DEAMMONIFICATION MBBR (ANITA™ MOX), INCREASED EFFICIENCY IN IFAS CONFIGURATION

ANITA™ Mox: Experience from Start-up and Operation of Deammonification MBBR and perspective of a New Deammonification IFAS configuration

B. Nussbaum¹, S. Piveteau¹, C. Rosén, M. Christensson¹, R. Lemaire², B. Bigot³

Corresponding Author: Brandy Nussbaum ph: +46 725770608
brandy.nussbaum@anoxkaldnes.com

¹AnoxKaldnes AB, Klosterängsvägen 11A, 226 47 Lund, Sweden
²Veolia Water Technical and Performances Department, 1 rue Giovanni Battista Pirelli, 94417 St-Maurice, France
³Veolia Water Technologies, Aqua House 2620, Kings Court, Birmingham Business Park, Birmingham B37 7YE

Abstract

Energy optimisation and carbon footprint reduction are key goals for many wastewater treatment plants that are looking toward the future. Production of renewable biogas energy from anaerobic sludge digestion is key to achieving these goals. Treatment of ammonia-rich digester centrate with the use of anammox bacteria is recognized for valuable savings in oxygen consumption and external carbon source.

Veolia Water Technologies has proven that thermal hydrolysis, either in batch (Bio Thelys™) or continuous form (Exelys™), is a very effective pre-treatment process available for enhanced digestion. The many advantages of the thermal hydrolysis pre-treatment step result in a highly concentrated centrate stream following dewatering.

ANITA Mox, a 1-stage deammonification process based on the MBBR technology, has proven to be a suitable solution to treat these ammonia-rich effluents and solve the drawback of conventional and advanced anaerobic sludge digestion. Startup of these installations is accelerated using a seeding strategy whereby 3-15% of carriers with established Ammonium Oxidizing Bacteria (AOB)/Anammox Bacteria (AnAOB) biofilm are mixed with new carriers.

Recently, the performance of the ANITA Mox process was enhanced by operating the system under IFAS configuration, where the nitritation and anammox reactions are spatially separated allowing the AOB to grow in suspended phase to better utilize DO, while allowing the biofilm to specialize in anammox reaction to achieve higher rates.
Results from full-scale ANITA Mox MBBR treating sidestream effluent are presented together with ANITA Mox IFAS results from a 50m³ full-scale prototype showing an increase in N-removal rate of up to 3 times that usually achieved in pure MBBR configuration.

**KEYWORDS**

Anammox, ANITA Mox, IFAS, MBBR, Nitrogen removal, Nitritation, Digester Centrate

**INTRODUCTION**

Deammonification process combines nitritation and anammox processes to achieve autotrophic nitrogen removal. ANITA™ Mox is a single-stage deammonification process utilizing moving bed biofilm reactor (MBBR) technology. The biofilm on the MBBR carriers consists of multi-layers, where anammox bacteria grow on inner layers and Ammonia Oxidising Bacteria (AOB) grow on the outer layers. Currently, a total of 6 full-scale ANITA™ Mox plants are in operation. Three more plants are in their final construction phases and will be starting up within the next 6 months. Volumetric NH₄-removal rate up to 1.2 kgN/m³.d can be achieved with this MBBR ANITA Mox process for sidestream reject water treatment (Lemaire et. al., 2013).

The multi-layer structure provides suitable environments for growth of both AOB and Anammox in one reactor. However, it may present mass transfer limitations for substrates, such as DO, nitrite and ammonia. In fact, it has been observed that the capacity of MBBR configuration is always limited by the first step of two processes, i.e., the nitritation step. Moreover, increasing aeration to improve the first step may not be an option due to the risk of over production of nitrate, i.e., overgrowth of undesirable Nitrite Oxidizing Bacteria (NOB). Therefore, to improve the performances of the MBBR configuration, substrate transport limitation must be reduced; in other words, the multiple layer structure of biofilm must be reduced or removed.

