13 | 3605.8 | 50.1 | 279.4 | 97.2 |
| 19-Feb-13 | 5768.8 | 66.3 | 243.1 | 83.0 |
| 22-Feb-13 | 1528.1 | 39.1 | 151.1 | 71.8 |
| 26-Feb-13 | 2680.1 | 71.6 | 179.0 | 97.0 |
| 01-Mar-13 | 1566.5 | 83.5 | 217.3 | 94.0 |
| 04-Mar-13 | 3359.0 | 47.5 | 195.5 | 117.6 |
| 06-Mar-13 | 3415.2 | 45.2 | 172.8 | 110.5 |
| 08-Mar-13 | 4216.2 | 67.5 | 247.0 | 127.3 |
| **Average** | **3076.0** | **59.0** | **209.2** | **101.8** |

## 3.6 Mixed Liquor Suspend Solids in SBRs

Figure 3.7 is the plot of MLSS, MLVSS, and MLVSS/MLSS in the SBR. The MLSS concentration showed some variation in response to the COD variation in the feed. The MLVSS/MLSS ratio had an averaged value of 0.76 in the SBR, which is typical for an activated sludge fed with domestic wastewater. The solids concentration in the SBR stabilized before the start of the extensive monitoring period, which indicated that a quasi-steady state had been reached for the intensive tests.

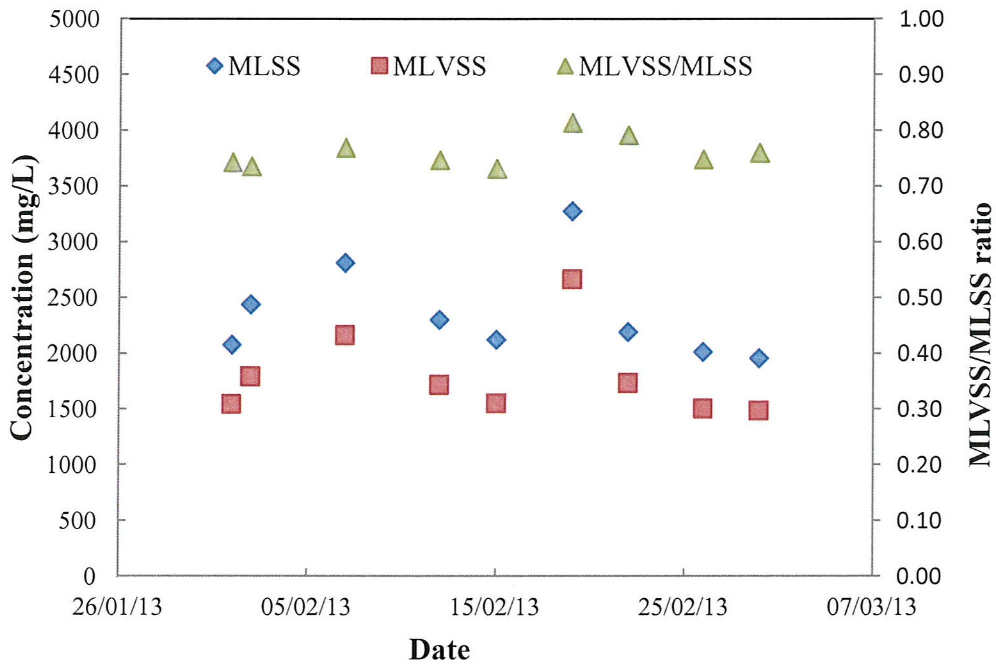



**Figure 3.7 MLSS, MLVSS and MLVSS/MLSS in SBR**

## 3.7 TSS, VSS and $NO_3$-N in Effluent

Figure 3.8 present the TSS, VSS, and $NO_3$-N in the effluent from the SBR. It is shown full nitrification was reached from the beginning of the acclimation period since there were nitrifiers in the seed from WEWPCC in Winnipeg. $NO_3$-N concentration in the effluent had the same variation trend as the TN in the feed, indicating a high degree of stability in the SBRs' nitrification process. This is favorable for the estimation of nitrifier maximum specific growth rate since this performance impacts the population of nitrifiers present in the system during the extensive monitoring period. The effluent TSS had some variation but stabilized at below 20 mg/L towards the end of the acclimation period in the SBR. The stabilization of effluents indicates a quasi-steady state had been reached before the extensive monitoring period began.

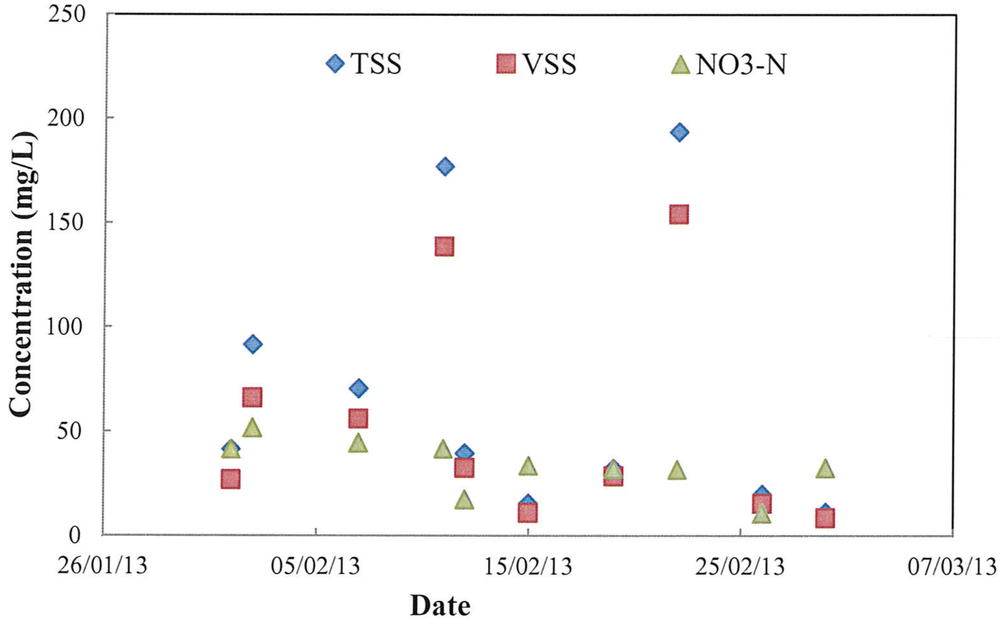



**Figure 3.8 TSS, VSS and $NO_3$-N in Effluent from SBR**

# CHAPTER 4 RESULTS FROM SBR EXTENSIVE MONITORING PERIOD

## 4.1 Preamble

This chapter describes the results from analysis of the data collected during the extensive monitoring period for the SBR. The methods used in the analysis were in accordance with the procedures described in Chapter 2.

## 4.2 Raw Results Data

The raw results from the analysis of the data collected during the extensive monitoring period in summer are presented in Table 4.1 through Table 4.5. The data included the analysis on raw wastewater from three sources: LS8 (feed to the SBR), Lift Station 5, and Saputo. The performance of the SBR was monitored by analysing the effluent and WAS from the bioreactor.

## 4.3 SBR Data Validation: Nitrogen Balance

A complete nitrogen balance was performed on the data collected during the extensive monitoring period for the SBR. The results are presented in Table 4.6. There was 75% of nitrogen recovery in the SBR. The nitrogen loss could be through denitrification at the beginning of the cycle due to low DO in the bioreactor resulting from the high readily biodegradable COD present in the raw sewage.

## 4.4 Relevant Influent and Mixed Liquor Ratios

Various influent and mixed liquor ratios and fractions are presented in Table 4.7. All of the ratios and fractions showed consistency through the course of the extensive monitoring period, indicating that the collected data was valid.

Influent TSS/TCOD ratio: The average TSS/TCOD ratio for the raw sewage was 0.30 mg TSS/mg TCOD. The ratio is lower than the typical value for a domestic wastewater, which indicated there was large amount of soluble organics available in the wastewater.

Influent TKN/TCOD ratio: The average TKN/TCOD ratio for the raw sewage was 0.08 mg TKN/mg TCOD. The ratio is lower than the typical value for a domestic wastewater. The low value is favorable for the proposed wastewater treatment plant should nitrogen removal be required.

Influent sCOD/TCOD ratio: The average sCOD/TCOD ratio for the raw sewage was 0.60 mg sCOD/mg TCOD. The value is higher than the typical value, which also indicated more than normal amount of soluble organics present in the raw sewage.

