Process Evaluation Provides Optimization and Energy Reduction

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ABSTRACT
Due to increasing public interest in water purity, and projected sharp increases in energy costs in the near future, Wastewater Treatment Plants (WWTP) are becoming interested in optimizing their activated sludge process to reduce operating costs, and stabilize process operation. This paper presents an activated sludge process evaluation that describes how aeration energy savings of 23 to 45% and process stability can be obtained by controlling the Solids Retention Time (SRT) and Dissolved Oxygen (DO).

KEYWORDS
Process Optimization, Energy Savings, Aeration Control,

INTRODUCTION
An activated sludge process evaluation was performed on a Wastewater Treatment Plant (WWTP) that treats 662,500 cubic meters per day (m^3/d). The WWTP performs well with respect to pollutant removal by achieving permit limits. However, with increased public interest in water purity, and with a projected sharp increase in energy costs in the near future, the WWTP has become interested in optimizing the process to minimize Dissolved Oxygen (DO) fluctuation, reduce operating costs, and stabilize the process operation. The primary objective of this evaluation was to optimize the treatment process for stability and energy savings.

To accomplish the objectives of the process evaluation the following tasks were completed:

> **Data Acquisition:** In order to evaluate the nitrification process and identify potential process optimization opportunities, a thorough review of existing process conditions, analysis of operational data, and monitoring of process nutrients was performed.
>
> **Process Modeling:** A computer based model of the plant's activated process was constructed and calibrated based on information and data gathered from the operational data analysis, and process nutrient monitoring.
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> **Nitrification Evaluation:** Currently, the WWTP operates at a low Solids Retention Time (SRT) of approximately 5 days to prevent nitrification, but during higher wastewater temperatures in the summer nitrification occurs, which requires the WWTP to use more air to prevent low DO concentrations in the basins. A nitrification sensitivity analysis was performed to determine whether manipulating the SRT and/or DO concentration aided in controlling the nitrification process.

BACKGROUND
The current facility consists of preliminary treatment processes that include mechanical screening, grit removal, and primary clarifiers. Secondary treatment includes an activated sludge process, final clarifiers, and disinfection. Primary sludge and waste activated sludge are thickened and then stabilized within the digesters.

The main focus of this evaluation was the activated sludge process. The existing activated sludge process configuration is considered a step feed process with anoxic selectors. The activated sludge process consists of seven trains, each with four passes. The first pass consists only of aerated return activated sludge. Primary effluent enters at the anoxic selector of the second and third passes. The fourth pass is aerobic. Figure 1.0 presents a process schematic for the existing activated sludge process.

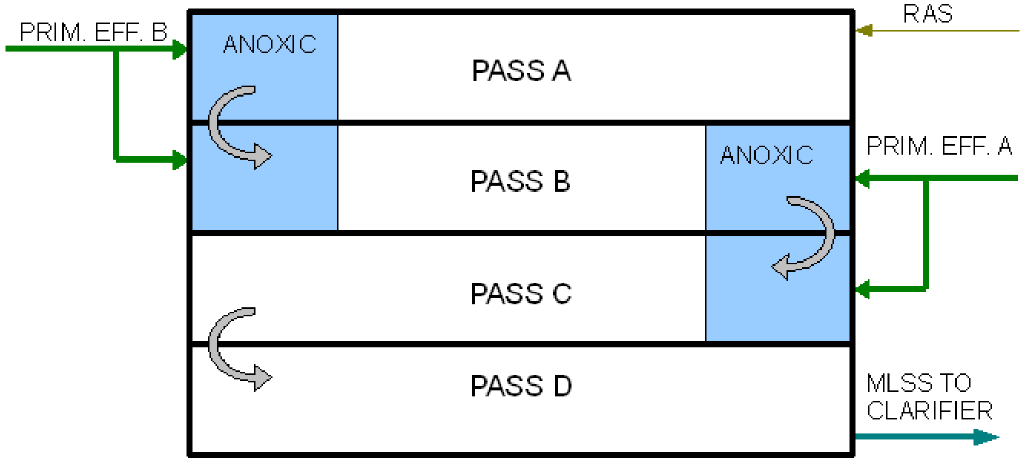

Figure 1.0 - Process Schematic

Recent upgrades to the WWTP's aeration control system have the capability to allow process optimization. The activated sludge process trains were upgraded with air control valves, air flow meters, dissolved oxygen analyzers, and fine bubble diffusers. The DO set points for the aeration control system currently run between 2 to 5 mg/l depending upon the season, and average 4.0 mg/l. The DO set points are set high to compensate for the existing aeration control system's poor DO control.

