

# **The Low Methanol Diet - A Utility's Recipe for Process Optimization through Advanced Controls and Operational Excellence**

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## **ABSTRACT**

The AlexRenew WRRF (204 ML/d AADF) has recently been upgraded to meet an annual average TN concentration of 3 mgN/L. Recent upgrades have been targeted to increase efficiency including an attempt to “activate” the anammox granules for mainstream nitrogen removal. Customized strategies were developed using BioWin for aeration and supplemental carbon dosing. The control algorithms include ammonia-based aeration control (ABAC), intermittent aeration, automated methanol dosing and automated ORP control to prevent anaerobic conditions in the post-anoxic zone.

Since the systems were placed in service in 2016, the facility has reduced aeration requirements by 30% and methanol consumption by 50% compared to previous years, all the while meeting the more stringent final effluent total nitrogen limits. The facility has saved almost \$300,000 per year in chemical expenditures.

The increased reliance on instrumentation and controls has created additional demands on AlexRenew's staff and required implementation of a probe maintenance program.

## **KEYWORDS**

Ammonia-based DO control, rapid anoxia. NOB suppression, deammonification, supplemental carbon dose control

## **INTRODUCTION & BACKGROUND**

Utilities around the world are striving to reduce their reliance on chemicals and energy in the operation of their Water Resources Recovery Facilities (WRRFs). This is especially true for facilities facing more stringent effluent requirements for total nitrogen (TN), which often results in a greater reliance on organic carbon to drive denitrification. This reliance can often result in:

- 1) Constraints in terms of carbon redirection, reducing the opportunities to optimize secondary treatment aeration and biogas production; and

- 2) The need to add substantial quantities of supplemental carbon to further drive TN removal.

The AlexRenew WRRF is one such facility, which has recently been upgraded to meet an annual average TN concentration of 3 mgN/L to meet discharge requirements to the Chesapeake Bay. This 204 ML/d average day flow facility, while designed with an efficient step feed BNR configuration, has relied on the addition of approximately 1,000 gallons per day of methanol to achieve these stringent effluent requirements. Recent upgrades have been targeted to significantly mitigate the higher reliance on methanol and higher energy demands, and have included:

- Centrate treatment using deammonification to remove the highly concentrated ammonia load that is produced when dewatering anaerobically digested biosolids (Yin, 2018).
- Implementation of a customized ammonia-based aeration control (ABAC) strategy to assist in out-selection of nitrite oxidizing bacteria (NOBs) and reduce aeration energy.
- Mainstream WAS hydrocyclones to retain anammox granules seeded from the sidestream reactor to provide concomitant improvements in N-removal and mixed liquor settleability.
- Primary effluent flow/load equalization to diminish fluctuations in C:N ratio of the bioreactor feed, aeration demand, and methanol dosage requirements.

This paper summarizes the work carried out at AlexRenew to optimize reactor loading, aeration, and supplemental carbon dosing, including the results obtained to date (i.e. methanol savings, energy reduction, and improvements to effluent quality) as well as the changes to operations and maintenance procedures to maintain the new equipment, instrumentation, and associated systems.

## METHODOLOGY

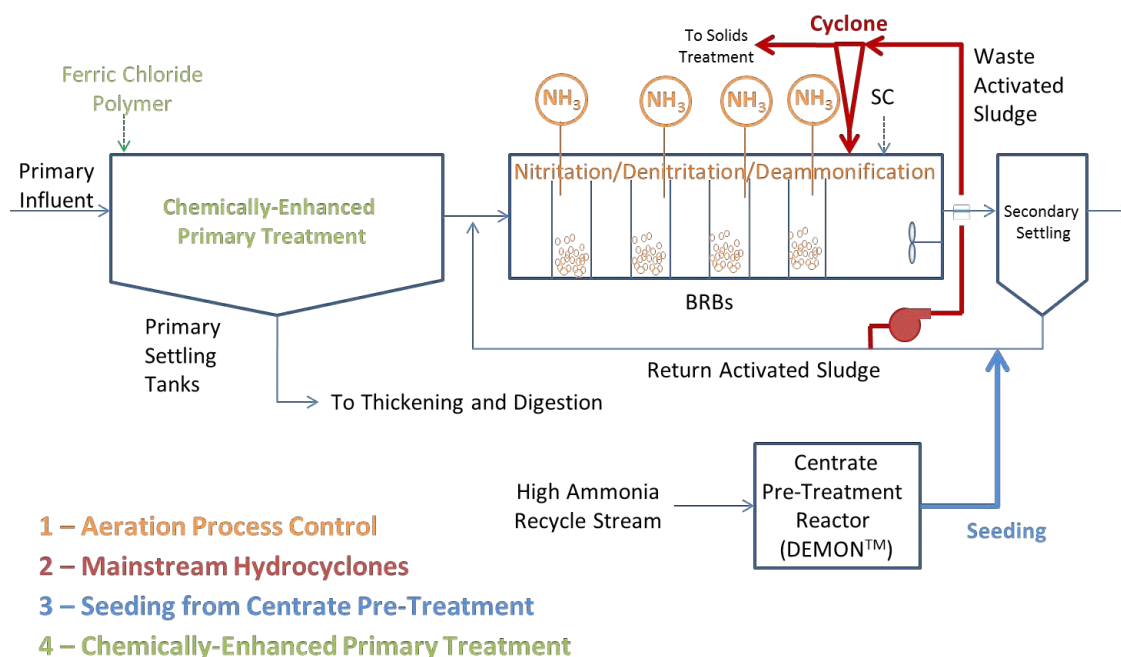
The goal of this project was to modify the liquids treatment system at AlexRenew WRRF in order to reduce operating costs (energy and chemicals) by redirecting the nitrogen removal pathways from the conventional nitrification-denitrification to the more efficient nitritation-denitritation and deammonification. This shift requires creating the particular environmental conditions necessary to suppress NOB activity and increase the deammonification rates, the latter of which includes the simultaneous access to ammonia and nitrite in the presence of low dissolved oxygen concentrations (WERF, 2015). There are numerous challenges to creating these conditions within the mainstream activated sludge process including lower temperatures and substrate concentration (as compared to sidestream conditions).