Influent ffCOD/TCOD ratio: The average ffCOD/TCOD ratio for the raw sewage was 0.39 mg ffCOD/mg TCOD. This ratio, the same as the sCOD, is higher than the typical value for a domestic wastewater.

Influent VSS/TSS ratio: The average VSS/TSS for the raw sewage was 0.74 mg VSS/mg TSS. The ratio is close to the typical value for a domestic wastewater.

Mixed liquor VSS/TSS ratio: The average VSS/TSS for the mixed liquor in the SBR was 0.75 mg VSS/mg TSS. The value is close to the typical ratio for a system treating a domestic wastewater. It was noticed that this value was in agreement with the VSS/TSS ratio in the feed.

### Table 4.1 Raw Sewage Results from Extensive Monitoring Period – LS8

| Date | TSS (mg/L) | VSS (mg/L) | TCOD (mg/L) | sCOD (mg/L) | ffCOD (mg/L) | TP (mg/L) | $PO_4$-P (mg/L) | TN (mg/L) | $NH_3$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **05/03/2013** | 281 | 226 | 1088 | 712 | 455 | 24.0 | 16.3 | 83.7 | 41.1 | 0.9 | 0.1 |
| **07/03/2013** | 151 | 128 | 813 | 524 | 314 | 22.4 | 19.1 | 53.3 | 26.0 | 0.3 | 2.6 |
| **09/03/2013** | 209 | 148 | 633 | 399 | 288 | 13.4 | 5.7 | 69.5 | 39.6 | 0.2 | 0.5 |
| **12/03/2013** | 402 | 286 | 1195 | 658 | 469 | 28.1 | 15.1 | 82.4 | 41.1 | 0.4 | 2.3 |
| **14/03/2013** | 284 | 184 | 757 | 385 | 232 | 19.7 | 10.8 | 71.0 | 42.3 | 0.5 | 1.0 |
| **Average** | **265** | **194** | **897** | **535** | **351** | **21.5** | **13.4** | **72.0** | **38.0** | **0.4** | **1.3** |
| **Std. Dev.** | **94** | **64** | **235** | **148** | **105** | **5.5** | **5.3** | **12.2** | **6.8** | **0.3** | **1.1** |

### Table 4.2 Raw Sewage Results from Extensive Monitoring Period – Saputo

| Date | TSS (mg/L) | VSS (mg/L) | TCOD (mg/L) | sCOD (mg/L) | ffCOD (mg/L) | TP (mg/L) | $PO_4$-P (mg/L) | TN (mg/L) | $NH_3$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **05/03/2013** | 461 | 395 | 3825 | 2961 | 2529 | 77.5 | 15.4 | 133.9 | 17.7 | 0.1 | 4.8 |
| **09/03/2013** | 520 | 464 | 4265 | 3332 | 2622 | 66.1 | 17.4 | 149.8 | 15.8 | 0.1 | 3.8 |
| **Average** | **491** | **430** | **4045** | **3147** | **2576** | **71.8** | **16.4** | **141.9** | **16.7** | **0.1** | **4.3** |
| **Std. Dev.** | **42** | **49** | **311** | **262** | **66** | **8.1** | **1.4** | **11.3** | **1.3** | **0.0** | **0.7** |

**Table 4.3 Raw Sewage Results from Extensive Monitoring Period – LS5**

| Date | TCOD (mg/L) | sCOD (mg/L) |
|---|---|---|
| 05/03/2013 | 274 | 210 |
| 07/03/2013 | 197 | 153 |
| 09/03/2013 | 302 | 209 |
| 12/03/2013 | 204 | 160 |
| 14/03/2013 | 474 | 222 |
| **Average** | **290** | **191** |
| **Std. Dev.** | **112** | **32** |

**Table 4.4 SBR Effluent Results from Extensive Monitoring Period**

| Date | TSS (mg/L) | VSS (mg/L) | TCOD (mg/L) | sCOD (mg/L) | ffCOD (mg/L) | $PO_4$-P (mg/L) | sTN (mg/L) | $NH_3$-N (mg/L) | $NO_2$-N (mg/L) | $NO_3$-N (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| 05/03/2013 | 12 | 8 | 49 | 40 | 28 | 9.9 | 36.6 | 0.2 | 0.1 | 31.5 |
| 07/03/2013 | 7 | 5 | 43 | 31 | 25 | 11.2 | 29.0 | 0.0 | 0.2 | 25.5 |
| 09/03/2013 | 11 | 9 | 45 | 34 | 21 | 8.0 | 41.5 | 0.1 | 0.2 | 39.3 |
| 12/03/2013 | 12 | 8 | 54 | 41 | 24 | 6.9 | 39.2 | 0.0 | 0.1 | 35.2 |
| 14/03/2013 | 19 | 15 | 62 | 41 | 24 | 10.4 | 49.2 | 0.0 | 0.2 | 46.0 |
| **Average** | **12** | **9** | **51** | **37** | **24** | **9.2** | **39.1** | **0.1** | **0.2** | **35.5** |
| **Std. Dev.** | **4** | **4** | **7** | **5** | **3** | **1.8** | **7.3** | **0.1** | **0.0** | **7.7** |

**Table 4.5 Mixed Liquor Results from Extensive Monitoring Period**

| Date | TSS (mg/L) | VSS (mg/L) | TCOD (mg/L) | TN (mg/L) |
|---|---|---|---|---|
| **05/03/2013** | 2235 | 1698 | 2657 | 197.0 |
| **07/03/2013** | 2440 | 1853 | 2825 | 182.4 |
| **09/03/2013** | 2448 | 1863 | 2777 | 207.2 |
| **12/03/2013** | 2798 | 2083 | 3192 | 228.5 |
| **14/03/2013** | 2815 | 2088 | 3217 | 221.5 |
| **Average** | **2547** | **1917** | **2934** | **207** |
| **Std. Dev.** | **252** | **167** | **255** | **19** |

**Table 4.6 Nitrogen Balance in SBR from Extensive Monitoring Period**

| Date | INPUT (mgN/d) | $NO_3$-N out (mgN/d) | $NO_2$-N out (mgN/d) | $NH_3$-N out (mgN/d) | Nos+Nus out (mgN/d) | Eff. VSS (mgN/d) | WAS (mgN/d) | OUTPUT (mgN/d) |
|---|---|---|---|---|---|---|---|---|
| **05/03/2013** | 335 | 140 | 0 | 1 | 5 | 3 | 50 | 199 |
| **07/03/2013** | 213 | 106 | 1 | 0 | 9 | 2 | 54 | 172 |
| **09/03/2013** | 278 | 157 | 1 | 0 | 8 | 3 | 55 | 224 |
| **12/03/2013** | 330 | 149 | 0 | 0 | 7 | 3 | 61 | 220 |
| **14/03/2013** | 284 | 184 | 1 | 0 | 12 | 5 | 61 | 263 |
| **Total** | **1440** | **Overall % = 75%** | | | | | | **1078** |

Note: The table shows the nitrogen mass balance was 75% and that nitrogen was lost through denitrification due to low DO concentration at the beginning of the cycle caused by the high readily biodegradable COD present in the raw sewage.

**Table 4.7 Influent and Mixed Liquor Ratios and Fractions**

| Date | Raw Sewage | | | | | | | | Mixed Liquor | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TSS/ TCOD | ISS/ TSS | ISS/ TCOD | VSS/ TSS | TKN/ TCOD | TP/ TCOD | sCOD/ TCOD | ffCOD/ TCOD | ISS | VSS/ TSS |
| 05/03/2013 | 0.26 | 0.19 | 0.05 | 0.81 | 0.08 | 0.02 | 0.65 | 0.42 | 538 | 0.76 |
| 07/03/2013 | 0.19 | 0.15 | 0.03 | 0.85 | 0.06 | 0.03 | 0.64 | 0.39 | 588 | 0.76 |
| 09/03/2013 | 0.33 | 0.29 | 0.10 | 0.71 | 0.11 | 0.02 | 0.63 | 0.45 | 585 | 0.76 |
| 12/03/2013 | 0.34 | 0.29 | 0.10 | 0.71 | 0.07 | 0.02 | 0.55 | 0.39 | 715 | 0.74 |
| 14/03/2013 | 0.38 | 0.35 | 0.13 | 0.65 | 0.09 | 0.03 | 0.51 | 0.31 | 727 | 0.74 |
| **Average** | **0.30** | **0.26** | **0.08** | **0.74** | **0.08** | **0.02** | **0.60** | **0.39** | **631** | **0.75** |
| **Std. Dev.** | **0.08** | **0.08** | **0.04** | **0.08** | **0.02** | **0.00** | **0.06** | **0.06** | **85** | **0.01** |

## 4.5 Model Parameters from Direct Measurement and Calculation

Various influent wastewater fractions and stoichiometric values are presented in Table 4.8. The values were required for process modelling through BioWin™.