METHODOLGY

To accomplish the objectives of the process evaluation, data analysis, intensive sampling, process modeling, and nitrification analysis were completed.

Historical Plant Data Analysis

The WWTP daily operation datasheets from January 2008 to December 2008 were used as historical influent plant data. The daily influent composite data consisted of carbonaceous biological oxygen demand (cBOD), total suspended solids (TSS), and influent flow. A statistical analysis of the 2008 daily influent composite data was performed to provide methods to predict and forecast process operating parameters to be used in the nitrification analysis. Table 1.0 presents the annual average and statistical analysis summary of the parameter loadings.

Table 1.0 - Summary of 2008 Wastewater Statistical Analysis

	Raw cBOD		*Raw TSS*		Pri. cBOD		*Pri. TSS*	
	kg/day	mg/l	kg/day	mg/l	kg/day	mg/l	kg/day	mg/l
Mean	104,740	160	148,365	227	63,100	97	48,736	75
Stand. Dev.	22,488	34	42,536	65	26,009	18	14,513	22
Minimum	61,675	94	40,347	62	11,782	58	16,195	25
Maximum	270,484	414	400,790	613	139,511	213	132,112	202
7.7%	72,682	111	87,727	134	46,308	71	28,048	43
92.3%	136,799	209	209,000	320	79,898	122	69,425	106

All concentrations were calculated with the annual average flow of 662,500 m^3/d

Intensive Sampling

Intensive sampling entailed collection of grab samples throughout the process roughly every three hours for a sixteen hour period. Grab samples were collected from nine different locations throughout the plant. Analyses were performed on site using prepared reagents and a compatible spectrophotometer.

The main focus of the intensive sampling was to create soluble substrate profiles through the four pass train and their variation with time. The average results for all samples at each location are given in Figure 2.0. The intensive sampling concentration profile across the plant followed the expected pattern for a step-feed process.

