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Energy Optimization using Dynamic Simulation Technique

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Abstract: Aeration systems typically consume between 50-70% of the total energy demand of a wastewater treatment plant that uses activated sludge for secondary treatment and are therefore a major part of the operations expenditures [2]. Oxygen concentration is also a key process variable for controlling nutrient removal. Tailored and plant-specific design of the aeration system is therefore mandatory for efficient plant operation. The focus of this case study is the use of dynamic simulation in the design process. Current procedures are discussed and compared with model-based designs taking full advantage of dynamic simulators and available models and modelling tools. Industrial flows can cause a decrease in aeration system oxygen transfer and does not attempt to provide a life cycle cost analysis that reviews equipment life, maintenance costs, or the impact on sludge disposal costs. This Case Study is done to identify how operational control will impact the efficiency of the aeration process. Operational strategies of a wastewater treatment facilities aeration system will impact the energy savings. Using mixing energy to maximize the treatment efficiencywhile minimizing the energy demand. DO probes and analyzers are used to measure the level of DO in the wastewater and provide a variable signal to adjust air flow, tank level (using adjustable weirs) or mechanical aerator speed. The goal of the modeling is to also reduce costs and energy usage associated with plant operation.Online aeration control based on ammonia concentration enables the user to observe the virtual effect of changes in operation and influent loading relatively quickly. The online analyzers will be able to respond more quickly to changes in influent ammonia loads. Models several simulations were run to observe relationships between Ammonia, DO, Nitrate and influent loads. Data reconciliation conducted during this study highlighted many good practices in plant operation and monitoring.On-Line analyzer can measure concentrations quickly and more frequently and can be coupled with the SCADA system.The use of online analyzers allows for more frequent monitoring of aeration basin conditions and automatic adjustment based on pre-defined parameters. The dynamic simulation for aeration power is saving 35% compared to steady operation.

Key words: Dynamic Simulation・SRT・C-N・OTR・OUR・DO・SVI・SCADA

INTRODUCTION

Aerobic bio-treatment processes, in which activated sludge system is at the center of the attention, are extensively applied in sewage treatment plants around the world.

Increases of the cost of energy, operating a wastewater treatment plant (WWTP) as efficiently as possible has become one of the most important factors facing today.

Aeration systems for conventional wastewater activated sludge plants typically account for 50 to 70% of a treatment facility's total energy use. The ability to define what improvements will be most cost effective.

Although there are many types of aeration systems, the two basic methods of aerating wastewater are through mechanical surface aeration to entrain air into the wastewater by agitation, or by introducing air or pure oxygen with submerged diffusers [1].

Optimal air volume and the corresponding dissolved oxygen (DO) setpoint shall be obtained at steady state conditions. Industrial flows can cause a decrease in aeration system oxygen transfer and does not attempt to provide a life cycle cost analysis that reviews equipment life, maintenance costs, or the impact on sludge disposal costs.

This Case Study is done to identify how operational control will impact the efficiency of the aeration process.

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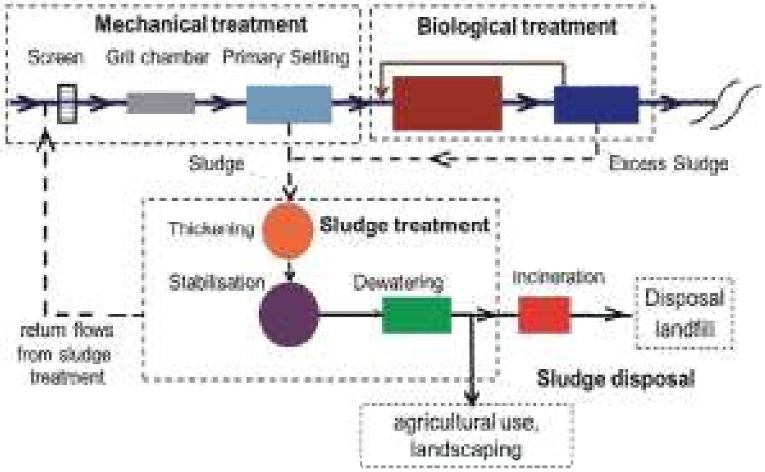