Influent soluble readily biodegradable COD fraction ($f_{BS}$): The average $f_{BS}$ for the raw sewage was 0.36 mg COD/mg COD. The ratio is much higher than the typical value of 0.16 mg COD/mg COD for a municipal wastewater.

Influent soluble unbiodegradable COD fraction ($f_{US}$): The average $f_{US}$ for the raw sewage was 0.03 mg COD/mg COD. This ratio is lower than the typical value of 0.05 mg COD/mg COD.

Influent ammonia/TKN fraction ($f_{NA}$): The average $f_{NA}$ for the raw sewage was 0.54 mg N/mg N, which is lower than the typical value for a domestic wastewater. The ratio indicated there was larger amount of organic nitrogen than normal present in the raw sewage.

Influent soluble unbiodegradable TKN fraction ($f_{NUS}$): The average $f_{NUS}$ for the raw sewage was 0.02 mg N/mg N, which is a typical value. The low $f_{NUS}$ for the raw sewage is favorable if an effluent TN limit were imposed on the upgraded wastewater treatment plant because this portion of the TKN cannot be removed irrespective of the plant process configuration.

Mixed liquor COD/VSS ratio ($f_{CV,\ ML}$): An average $f_{CV,\ ML}$ value of 1.51 mg COD/mg VSS was found for the mixed liquor in the SBR. The value is slightly higher than the typical value of 1.48 mg COD/mg VSS for a system treating municipal wastewater.

Nitrogen content of mixed liquor ($f_N$): An average $f_N$ value of 0.09 mg N/mg VSS was found for the mixed liquor in the bioreactor, which is close to the typical value of 0.10 mg N/mg VSS for a system treating municipal wastewater.

### Table 4.8 Raw Sewage Concentration and Fractions– LS8

| Date | Influent concentrations in (mg/L); fractions (-) | | | | | | | | | | | Mixed Liquor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TCOD | TSS | ISS | TKN | TP | $f_{BS}$ | $f_{US}$ | $f_{CV}$ | $f_{NUS}$ | $f_{PO4}$ | $f_{NA}$ | $f_{CV}$ | $f_N$ |
| **05/03/2013** | 1088 | 281 | 55 | 83 | 24.0 | 0.39 | 0.03 | 1.66 | 0.01 | 0.68 | 0.50 | 1.54 | 0.09 |
| **07/03/2013** | 813 | 151 | 23 | 50 | 22.4 | 0.36 | 0.03 | 2.27 | 0.03 | 0.85 | 0.51 | 1.51 | 0.08 |
| **09/03/2013** | 633 | 209 | 61 | 69 | 13.4 | 0.42 | 0.03 | 1.58 | 0.02 | 0.42 | 0.58 | 1.47 | 0.09 |
| **12/03/2013** | 1195 | 402 | 116 | 80 | 28.1 | 0.37 | 0.02 | 1.88 | 0.02 | 0.54 | 0.52 | 1.51 | 0.09 |
| **14/03/2013** | 757 | 284 | 100 | 70 | 19.7 | 0.27 | 0.03 | 2.02 | 0.04 | 0.55 | 0.61 | 1.52 | 0.08 |
| **Average** | **897** | **265** | **71** | **70** | **21.5** | **0.36** | **0.03** | **1.88** | **0.02** | **0.61** | **0.54** | **1.51** | **0.09** |
| **Std. Dev.** | **235** | **94** | **37** | **13** | **5.5** | **0.06** | **0.01** | **0.28** | **0.01** | **0.16** | **0.05** | **0.03** | **0.01** |

## 4.6 Model Parameters Estimated from Simulation

Certain model parameters cannot be determined directly by measurement or calculated from the collected data. For this study, these parameters were estimated iteratively through BioWin™ modelling.

The simulation study of the SBR was conducted to model system response over the extensive monitoring period. Operating conditions such as the influent volume and the various periods in the SBR cycle time were set up in the simulator. The influent COD, TKN, and ISS concentrations for each day were specified in the influent element, together with the fractional characteristics determined from the direct measurements.

A number of simulation runs were performed, iteratively varying the values of the parameters to be estimated (*e.g.* $f_{UP}$, $\mu_{maxAOB}$, $\mu_{maxNOB}$). The objective was to obtain a reasonable agreement between simulated response and observed data over the intensive period using a single model parameter set.

### 4.6.1 Influent Unbiodegradable Particulate COD ($f_{UP}$)

A series of BioWin™ simulations were run by iteratively varying the value of the unbiodegradable particulate COD fraction, $f_{UP}$. The objective was to find the best fit of the simulated response of the mixed liquor in the SBR to the actual observations.

A value for $f_{UP}$ of 0.09 mg COD / mg COD produced a good fit between the simulated and observed TCOD, TSS, and VSS concentrations in the SBR, which accepted raw sewage as feed (Figures 4.1, 4.2, 4.3). In the figures, the dots are the measured data and the lines are the simulated response.

The $f_{UP}$ for the raw sewage was within the typical range of 0.07 – 0.22 mg COD/mg COD, but closer to the lower bracket. The low $f_{UP}$ ratio may indicate a low sludge production, which can benefit the sludge handling in terms of the cost.