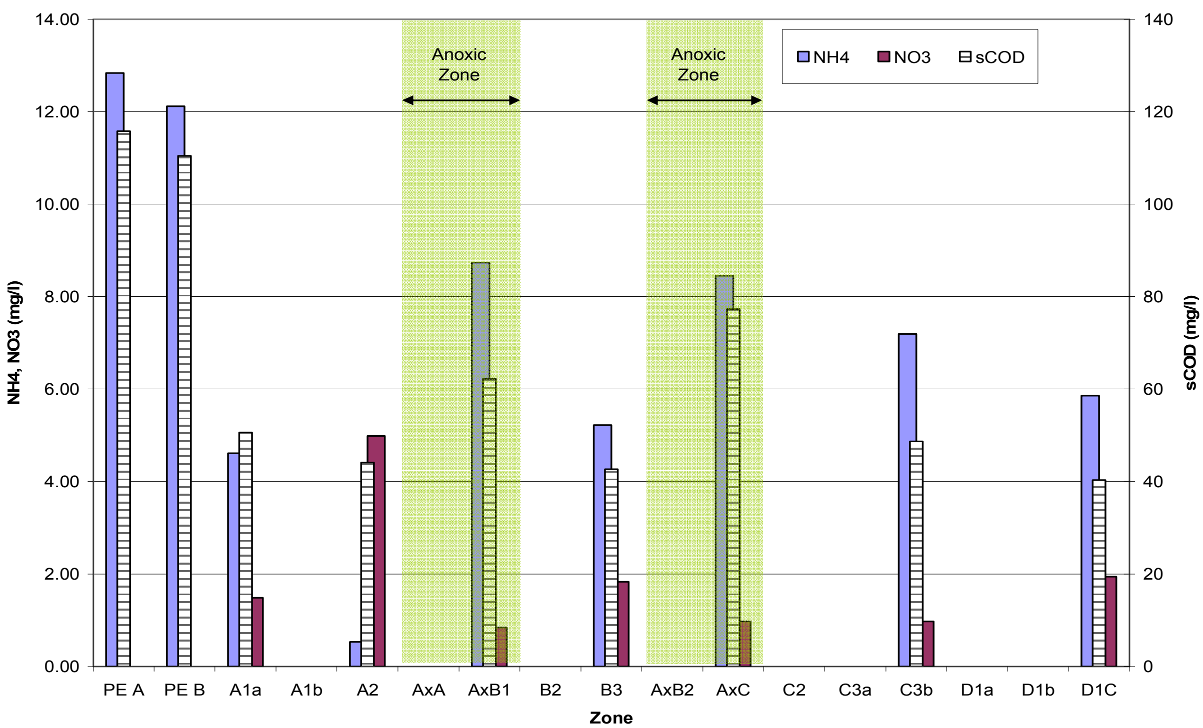

Figure 2.0 – Nutrient Profile

Calibrated Process Modeling

All of the above information and data was utilized to develop and calibrate a model of the existing treatment process. The intent of modeling the current process was to develop a better understanding of the process operation, and more importantly, to derive some key model parameters that would then be applied to predictive process models. A description of the model's methodology, configuration and results follows.

A computer based mathematical model of the activated sludge process was developed to represent the existing process. The mathematical model for biological wastewater treatment that was employed was the Activated Sludge Model 1 (ASM1), as published by the International Water Association (Henze, 2002). The ASM1 and all ASM models are accepted methods for design and operation of such systems treating municipal wastewater. The ASM1 model includes components that dynamically simulate the biological processes for Chemical Oxygen Demand (COD) and nitrogen removal. A proprietary software package (GPS-X) designed for this type of modeling was used to execute the mathematical model and develop multiple operational scenarios. The software also includes models of associated physical/chemical processes (i.e. clarification) so that fully representative models can be developed.

The WWTP treatment process model was solely focused on operation of the activated sludge process and clarifiers. The model did not contain additional unit processes such as preliminary treatment (screening, grit removal, and primary clarifiers), disinfection or solids handling.

The initial calibration of the model was conducted using the yearly average primary effluent data (NH4, TSS, COD, etc.), and the model was run as steady state. To confirm if the model was calibrated the steady state results were compared to yearly average MLSS, %VSS and effluent parameters (NH4, TSS, NO3, etc.).

Comparison of the measured (actual) and predicted (model) concentrations of NH_3-N, NO_3-N, and other parameters for the calibration period are given in Table 2.0.

Table 2.0 Steady State Model Prediction Compared to Actual Yearly Average

		Model Predicted	Actual Yearly Average
Eff. BOD	mg/L	5.5	5.7
Eff. TSS	mg/L	7.2	6.5
MLSS	mg/L	1540	1506
%VSS	%	82	82
WAS Loading	kg/day	45,200	44,500
Airflow	m^3/hr	136,000	139,400

The steady state modeling had acceptable results, because all of the parameters were within 10% of the actual yearly average.

Nitrification Evaluation
The current NPDES permit does not include ammonia as part of the effluent parameters. Therefore, the WWTP is not designed or operated to remove ammonia.

Nitrification is a two step biological process of converting ammonia to nitrite and then to nitrate by the use of *Nitrosomonas* and *Nitrobactor* bacteria in the presence of dissolved oxygen (aerobic conditions). The design requirements for nitrification are to establish a minimum aerobic Sludge Residence Time (SRT), and dissolved oxygen concentration that supports the growth and reaction rates of *Nitrosomonas,* the limiting nitrification reaction step. The nitrification process uses approximately 4.57 lbs of oxygen for every pound of ammonia converted to nitrate. If the plants aeration system is not designed to handle the higher oxygen demand produced by nitrification, the plant can have problems with low DO concentration, which can lead to common plant operation problems, such as odors and poor settable sludge (high Sludge Volume Index (SVI)).

