A Five Year Case Study of a Feed Forward Nitrogen Reduction Process Control System

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ABSTRACT

As operational and capital budgets for wastewater treatment shrink and effluent limitations become more stringent, it is very important to reduce energy consumption of aeration systems and improve treated water quality. Monitoring of influent loading and plant operating conditions, together with a Feed Forward Process Control system, allows DO and internal recycle set-points to be continuously adjusted based on the actual loading. This optimization results in improved nitrogen removal and a significant reduction in electrical energy consumption. This paper discusses the monitoring technology, optimization of the biological processes and control techniques. Results achieved, potential problems and solutions over the last five years at Enfield, CT will be presented.

KEYWORDS

Feed forward control; nitrogen removal; reduced energy consumption of aeration; Long Island Sound.

INTRODUCTION

Connecticut's Nitrogen Control Program (NCP) is the state's official plan to reduce nitrogen discharges to Long Island Sound (LIS), which is designated as an impaired water body due to excessive nutrients. For the NCP to meet the objective new nutrient effluent limits were applied to the existing NPDES permits for point source facilities (Water Pollution Control Facilities, or WPCFs). The nutrient effluent limits will be an annual mass loading cap for Total Nitrogen (TN).

In 2002 the Town of Enfield (Enfield) contracted with SEA Consultants to determine the feasibility of removing the nitrogen entering the facility or paying credits to meet the goals of Connecticut's NCP. The study stated that the Enfield’s best option was to install a biological nutrient removal (BNR) activated sludge process, specifically the Modified Ludzack-Ettinger (MLE). It was also concluded that it would be necessary to fine tune the system to maintain the design capacity of the facility of 10 mgd. To this end, Enfield was introduced to BioChem Technology, Inc. (BioChem), which was looking for a facility to demonstrate its proprietary feed forward control system.

In order to quantify the advantages of the feed forward control system for nitrogen removal and energy savings, a side by side comparison was conducted. In January of 2004, the feed forward control system was installed in process train 4, and in March , the control system started to control both the DO levels and the internal recycle ratio of process train 4. Meanwhile, process trains 1, 2, and 3 were operated at constant DO and internal recycle ratios according to the facility's standard operating procedures. The comparison study was completed in May of 2004, and ongoing responsibility transferred to the Enfield WPCF personnel. The side by side comparison study demonstrated that the total nitrogen removal was improved by 36% and the aeration requirement was decreased by 19%. The feed forward control system has been controlling all four process trains since June, 2004.

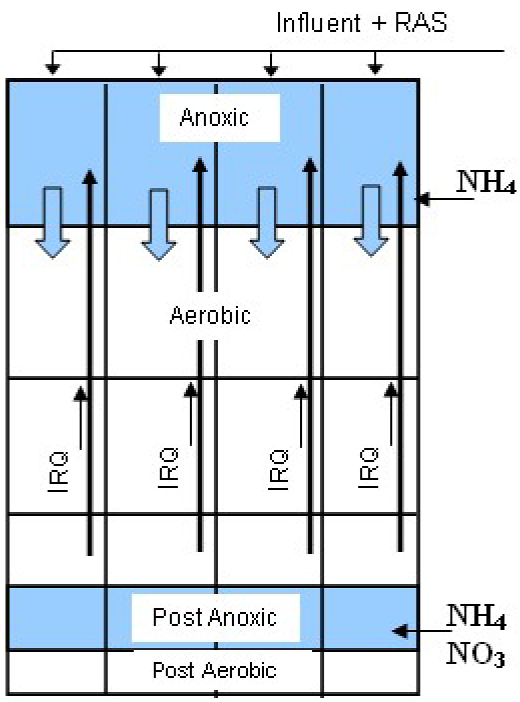

Figure 1 - Enfield WPCF Layout, showing location of ammonia and nitrate analyzers

The secondary treatment process at the Enfield WPCF, which currently treats approximately 5.5 MGD (26,500 m^3/day), consists of four parallel treatment trains each with an anoxic zone followed by three aerobic zones, post anoxic zone , and post aerobic (Fig. 1). The post anoxic and post aerobic zones were installed in 2007. All the aerobic zones have independent PI control to maintain discrete DO set points and air flow meters to monitor the air consumption for aeration. For each treatment train, a variable speed pump transports IRQ flow from the third aerobic zone to the anoxic zone. Prior to installing the feed forward process control, the WPCF operated its MLE process using constant DO set-points of 2.75 mg/l, 2.0 mg/l, and 0.5 mg/l for aerobic zones 1, 2, and 3, respectively. It also maintained a constant IRQ ratio of 275% to the anoxic zone.