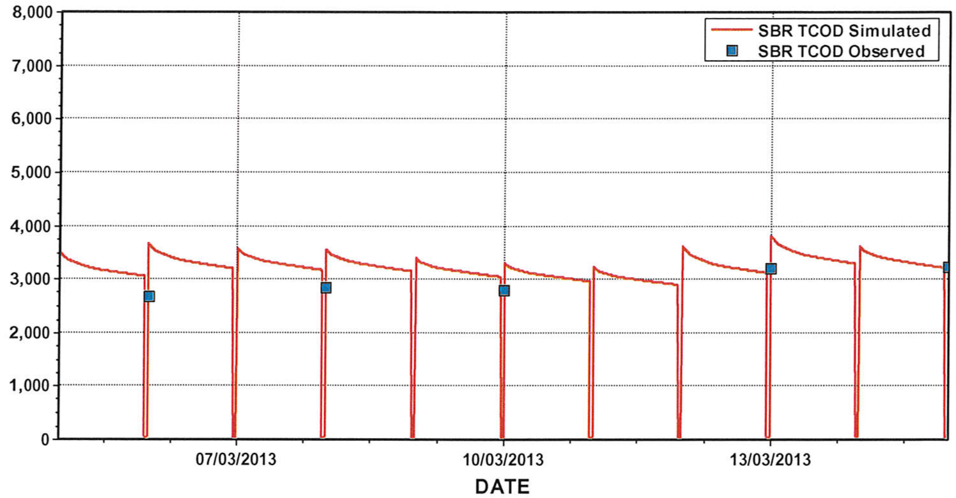



**Figure 4.1 Simulated Mixed Liquor TCOD vs. Observed Mixed Liquor TCOD in SBR**

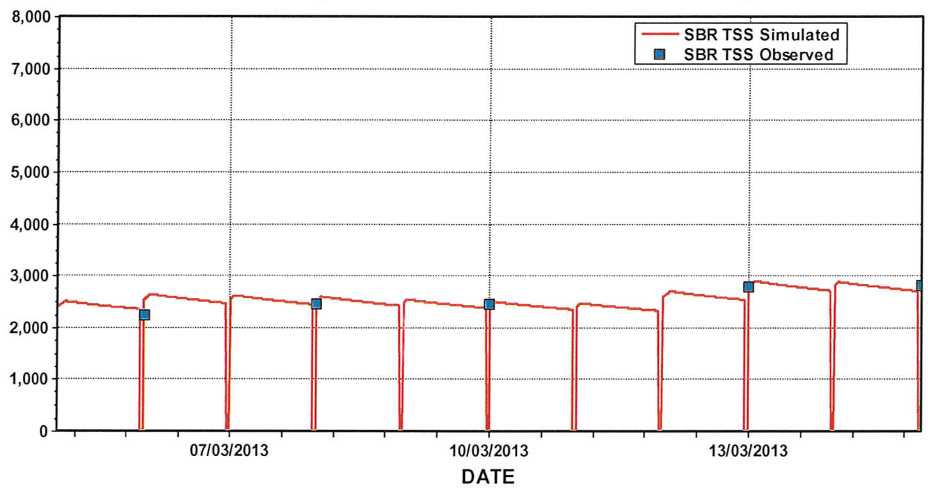



**Figure 4.2 Simulated Mixed Liquor TSS vs. Observed Mixed Liquor TSS in SBR**

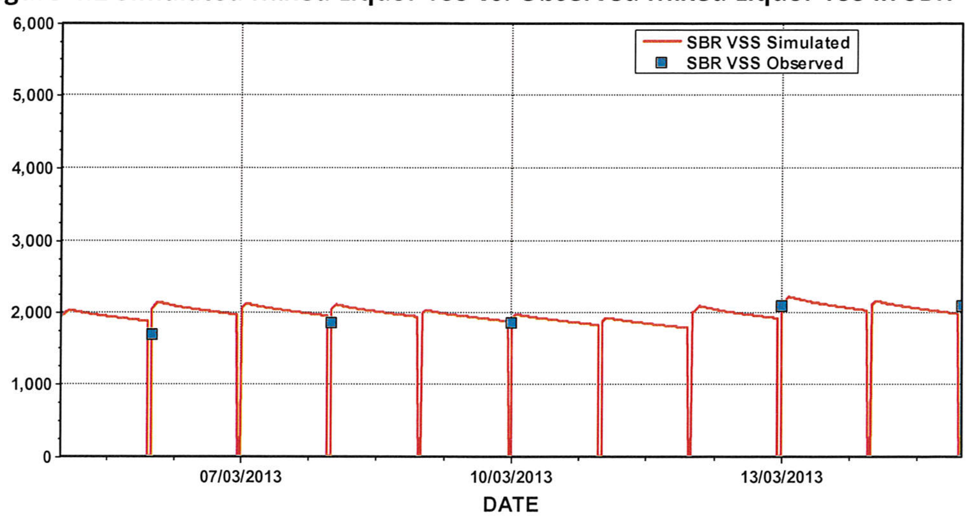



**Figure 4.3 Simulated Mixed Liquor VSS vs. Observed Mixed Liquor VSS in SBR**

Other simulated responses were available to serve as secondary checks for the $f_{UP}$ estimation. The BioWin™ program requires the inputs of COD, TKN, TP, ISS, etc. in the influent. TSS and VSS data are not directly accepted as inputs. The simulator calculates influent TSS and VSS as a result of the TCOD input and other wastewater characteristic fractions inputted. The unbiodegradable particulate COD fraction has a significant impact on the influent TSS predicted by the simulator. How well the TSS predictions match the observed values can be used to check the $f_{UP}$ estimation. Another factor that affects the prediction of influent TSS is COD/VSS ratio ($f_{CV}$). By setting $f_{CV}$ to 1.9 mg COD/mg VSS for raw sewage, there was a good match between the observed influent TSS and the predicted values by the simulator (Figures 4.4). These simulated results further confirmed the estimation of $f_{UP}$ and $f_{CV}$.

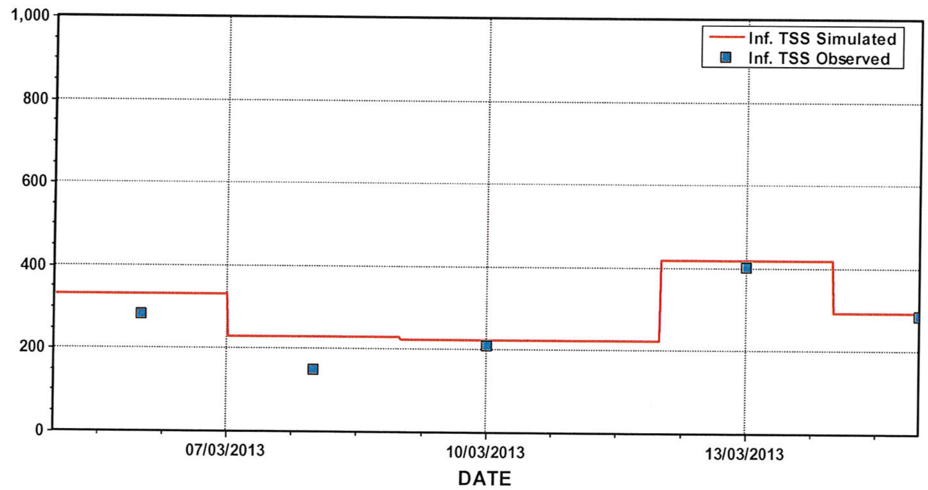



**Figure 4.4 Simulated TSS vs. Observed TSS in Raw Sewage**

### 4.6.2 Nitrifier Maximum Specific Growth Rate

The nitrifier maximum specific growth rate was also determined through BioWin™ simulations. For the estimation, five batch tests were run for the SBR during the course of the extensive monitoring period. One additional parallel batch test using waste from the SBR was also conducted every time when the batch test was performed on the SBR. The simulation purpose was to best match the predicted $NH_3$-N, $NO_2$-N, and $NO_3$-N concentrations with the measured ones by varying the set points of $\mu_{maxAOB,20}$ and $\mu_{maxNOB,20}$.

The simulation results are presented in Figures 4.5 through 4.13 and the growth rates are summarized in Tables 4.9 and 4.10.

It was found that:

- AOB maximum specific growth rate was estimated at 0.95 1/d in the SBR, which was fed with raw sewage. When the growth rate was analyzed by dosing $NH_4Cl$ to the WAS from the bioreactor, the AOB maximum specific growth rate of 0.94 1/d was obtained. Both of the rates are close the typical value of 0.9 1/d.

- NOB maximum specific growth rate was evaluated at 0.74 1/d in the SBR, which was fed with raw sewage. When the growth rate was assessed by dosing $NH_4Cl$ to the WAS from the bioreactor, the NOB maximum specific growth rate of 0.75 1/d was obtained. Both of the rates are close the typical value of 0.7 1/d.

- The typical nitrifiers growth rates attained from both of the methods and the similarity of the rates demonstrated there was no inhibition of the nitrifiers by the raw sewage from LS8.