Fig. 1: WWTP Process Flow Diagram

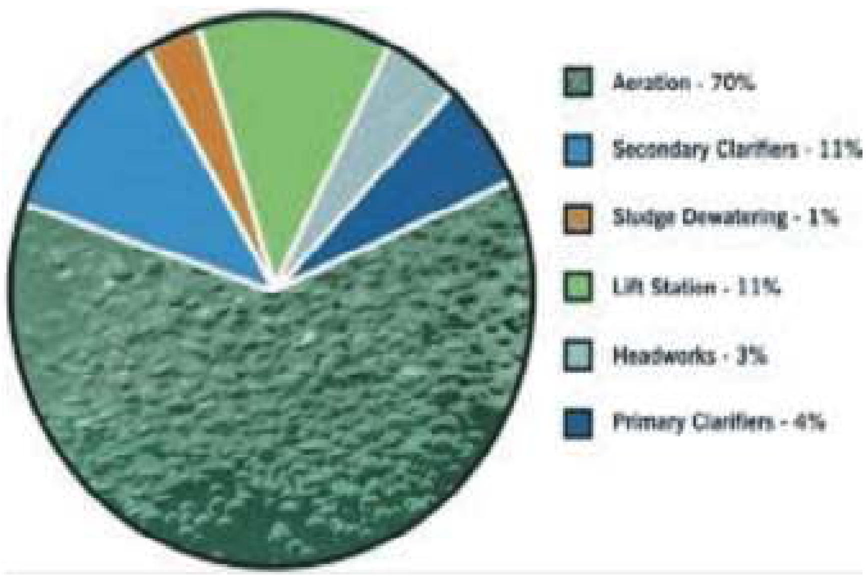

Fig. 2: WWTP Power Distribution

1 $$NH_4^+ + 1.5\ O_2 \xrightarrow{\text{Nitrosomonase}} NO_2^- + 2H^+ + H_2O$$

2 $$NO_2 + 0.5\ O_2 \xrightarrow{\text{Nitrobacteria}} NO_3^-$$

3 $$NH_4^+ + 2\ O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$

Oxygen demand: 4.6 g O per 1 g N

CO_2-demand: Per millimole NH_4-N there is released 2 millimole H^+ which corresponds to 2 milliequivalents or 120 mg HCO_3^-.

Fig. 3: Biological C-N Removal Process

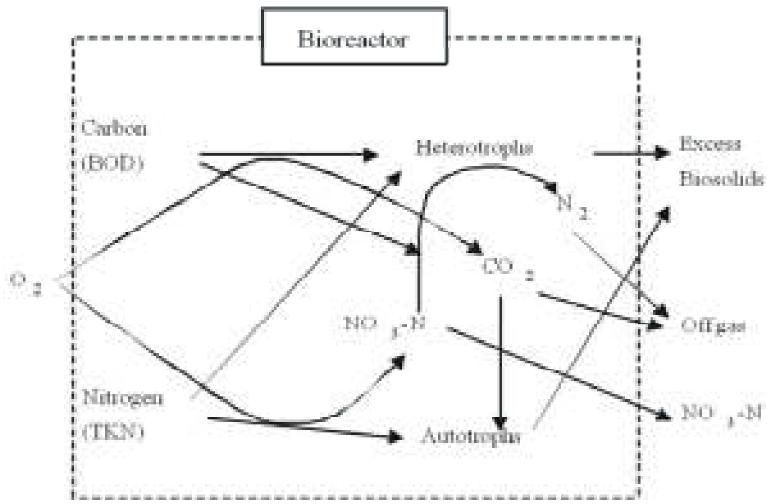

Fig. 4: Biomass Activity

Operational strategies of a wastewater treatment facilities aeration system will impact the energy savings.

Dynamic Simulation will improve the control of DO levels. Using mixing energy to maximize treatment efficiency while minimizing energy demand. DO probes and analyzers are used to measure the level of DO in the wastewater and provide a variable signal to adjust air flow, tank level (using adjustable weirs) or mechanical aerator speed [2].

