

# Deammonification of Dewatering Sidestream from Thermal Hydrolysis-Mesophilic Anaerobic Digestion Process

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## ABSTRACT

In 2014, DC Water will begin operating a new solids processing train at the Blue Plains Advanced Wastewater Treatment Plant consisting of the CAMBI thermal hydrolysis process for solids pretreatment prior to mesophilic anaerobic digestion. DC Water has chosen sequencing batch reactors capable of nitrification-denitrification or deammonification (using the DEMON process) for separate biological treatment of the dewatering sidestream. As part of the sidestream treatment alternatives evaluation, studies were conducted using sidestream generated from an existing CAMBI-digestion plant to confirm the suitability of the DEMON process to treat such a sidestream and to provide insight on design loading rates and related issues. Experimental results reveal a significant reduction in nitrogen conversion rates – rather for the aerobic ammonia oxidizers than for the anammox organisms. Both biomass acclimation and decrease in refractory soluble COD concentrations could alleviate inhibitory impacts.

**KEYWORDS:** sidestream, centrate, filtrate, nitrogen, ammonium, deammonification, anammox, thermal hydrolysis, CAMBI, DEMON

## INTRODUCTION

In 2014, DC Water will begin operating a new solids processing train at the Blue Plains Advanced Wastewater Treatment Plant (Blue Plains) consisting of the CAMBI thermal hydrolysis process for solids pretreatment prior to mesophilic anaerobic digestion. In this same year, a new annual total nitrogen (TN) discharge load will become effective. During a wet year (defined as 435 mgd at projected 2030 design conditions), the average plant effluent TN concentration must be 3.3 mg/L to meet the permitted annual load limit.

As a result of the thermal hydrolysis-digestion process, which allows for digester feed solids content on the order of 10% wt solids (Kepp et al., 2001), the sidestream contains higher ammonium-N and VFA concentrations than conventional anaerobic digestion processes. For Blue Plains, the sidestream is expected to contain 2,500 to 3,000 mg-N/L of ammonium and VFA potentially in excess of 2,000 mg/L.

Over the course of a comprehensive sidestream treatment alternatives evaluation (Figdore et al., 2010), DC Water came to favor sequencing batch reactors (SBRs) capable of nitrification-denitrification or deammonification for biological treatment of the dewatering sidestream. A

multiple-SBR facility which affords this operational flexibility would accommodate a phased implementation of deammonification. Because the Blue Plains facility would be far beyond the scale of existing deammonification plants, it could be a challenging logistic undertaking to provide sufficient seed sludge containing slow-growing anammox bacteria to rapidly startup the entire Blue Plains sidestream reactor system in a deammonification mode. Therefore, SBRs are particularly attractive because they can accommodate nitrification-denitrification (as a temporary mode) as well as phased implementation of deammonification using the DEMON process.

As part of the sidestream treatment alternatives evaluation, studies were conducted using sidestream generated from an existing CAMBI-digestion plant to confirm the suitability of the DEMON process to treat such a sidestream, provide insight on design loading rates, and potentially reveal other issues pertinent to design.

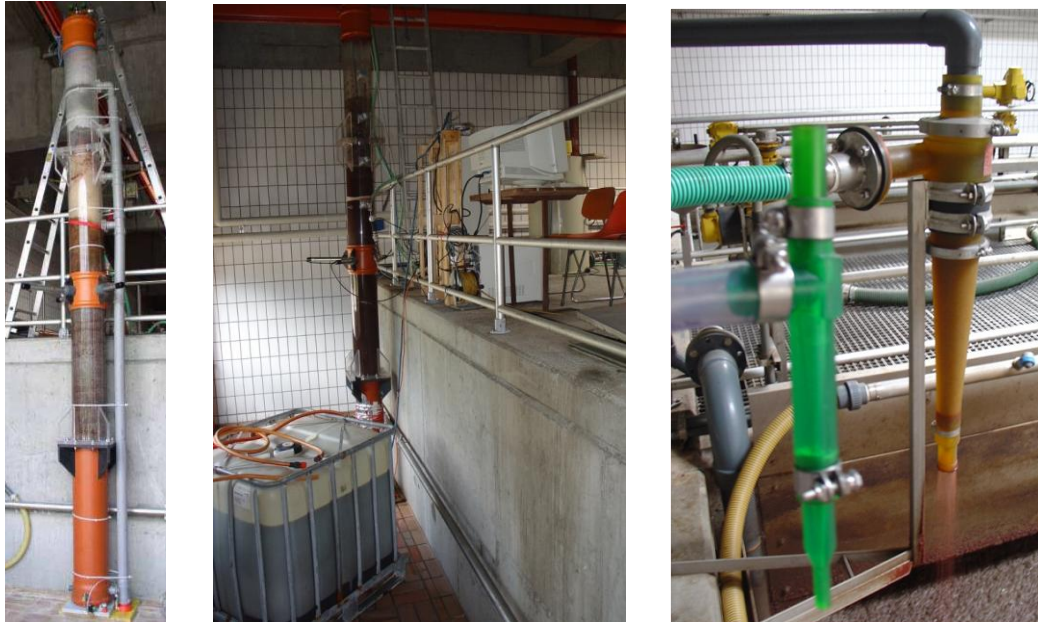
## **METHODS**

CAMBI-digestion sidestream used in the study was obtained from Anglican Water Cotton Valley Sludge Treatment Centre in Milton Keynes, Buckinghamshire, United Kingdom. Centrate was shipped in totes (approximately 250 gal) from Cotton Valley to WWTP Strass, Austria, where the studies were conducted during the period July-October 2010. Centrate was not filtered prior to feeding the pilot and benchtop reactors.

### **DEMON pilot system**

The DEMON pilot system (Figure 1) previously described by Wett et al. (2010a) was transported to Strass for use in this study and is described here for reference. The pilot reactor is a pipe-shaped plexi-glass SBR with a diameter of 0.25 m and minimum volume of 150 L. Tall reactor geometry was selected in order to achieve a realistic representation of aeration and gas stripping effects. Moreover, oxygen intrusion is prevented by such a low surface/volume ratio. Sludge settling characteristics are not significantly influenced by side-wall effects at diameters of at least 0.25 m. The bottom of the reactor is covered with a fine bubble membrane diffuser, and the flow of pressurized air is continuously metered. On-line probes for pH (WTW: SensoLyt SEA) and dissolved oxygen (WTW: TO700IQ) measurements are installed and connected to the programmable logic controller (Siemens Logo). Process temperature was kept stable at 35°C by controlling a heating element. For performance monitoring (i.e., outside the control loops), ammonia and nitrate (WTW: VARIION 700Plus IO) is measured on-line and a pressure meter detects water level. All the collected data is transmitted to allow remote operation monitoring and control.