The integration of the activated sludge and biofilm can be an effective approach to improve single-stage biofilm deammonification process performance due to the capability of the suspended growth to enrich nitrifiers and improve the rate of nitritation at low DO level due to less limitation on mass transfer. Two recent studies (Veuillet et al., in press; Zhao et al., 2013) reported an improvement in N-removal rate in the integrated fixed-film activated sludge (IFAS) configuration (up to 3.0 kgN/m³/d) compared to the pure MBBR design (1.2 kgN/m³/d), this improvement was observed at both lab-scale and full-scale level. The operating parameters, such as DO, ammonia, nitrite, and MLSS levels, were also studied. It was found that the optimal operating conditions for IFAS configuration, compared to MBBR, are lower DO (0.2-0.8 mg/L vs. 0.5-1.5 mg/L), higher nitrite (5-15 mg/L vs. 0-5 mg/L) and a MLSS of 4-5 g/L for IFAS.

Molecular tools were also used to determine the distribution of the Anammmox and AOB between suspended sludge and biofilm in the lab-scale trials by Veuillet et al., (in press). It was found that the IFAS configuration induced a segregation of the bacterial N-removal activity: Anammox activity mainly occurring on the biofilm (96% of total), whereas nitritation mostly taking place in the suspended phase (93% of total).
This paper reports the latest results from two IFAS studies – one at a full-scale plant in Malmö, Sweden, comparing the IFAS and MBBR performance side-by-side and one at a Pilot-scale unit conducted at Joint Water Pollution Control Plant (JWPCP), Los Angeles County, CA. This paper discusses the suitability of MBBR and IFAS configurations for full-scale applications.

MATERIAL AND METHODS

Full-Scale IFAS Demonstration Study
Experimental Setup. A full-scale demonstration of IFAS configuration was conducted in the full scale ANITA™ Mox plant at Sjölunda WWTP (550,000 PE), Malmo, Sweden. The full-scale plant consists of four separate 50m³ insulated and covered fibre glass cylindrical tanks, which are 6m high with a water depth of 5.5m and a diameter of 3m. All four tanks were started up and operated in the MBBR configuration.

Between Jan-Feb of 2013, one of the four MBBR tanks was converted to an IFAS configuration by installing a conical, in-tank, clarifier for sludge retention as shown in Figure 1. The clarifier had to be fitted inside of the existing MBBR due to space constraint at the site. The clarifier has a surface area of 2.5m² and a total volume of 7.5m³. The second MBBR tank continued to be operated in the MBBR configuration for side-by-side comparison purpose. AnoxKaldnes K5 carriers (effective protected surface area of 800 m²/m³) with a filling degree of about 50% were used in both systems. Medium bubble stainless steel air grids were provided in both systems. On-line instruments such as airflow, DO, NH₄, NO₃ and pH were installed for both systems.

Figure 1: Retrofit of Existing MBBR ANITATM Mox Reactor to IFAS Configuration.
The feed to this full-scale demonstration study was the reject water from mesophilic anaerobic sludge digesters. The feed characteristics are presented in Table 1. As shown, the reject water was relatively high in TSS, which was caused by frequent TSS spikes from non-optimal centrifuges operation. The feed ammonia was relatively high but with small variations, indicating a stable ammonia concentration.

| Table 1: | Reject water characteristics during the full-scale demonstration study. |
|-----------------|-----------------|-----------------|
|                | NH₄-N (mg/L)    | sCOD (mg/L)    | TSS (mg/L)    |
| Average         | 929             | 313             | 1181           |
| Std Dev         | 88              | 51              | 1688           |
| Min             | 680             | 211             | 108            |
| Max             | 1143            | 422             | 7720           |

**Pilot Testing of ANITA Mox IFAS Process in USA**

The IFAS pilot unit was constructed in a trailer. As shown in Figure 2, the unit consists of a round reactor tank and a lamella clarifier. The working volume of the reactor is 803 gallon, and the side water depth is about 5 ft. The clarifier consists of a coagulation-flocculation zone, an influent distribution zone, a lamella settling zone, a sludge collection zone, and an effluent collection box. The total volume is 480 gallon. The lamella settling zone is about 85 gallon, consisting of 20 lamella plates with a total plate surface area of about 80 ft².