Aeration Control Process: Aeration operation is required to supply the oxygen demand of the microorganisms and to obtain a good aerobic environment for nitrification.

On the other hand, over-aeration leads to too high dissolved oxygen (DO) levels in the internally recirculated water, which make de-nitrification less efficient.

Aeration requires high energy costs, which are the major expenditure of an activated sludge biological wastewater treatment plant.

It is difficult to choose an optimal DO setpoint, which both minimizes the aeration energy cost and satisfies effluent water quality restrictions.

The best solution is to provide oxygen according to the biological reaction process's demands.

For regular or large size WWTPs, aeration optimization shall be based on dynamic simulation model.

Dynamic Simulation Technique: The Dynamic Simulation tool can be used to model complex wastewater treatment plant processes such as aeration savings based on dynamic actual loading, solids retention time (SRT) and temperature conditions for given process configurations [3].

Based on the aeration airflow savings predicted by Model, an energy savings can be calculated.

The Model is used to calculate aeration savings as each of the zones in the aeration tank can be modeled under dynamic conditions.

Airflow can be reduced in aeration zones and potential effects in downstream zones were important to capture.

The data is dynamically varying and thus required dynamic model analysis.

SCADA is used in this study to enhance the process control and saving the power requirements for the aeration process [4].

An aeration system can be broken into three separate parts: airflow generation, airflow distribution and aeration control. Airflow generation consists of aeration blowers. Airflow distribution consists of air piping, air control valves and diffusers. Aeration control consists of blower control, air flow calculations, airflow meters and dissolved oxygen meters.

The aeration system is based on the oxygen transfer requirements (OTR). The amount of oxygen required is dynamic and will vary by time and location within the aeration basin. Oxygen demand is dynamic because the influent loading and ammonia concentration is diurnal [1].

The results from the simulation will provide the complete range of OTR needed to calculate airflow requirements both dynamically and spatially.

Inadequate aeration during high loading can lead to ineffective treatment of ammonia and increased SVI due to low DO sludge bulk. Excessive aeration can also lead to higher SVI because of flock breakup [5].