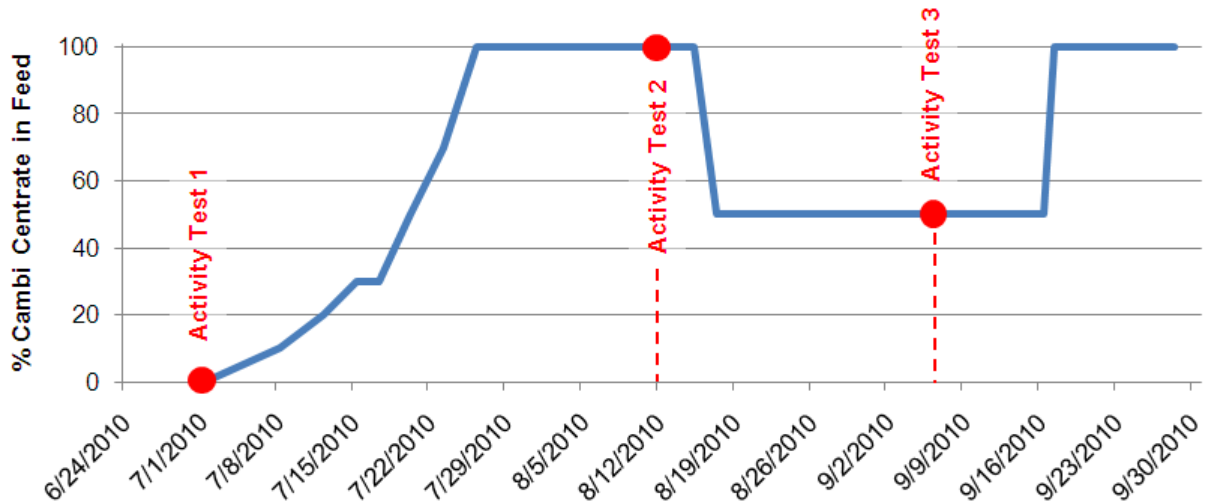
For the DEMON pilot system a similar waste sludge selection principle was applied as it is used for all full-scale DEMON-plants in practice (Wett et al., 2010b). The current study employed the use of a small-scale hydrocyclone to promote selective retention of anammox granules and wasting of non-anammox biomass. Due to limitations of scale (frequent clogging of the cyclone bottom-opening of 2.5 mm; insufficient centrifugal acceleration), the effectiveness of anammox retention and selective wasting was limited. For improved selection sludge was wasted from the top of the settled sludge blanket. Since predominantly the process rate of AOBs and not of anammox biomass has been affected by inhibition from Cambi-liquor this pilot artifact regarding anammox retention is considered of minor importance to the outcome of the tests.



**Figure 1. Pilot reactor (left); Pilot setup showing tote, reactor, and controls (middle); hydrocyclone for pilot unit (foreground) and full-scale plant (right)**

**Table 1. Chronological Outline of Study**

Period	Description	Start Date	Key Dates
1	CAMBI feed ramp-up: Increasing % Cambi Centrate Decreasing % Strass Centrate	7/1	7/1 – Activity test
2	100% CAMBI Centrate	7/26	8/9 – Stress test 8/12 – Activity test
3	50% CAMBI Centrate 50% Strass Pri. Effl.	8/16	9/7 – Activity test 9/16 – Stress test
4	Iron pre- and post- treatment w/ 100% CAMBI Centrate	9/17	9/17 – Stress test



**Figure 2. Chronological Outline of Percent Cambi Centrate in Feed**

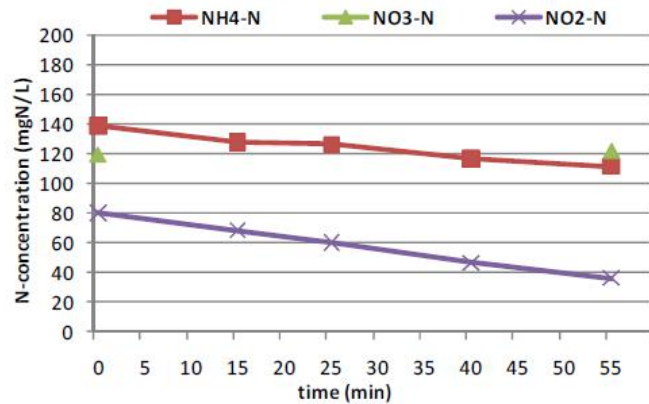
Table 1 and Figure 2 provide chronological outlines of the different study periods and key dates within each period. The amount of CAMBI centrate in the pilot unit feed was gradually increased from 0% to 100% over 26 days (Period 1). For the initial ramp-up period, CAMBI centrate was blended with Strass centrate. In Period 2 the pilot reactor was fed 100% CAMBI centrate, and in Period 3 the pilot reactor was fed 50% CAMBI centrate and 50% Strass primary effluent (i.e, a 1:1 dilution). 100% CAMBI centrate provides a baseline for performance and is also representative of a potential operation condition in winter. Heat balances indicate that no reactor cooling water is needed during a winter ambient condition; addition of unheated primary or plant effluent during a winter ambient condition would depress reactor temperature below 30°C, potentially approaching the low to mid-20°C range at a 1:1 dilution. For a more typical ambient condition, a 1:1 dilution is expected to allow for operation in the low to mid-30°C range, hence the reason for pilot operation and stress testing at 1:1 dilution. Period 4 tested 100% CAMBI centrate feed with iron pre- and post-treatment.

### Biological activity testing

The impacts of CAMBI-digestion sidestream on anammox and ammonia oxidizing bacteria (AOB) were evaluated by ex-situ batch tests determining nitrite degradation or production rate, respectively, after a spike loads. The biological activity testing protocol employed was described by Wett et al. (2010a) and is described here for reference:

#### *Anammox activity tests*

- 1) Sample 5 L of MLSS and spike with NaNO<sub>2</sub> (results NO<sub>2</sub>-N > 50 mg/L). For activity tests with CAMBI centrate, 5 L volume is reduced by desired CAMBI blend (e.g. 4.5 L MLSS and 0.5 L CAMBI centrate for 10% CAMBI blend).
- 2) Cover vessel, start mixing and wait 5 minutes for complete dissolution of salt
- 3) Measurement from filtered samples every 15 minutes: 5 data points for NH<sub>4</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, temperature, DO, time (Figure 3)
- 4) Determine TSS concentration and calculate nitrite depletion and total N-turnover rates on mass and volumetric basis: [g N \* g TSS<sup>-1</sup> \* h<sup>-1</sup>] and [g N \* L<sup>-1</sup> \* h<sup>-1</sup>]