![Figure 2: Pilot Scale ANITA Mox IFAS System – Side View.](image-url)

About 295-gallon pre-colonized biofilm carriers (K5), as shown in Figure 3, were obtained from the full-scale biofarm plant at Sjölunda WWTP, Malmo, Sweden and were installed in the reactor tank, which resulted in a carrier filling degree of 37%. It must be noted that seeded sludge for suspended growth was not provided for this pilot. A medium bubble stainless steel air grid and mechanical mixer were provided in the reactor tank. In addition of a feed centrate pump, a return sludge
(RAS) pump was provided at a range capacity of 50%-300% of the feed pump. On-line instruments such as feed flow, airflow, DO, and pH were installed.

**Figure 3:** Typical K5 carrier fully colonised with Anammox bacteria.

**Influent Characteristics.** The feed to the pilot was the centrate from dewatering of anaerobic digested sludge at JWPCP, LACSD, CA. The feed characteristics during the testing period are presented in Table 2. The centrate was characterized as low in TSS, BOD and COD. The influent soluble biodegradable COD (sbCOD) to NH$_4$-N ratio was around 0.15.

**Table 2:** JWPCP centrate characteristics during the pilot test

<table>
<thead>
<tr>
<th></th>
<th>NH$_4$-N</th>
<th>Alkalinity*</th>
<th>TSS</th>
<th>tCOD</th>
<th>sCOD</th>
<th>tBOD</th>
<th>sBOD</th>
<th>PO4-P</th>
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<tr>
<td>Average (mg/L)</td>
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<td>2,345</td>
<td>259</td>
<td>369</td>
<td>139</td>
<td>59</td>
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<tr>
<td>Std Dev (mg/L)</td>
<td>109</td>
<td>400</td>
<td>584</td>
<td>109</td>
<td>28</td>
<td>33</td>
<td>7</td>
<td>3.6</td>
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<tr>
<td>Min (mg/L)</td>
<td>44</td>
<td>416</td>
<td>21</td>
<td>159</td>
<td>60</td>
<td>10</td>
<td>6</td>
<td>1</td>
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<tr>
<td>Max (mg/L)</td>
<td>783</td>
<td>2,970</td>
<td>1970</td>
<td>650</td>
<td>166</td>
<td>149</td>
<td>31</td>
<td>16</td>
</tr>
</tbody>
</table>

*As CaCO3

**Operational conditions.** A 120-day pilot testing was divided into three phases – startup phase and two phases with two constant feed flow rates (2.0 gpm and 2.4 gpm) resulting in two different ammonia loading rates. The objective of the pilot trial was to demonstrate the startup and steady-state performance and find the maximum ammonia removal rate of the pilot system.

**Analytical Methods**

Grab samples were taken daily and filtered at 0.45µm immediately for soluble compounds analysis. NH$_4$-N, NO$_2$-N, NO$_3$-N, PO$_4$-P, COD and sCOD were measured using a colorimetric method with HACH kits. Alkalinity was determined by titration with a standardised sulphuric acid solution (0.02N). Mixed Liquor Suspended Solids (MLSS) and the Mixed Liquor Volatile Suspended Solids (VSS) were measured according to Standard Methods.