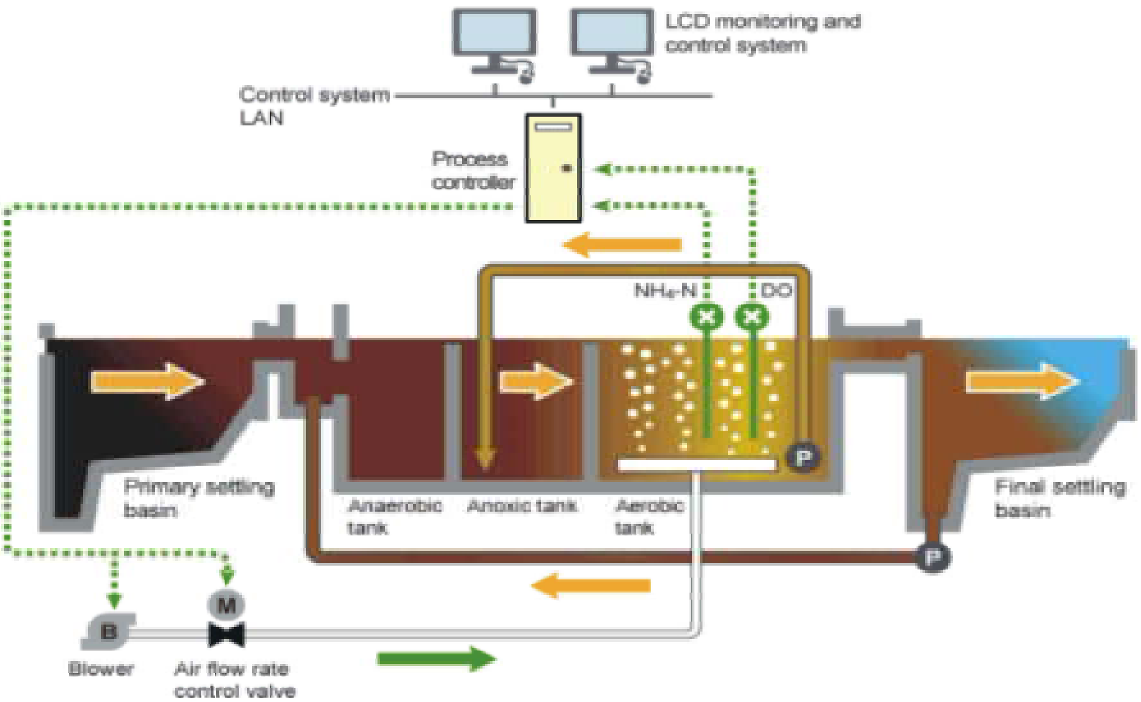

Fig. 5: Aeration Process – SCADA Control Scheme

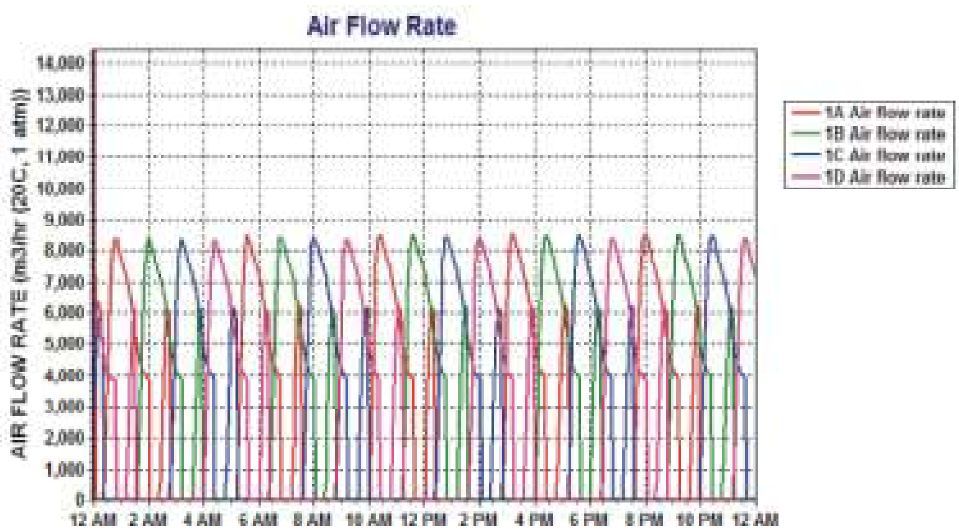

Fig. 6: Air Flow Rate

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

The process-based control concept allows the aeration control system to respond accurately to any changes in the operating conditions and influent loading. It differentiates the aeration control system from a control loop that has a fixed gain independent of the process changes, so outside of a narrow band for which it is tuned, the controller will either over- or under-react to daily and seasonally changing conditions. The system is self-tuning and stabilizes quickly after process disturbances [6].

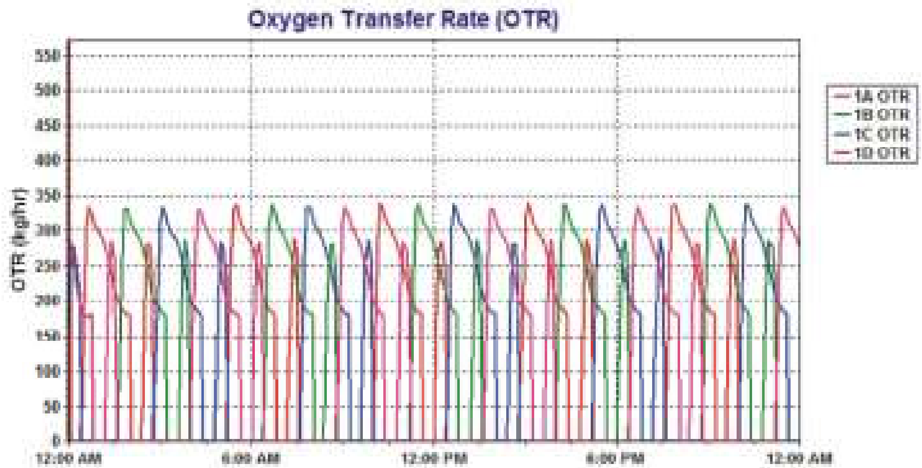

Fig. 6: Oxygen Transfer Rate

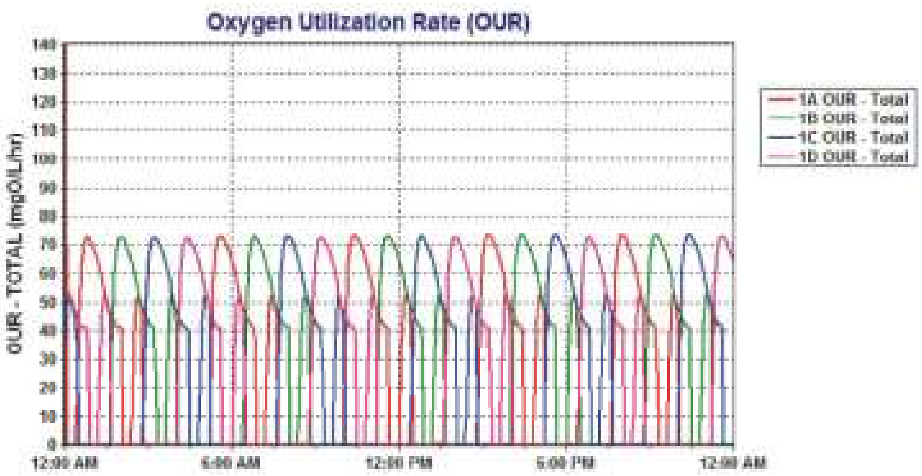

Fig. 7: Oxygen Utilization Rate

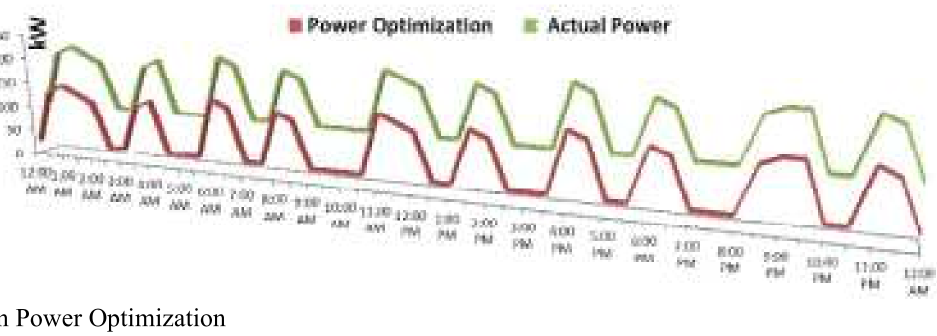

Fig. 8: Aeration Power Optimization

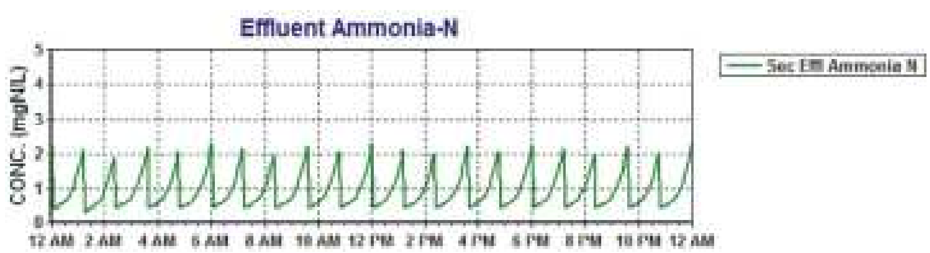

Fig. 9: Effluent Ammonia-N

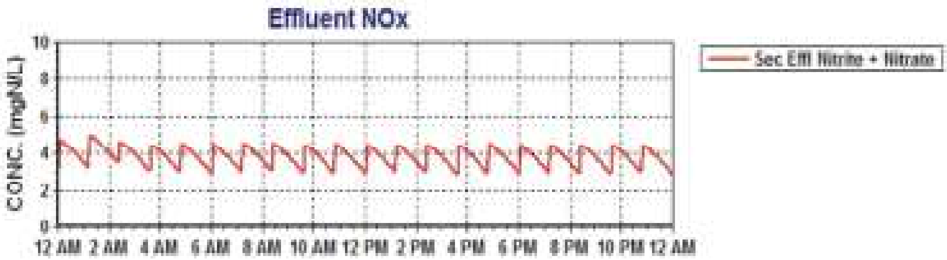

Fig. 10: Effluent NOx

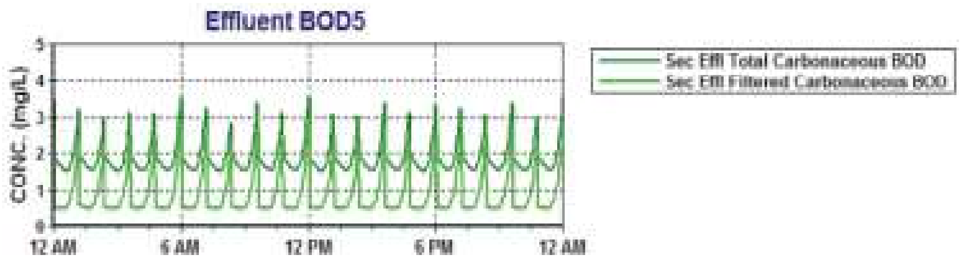

Fig. 10: Effluent BOD_5

Dynamic Simulation Results:

- Model calculated airflow rates
- Entered actual observed DO data
- Calculated power consumption from airflow
- Compared cumulative power consumption
- The dynamic simulation for aeration power is saving 35% compared to steady operation based on the following concept:
- On-off control of the blowers based on the ammonia concentration
- DO set-point adjustment based on the ammonia concentration
- ORP feedback (from +100 to +250 mV) as CBOD is converted to carbon dioxide and biomass and ammonia is converted to nitrite / nitrate.

CONCLUSION

- Dynamic Simulation Modeling is used in the optimization of wastewater treatment plants. Modeling can be a powerful tool for troubleshooting and increasing understanding of plant operation.
- Models are used to assess the effect of projected flow increases on effluent quality, oxygen demand and to make decisions about process control and capital investment.
- Process results from the SCADA system are used to observe overall responses to changes.
- Aeration adjustments are made based on the on-line Analyzers and ORP readings. The Field measurements for ammonia and nitrate are comfortable for control of aeration process.