METHODS AND DISCUSSION

The Modified Ludzack-Ettinger (MLE) is one of the most commonly used processes to remove nitrogen from wastewater. The process involves an anoxic zone followed by an aerobic zone where nitrification takes place. Mixed liquor, high in nitrate, is then recycled back to the anoxic zone where denitrification takes place. Many large-scale municipal Water Pollution Control Facilities (WPCF) use the MLE process for nitrogen removal. The denitrification and nitrification sections of the MLE process are integrated into many other biological nutrient removal (BNR) processes, such as the 4 and 5-stage Bardenpho process, A^2O process, etc. Therefore, it is desirable to develop a generic control system to optimize the MLE process, which may then be applied to related BNR processes. The purpose of the control system is to ensure that the WPCF can meet the effluent limits while minimizing energy consumption for aeration. For WPCFs in areas of high power costs, or areas where nitrogen credits can be realized, the savings afforded by such a control system can be substantial.

The two main operational parameters for the MLE process are the dissolved oxygen levels (DO) in the aerobic zone and the internal recirculation flow (IRQ) ratio. At present, most WCPFs are operated at constant DO and IRQ. This philosophy assumes that the plant is operating under steady state conditions, which is never the case. Both inlet wastewater concentration and flow rate vary dynamically throughout the day, week, and seasonally. Water temperature, sludge age and mixed liquor concentration (MLSS) can also change. Due to a lack of real-time plant data and control options, treatment plants are commonly operated at high DO set-points to insure maximum nitrification under peak load conditions. However a constantly high DO concentration requires much more aeration energy than would be required to achieve the target. It is also common for facilities to be operated at a constant IRQ ratio, where nitrate removal or denitrification will not be optimized under most operating conditions.

The BioChem Feed Forward Control System that is described in this paper dynamically controls the DO in the aerobic zone and IRQ flow rate. This system can be used for the control of the MLE process, Bardenpho processes, and the A^2O process and can also be used to control DO in the aeration zone of conventional activated sludge or extended aeration processes for BOD and ammonia oxidation.

Feed Forward Process Control System

The feed forward process control system has been designed to optimize the operation of an MLE treatment process. It conducts simulation calculations based upon online measurement of ammonia, nitrate, influent wastewater flow rate and temperature, and laboratory results for mixed liquor suspended solids (MLSS). The feed forward process control system continuously provides optimal dissolved oxygen (DO) set points according to the load entering the bioreactor. The internal recirculation (IRQ) from the aerobic zone to the upstream anoxic zone is also optimized in order to achieve the best total nitrogen removal.

Description of the control algorithm

The control algorithm is an online process simulation program integrated with data input and output modules (Liu *et al*, 2003). This program calculates the hydraulic flow and biological reactions in the bioreactor.