**Results**

**Full-scale IFAS and MBBR side-by-side comparison**

This section presents the full scale performance data for a side-by-side comparison between the MBBR and IFAS configurations. The clarifier was installed on Day 960 and a stable sludge separation performance was achieved by the clarifier after Day 985. The MLSS level was about 2 to 2.5 g/L.
Figure 4a presents influent and effluent nitrogen profiles in the IFAS reactor from Day 870 to Day 1185 while Figure 4b presents the same profiles in the MBBR reactor between Day 985 and Day 1185. The performance of the two systems was therefore directly compared from Day 985 onwards. It should be noted that there was a short period of about 30 days starting on Day 1100, during which no centrate was available on site meaning that both reactors were not fed. Both systems achieved stable effluent nitrogen concentrations with average NH₄ at 90 mgN/L and average NO₃ at 70 mgN/L. The main difference was for NO₂ level with that in IFAS being 50% higher than in the MBBR (6 mgN/L vs. 3 mgN/L).

Figure 5 presents the volumetric N-loading rate (VLR) and volumetric total inorganic nitrogen (TIN) removal rate (VRR), N-removal efficiency and the % of NO₃produced/NH₄removed for both IFAS and MBBR reactors. As shown in Figure 5a (i.e. IFAS), the TIN VRRs after switching to the IFAS mode increased from 0.8-1.0 kg/m³/d to 2.0-2.5 kgN/m³.d. The corresponding VRR for the MBBR reactor was relatively stable for the whole comparison period at 0.8-1.0 kg/m³/d (Figure 5b). The N-removal rate achieved in the full-scale IFAS ANITA Mox was therefore 2-2.5 higher than in the pure MBBR. Both reactors achieved consistently 80% TIN removal and 90% NH₄ removal. The % NO₃produced/NH₄removed was also very stable and close to the stoichiometric 10% in both reactors.
**Figure 4:** Nitrogen Profiles in the two side-by-side 50m³ systems: IFAS ANITA Mox (A) and pure MBBR ANITA Mox (B)
Figure 5: Volumetric N-loading rates, TIN-removal rate, TIN-removal efficiency and % NO3\textsubscript{produced}/NH4\textsubscript{removed} for both IFAS (A) and MBBR reactors (B).

This IFAS full-scale study also investigated sludge settleability and clarifier performance of the IFAS system as reported in Figure 6. The clarifier was able to maintain an average MLSS of about 4 g/L. SVI fluctuated between 70 and 100 mL/g indicating very good sludge settleability. A sludge concentration factor of about 2 was calculated based on the RAS and MLSS in the IFAS demonstrating that the clarifier was capable of thickening the sludge to satisfactory level. However, the effluent TSS was relatively high (about 460 mg/L, data not shown) with a large standard deviation (552 mg/L).

Figure 6 also presents the ammonia applied and removal load rates in the IFAS system and the incoming TSS in the reject water. The best NH4\textsubscript{4} removal rates (about 2.8 kg/m\textsuperscript{3}/d) were achieved when the inlet TSS was consistently low and the MLSS was moderate and stable. Despite of the large MLSS variation in the IFAS tank, mostly due to frequent influent TSS spikes up to 7 g/L, nitritation in the suspended sludge was enhanced at bulk DO concentration between 0.2 to 0.5 mg/L. As
indicated by the low ratio of NO$_3$-N$_{prod}$/NH$_4$-N$_{rem}$ measured in the reactor (<10%), the low DO condition applied in the IFAS reactor was sufficient to repress the NOB growth in the suspended sludge even with the higher nitrite level. Due to the improvements on both nitritation and anammox activities with the IFAS mode and optimal microbial population distribution between biofilm and suspended sludge, the NH$_4$ removal rate increased by 200-250% compared to the pure MBBR configuration. However, although it was lower, the removal rate in the MBBR reactor was relatively stable, which indicates that the influent TSS does not affect the performance in the MBBR as much as that in the IFAS.