**Figure 3. Set-up for ex-situ activity tests in the lab (left) and measured removal of N-compounds (right)**

#### *AOB activity tests*

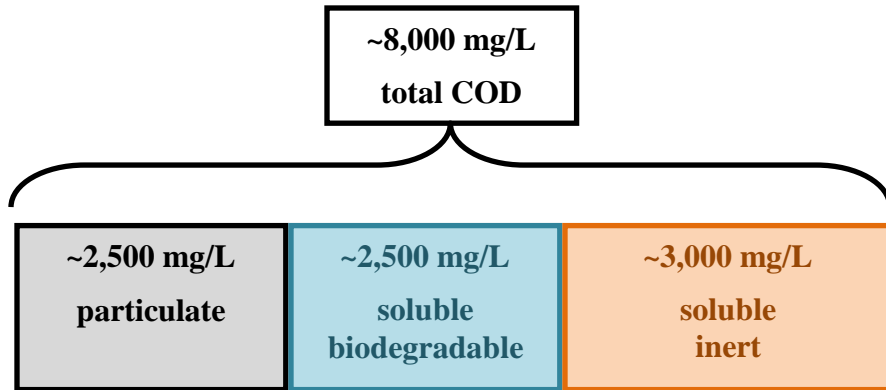
- 1) Same sample of 5 L as before (aerobic test after the anaerobic test)
- 2) Start mixing and aerating and wait at least 5 minutes for stable DO-level (at least 3 mg DO/L)
- 3) Measurement from filtered samples every 15 minutes: 5 data points for NH<sub>4</sub><sup>+</sup>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, temperature, DO, time
- 4) Determine TSS concentration and calculate nitrite production rate on mass and volumetric basis: [g N \* g TSS<sup>-1</sup> \* h<sup>-1</sup>] and [g N \* L<sup>-1</sup> \* h<sup>-1</sup>]
- 5) Additional oxygen uptake rate (OUR) test (DO-depletion profile after aeration has been turned off) to quantify AOB activity

## **RESULTS AND DISCUSSION**

### **CAMBI Centrate Characteristics**

The average CAMBI centrate ammonium over the course of the study was 2200 mgNH<sub>4</sub><sup>+</sup>-N/L and ranged from 2050-2350 mgNH<sub>4</sub><sup>+</sup>-N/L. Effluent refractory dissolved organic nitrogen (rDON) was measured once during the course of the study; a value of 132 mgN/L was obtained.

A generalized COD characterization for the CAMBI centrate is shown in Figure 4. Soluble inert COD (~3,000 mg/L) is measured from the pilot unit effluent and constitutes a significant portion of the CAMBI centrate COD. Though some degradable anaerobic biomass contributes to particulate COD (~2,500 mg/L), the significant majority of particulate COD is assumed to be refractory material from the thermal hydrolysis process, leaving approximately 2,500 mg/L as soluble biodegradable COD.

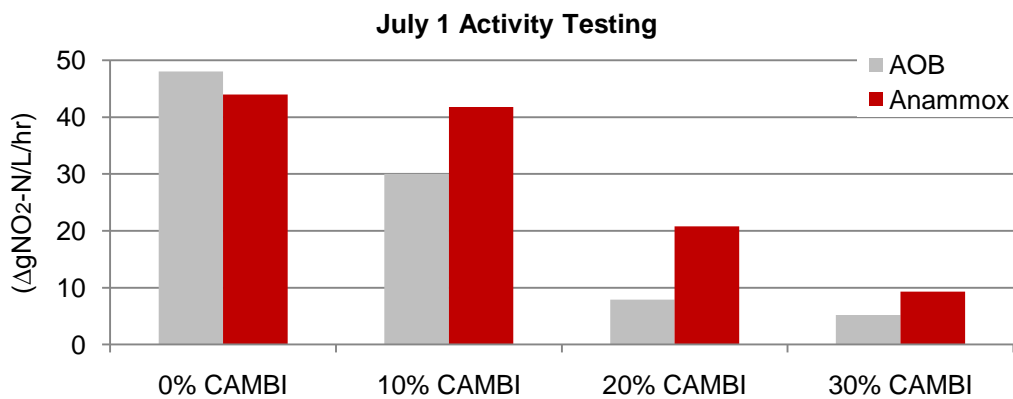


**Figure 4. Generalized CAMBI centrate COD characterization**

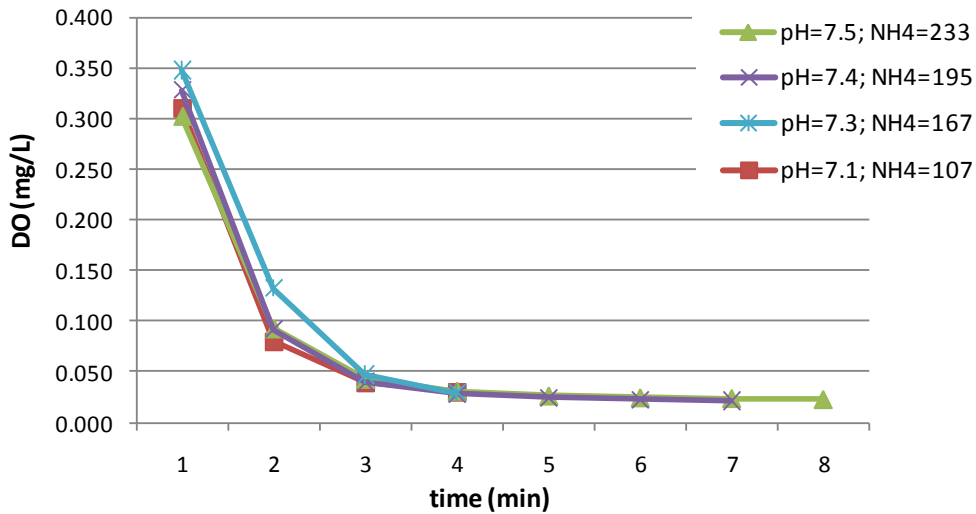
### Biological activity testing

Initial biological activity testing (July 1, 2010) using Strass DEMON sludge showed that increasing amounts of CAMBI centrate resulted in decreasing biological activity for both the anammox and AOB populations (Figure 5), which suggests that sidestream from CAMBI-digestion contains compounds that are inhibitory to both of these rate-controlling microbial groups. Inhibitory impacts on AOB were greater than that on anammox.

Figure 6 shows that in-situ OUR measurements were consistent over a range of free ammonia levels (highest corresponding to 233 mg/L  $\text{NH}_4^+\text{-N}$  at pH 7.5 and lowest corresponding to 107 mg/L  $\text{NH}_4^+\text{-N}$  at pH 7.1). This suggests that free ammonia was not contributing to the AOB inhibition, providing further evidence that the CAMBI centrate itself contained the inhibitory compounds.