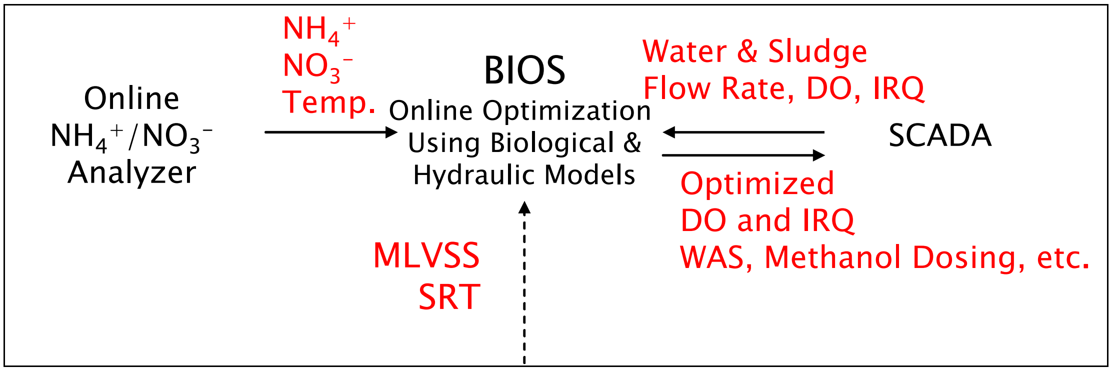

Figure 2 – Inputs and Outputs of the feed forward control system

Figure 2 depicts how information flows to and from the feed forward control system to optimize the treatment process. An ammonia analyzer located in the anoxic zone provides the control system with the ammonia concentration in the aerobic zone influent and a nitrate analyzer located at the end of the aerobic zone provides the control system with the nitrate concentration in the IRQ stream and the effluent. The control system conducts iterated biological and hydraulic simulations that predict nitrification reaction rates in the aerobic zones and de-nitrification reaction rates in the anoxic zone under different DO concentrations and IRQ rates. The iterative calculations take into account that the IRQ flow rates will dilute ammonia concentrations in the anoxic zone and decrease the contact time in both the anoxic zone and the aerobic zone. In this way, optimal DO set-points and IRQ rates are calculated in real-time based on the changing characteristics of the wastewater.

In the Enfield system, which has been modified so that there is an anoxic zone, three aerobic zones , post anoxic zone, and post aerobic zone, the control has been modified so that the nitrates are measured at the end of the post anoxic zone, although the IRQ is taken from the last aerobic zone.

RESULTS

The feed forward process control system has been installed at the Enfield WPCF for approximately five years. Prior to the full installation a side by side comparison study demonstrated that the total nitrogen removal was improved by 36% and the aeration requirement was decreased by a total of 19%. The dynamic DO set point control contributed to 13% of the savings, with the remaining 6% coming from the increased denitrification in the anoxic zone, achieved through the dynamic IRQ control. Figures 3 and 4 show a comparison of air consumption and total inorganic nitrogen during the study.

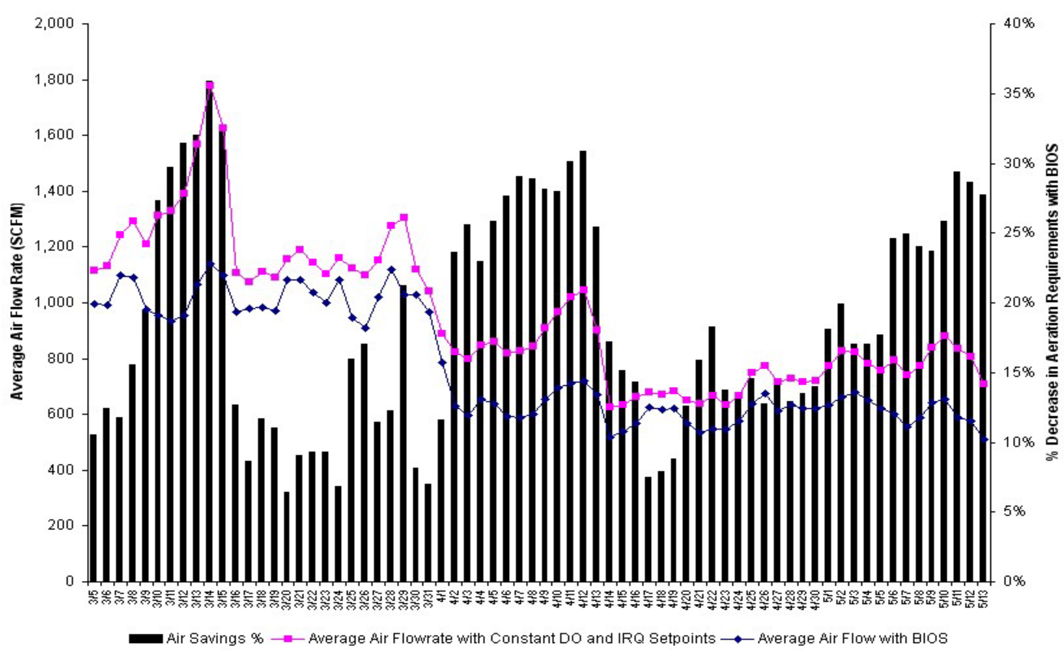

Figure 3 - Air Consumption - Average Savings of 19% with DO and IRQ Set point Optimization