By manipulating the SRT and/or DO concentration, the nitrification process can be controlled. Currently, the WWTP operates at a low Solids Retention Time (SRT) of approximately 5 days to prevent nitrification, but during higher wastewater temperatures of the summer, nitrification occurs. Nitrification requires that the aeration system supply more oxygen by operating at higher air flow rates to prevent low DO concentration in the basins.

To effectively evaluate the nitrification process, a nitrification sensitivity analysis was performed. A sensitivity analysis is a simple iterative procedure that varies one parameter for analysis by running multiple simulations. The nitrification sensitivity analysis performed varied the SRT and DO concentration and recorded the effects on the effluent concentrations of Biological Oxygen Demand (BOD) and Ammonia (NH_4-N), loading of Wasted Activated Sludge (WAS), aeration requirements such as Oxygen Transfer Requirement (OTR) and required air flow. The results of each analysis are then compared to the current operations to gauge the sensitivity of each parameter to SRT and DO concentration. To separate the benefits of lowering the SRT verses the lowering of DO to prevent nitrification, two analyses were performed, varying SRT only, and varying SRT and DO.

The first nitrification sensitivity analyses varied the SRT by the addition of primary effluent to Pass A. Currently, the Return Activated Sludge (RAS) from the clarifiers enters Pass A, and the primary effluent enters at Pass B and C. With only RAS within Pass A there is a high concentration of Mixed Liquor Suspended Solids (MLSS) which lead to an overall higher SRT. The addition of primary effluent to Pass A will dilute the MLSS concentration and lower the overall SRT. The percent of total primary effluent to Pass A was evaluated at 0% (current), 16.7% and 25%. Each variation of total primary effluent to Pass A was evaluated at variable temperatures of 12, 16 and 20C to represent winter, spring/fall, and summer seasons. The DO and MLSS concentrations were held at the typical operating values of 4.0 and 1,500 mg/l.

The second nitrification sensitivity analyses varied the SRT by the addition of primary effluent to Pass A and decreased the DO concentration from 4 to 2 mg/l. The decrease in the DO concentration will increase the required SRT for nitrification and lower the overall aeration requirements. The percent of total primary effluent to Pass A was evaluated at 0% (current), 16.7 % and 25 %. Each variation of total primary effluent to Pass A was evaluated at variable temperatures of 12, 16 and 20C to represent winter, spring/fall, and summer seasons. The MLSS concentration was held at the typical operating value of 1,500 mg/l.

A summary of the optimal operation scenarios for each season is summarized in Table 3.0.

Table 3.0 Nitrification Analysis Summary

Season	Winter	Fall/Spring	Summer
Temperature	12 C	16 C	20 C
Solid Retention Time	4.8 d	5.4 d	4.2 d
DO Concentration	2 mg/l	2 mg/l	2 mg/l
Primary Effluent to Pass A	0%	0%	16.7%
Sludge Generation	0%	0%	7%
Aeration Savings	23%	33%	45%

The DO concentration for each optimal operation scenario was 2 mg/l. DO concentration had the largest impact on the aeration savings and operational SRT. Dropping the DO concentration from 4 to 2 mg/l accounted for approximately 66% of the aeration savings, and prevented nitrification during the fall/spring scenario and did not increase solids generation. The addition of primary effluent to Pass A is suggested during the summer when the minimum SRT requirement is the smallest, because it allows the greatest amount of aeration savings.

DISCUSSION

To obtain the estimated aeration energy savings of 23 to 45%, the WWTP will need to be able control at the lower DO concentration. Having an effective aeration control system for the activated sludge process, which incorporates blower and valve control, will result in the ability to lower the DO concentration in a controlled manner.

Aeration Control System

Aeration control is the only practical way a well designed activated sludge system can be effectively manipulated to meet treatment goals, satisfy oxygen demand, minimize operational problems associated with inadequate or excessive aeration, and minimize aeration energy consumption.

The aeration basin energy consumption usually represents 50-65% of the total energy demand for activated sludge plants. An effective aeration control system for the activated sludge process that incorporates blower and valve control can result in considerable energy savings.