The implementation strategy at AlexRenew consists of the following four components:

1. Aeration process control creates conditions in the biological reactor basins (BRBs) that are favourable for nitritation/denitritation/deammonification
2. Hydrocyclones on the waste-activated sludge (WAS) flow stream separate the anammox granules and keep them in the system while wasting NOBs and others. In addition, hydrocyclones can improve sludge settleability by keeping larger particles in the system.

3. Seeding Anammox bacteria from centrate pre-treatment (CPT) augment the population and increase activity in the mainstream process.
4. Chemically-Enhanced Primary Treatment (CEPT) is used to remove carbon in the primary settling tanks and convert it to biogas in the digesters. Anammox bacteria do not need carbon to nitrify ammonia therefore lowering the carbon content in the influent helps anammox outcompete heterotrophs in the anoxic environment for available nitrite. The carbon contained in the influent can be captured in the primaries and better utilized to produce energy-rich biogas in AlexRenew's anaerobic digesters.

The four components of the optimization strategy are illustrated in Figure 1.



**Figure 1 – Process Optimization Implementation Strategy at AlexRenew WRRF**

The first element, aeration process control, was needed to “activate” the anammox granules for mainstream nitrogen removal, which is known to be a challenge at the lower temperatures and substrate concentrations compared to the sidestream process (WERF, 2015). Customized strategies were developed using BioWin for aeration and supplemental carbon dosing.

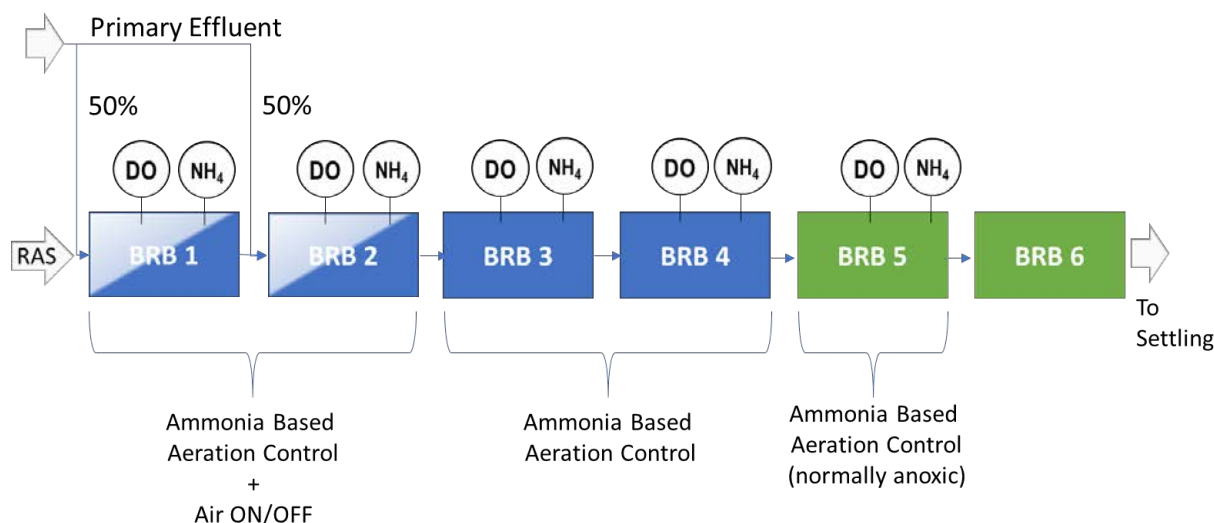
### BioWin Modelling

BioWin was used to design a reactor configuration and aeration control scheme to achieve NOB out-selection in the mainstream, as follows:

1. Aeration in the first two reactors is turned on-off to create transient anoxia and generate a selective pressure for NOB out-selection (Al-Omari, 2012). The ammonia concentration is maintained at  $> 4$  mgN/L in the first two reactors in service and the resulting high ammonia relative to nitrite provides AOBs a kinetic advantage over NOBs during air “on” periods.