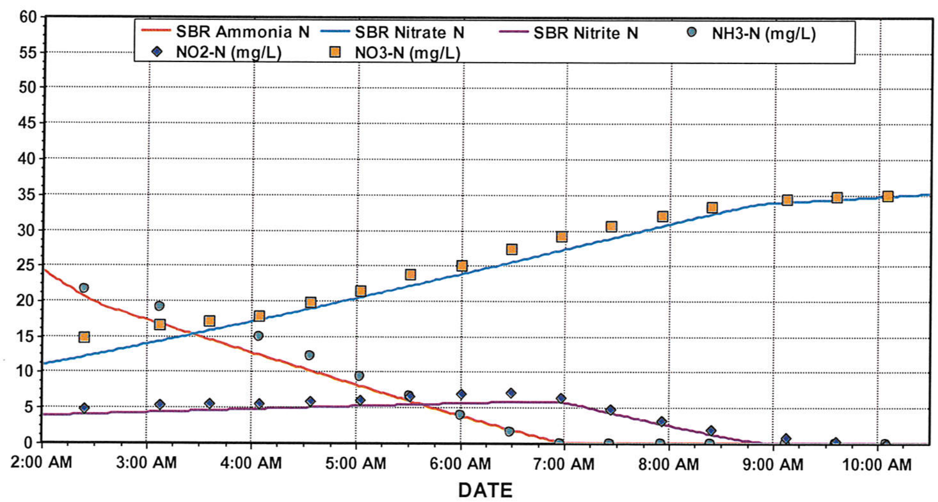



**Figure 4.5 Batch Test 1 – SBR Fed with Raw Sewage**

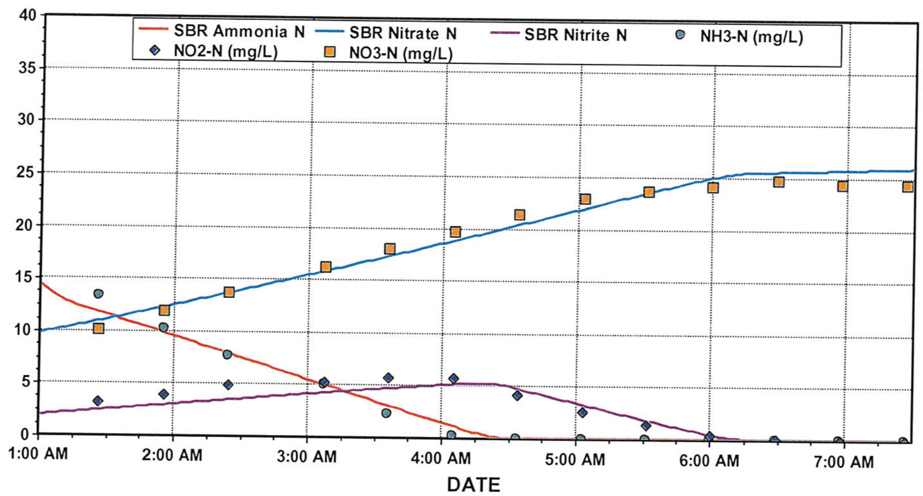



**Figure 4.6 Batch Test 2 – SBR Fed with Raw Sewage**

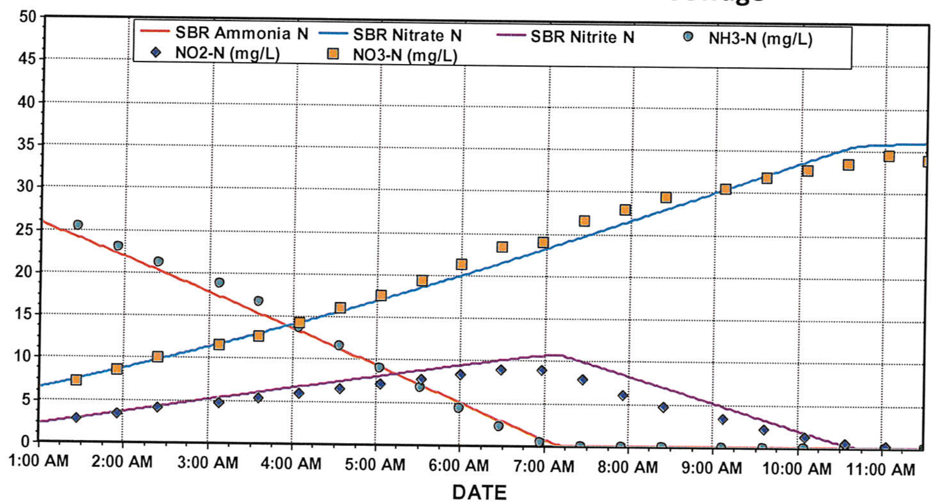



**Figure 4.7 Batch Test 3 – SBR Fed with Raw Sewage**

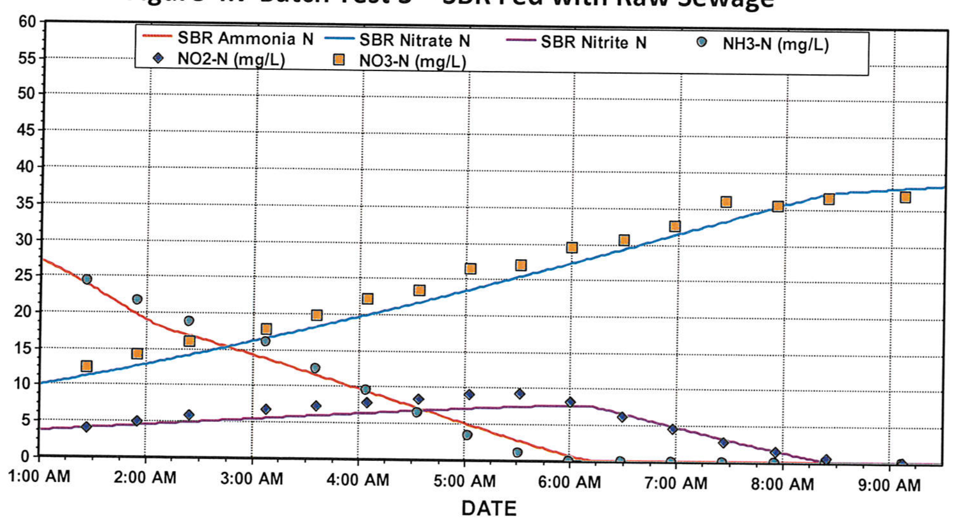



**Figure 4.8 Batch Test 4 – SBR Fed with Raw Sewage**

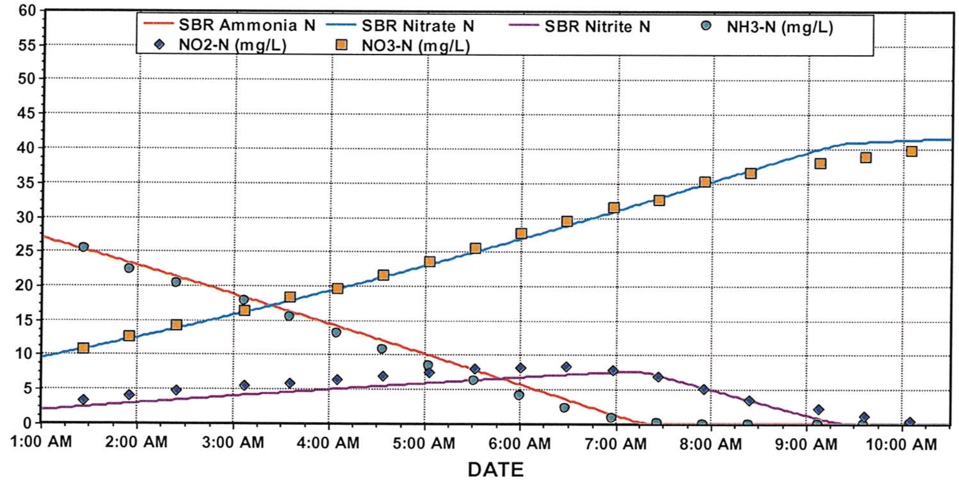



**Figure 4.9 Batch Test 5 – SBR Fed with Raw Sewage**

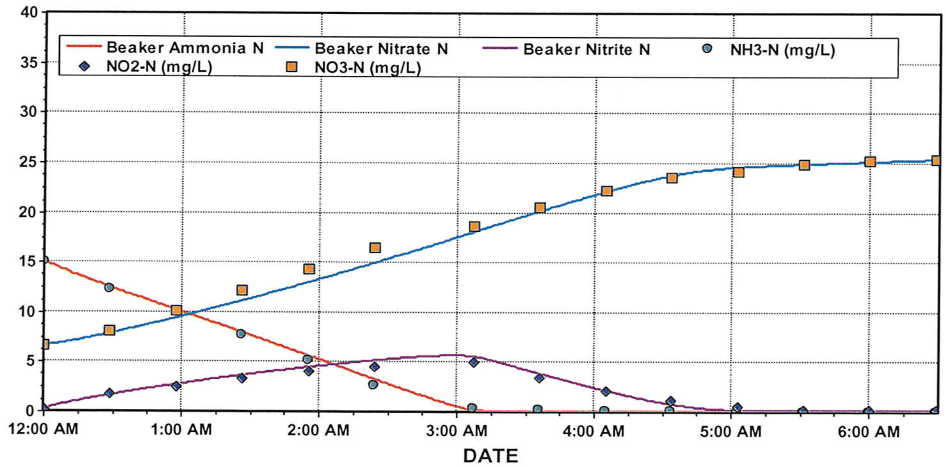



**Figure 4.10 Batch Test 1 – WAS with $NH_4Cl$ Dosing**

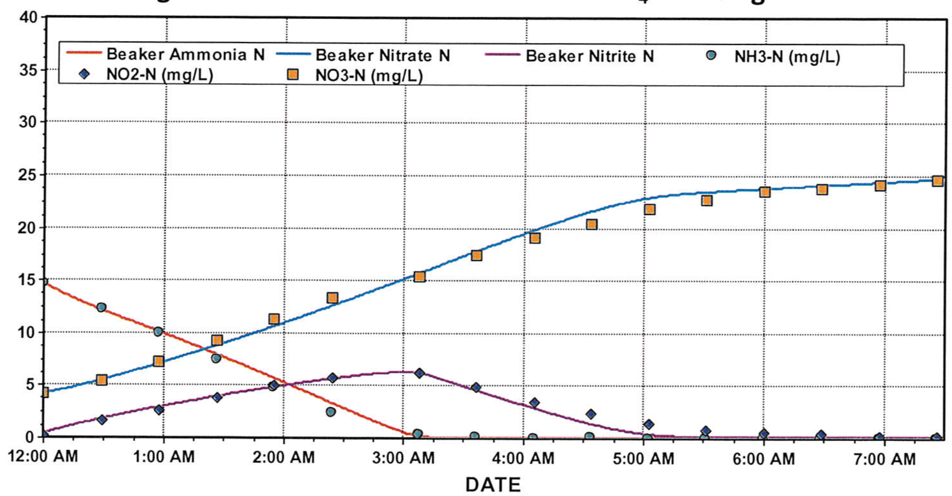



**Figure 4.11 Batch Test 2 – WAS with $NH_4Cl$ Dosing**

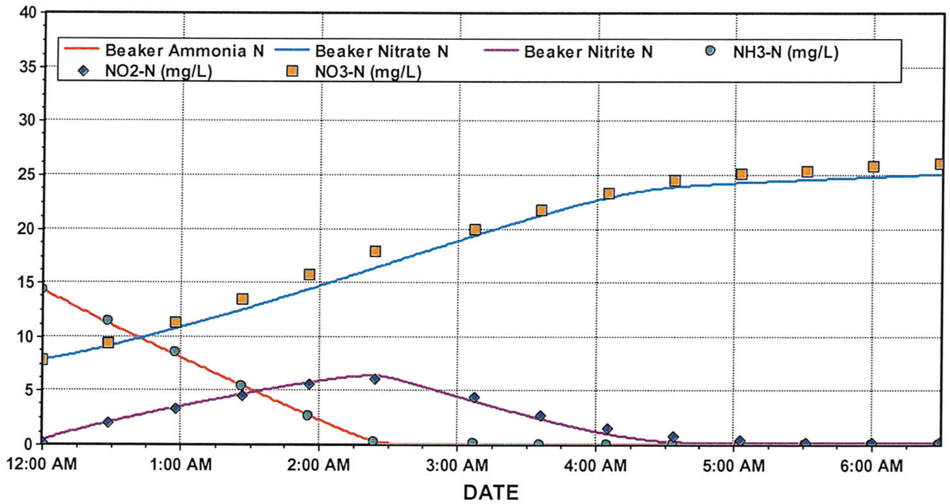



**Figure 4.12 Batch Test 3 – WAS with $NH_4Cl$ Dosing**

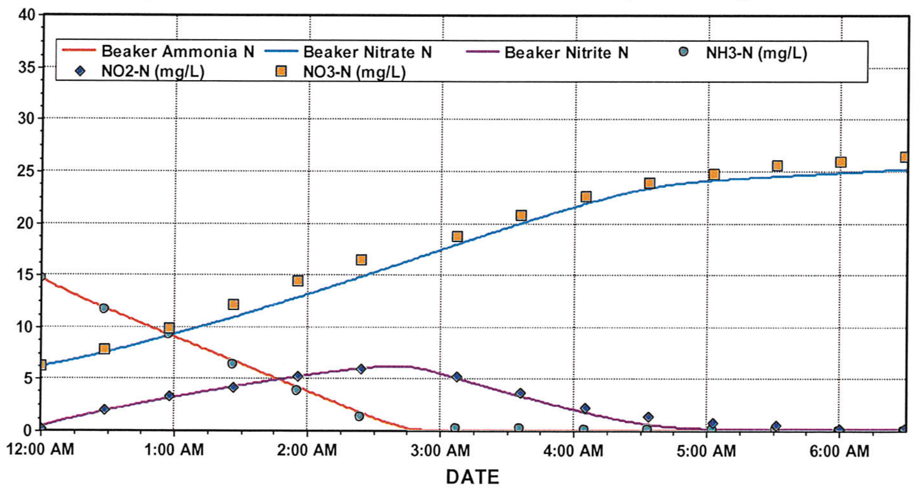



**Figure 4.13 Batch Test 4 – WAS with $NH_4Cl$ Dosing**

**Table 4.9 Summary of $\mu_{max,AOB,20}$ and $\mu_{max,NOB,20}$ of Raw Sewage**

| Kinetic Parameters for AOB | Default | Batch Test 1 | Batch Test 2 | Batch Test 3 | Batch Test 4 | Batch Test 5 | Average | Arrhenius |
|---|---|---|---|---|---|---|---|---|
| Max. spec. growth rate [1/d] | 0.9 | 0.9 | 0.95 | 0.95 | 0.95 | 1 | 0.95 | 1.072 |
| Substrate ($NH_3$) half sat. [mgN/L] | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 1 |
| Aerobic decay rate [1/d] | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 1.029 |

| Kinetic Parameters for NOB | Default | Batch Test 1 | Batch Test 2 | Batch Test 3 | Batch Test 4 | Batch Test 5 | Average | Arrhenius |
|---|---|---|---|---|---|---|---|---|
| Max. spec. growth rate [1/d] | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.74 | 1.06 |
| Substrate ($NO_2$) half sat. [mgN/L] | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 1 |
| Aerobic decay rate [1/d] | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 1.029 |

**Table 4.10 Summary of $\mu_{maxAOB,20}$ and $\mu_{maxNOB,20}$ of WAS with $NH_4Cl$ Dosing**

| Kinetic Parameters for AOB | Default | Batch Test 1 | Batch Test 2 | Batch Test 3 | Batch Test 4 | Average | Arrhenius |