![Graph showing NH$_4$ removal rates vs. MLSS, influent TSS, and SVI in IFAS reactor](image)

**Figure 6:** Volumetric NH$_4$-removal rates vs. MLSS, influent TSS, and SVI in IFAS reactor

**Pilot Testing of IFAS Configuration at JWPCP, LA County, CA**

The pre-colonized media were installed on October 8. No seeded sludge for suspended growth was added. After four day batch operation, the pilot system started receiving continuous centrate flow with continuous aeration controlled by manually adjusting the airflow setpoint. During the start-up period, the feed flow and airflow rates were adjusted on daily base. The airflow rate was set to give a relative high DO to quickly develop AOB activity in the sludge.
Figure 7 presents the feed flow rate, airflow rate, and reactor DO level. The DO data were an instantaneous reading when grab samples for nutrient analyses were taken. The feed flow rate started from 0.3 gpm and reached 2.0 gpm within the 40 days. The return activated sludge flow was controlled at 100% of the feed flow for all three phases, except for the week just starting Phase 2, i.e., the Thanksgiving week. During this week, the RAS flow was increased to 200% of the feed flow, which led to too much headloss in the pipe between the reactor and clarifier. The high headloss caused the water level in the reactor tank to increase to the level of the emergency overflow pipe. The mixed liquor was washed out to the drain. But biofilm carriers were kept in the reactor by a screen.

The recovery from this accidental solids washout took about 7 days. After recovery, the feed flow was reset at 2.0 gpm for Phase 2. An airflow rate of 32 scfm appeared to be optimal for Phase 2 ammonia load. During Phase 3, the feed flow was increased to 2.4 gpm first with airflow of 32 scfm and later the airflow rate was increased to 35 scfm to investigate the effect of airflow rate on the performance.

![Figure 7: Feed flow and Airflow rates and DO level during the IFAS ANITA Mox pilot study.](image)

Figure 8 presents the influent ammonia and the effluent ammonia, effluent nitrate and effluent nitrite during the entire pilot study. Figure 9 presents the percentages of ammonia and nitrogen removal efficiencies and the \( \% \text{NO}_3\text{produced}/\text{NH}_4\text{removed} \). Figure 10 presents the surface NH\(_4\) loading rate and the surface NH\(_4\) and TIN removal rates during the pilot study. Figure 11 presents the MLSS in the tank, TSS in RAS, clarifier effluent TSS and the sludge concentration factor during the pilot test.
Figure 8: Influent and effluent nitrogen concentrations during the IFAS ANITA Mox pilot study.

Figure 9: NH₄ and TIN removal efficiencies and % NO₃ produced/NH₄ removed during the IFAS pilot study.
Figure 10: Surface NH₄ loading rate and surface NH₄ and TIN removal rate during the IFAS pilot study.

Figure 11: MLSS, effluent TSS, Return sludge TSS and sludge concentration factor in the IFAS pilot.
**Start-up Period** - As shown in Figures 7, it took about 40 days to develop the AOB activity in the suspended growth. During this 40 day period, the feed flow rate reached 2 gpm, the MLSS reached about 4,000 mg/L (Figure 11), the ammonia SRR reached 6.0 g/m²/d with an 85% ammonia removal, and the TIN SRR reached about 5.0 g/m²/d with 75% nitrogen removal (Figure 9 and 10). During this start-up period, the nitrite started to build up and reach about 15 mgN/L (Figure 8). Nitrate production was higher than the stoichiometric value due to the relatively high DO levels initially applied in the reactor but quickly went down to less than 10% of NH₄-removed (Figure 9).

**Washout Recovery** – The washout event has lasted probably for 7 days because it was the Thanksgiving week and was stopped on the Monday of the next week, Dec. 2. The lowest MLSS observed was about 300 mg/L, indicating a complete washout because influent TSS was at the same level. It took about 10 days to build up MLSS back to previous 4.0 g/L level (Figure 11), reduce effluent ammonia to previous 100 mg/L level (Figure 8) and increase the SRR rates back to 6.0 g/m²/d for ammonia and 5.0 g/m²/d for TIN (Figure 10).

**Phase 1** – During this phase, the MLSS level was stabled at about 5.0 g/L. The ammonia SRR was between 7 to 8 g/m²/d and the TIN SRR was between 6 to 7 g/m²/d (Figure 10). The corresponding volumetric removal rates were 2.1-2.4 kg/m³/d for ammonia and 1.8-2.1 kg/m³/d for TIN. The removal efficiency was between 80-90% for ammonia and 70-80% for TIN (Figure 9). The nitrite level was very stable and stayed between 25 to 30 mg/L (Figure 8). The ratio of nitrate production was very stable and averaged 9% after Dec. 12. The optimal airflow rate was 32 SCFM and optimal DO appeared to be between 1 to 2 mg/L.

**Phase 2** – During this phase, the MLSS level was even more stable and was about 4,500 mg/L (Figure 11). As the feed flow rate increased by 20%, the applied load was increased from about 8.5 g/m²/d to 10 g/m²/d (Figure 10). However, the ammonia and TIN SRRs stayed the same as Phase 1, even with an increased airflow rate from 32 scfm to 35 scfm. Because of no improvement in SRR at an increased applied load, the removal efficiencies decreased from 90% to 80% for ammonia and from 80% to 70% for TIN (Figure 9).

**Clarifier Performance** - Figures 10 and 11 indicate that a steady state was achieved in the pilot after Dec. 31 in terms of MLSS and SRR. It was observed that the scum layer floated on the clarifier surface was grey/black, sticky/gluey, and looked like anaerobic sludge with lots of polymer. The sludge on the bottom of the settleometer was brownish, floc-type, aerobic-look sludge. The biofilm on the floating media carriers on the surface of the settleometer appeared red and dense. The scum layer was scrapped off manually on daily basis but it was difficult to quantify the mass.

Sludge concentration factor and SRT were calculated based on the effluent TSS, MLSS, and RAS TSS concentrations during the stable period (after Dec. 31) and these parameters are summarized in Table 3 together with SVI data obtained during the entire study. As shown in Table 3, the clarifier was able to consistently maintain an average MLSS of about 4,169 mg/L. The average SVI was about 93 mL/g with a small standard deviation of 9.8 mL/g. The sludge concentration factor of about 2.1, which was almost identical to the ratio of $(Q_{\text{INF}} + Q_{\text{RAS}})/Q_{\text{RAS}} = 2.0$. This indicates that the clarifier was capable of thickening the sludge. The effluent TSS was about 150 mg/L with a large standard deviation (170 mg/L), which resulted in an SRT of 13 day for the IFAS system. The large
variation on SRT (10.9 days) was probably a result from the variation in the effluent TSS. It must be noted that sludge wasting was not conducted and the solids loss from the scum layer was not considered in SRT calculation.

| Table 3: Summary of average sludge concentration and settling characteristics |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | MLSS mg/L       | TSS in RAS mg/L | Eff. TSS mg/L   | Sludge Conc. Factor | SVI mL/g | SRT day |
| Average        | 4,169           | 8,955           | 151             | 2.1              | 93       | 13.3    |
| Std. Dev.      | 887             | 1,460           | 171             | 0.2              | 9.8      | 10.9    |

Conclusions

The conclusions below are drawn based on the results from the studies reported in this paper.

- Both studies confirmed that the removal rate in the IFAS ANITA™ Mox process was 2 to 2.5 times of that in the MBBR. The nitrogen SRR can reach up to 8 g/m²/d with with similar high TIN and NH₄ removal efficiencies observed in the MBBR (80% and 90%, respectively).
- Compared to the MBBR, the IFAS configuration was more adapt to the feed with high C/N ratios and more sensitive to high influent TSS.
- The efficient control of MLSS in the IFAS reactor is a key parameter to enhance the nitrite production by AOB and increase the substrate availability in the anammox-enriched biofilm leading to higher N-removal rate. The optimal operating conditions for the IFAS reactor are typically 2.5-5 g/L for MLSS and 0.3-0.8 mg/L for DO.
- The sludge settleability from the IFAS system was very good as indicated by SVI between 70 to 100 mL/g. The clarifier was able to retain the suspended biomass required for the better performance
- N-removal performance quickly recovered after solids washout confirming the robustness of the IFAS configuration.

References