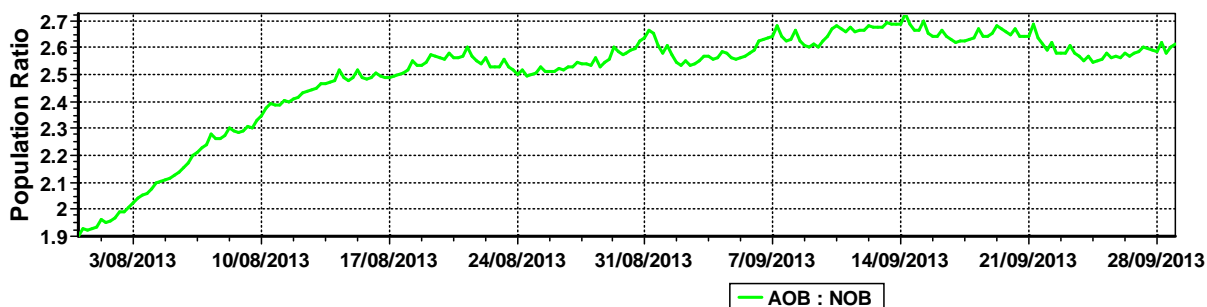
2. The aeration in the second two reactors is controlled to target complete removal of ammonia.
3. The last two reactors in service operate in anoxic mode and methanol is added to reduce the final effluent TN to < 3 mgN/L.

Figure 2 illustrates the reactor configuration and aeration control scheme developed for AlexRenew.



**Figure 2 – Aeration Control at AlexRenew**

BioWin results indicate that the ratio of AOBs to NOBs in the mainstream would increase from about 2:1 to closer to 3:1, thereby providing a degree of NOB suppression. Figure 3 illustrates the results from the BioWin simulation.

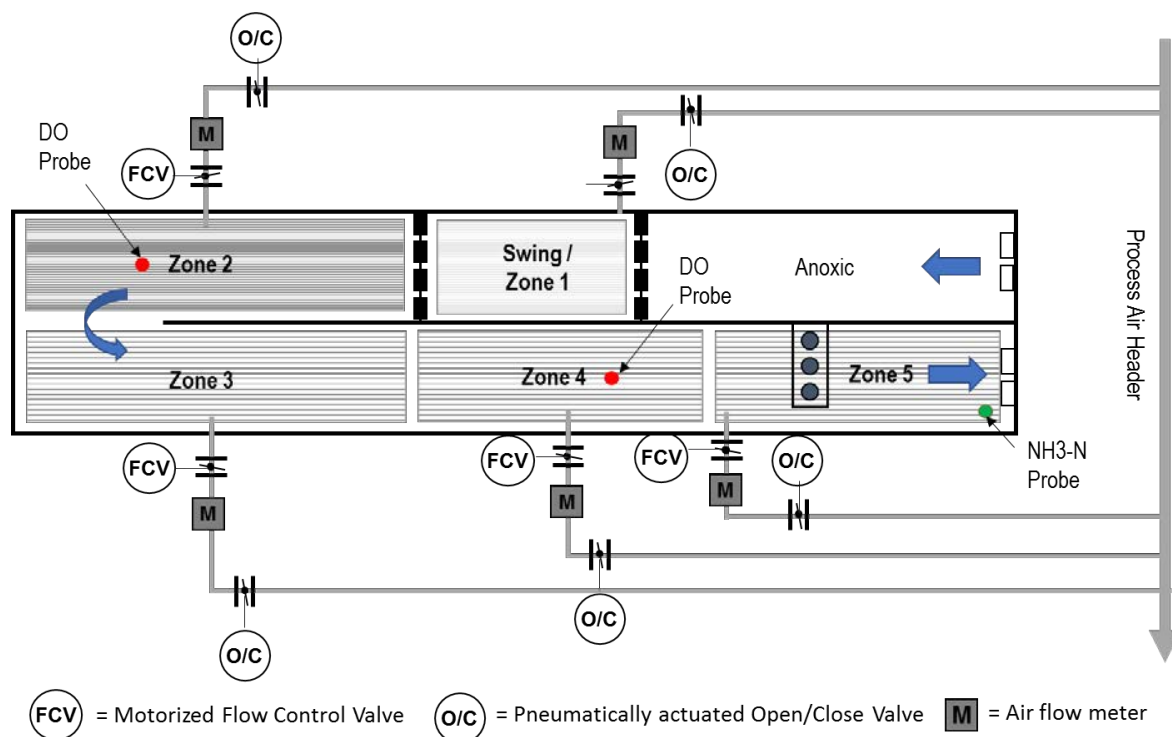


**Figure 3 – BioWin Results: Ratio of AOB:NOB in BRB 1 mixed liquor**

## Modifications to Existing Reactors

Pneumatically-actuated valves with rapid open/close action were installed on the air diffuser drop legs to rapidly “swap” the air from one end of the basin to the other and minimize swings in header air pressure. This approach allows the system to operate with a single blower while achieving the air on/off effect in each half of the basin. Each drop leg has two valves, an

isolating and a modulating valve, and an air flow meter as illustrated in Figure 4. The modulating valve operates during the air on cycle to maintain the target air flow rate. When the air is turned off (via the isolation valve), the modulating valve holds its last position until the next aerated cycle begins.