|---|---|---|---|---|---|---|---|
| Max. spec. growth rate [1/d] | 0.9 | 0.9 | 0.95 | 0.95 | 0.95 | 0.94 | 1.072 |
| Substrate ($NH_4$) half sat. [mg N/L] | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 1 |
| Aerobic decay rate [1/d] | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 1.029 |
| **Kinetic Parameters for NOB** | **Default** | **Batch Test 1** | **Batch Test 2** | **Batch Test 3** | **Batch Test 4** | **Average** | **Arrhenius** |
| Max. spec. growth rate [1/d] | 0.7 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 1.06 |
| Substrate ($NO_2$) half sat. [mg N/L] | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 1 |
| Aerobic decay rate [1/d] | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 1.029 |

## 4.7 Diurnal Pattern

Diurnal pattern investigation was conducted three times during the same time as the extensive monitoring testing. The samples were measured for TCOD, TSS, VSS, TN, TP, pH, and $NH_3$-N. The results are presented in Table 4.11. The diurnal variation patterns of major constituents may be different in terms of days of the week, which is demonstrated in Figures 4.14 to 4.16. Figure 4.17 presents the average diurnal variations.

In general, the change of concentrations of TSS, VSS, TN, and TP followed the same pattern as the change of TCOD concentrations. The concentrations of major constituents peaked between 10 am to 12 pm in all three days. There was another peak occurred between 2 am to 4 am in two out of the three days. The pollutants' concentrations were fairly constant during the time besides the peak hours. The solids concentrations showed a larger variation than the other parameters due to the nature of the samples, some of which had large solid particles resulting in nonhomogeneous mixing.

The TP concentration and flow data for LS8 and Saputo on March 4 and 8 indicate that 59.8% and 46.9% of the TP in LS8 comes from Saputo.