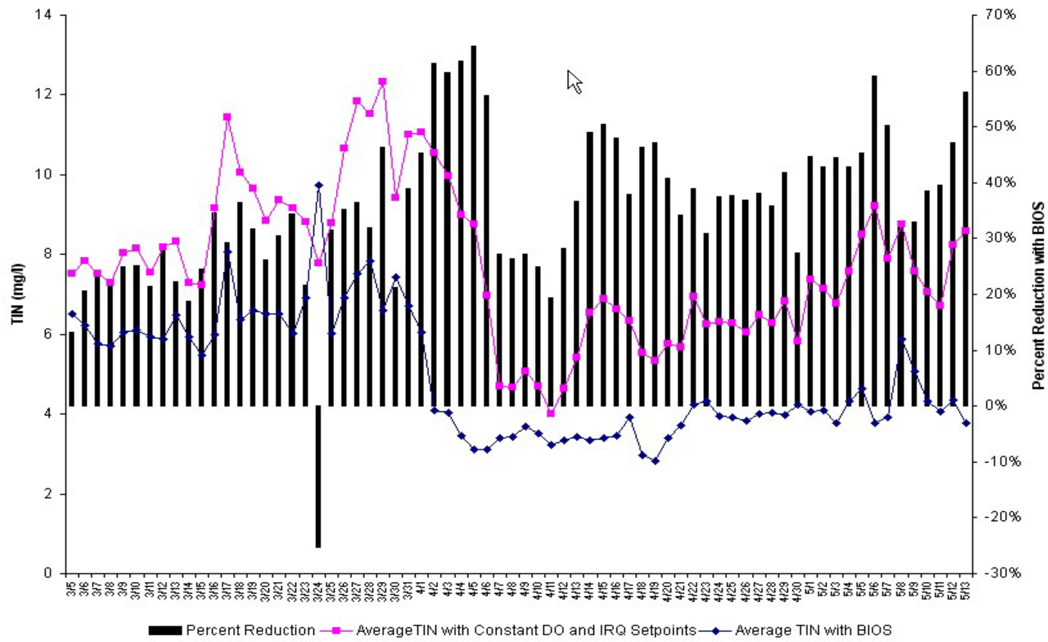

Figure 4 - Effluent TIN – Average Total Inorganic Nitrogen Reduction of 36%

Since the full installation of the feed forward process control system in June 2004, Enfield WPCF has meet the annual TN limits as required by the Connecticut Nitrogen Control Program (Fig 5), with the exception of 2005. During March and April of 2005 the WPCF had high volumes of cold flows from snow melt, which affected the plants ability to nitrify and denitrify leading to high TN loading in the effluent.