**Figure 4** – Typical aeration system configuration for Reactors 1, 2 and 3

In-situ ammonia, NO<sub>x</sub>, and ORP analyzers were installed in the effluent end (Zone 5) of each of the six BRBs. The ammonia analyzers are ion-selective electrode (ISE) probes and they need to be installed in a mixed area to work properly (otherwise the ions around the electrode are depleted and the reading is inaccurate). Therefore the air in Zone 5 of BRBs 1, 2 and 3 is always kept on at a minimum air flow rate in order to provide mixing. Installing mixers in those zones was considered but not implemented due to cost and disruption to plant operations as reactors would have to be taken out of service for mixer installation. BRBs 4 and 5 already had submersible mixers in Zone 5 of the reactor.

The submersible mixers in BRBs 4 and 5 were automated so that they turn on when the air is turned off in an aeration zone to maintain mixing. This allows the control system to completely turn air off in BRBs 4 and 5 during low loading periods of the day. BRB 6 is a post-anoxic zone and it only has mixers (no aeration).

Total cost for these improvements was approximately US \$1 M.

## Hydrocyclones

Specially-designed hydrocyclones were procured in order to separate the anammox granules from the WAS prior to discharge to solids handling (Figure 5). The hydrocyclones also help increase the granular content of the mixed liquor which in turn could help settleability.

The hydrocyclones require a high inlet pressure (1.6 bar or 23.5 psi) and this is achieved by pumping the WAS to the hydrocyclones. The outlet of the hydrocyclones (overflow and underflow) is required to be at atmospheric pressure and because of this, specially designed launders were required to direct the hydrocyclone underflow back to the BRBs and the hydrocyclone overflow to WAS thickening.



**Figure 5** – Hydrocyclone clusters at AlexRenew

### Startup and Optimization

The system was started up in several steps, first implementing sidestream deammonification, then mainstream ABAC, followed by hydrocyclones and air On-Off aeration in the first two BRBs. System tuning and optimization has been ongoing. Introduction of the anammox granules from the sidestream process is expected in mid-2019.

Chemically enhanced primary treatment (CEPT) has not been implemented to-date although a pilot study was carried out in 2016. The results indicated that the existing chemical addition system at AlexRenew did not adequately distribute the chemical among the primary settling tanks in service resulting in uneven results. The system will be tested again in 2019. Process modelling using BioWin indicates that implementation of CEPT could further reduce aeration demand and increase biogas production. However, more carbon may be required for denitrification. As AlexRenew currently produces more biogas than it uses (excess biogas is currently flared), there is no financial incentive to implement CEPT as the cost of methanol currently outweighs the potential energy savings resulting from reduced aeration demand.

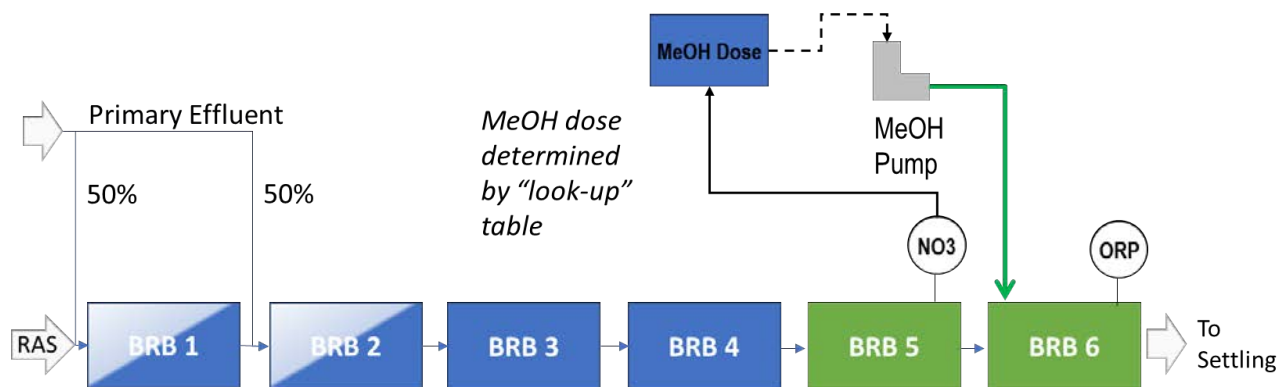


## Description of Control Algorithms

The following control algorithms were programmed as part of the optimization effort at AlexRenew:

- **ABAC:** The ammonia concentration is measured at the end of the basin using in-situ ion-selective electrode (ISE) probe. The system modulates the dissolved oxygen (DO), within an operator-set range, to maintain a target ammonia setpoint at the end of the reactor and the airflow is adjusted accordingly. Some aeration zones in BRBs 4 and 5 are set to turn completely off if the effluent ammonia drops below a setpoint. The mixers are automated to turn on when the air turns off to maintain adequate mixing.
- **Air ON/OFF:** The air switches every 15 minutes from Zones 1 and 2 of the BRB aeration grid to Zones 3 and 4 (refer to Figure 4). Zone 5 air is always on in order to provide the mixing needed for accurate ammonia measurement with the ISE probe. When air is ON in the “control” side, the ABAC system modulates air flow (using the motorized modulating valve) to achieve the target DO. When the air switches to the “lag” side, the same air flow is introduced to maintain constant air header pressure. ABAC is inactive during those 15 minutes. When the system switches back to the “control” side, the ABAC re-engages. The switching is done by opening and closing the pneumatic open-close valves on each drop leg. The system sends the open signal first to the closed valves and when the open limit switch activates, it sends the closed signal to the open valves. The travel time for opening and closing the valves is about 5-10 seconds. The system pressure dips momentarily during the switch event but it comes back quickly. During the switch event all the other modulating valve positions are set to hold. Once the system pressure is back to normal the active air flow modulating valves re-engage to maintain their air flow setpoint.
- **Automated Methanol Dosing:** NO<sub>x</sub> is measured as it enters the last post-anoxic BRB and the methanol dose setpoint is automatically determined using an operator-adjustable look-up table that increases the dose in proportion to NO<sub>x</sub> concentration.
- **ORP-based Control:** To avoid anaerobic conditions in the post-anoxic zone, an ORP probe was installed at the end of BRB6. If the ORP drops below the setpoint, methanol addition is stopped and one of the aeration zones is turned on. When the ORP rises back above the setpoint the air is turned off and methanol addition resumes.

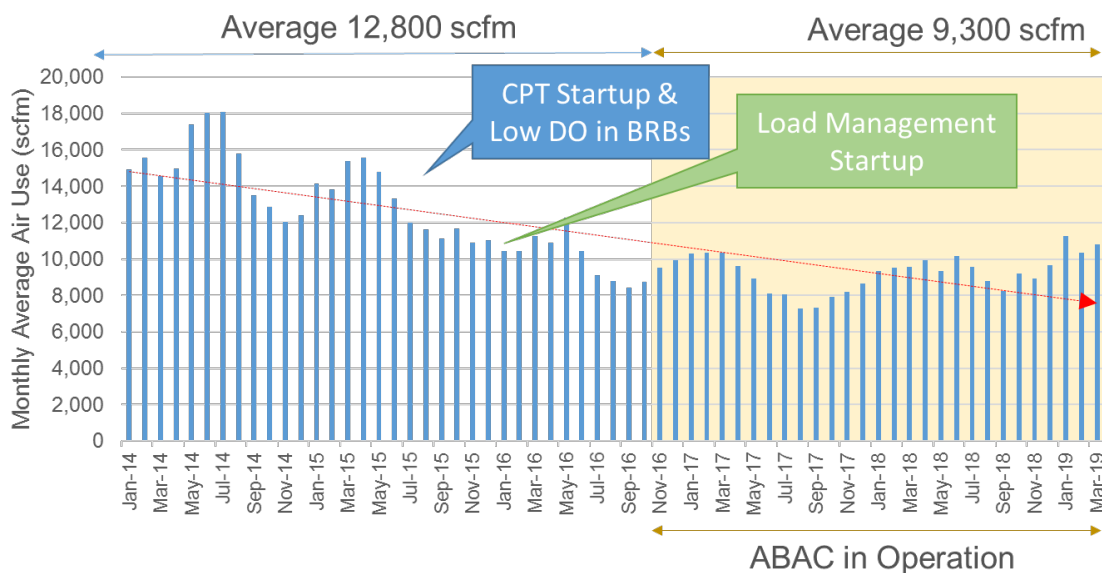
Figure 6 illustrates the automated methanol dosing and the ORP control.



**Figure 6** – Automated Methanol Dosing and ORP control at AlexRenew

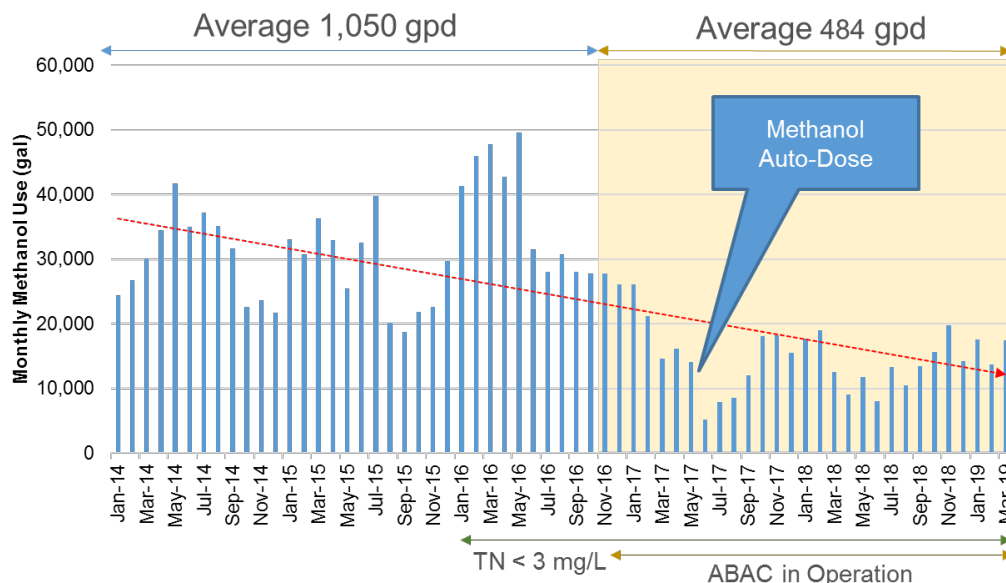
## RESULTS

Since the systems were placed in service in 2016, the facility has reduced the aeration by 30% (Figure 7), methanol consumption by 50% in 2017 and 2018 (Figure 8) compared to previous years, all the while meeting the more stringent final effluent total nitrogen limits. As shown in Figure 9, the final effluent TN concentration has been reduced from 3.8 mg/L (average in 2014 and 2015) to 2.7 mg/L (average in 2016, 2017 and 2018). The facility has saved almost US\$300,000 per year in chemical expenditures.

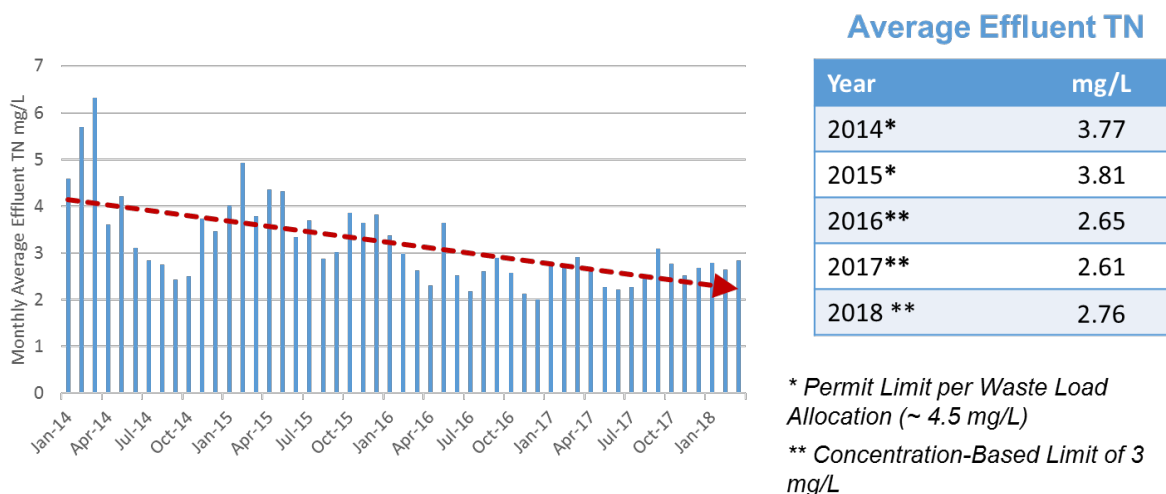


**Figure 7** – Average Monthly Aeration Demand 2014 to March 2019





**Figure 8** – Average Monthly Methanol Demand 2014 to March 2019



**Figure 9** – Average Monthly Methanol Demand 2014 to March 2019

Ongoing work will introduce anammox granules from the sidestream into the mainstream and further tuning of the system will be carried out to further improve NOB suppression. In addition, a pilot test of CEPT will be implemented to determine the effectiveness of implementing carbon re-direction using primary treatment and the impact on aeration and supplemental carbon demand.