- Fine-tuning the model aeration settings to better reflect the aeration practices of WWTP.
- The goal of the modeling is to also reduce costs and energy usage associated with plant operation.
- Online aeration control based on ammonia concentration enables the user to observe the virtual effect of changes in operation and influent loading relatively quickly. The online analyzers will be able to respond more quickly to changes in influent ammonia loads.
- Models several simulations were run to observe relationships between Ammonia, DO, Nitrate and influent loads.
- Data reconciliation conducted during this study highlighted many good practices in plant operation and monitoring.
- On-Line analyzer can measure concentrations quickly and more frequently and can be coupled with the SCADA system.
- The use of online analyzers allows for more frequent monitoring of aeration basin conditions and automatic adjustment based on pre-defined parameters.
- The dynamic simulation for aeration power is saving 35% compared to steady operation

List of Abbreviations:

C-N CARBON-NITROGEN
DO Dissolved Oxygen
BOD5 Biological oxygen demand (5 days)
OTR Oxygen Transfer Rate
OUR Oxygen Utilization Rate
ORP Oxygen Reduction Potential
SCADA Supervisory Control and Data Acquisition
SVI Sludge Volume Index
SVI (ml/gm) = settled sludge volume/sample volume (ml/l) * 1000 (mg/g)/ suspended solid concentration (mg/l)
SRT Solids Retention Time
Solids Retention Time (SRT) on the other hand is the average time a unit of cell mass stays in the activated sludge system
WWTP Wastewater Treatment Plant
NOx Nitrite, Nitrate

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