Existing Aeration Control System

The existing Aeration System at the WWTP consists of multistage centrifugal blowers, stainless steel aeration manifold system, manual inlet guide vanes, fine bubble diffusers, air flow meters, and air control valves.

The current aeration control system is considered a cascade DO control with constant pressure blower control. The operation of the system is based upon having two control loops, an airflow-DO control loop and a constant pressure control loop. The airflow-DO control loop is a Proportional-Integral (PI) loop that regulates the airflow to the aeration zones by manipulating the air control valve positions to maintain the DO set-points. The constant pressure control loop is a PI loop that regulates the blower output by manipulating the inlet control guide vanes positions to maintain a pressure set-point in the main header

The performance of the existing aeration control system has been poor, because the aeration system has problems maintaining the DO concentration at the set point. The constant header pressure control loop is not in use due to the fact that the actuator of the inlet guide vane deteriorated due to excessive operation required by the control loop. Currently, the blowers are manually controlled throughout the day and the air control valves are under the control of the airflow-DO control loop, and oscillate severely throughout the day. Figures 4.0 and 5.0 are examples of the existing aeration control system results.

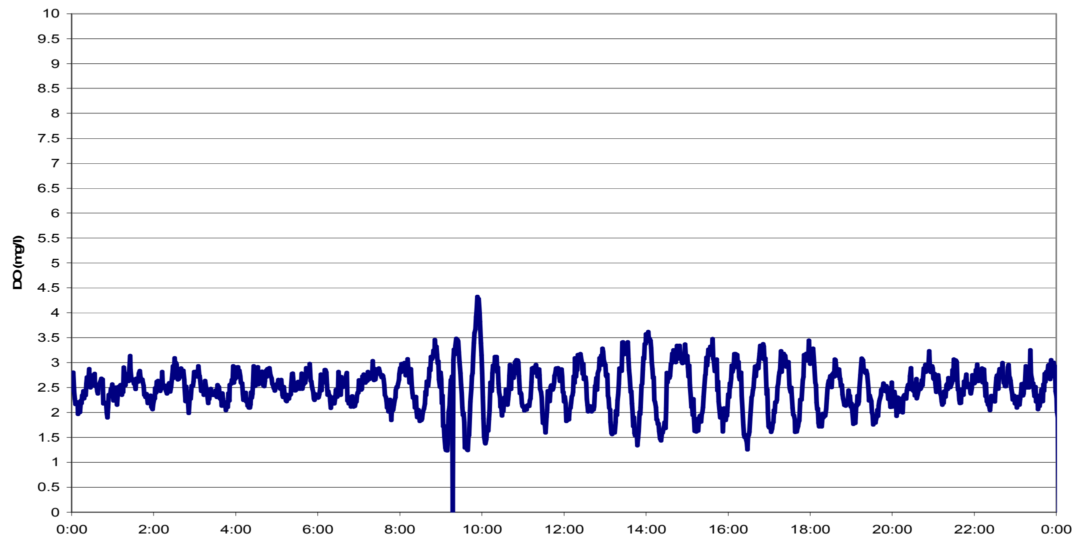

Figure 4.0 - Actual Dissolved Oxygen

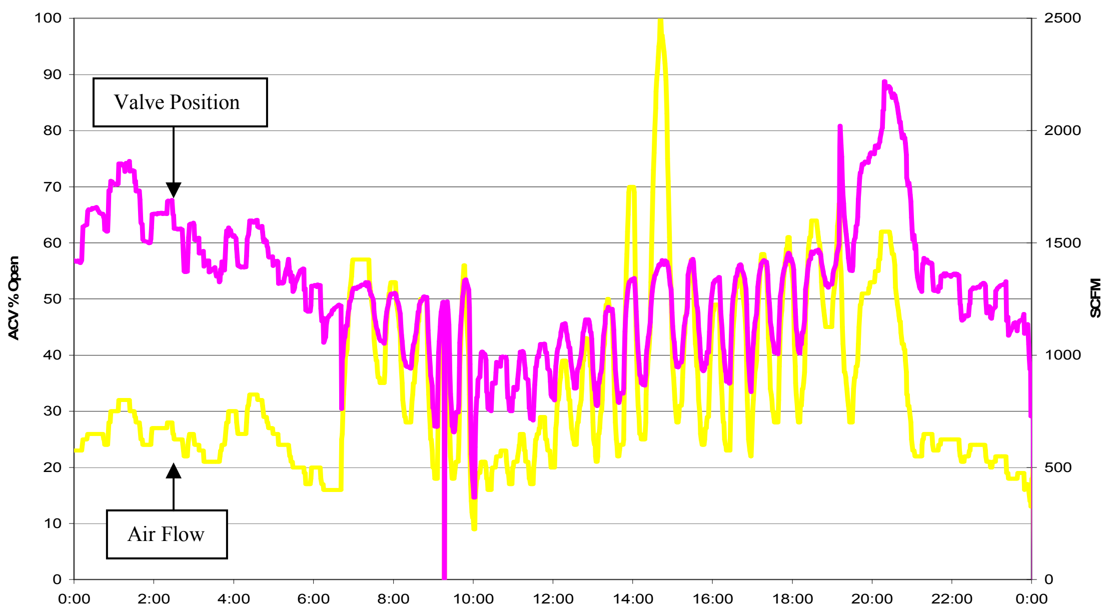

Figure 5.0 - Actual Air Flow and Valve Position

Blower and DO control strategies that involve conventional PI can have oscillation problems. The problem with PI control is that the proportional (P) and integral (I) gains have to be tuned to a certain operating condition. For aeration control where the dynamics are nonlinear and time varying, the optimum PI tuning parameters for maintaining DO control under peak diurnal loading periods may not sustain that level of DO control during low diurnal loading periods. Also the difference between the airflow required and supplied by the constant pressure header control loop, can lead to DO and valve oscillation.

Alternative Aeration Control System

The successful application of an aeration control system is dependent upon a successful operation of control system components. The control system components must be correctly sized and installed to ensure the successful operation.