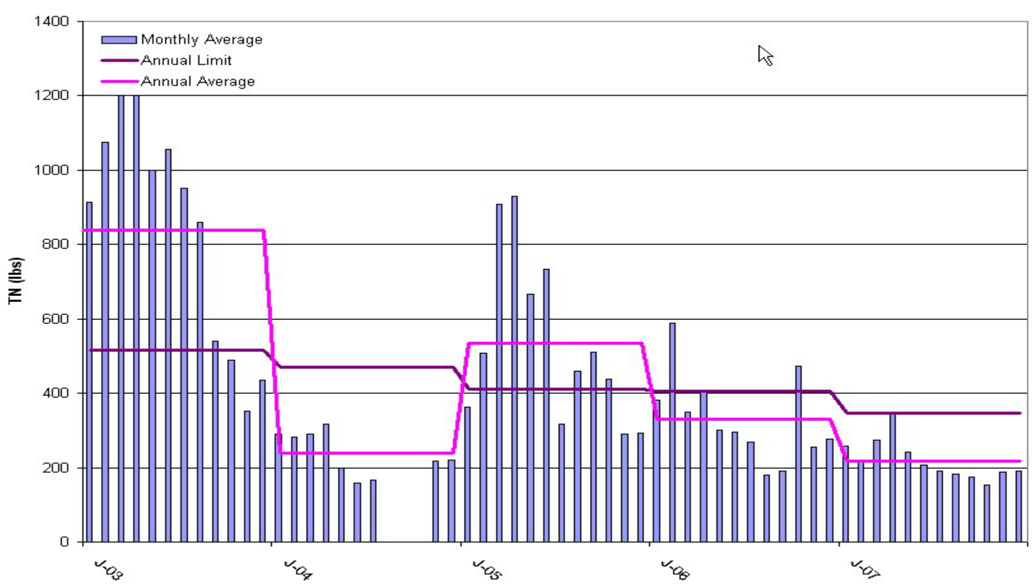

Figure 5 – Actual TN discharge compared to TN limit

As stated above, prior to the installation of the control system Enfield WPCF operated with DO set points of 2.75 mg/l, 2.0 mg/l, 0.5 mg/l for aerobic zones 1, 2, and 3, respectively. Since the installation the average DO set point from the controller was 1.3mg/l, 1.3 mg/l and 0.5 mg/l for aeration zones 1, 2 and 3. The actual average DO readings showed very little deviation from the set points at 1.3 mg/l, 1.3 mg/l and 0.7 mg/l for aeration zones 1, 2 and 3, respectively. Based upon comparing the actual DO readings to previous DO set points the estimated aerations savings is 13.5%, as calculated according to the methods described in the EPA fine bubble manual. The aeration savings achieved through improved denitrification cannot be estimated due to the absence of a baseline.

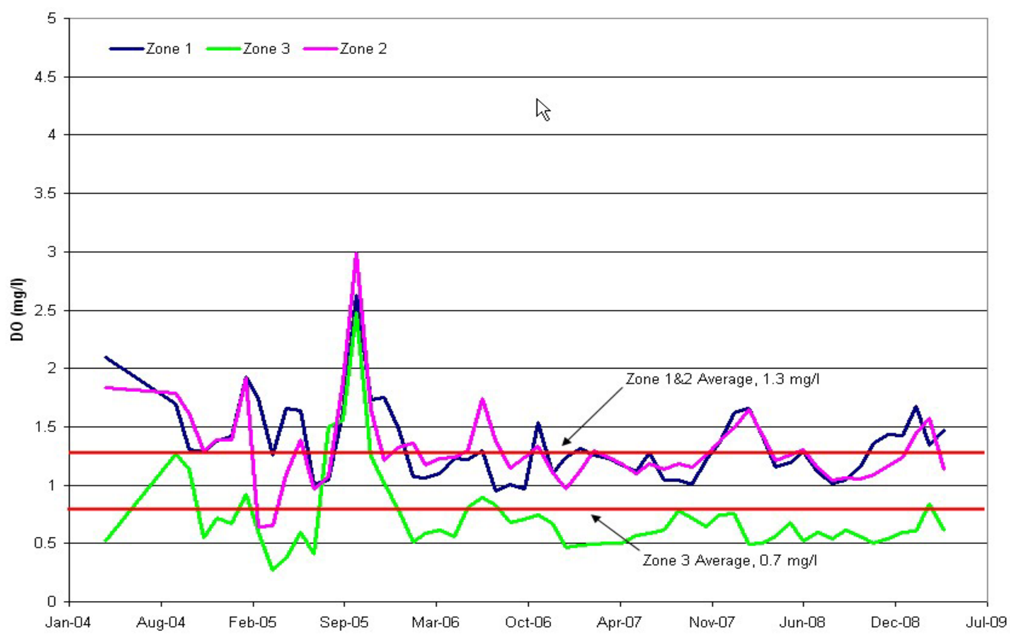

Figure 6 – Average Actual DO readings from aeration Zones 1, 2 and 3.

CONCLUSIONS

Based upon the five years of operational data the feed forward process control system has provided results that are consistent with the previous side by side comparison. In early 2008 the US EPA performed an energy use benchmark for activated sludge plants; Enfield was ranked first in energy efficiency for WPCFs between 5-10 mgd with similar processes. The use of feed forward process control system to provide dynamic DO and IRQ set points to optimize energy usage and nitrogen removal has been successful at Enfield. The feed forward process control system also allowed Enfield to retain the capacity of 10 mgd, and has been useful as a early warning system for plant upsets.

REFERENCES

Liu, W., Lee, G. and Goodley, J. (2003). Using Online Ammonia and Nitrate Instruments to Control Modified Ludzack-Ettinger (MLE) Process. *Proceedings of WEFTEC 2003 (CD).* Los Angeles.