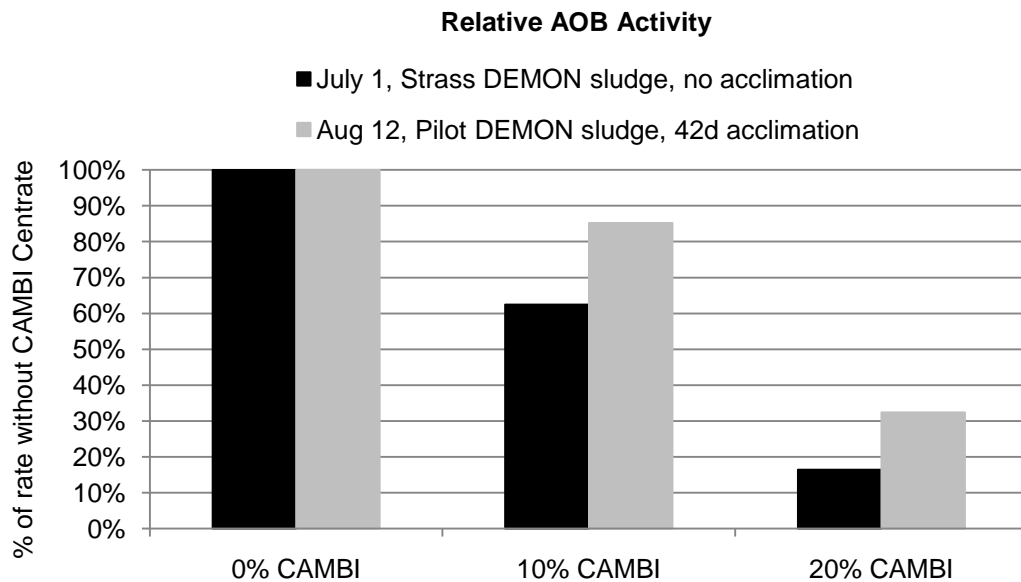


**Figure 5. Results of ad hoc activity test on Strass DEMON sludge at varying CAMBI-liquor dosage**



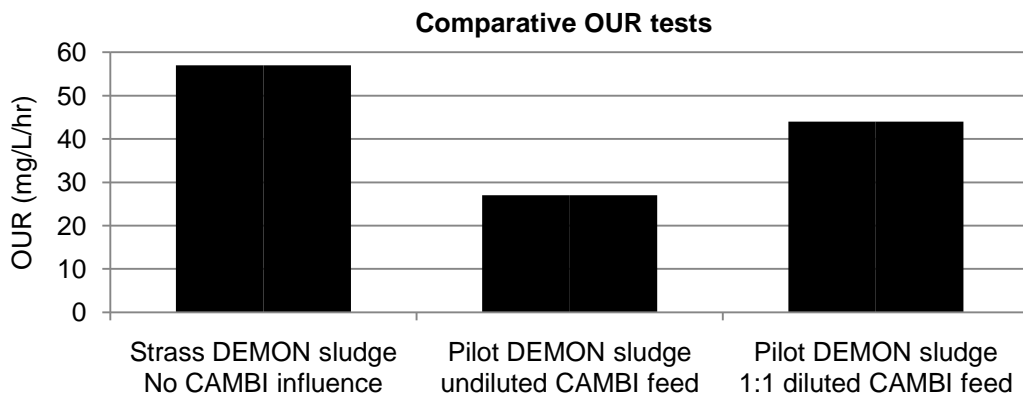
**Figure 6. Oxygen uptake measurements at different free ammonia concentrations**

A subsequent biological activity test was conducted on August 12, 2010 using pilot reactor sludge after 42 days of exposure to increasing amounts of CAMBI centrate. Though the absolute value of activity rates for the first and second test cannot be directly compared because the nitrogen loading rates (and, consequently, biomass inventory) of the full scale and pilot scale reactor were different, it is useful to evaluate the sensitivity of the test sludge to CAMBI addition by comparing activity rates relative to the initial rate without CAMBI addition. Figure 7 shows a more significant AOB activity drop at 10% and 20% CAMBI relative to activity at 0% CAMBI for the July 1 compared to August 12 activity tests, suggesting that acclimation occurred.



**Figure 7. Relative AOB activity with and without acclimation to CAMBI centrate**

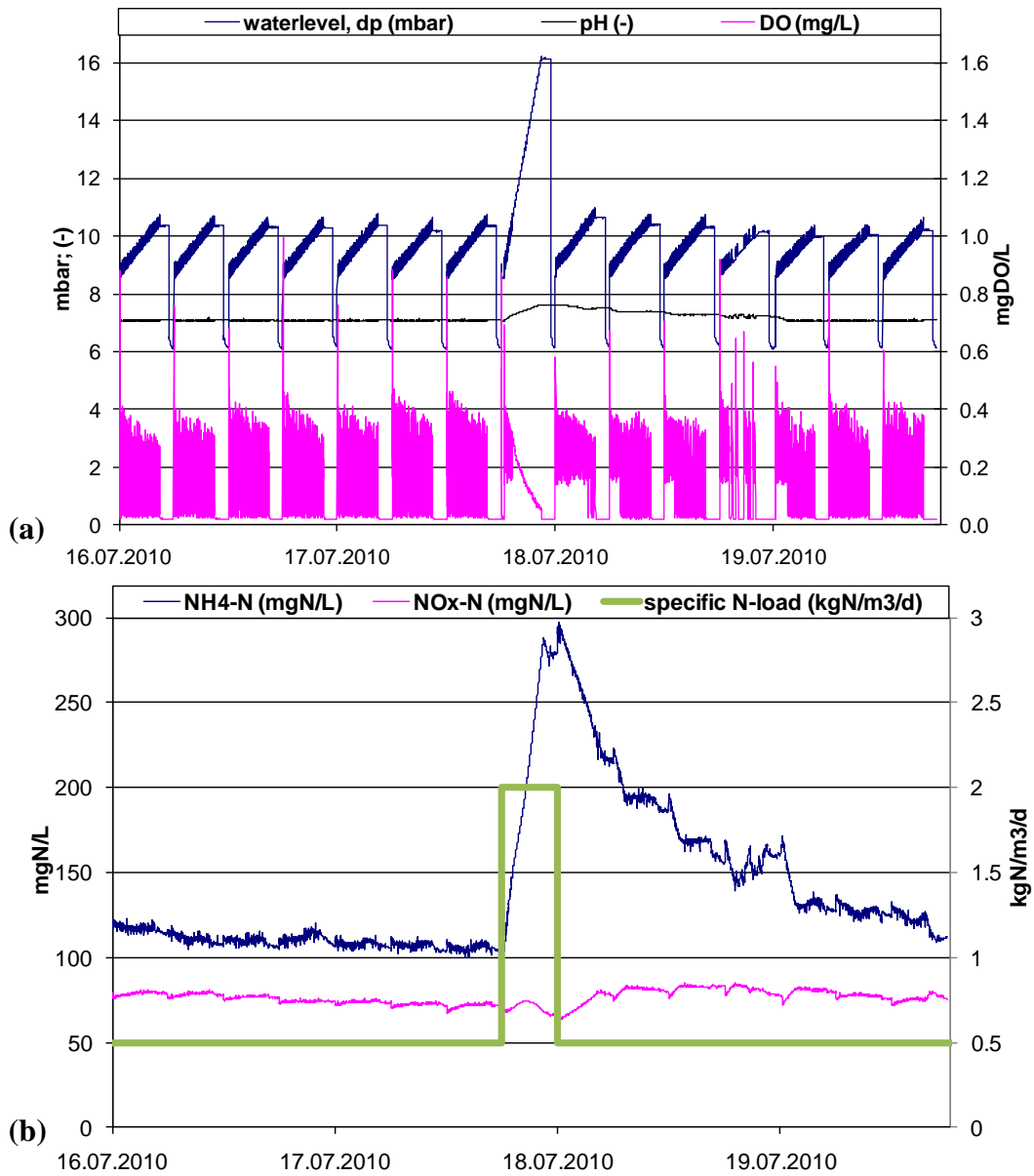
In addition to OUR tests conducted as part of biological activity testing protocol, OUR tests were conducted on July 6 (on Strass DEMON sludge without exposure to CAMBI centrate), August 12 (on Pilot DEMON sludge after an extended period of undiluted CAMBI centrate feed), and September 7 (on Pilot DEMON sludge after an extended period of 1:1 diluted CAMBI centrate feed). Oxygen uptake rates of 57, 26, and 43 mg/L/hr were obtained, respectively (Figure 8). Since OUR reflects the preceding operation history (e.g., loading rate), it is not an absolute measure of AOB activity, but it serves as an appropriate indicator thereof. An increase in OUR was obtained with time and dilution. Though this measurement does not differentiate the effects of acclimation versus dilution, it does further confirm the observed inhibition.



**Figure 8. Comparative OUR at different points in pilot operation**

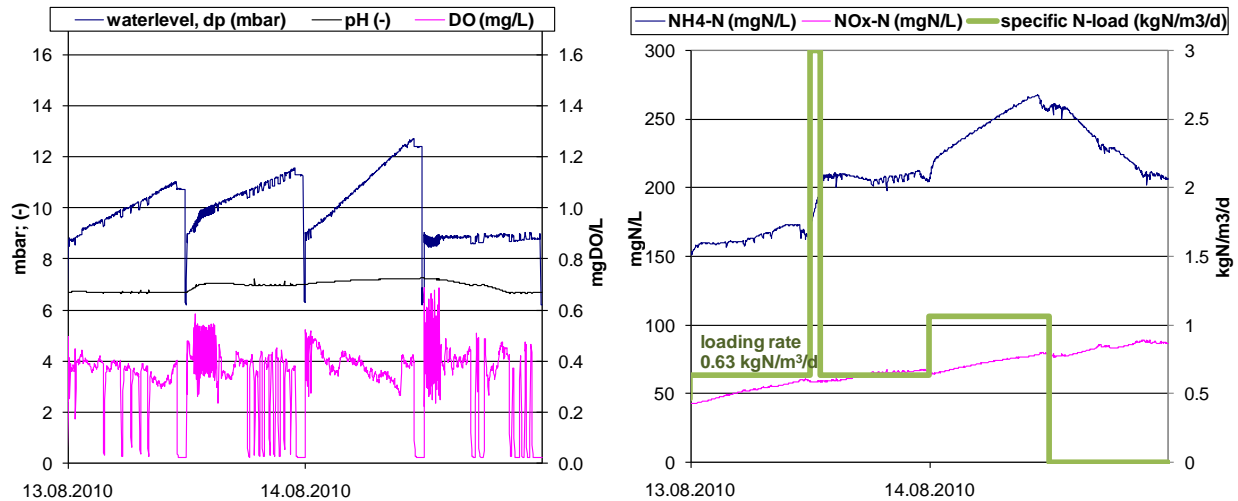
### **Study Periods 1 – 3: Ramp-Up, 100% CAMBI and 50% CAMBI at 35°C**

Before discussing the impacts of dilution on reactor loading rate, it is informative to present an extreme shock loading condition to illustrate several concepts. This particular shock load was conducted on July 17 during the ramp-up period on a blend of 30% CAMBI centrate and 70% Strass centrate. Prior to the shock event, the reactor loading rate was 0.5 kgN/m<sup>3</sup>/d and operation was stable. The reactor was shocked by increasing the loading rate to 2.0 kgN/m<sup>3</sup>/d for one 6-hr reactor cycle. The response of reactor control parameters and effluent nitrogen concentrations are shown in Figure 9. Prior to the shock event the reactor pH was stable, as ammonia and alkalinity were balanced. As a consequence of the shock load, the alkalinity input exceeded the nitrification capacity, resulting in an increase in pH. There are no significant breaks in aeration for the shock feed and subsequent cycle. Ammonium accumulated during the shock load and was gradually removed after the shock as governed by allowable changes to pH setpoints. The response of the DEMON controls in this example illustrates the signs of excessive loading in a DEMON reactor – pH increase and lack of anaerobic conditions. It is important to note that this overload condition (and other stress tests conducted in this study) are only achievable due to manual control of the pilot reactor. The automated controls of full scale DEMON reactors would prevent an overload event from occurring by reducing the feed rate.