The blower and DO control strategy should be based on an activated sludge aeration model that determines the oxygen uptake rate (OUR), calculates the total amount of airflow required (production side) and calculates the exact amount of airflow required in each aeration zone (distribution side) to maintain the DO at the set-point. The air control valves should use the Most Open Valve (MOV) control strategy to adjust the valves to distribute the airflow as required to save energy.

Minimal instrumentation and equipment is required to upgrade the existing aeration control system, due to the fact that most of the required instrumentation and equipment is existing and functional. The following instrumentation and equipment is needed:

- Aeration Controller that calculates air flow required to meet the DO set-point based on the activated sludge OUR.

- Blower Controller that manipulates the existing blower inlet guide vane to provide the required total air flow as calculated by the Aeration Controller.

- Air Control Valve Controller that manipulates the position of the air control valves to provide the required air flow to the aeration zone as calculated by the Aeration Controller.

CONCLUSION

The primary objective of this evaluation was to optimize the process to minimize DO fluctuation, reduce operating costs, and stabilize the process operation.

Currently the WWTP operates at a low SRT of approximately 5 days to prevent nitrification, but during higher wastewater temperatures in the summer nitrification occurs, which requires more air to be used to prevent low DO concentration in the basins. By manipulating the SRT and DO concentration the nitrification process can be controlled. It was determined that nitrification can be prevented by lowering the DO concentration set point and providing some primary effluent to Pass A during the summer to lower the SRT. By controlling the SRT and DO throughout the year, the estimated aeration energy savings could be 23 to 45% compared to the current operation. During the summer sludge generation will increase 7% compared to current operation.

To obtain the estimated aeration energy savings of 23 to 45%, the WWTP will need to be able control aeration at the lower DO concentration. Having an effective advanced aeration control system for the activated sludge process, which incorporates blower and valve control, will result in the ability to lower the DO concentration in a controlled manner.

REFERENCES

Henze, M., Gujer W., Mino T., Van Loosdrecht M.C.M. (2002) *Activated Sludge Models ASM1, ASM2, ASM2d and ASM3*; International Water Association Publishing, London, UK: