OPTIMIZATION OF AN AERATION SYSTEM AT AN INDUSTRIAL WASTEWATER TREATMENT PLANT

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ABSTRACT

The Rohm and Haas Company wanted to reduce O&M costs at their Industrial Wastewater Treatment Plant in Bristol, PA. Like most activated sludge facilities, the greatest opportunities for costs savings and optimization involved the Aeration System. It was clear the existing Aeration Blowers were well oversized and the existing instrumentation was not reliable. Therefore, Rohm and Haas embarked on a program to systematically review the entire Aeration System and answer the following key questions:

- How much air is really required for the process?
- Are the existing blowers correctly sized and operating efficiently?
- Do we have accurate data for D.O., air flow, blower amps and other key parameters? If not, should we install any new instruments?
- Should we modify the Aeration System controls?
- What else can we do to improve the operability of the system?
- How can our experiences benefit other Rohm and Haas Facility's and other WWTPs?

Rohm and Haas applied Reliability Engineering principles and basic common sense to try and answer the above questions and reduce costs. As a result, the following major changes were implemented:

- Interconnected the Aeration and Sludge Storage Tank Air Headers and eliminated the need to run two 40 HP blowers.
- Replaced the eight D.O. sensors and transmitters with new instruments.
- Replaced the eight annubars and differential pressure transmitters for air flow with new mass flow devices.
- Repaired and adjusted the eight motor operated air control valves and three blower inlet throttling valves.
- Removed half of the fine bubble diffusers in each aeration tank.
- Instituted new control schemes for the Aeration System in the computer control system in order to minimize energy usage while maintaining the process.

These changes have already resulted in operating cost savings of over $40,000 per year. The optimization work continues, primarily related to the three 300 HP Aeration Blowers which are considerably oversized and therefore operating very inefficiently.

The Authors believe this work can be applied at many activated sludge plants (both industrial and municipal) to optimize operations and save costs. Furthermore, engineers should keep in mind operating flexibility and efficiency when designing new plants or upgrading existing facilities.

INTRODUCTION

Rohm and Haas Company owns and operates a Biological Industrial Wastewater Treatment Plant at it's facility in Bristol, PA (see Figure 1 for a basic process flow diagram of the WWTP). The WWTP treats process wastewater resulting from the production of a wide variety of chemicals The wastewater plant has been operating since 1991 while successfully meeting it's effluent limits for direct discharge; however, yearly O&M costs have been very high. In particular, the Aeration System has contributed significantly to the high costs.

Therefore, in 1999 Rohm and Haas embarked on an ambitious project to drastically reduce O&M costs, including optimization of the Aeration System through the use of common sense and the application of Reliability Engineering Principles. In addition, actual plant operating data was compared to textbook and typical operating parameters for activated sludge systems in order to determine how much air was really required to support the process.

OBJECTIVE

The Objective of the Aeration System portion of the Reliability Engineering Initiative was to reduce O&M costs for the Aeration System by up to $90,000 per year. Reliability Engineering consisted of identifying the major inefficient or unreliable components, performing root cause analysis where necessary and then engineering and implementing improvements. As a follow-up to reliability engineering, the system was studied to determine exactly how much air was required both for mixing and to meet the oxygen requirements of the process. The major components studied were:

- The three 300 horsepower centrifugal aeration blowers and the associated motor operated inlet control valves
- The two 40 horsepower positive displacement blowers for the aerated sludge holding tank
- The eight motor operated air control valves (four aeration tanks with two zones each).
- The eight annubar air flow sensors and associated differential pressure transmitters for air flow.
- The eight dissolved oxygen meters.
- The 1,360 fine bubble diffusers.
- The Distributed Control System (DCS) used for process monitoring and control.

STATUS

The maintenance and capital work completed to date cost about $80,000 to implement but will reduce the O&M costs by approximately $50,000 per year. In additon, there are plans to install a new smaller blower which should save another $40,000 per year. The plant has already realized a monthly energy savings of $3,500, along with some significant improvements to the performance of the activated sludge process.