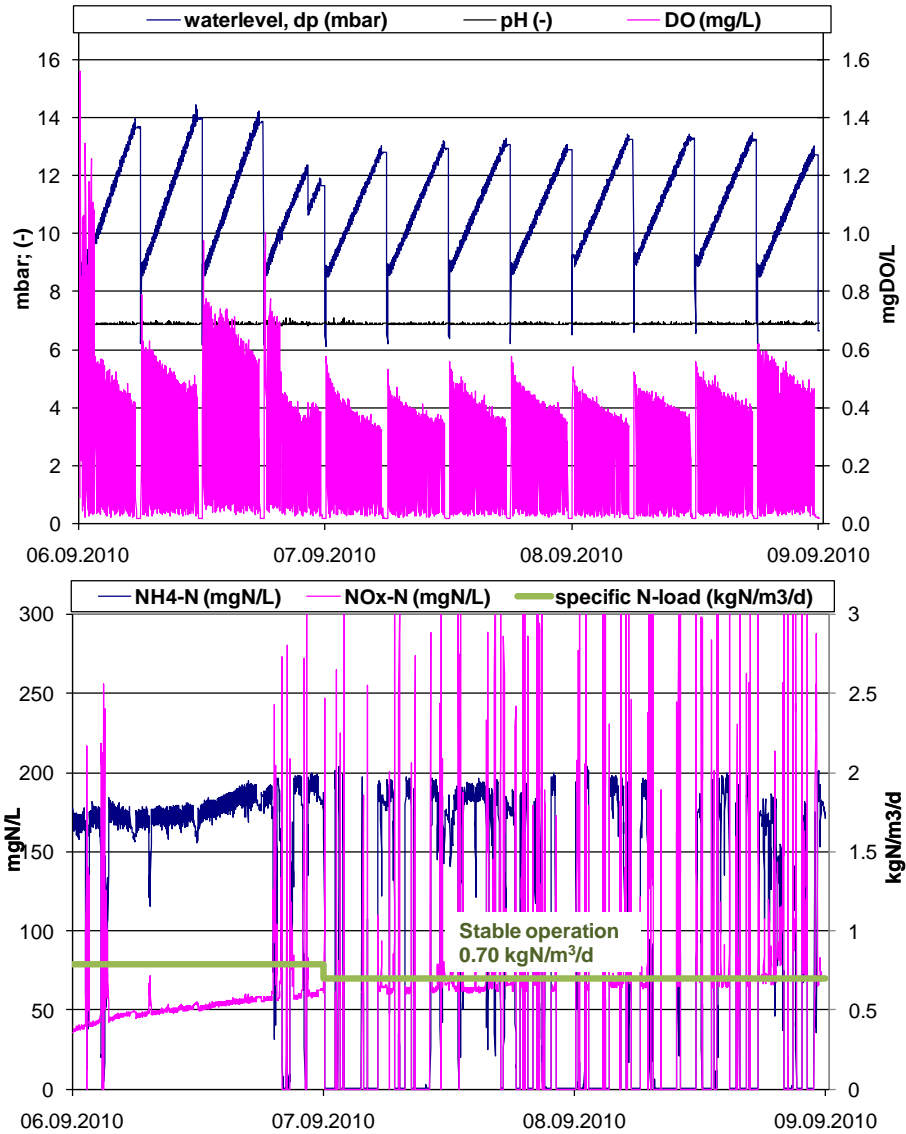
**Figure 9. Pilot reactor control parameters (a) and nitrogen loading rate and effluent response (b) to extreme shock load on July 17.**

For 100% CAMBI feed, stable operation was demonstrated by consistent pH and effluent nitrogen demonstrate up to a loading rate of  $0.63 \text{ kgN/m}^3/\text{d}$ . A loading rate of  $1.06 \text{ kgN/m}^3/\text{d}$  resulted in reactor instability, i.e. nitrification cannot use up all ammonia and alkalinity in the feed and consequently the pH-value increases and despite continuous aeration ammonia accumulates in the reactor(Figure 10). Though there is some noise in the graph showing reactor controls, this is simply an artifact of interruptions in signal recording.

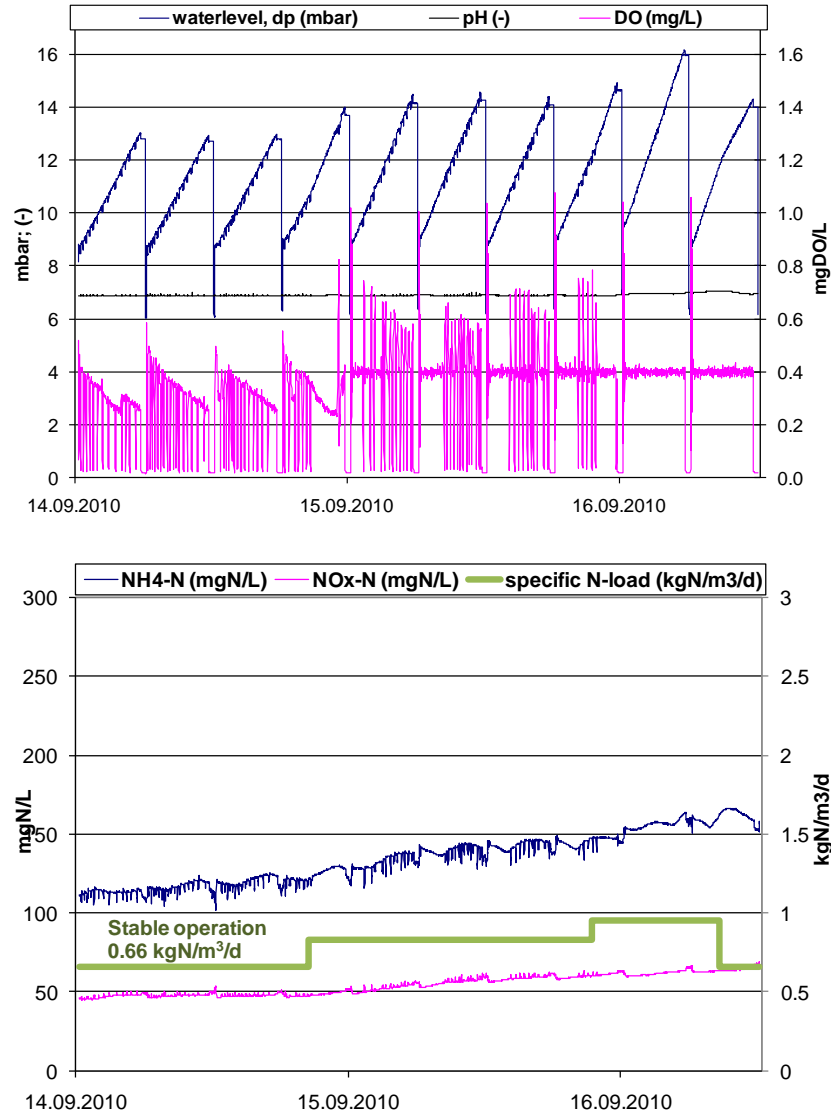


**Figure 10. Stable operation and onset of instability at 100% CAMBI feed**

For 50% CAMBI feed, Figures show reactor performance at loading rates of  $0.70$  and  $0.79 \text{ kgN/m}^3/\text{d}$ , respectively. For  $0.79 \text{ kgN/m}^3/\text{d}$ , though reactor pH was relatively stable, effluent ammonia and nitrate increased. Therefore the loading rate was reduced to  $0.70 \text{ kgN/m}^3/\text{d}$  on September 7 achieving steady effluent ammonia and nitrate concentrations. Then the loading rate was held relatively constant near  $0.70 \text{ kgN/m}^3/\text{d}$  until September 16, when the loading rate was step-wise increased to  $0.95 \text{ kgN/m}^3/\text{d}$  (Figure 12). Prior to this load increase, effluent ammonium and nitrate were approximately  $110 \text{ mgNH}_4^+-\text{N/L}$  and  $50 \text{ mgNO}_3^--\text{N/L}$ , respectively. The increase to  $0.95 \text{ kgN/m}^3/\text{d}$  resulted in a corresponding increase in effluent ammonium and nitrate and gradual increase in pH. This loading rate ( $0.95 \text{ kgN/m}^3/\text{d}$ ) was the maximum loading rate for the 50% CAMBI feed testing. Comparing process performance at 100% Cambi feed (Fig. 10) and at 50% dilution (Fig.11) a similar degree of stability was achieved at a loading rate of  $0.63 \text{ kgN/m}^3/\text{d}$  versus  $0.79 \text{ kgN/m}^3/\text{d}$ .