Table 4.11 Results from the Diurnal Pattern Investigation - LS8

| Date | Time | pH | TCOD (mg/L) | TN (mg/L) | TP (mg/L) | TSS (mg/L) | VSS (mg/L) | $NH_3$-N (mg/L) |
|---|---|---|---|---|---|---|---|---|
| 3/4/2013 | 0 am to 2 am | 7.26 | 837 | 82.2 | 9.7 | 381 | 339 | 49.5 |
| | 2 am to 4 am | 7.33 | 691 | 72.4 | 8.4 | 338 | 318 | 50.1 |
| | 4 am to 6 am | 6.53 | 3400 | 80.2 | 11.3 | 6174 | 5886 | 39.9 |
| | 6 am to 8 am | 7.33 | 450 | 63.8 | 9.2 | 1505 | 1427 | 44.7 |
| | 8 am to 10 am | 7.14 | 1258 | 49.2 | 10.3 | 240 | 228 | 25.1 |
| | 10 am to 12 pm | 7.15 | 1137 | 75.2 | 18.1 | 442 | 408 | 48.6 |
| | 12 pm to 2 pm | 7.10 | 1270 | 102.2 | 24.0 | 854 | 780 | 64.5 |
| | 2 pm to 4 pm | 7.07 | 1207 | 88.2 | 20.8 | 387 | 334 | 50.7 |
| | 4 pm to 6 pm | 7.25 | 1063 | 71.8 | 20.4 | 345 | 260 | 41.4 |
| | 6 pm to 8 pm | 7.20 | 945 | 56.6 | 19.6 | 323 | 229 | 36.3 |
| | 8 pm to 10 pm | 6.78 | 1922 | 73 | 21.4 | 3140 | 2982 | 40.2 |
| | 10 pm to 0 am | 7.18 | 1824 | 68.2 | 25.8 | 1512 | 1416 | 40.2 |
| 3/6/2013 | 0 am to 2 am | 6.57 | 2256 | 79.2 | 27.4 | 1386 | 1290 | 38.7 |
| | 2 am to 4 am | 6.57 | 3778 | 81.6 | 29.3 | 10719 | 10006 | 40.2 |
| | 4 am to 6 am | 6.70 | 2660 | 87.4 | 17.4 | 7971 | 7543 | 46.5 |
| | 6 am to 8 am | 7.31 | 586 | 60.8 | 12.9 | 431 | 418 | 37.5 |
| | 8 am to 10 am | 7.17 | 566 | 52 | 14.1 | 2985 | 2831 | 40.2 |
| | 10 am to 12 pm | 6.64 | 1640 | 59.8 | 15.3 | 8174 | 7668 | 42.6 |
| | 12 pm to 2 pm | 6.97 | 1470 | 83.4 | 12.4 | 3895 | 3649 | 60.3 |
| | 2 pm to 4 pm | 7.19 | 870 | 76.4 | 14.3 | 766 | 693 | 51.6 |
| | 4 pm to 6 pm | 6.87 | 1034 | 70.8 | 15.0 | 1071 | 921 | 45.3 |
| | 6 pm to 8 pm | 7.18 | 854 | 63.6 | 25.3 | 407 | 277 | 39.9 |
| | 8 pm to 10 pm | 7.33 | 958 | 63.8 | 19.1 | 476 | 408 | 39.3 |
| | 10 pm to 0 am | 6.97 | 790 | 59.6 | 20.6 | 271 | 225 | 40.8 |
| 3/8/2013 | 0 am to 2 am | 7.10 | 1450 | 64.6 | 25.7 | 380 | 324 | 39.0 |
| | 2 am to 4 am | 7.04 | 990 | 73 | 30.0 | 374 | 341 | 36.9 |
| | 4 am to 6 am | 8.78 | 758 | 76.2 | 15.4 | 162 | 126 | 38.4 |
| | 6 am to 8 am | 7.31 | 670 | 69.2 | 21.8 | 225 | 207 | 42.6 |
| | 8 am to 10 am | 6.99 | 770 | 46.8 | 21.8 | 68 | 68 | 29.6 |
| | 10 am to 12 pm | 6.67 | 1758 | 77.2 | 28.7 | 409 | 282 | 44.1 |
| | 12 pm to 2 pm | 6.91 | 3527 | 181 | 30.6 | 505 | 381 | 59.4 |
| | 2 pm to 4 pm | 7.01 | 1048 | 75.2 | 17.5 | 323 | 247 | 48.3 |
| | 4 pm to 6 pm | 7.19 | 1036 | 82.2 | 16.1 | 418 | 327 | 48.3 |
| | 6 pm to 8 pm | 7.12 | 974 | 63.2 | 21.9 | 262 | 169 | 37.2 |
| | 8 pm to 10 pm | 7.05 | 1148 | 68 | 16.3 | 332 | 240 | 39.3 |
| | 10 pm to 0 am | 6.81 | 1480 | 82.8 | 27.3 | 558 | 471 | 40.8 |

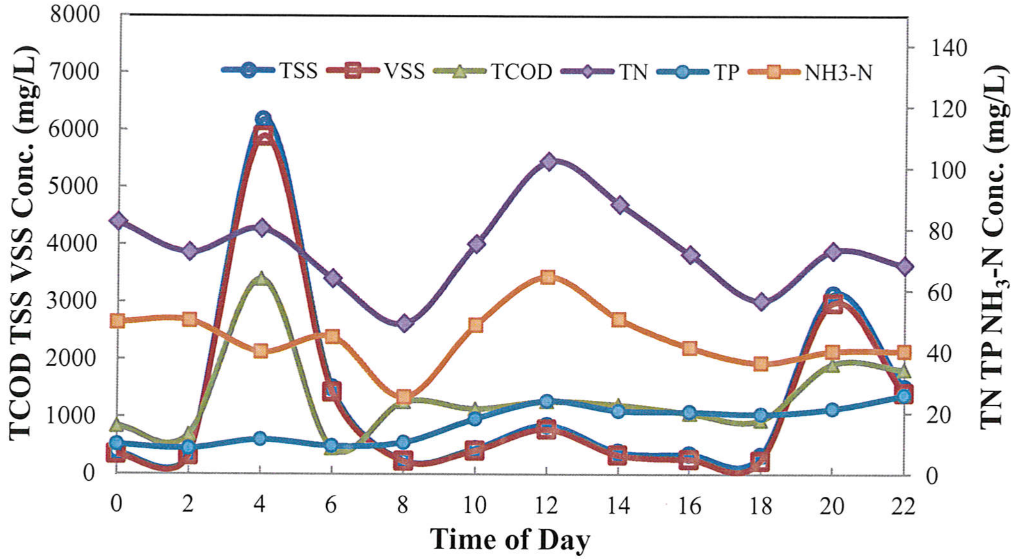



Figure 4.14 Diurnal Variations on Monday, March 04, 2013

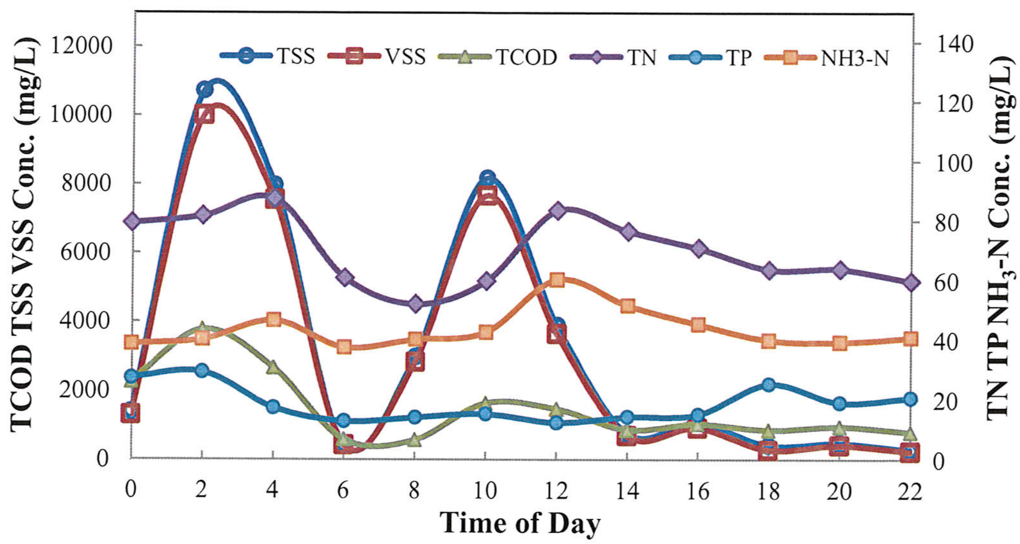



Figure 4.15 Diurnal Variations on Wednesday, March 06, 2013

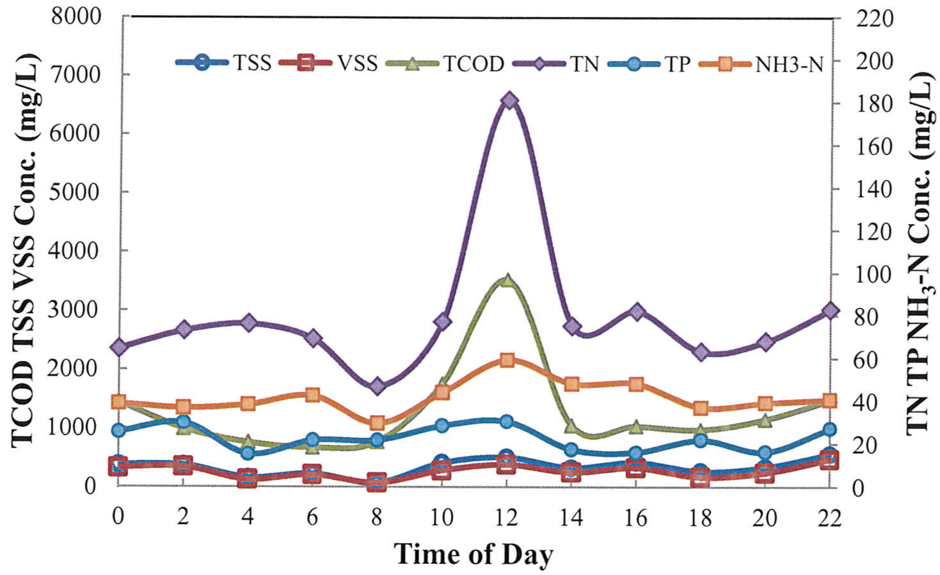



**Figure 4.16 Diurnal Variations on Friday, March 08, 2013**

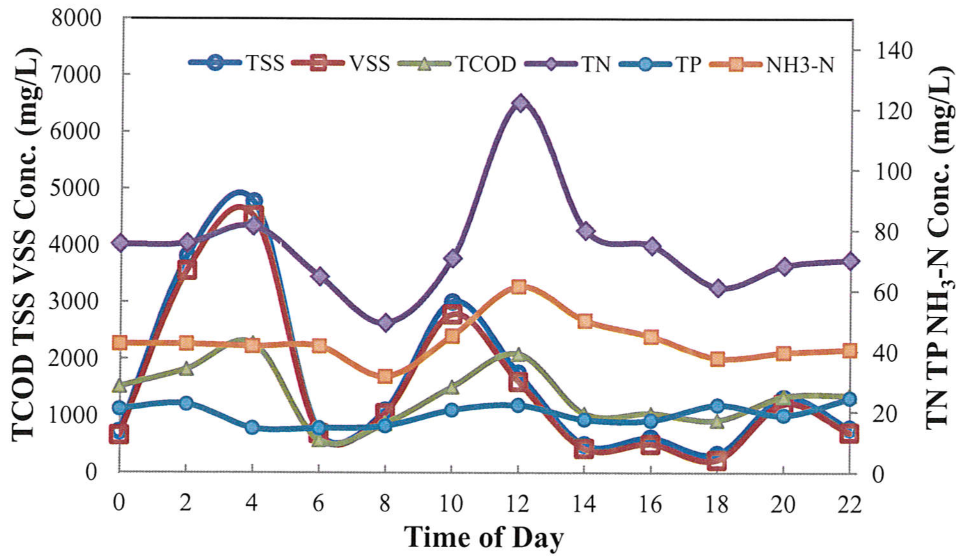



**Figure 4.17 Average Diurnal Variation of Main Constituents**

# CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The primary objectives of this work were to characterize the COD, suspended solids, and nitrogen fraction of the wastewater and to evaluate the nitrification kinetic parameters (i.e. the ammonium and nitrite oxidizing bacteria maximum specific growth rates, $\mu_{max,AOB}$ and $\mu_{max,NOB}$) for the proposed wastewater treatment plant in Winkler. The diurnal patterns of main pollutants were also investigated.

Important conclusions/observations from the study are listed below:

- Ammonia oxidizing bacteria (AOB) maximum specific growth rate was determined when the SRB were fed raw sewage and, to eliminate any potential inhibition, using $NH_4Cl$ dosing to biomass removed from the reactor. The rate was estimated at 0.95 1/d with raw sewage and 0.94 1/d was obtained with dosing $NH_4Cl$. Both of the rates are close to the typical value of 0.9 1/d.

- Nitrite oxidizing bacteria (NOB) maximum specific growth rate was determined when the SRB were fed raw sewage and, to eliminate any potential inhibition, using $NH_4Cl$. The rate was estimated at 0.74 1/d with raw sewage and 0.75 1/d was obtained with dosing $NH_4Cl$. Both of the rates are close to the typical value of 0.7 1/d.

- The typical nitrifiers' growth rates attained from both methods and the similarity of the rates demonstrated there was no inhibition of the nitrifiers by the raw sewage from LS8.

- Analysis of influent COD indicated a higher than normal percentage of readily biodegradable organic matter present in the raw sewage. The non-biodegradable portion of the total COD, in turn, was lower than typical.

    - The fractions for raw sewage were: $f_{BS}$ = 0.36 mg COD/ mg COD, $f_{US}$ = 0.03 mg COD/ mg COD, $f_{BP}$ = 0.52 mg COD/ mg COD, and $f_{UP}$ = 0.09 mg COD/ mg COD.

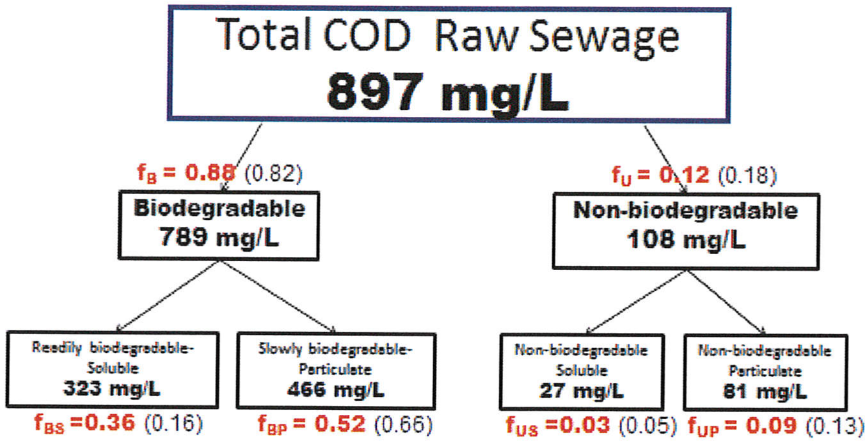



**Figure 1 COD Fractions in Raw Sewage – March 04 – 15, 2013**
**(Typical values in brackets)**

- The average TCOD, TN, TP concentrations were 897 mg/L, 72 mg/L and 21.5 mg/L, respectively, during the extensive monitoring period. The higher than normal values indicated the raw sewage from Lift Station 8 was a high strength wastewater.

- Influent TKN/TCOD ratio was 0.08 mg TKN/mg TCOD. The lower than typical ratio is favorable for the proposed wastewater treatment plant should nitrogen removal be required.

- Influent soluble unbiodegradable TKN fraction ($f_{NUS}$) was 0.02 mg N/mg N, which is a typical value and is beneficial if an effluent TN limit were imposed on the upgraded wastewater treatment plant because this portion of the TKN cannot be removed, irrespective of the plant process configuration.

- The diurnal change of concentrations of TSS, VSS, TN, and TP followed the same pattern as those of TCOD. The pollutants' concentrations were fairly constant during the period besides the peak hours: between 10 am to 12 pm in all three days and between 2 am to 4 am in two out of the three days. The solids concentrations showed a larger variation than the other parameters.

## 5.2 Recommendations

The following recommendations were made as a result of this investigation:

- The design of the wastewater treatment plant should adopt the values of
  $\mu_{max, AOB} = 0.9$ 1/d
  $\mu_{max, NOB} = 0.7$ 1/d

## REFERENCES

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## NOMENCLATURE

AOB - ammonia oxidizing bacteria

COD - chemical oxygen demand

$f_{BS}$ - influent readily biodegradable COD fraction

$f_{CV,ML}$ - mixed liquor COD/VSS ratio

ffCOD - flocculated and filtered COD

$f_{N, ML}$ - mixed liquor nitrogen content

$f_{NA}$ - ammonia fraction of the influent TKN

$f_{NUS}$ - soluble unbiodegradable TKN fraction

$f_{PO4}$ - phosphate fraction of the influent TP

$f_{US}$ - soluble unbiodegradable COD fraction

$f_{UP}$ - particulate unbiodegradable

ISS - mixed liquor inorganic suspended solids concentration

NOB - nitrite oxidizing bacteria

sCOD - soluble COD

SBR - sequencing batch reactor

sTN - soluble TN

TCOD - Total COD

TKN - total Kjeldahl nitrogen 0.

TN - total nitrogen

TP - total phosphorus

TSS – total suspended solid

$\mu_{max,AOB}$ - maximum specific growth rate of AOB

$\mu_{max,NOB}$ - maximum specific growth rate of NOB

VSS – volatile suspended solids