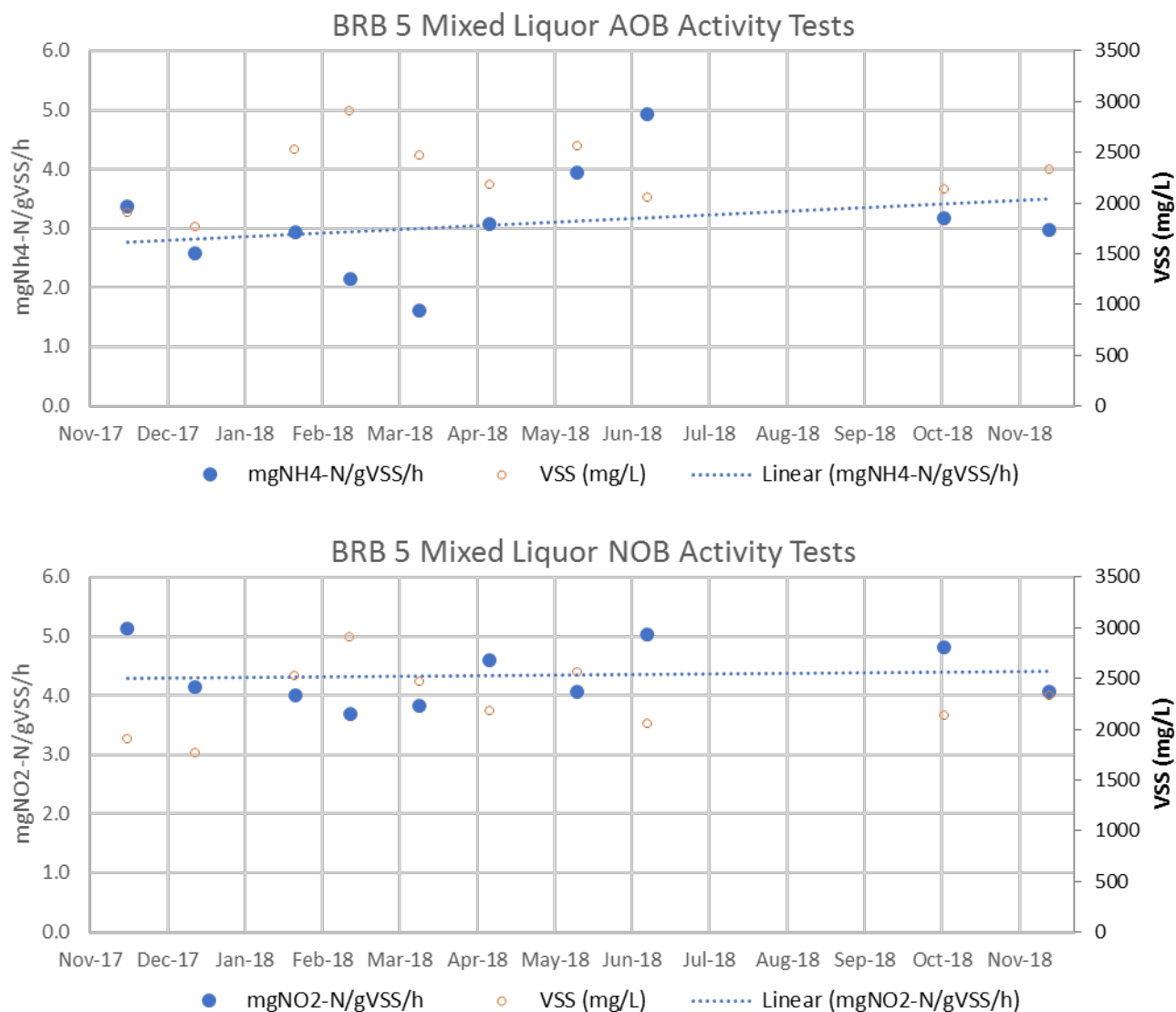
## DISCUSSION

The reduction in aeration demand and methanol use at AlexRenew indicate that the use of instrumentation and automation has been effective in optimizing the process. AlexRenew has also investigated whether the reduction in methanol and aeration are due to changes in the

metabolic pathways of nitrogen removal in the system, or simply due to reducing or eliminating existing system inefficiencies.

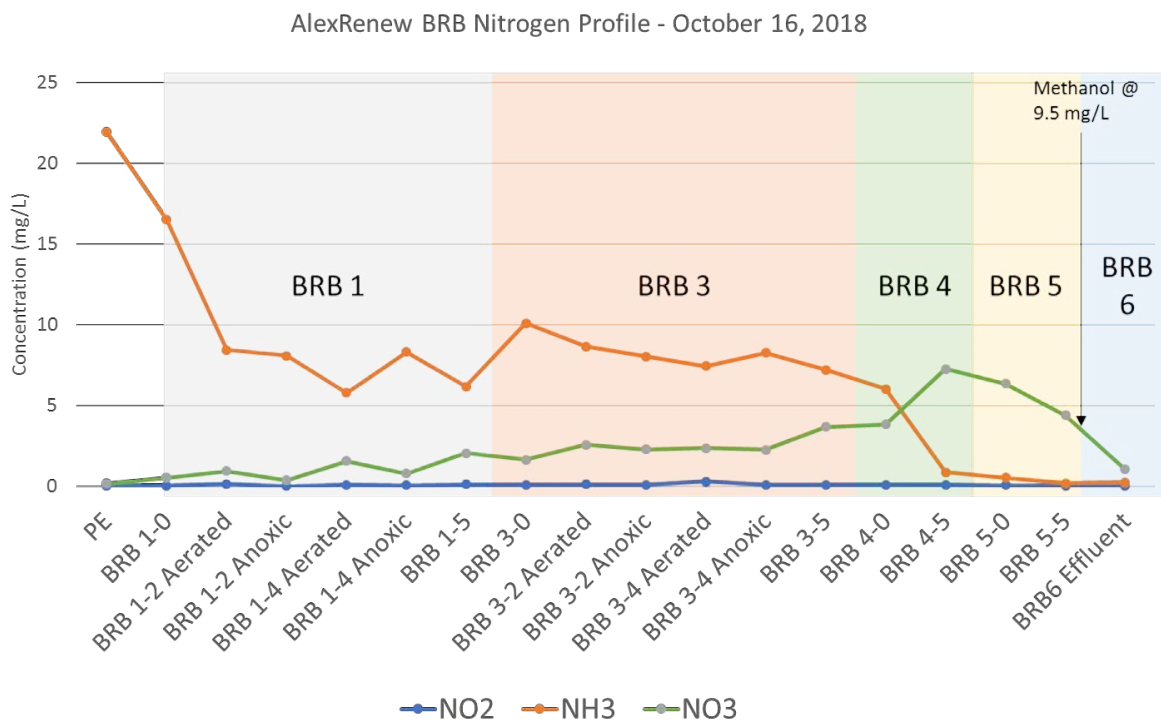
To this end, AlexRenew conducted several tests, including AOB and NOB activity testing in the mixed liquor and measuring the various nitrogen species across the biological reactor system.

Figure 10 illustrates the results of the activity tests.



**Figure 10** – AOB and NOB activity test results

Figure 11 illustrates the results of nitrogen species testing (ammonia, nitrite and nitrate) across the reactor system. When the testing was performed, the system was operating with five BRBs in service (BRB 2 was out of service). BRB 1 and BRB 3 were operating in air on/off mode. The samples were collected in the anoxic zone (Zone 0), during the air on and during the air off period in Zone 2 and Zone 4, and in Zone 5. BRBs 4 and 5 were only sampled in the anoxic zone (Zone 0) and in Zone 5.



**Figure 11** – Nitrogen species concentrations in the BRBs

In conclusion, NOB suppression does not appear to be occurring to a measurable degree in the system as evidenced by the normal NOB activity and the low NO2 concentration in the BRBs.

## LESSONS LEARNED

The data provided by the new instrumentation has allowed operators to observe, in real time, the impacts of the operational changes made, leading to greater understanding of the process, the system and more precise controls. Keeping the probes clean, calibrated, and accurate is key to system performance and therefore, AlexRenew implemented a probe maintenance program.

The probe maintenance program was started in 2017 and consisted of two main components: 1) recurring maintenance attention to process sensors to reduce the rate of deterioration; and 2) systematic application of engineering knowledge to confirm the proper functionality of process sensors. The program encompassed physical and analytical examinations of each probe to identify wear and tear, probe cleanings to reduce fouling, probe calibration to validate the collected data, and the replacement of minor probe components such as filters or reagents. The goal was to promote a more proactive approach to optimizing equipment performance and life.

### Implementation of the Probe Maintenance Program

The probe team was formed in May of 2017 and consisted of 4 operators, 2 control system technicians, and a process analyst. The program was implemented in the following stages:

Stage 1: Assess the Need

- Asset Inventory – AlexRenew conducted an inventory of the 66 sensors installed throughout the treatment process and determined their function (monitoring only or process control)
- Maintenance Requirements and Scheduling – For each of the 66 sensors installed, the routine maintenance, troubleshooting, and inventory tracking needs were determined.
- Personnel Requirements – As a result of the needs assessment, it was determined that a dedicated team would need to be formed to service and maintain the probes.

## Stage 2: Education and Documentation

- A training program was developed to teach operators the analytical lab skills needed for probe maintenance and calibration: batch processing techniques, dilutions, and reagent composition etc. The goal was to provide one-on-one demonstration and supervised practice. Routine tasks were performed on a weekly schedule to ensure repetition and for operator familiarization.
- Training Schedule – The probe maintenance training schedule was initially created for a year. Flexibility was incorporated into the schedule to accommodate operator availability. It was the responsibility of the operator to identify scheduling conflicts in advance and notify the process analyst if a particular training session had to be rescheduled.
- Effective Documentation – Documentation was established in order to maintain a good maintenance schedule. Troubleshooting logs also had to be developed anytime a problem arose to aid in troubleshooting future probe issues or process upsets.
- Service Visits – AlexRenew requested service visits from the different vendors to provide professional vendor training for the probe maintenance manager. Some of the probes were put on an annual service contract.

## Stage 3: Upgrade Equipment to Maintainable Condition and Continuously Improve

As a next step, the probe maintenance team has been identifying upgrades to the existing probes that would improve their ease of maintenance. Some of the areas of improvement that have already been identified include:

- Evaluate use of Ion Selective Electrode Ammonia Probes instead of wet chemistry analyzers for primary effluent ammonia measurement to reduce maintenance requirements. The primary effluent ammonia is measured and used for automated nutrient load balancing during the day. However the filters on the wet chemistry analyzers often clog and require frequent cleaning in order to maintain accuracy.
- Evaluate use of a wet chemistry analyzer instead of the ion selective electrode NH<sub>4</sub> and NO<sub>3</sub> probes in the secondary and tertiary effluent streams. These flow streams have lower total suspended solids which reduce filter clogging potential. Also, the wet chemistry analyzers are better suited to measure concentrations below 1 mg/L.
- Evaluate the use of additional TSS probes for clarifier blanket monitoring, solids processing automation and centrifuge operation improvements.

- Evaluate the use of the filter effluent turbidimeters to optimize filter backwashing and monitoring.

### **Challenges with Implementation of the Probe Maintenance Program**

There were several challenges associated with forming a probe maintenance team, most of which could be attributed to scheduling and time limitations. As highlighted in Stage 2: Education and Documentation section, probe maintenance entails extensive training and requires a serious commitment from each team member to develop the necessary analytical skills. Team members need to assume ownership of the program and personal responsibility for carrying out the necessary tasks.

There is a substantial amount of man-hours required to maintain the sensors and probes located throughout the treatment process. The 66 probes installed in the various unit processes throughout the treatment plant demand an estimated total of over 2,000 annual work hours to support reliable operating conditions. This is equivalent to a full-time employee.

Alternatively, AlexRenew has also explored the option of issuing service contracts to the probe manufacturers to perform the required maintenance and calibration. However, plant operations and maintenance staff would still have to perform regular probe inspection, cleaning and troubleshooting.

### **CONCLUSIONS**

The optimization program at AlexRenew has been successful in significantly reducing methanol demand and aeration requirements with a modest investment in capital improvements to their system. Instrumentation and advanced controls have worked effectively to increase operational efficiency and increase operator understanding of the process. This in turn has allowed operators to work more proactively to optimize the system and resulted savings of almost \$300,000 per year in chemical costs.

The increased reliance on instrumentation has created additional demands on the operations and maintenance staff at AlexRenew. Instruments need to be regularly cleaned and calibrated and significant training is required to prepare staff to carry out these tasks. Once trained, staff need to take ownership of the probe cleaning and maintenance program in order to maintain the high level of process efficiency.

Further knowledge will be gained with this optimization program once the anammox granules are seeded into the mainstream to determine if some degree of nitrogen removal via deammonification is possible with this system. The impact of the anammox granules on particle size distribution in the mixed liquor will also be studied.

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