**Figure 11.** 50% CAMBI Feed and loading rate of 0.79 kgN/m<sup>3</sup>/d (Sept. 6) and 0.70 kgN/m<sup>3</sup>/d (Sept. 7-9). Note that noise in bottom graph is erroneous



**Figure 12. Stress testing at 50% CAMBI Feed and loading rate of 0.95 kgN/m<sup>3</sup>/d (Sept. 16)**

### Study Period 4: Iron pretreatment w/ 100% CAMBI Feed

On September 17, reactor feed changed from 50% CAMBI – 50% primary effluent blend to 100% CAMBI, but with iron sulfate pretreatment at a dose of 150 mgFe/L. Reactor operation was stable at a loading rate of 0.66 kgN/m<sup>3</sup>/d. Performance began to decline steadily after an increase in loading rate to 0.88 kgN/m<sup>3</sup>/d, as shown in Figure 13. The stepwise change in effluent concentrations in Figure 13 is due to instrument calibration.

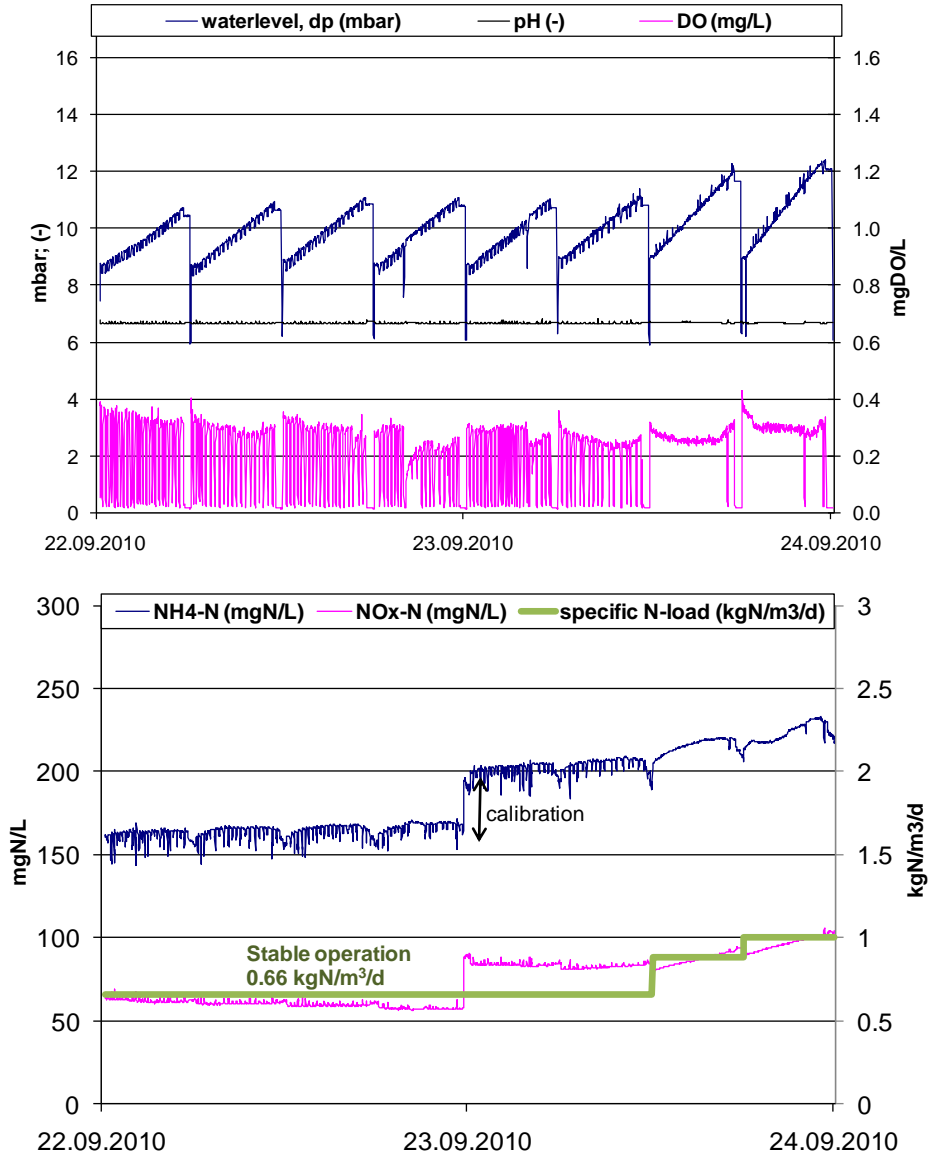
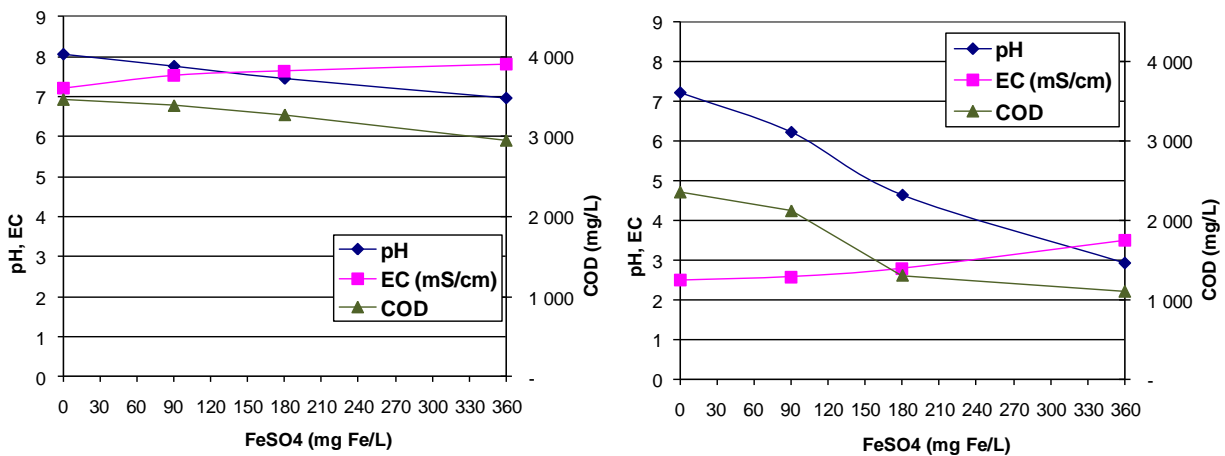


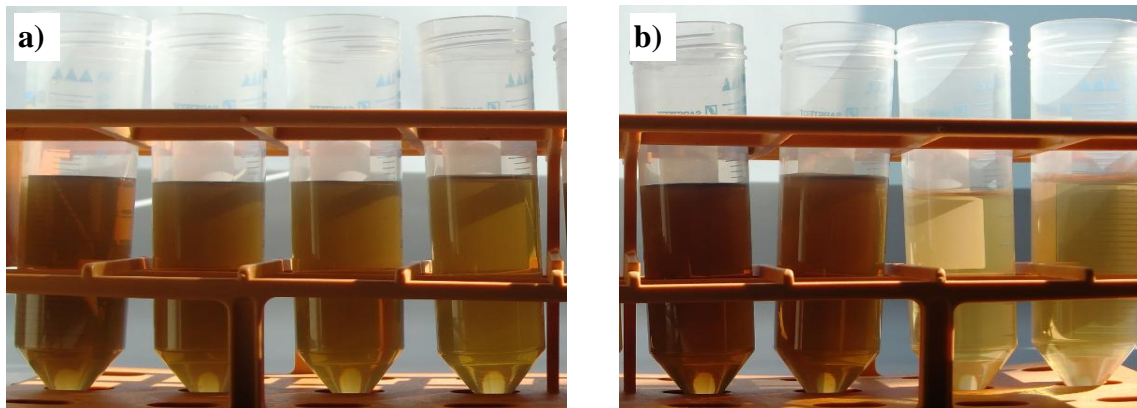
Figure 13. 100% CAMBI Feed with 150 mgFe(II)/L

As described previously, in-situ OUR measurements suggested that free ammonia was not contributing to the AOB inhibition. The inhibitory compounds were believed to be associated with the soluble inert COD ( $COD_{SI}$ ) in the CAMBI centrate; therefore, bench scale tests were conducted using varying amounts of ferrous sulfate (up to 360 mgFe/L) in an attempt to remove the  $COD_{SI}$ . Tests were conducted adding iron to the pilot unit feed (pre-treatment) and pilot unit effluent (post-treatment), only the former of which would potentially alleviate inhibition in biological sidestream treatment. Figure 14 shows the impacts of iron addition on pH, conductivity, and soluble COD for pilot unit feed (100% CAMBI-digestion sidestream) and effluent. The intent of conductivity was to serve as an indicator for ion concentration responsible for osmotic stress on nitrifying organisms. With respect to pre-treatment, iron addition achieved only a modest reduction in soluble COD (from approximately 3,500 mg/L without iron to 3,000 mg/L at the highest dose). However, this was accompanied by a 1 point drop in pH (from approximately 8.0 to 7.0), as would be expected due to alkalinity consumption associated with iron addition. Similarly, the increase in conductivity can be attributed to the iron salt pretreatment. The conductivity measured is within the typical range for dewatering sidestreams. In future studies it is desired to measure osmolality, as the measurement of soluble compounds (in the case of osmolality) rather than ions (in the case of conductivity) would provide a better indicator of potential impact on nitrifying organisms.

With respect to post-treatment, iron dosage was more effective in removing soluble COD (from approximately 2,400 mg/L without iron to 1,100 mg/L at the highest dose). The pH decrease was more severe (from approximately 7.2 without iron to 2.9 at the highest dose), as would be expected for the effluent after alkalinity consumption due to biological reactions. Figure 15 shows the clarity of the pilot unit effluent for pre- and post-treatment. The improvement in clarity is more pronounced for post-treatment corresponding to the greater degree of COD removal.



**Figure 14. Impact of iron addition on pH, conductivity, and soluble COD when added to (a) pilot unit feed and (b) pilot unit effluent**



**Figure 15. Addition of 0, 90, 180, and 360 mg Fe/L (left-to-right, respectively) (a) pre-treatment, after decanting; (b) post-treatment, after decanting**

## CONCLUSIONS

Thermal hydrolysis-digestion sidestreams appear to contain compounds at sufficient concentration to be inhibitory to key microbial consortia involved in sidestream biological treatment processes. The compounds causing the inhibition remain unknown, but are believed to be associated with soluble inert COD. Furthermore the extent of inert soluble COD-compounds for a specific sidestream is a function of CAMBI-digestion feed solids characteristics and temperature of the thermal hydrolysis process (Phothilangka et al., 2008). Biological activity tests suggested that over the course of the study, acclimation to the CAMBI-digestion sidestream occurred.

Dilution of CAMBI-digestion sidestream is an effective way to mediate the immediate-term inhibitory effects. However, dilution is not a requirement for treatment per se; rather, higher volumetric nitrogen loading rates can be maintained with a diluted feed stream than an undiluted feed stream.

Even at the very high iron doses (up to 360 mgFe(II)/L), pretreating the CAMBI-digestion sidestream prior to biological treatment showed minimal success in removing the inert COD, with which the inhibitory compounds are believed to be associated. As such, this pretreatment approach does not appear to be viable, as only a marginal reduction in inert COD was observed while alkalinity, which can be rate-limiting in sidestream nitrogen removal processes, is consumed as a result of the high iron dose.

Applying additional safety to the loading rates and associated performance observed during the pilot study, it is reasonable to suggest the following loading rates for DEMON reactors treating CAMBI-digestion sidestreams:

- For undiluted CAMBI-digestion sidestream without pretreatment 0.5 kgN/m<sup>3</sup>/d for sustained loads (including sustained peaks) should allow stable operation; onset of instability resulting from higher loading rates (approaching 0.7 kgN/m<sup>3</sup>/d) would be detected by the DEMON process control, and the feed rate would be reduced (either

resulting in an increase in equalization volume or bypassing the reactor) unless operation is changed from automated to manual control.

- For 1:1 diluted CAMBI-digestion sidestream or undiluted CAMBI-digestion sidestream with iron pretreatment, 0.7 kgN/m<sup>3</sup>/d at sustained loads (including sustained peaks) should allow stable operation; onset of instability resulting from higher loading rates (approaching 0.9 kgN/m<sup>3</sup>/d) would be detected by the DEMON process control, and the feed rate would be reduced (either resulting in an increase in equalization volume or bypassing the reactor) unless operation is changed from automated to manual control.

Absent plant-specific information, these loading rates serve as order-of-magnitude guidance. Higher loading rates could be supported by plant-specific testing. Additionally, if further acclimation to CAMBI-digestion sidestream is demonstrated over longer-term operation, higher loading rates could be achieved.

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