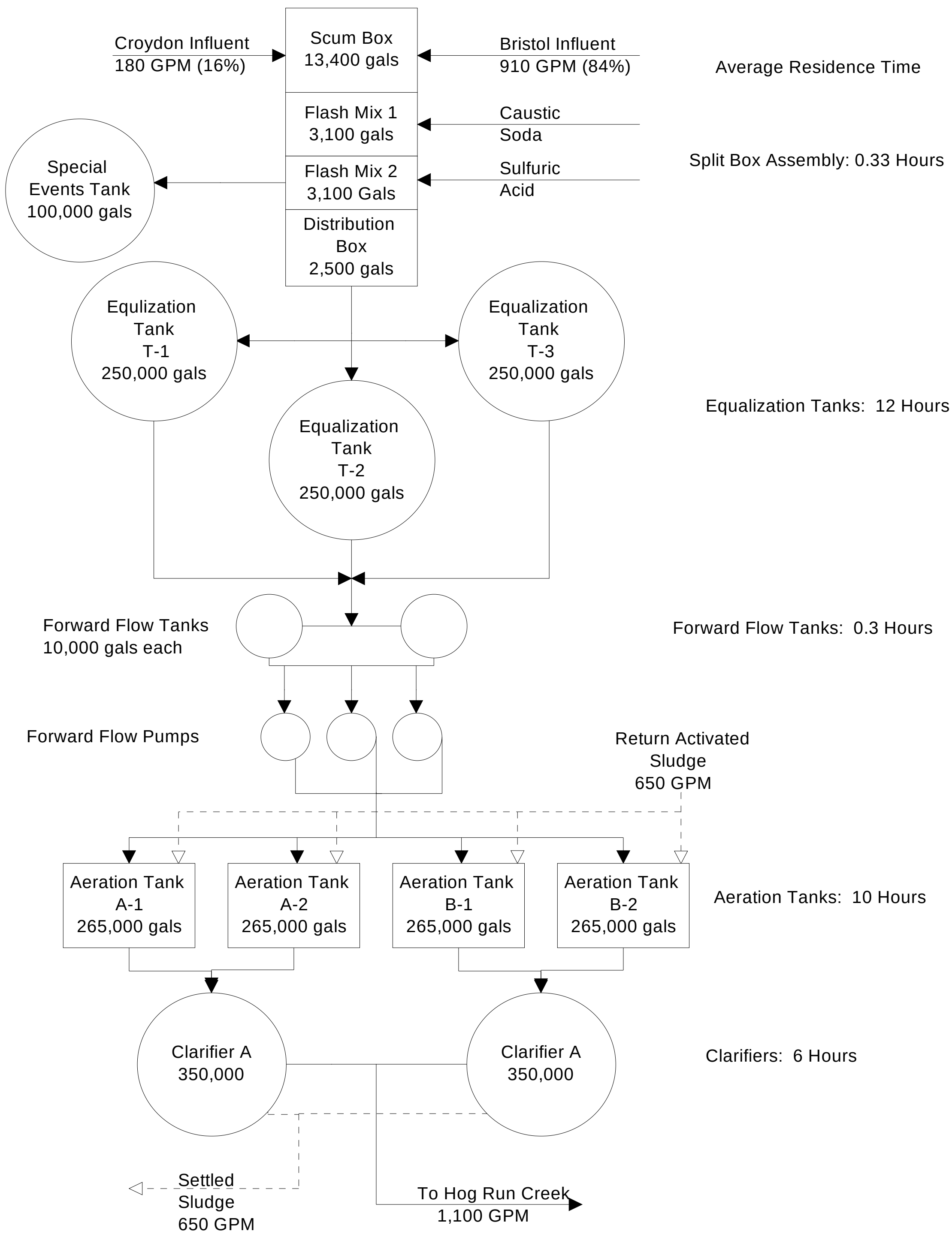

Figure 1 **Flow Diagram for Rohm and Haas Bristol/Croydon Complex WWTP**

DESCRIPTION OF EXISTING SYSTEM AND DESIGN PARAMETERS

The Rohm and Haas wastewater treatment plant is an activated sludge facility which treats industrial wastewater resulting from the production of a variety of chemicals, mainly polymers, adhesives and emulsions. The plant has a NPDES permit to discharge to a tributary of the Delaware River under the jurisdiction of the Pennsylvania Department of Environmental Regulations (PADER) and the Delaware River Basin Commission (DRBC). In addition, the effluent must meet the Organic Chemicals, Plastic and Synthetic Fibers (OCPSF) Industry guidelines for non-conventional pollutants and listed toxic chemicals.

The plant basically consists of pH equalization, followed by aeration, settling and polishing sand filters. The system was designed in the late 1980s and put on-line in 1991. The plant's key design parameters were:

- Average design flow 1.44 MGD (1,000 gpm)
- Average influent BOD: 195 mg/l
- Average influent ammonia: 40 mg/l
- Average aeration air requirement: 5,500 scfm
- Maximum aeration air requirement: 11,000 scfm
- Temperature Range of 15 to 30 degrees C
- Effluent BOD of 24 mg/l
- Effluent TSS of 40 mg/l

The major components of the Aeration portion of the plant are:

Aeration Tanks

- Four tanks, each tank is 265,000 gallons and originally included 340 20" diameter EPDM fine bubble disk type diffusers. Total aeration volume of 1,060,000 gallons with 1,360 diffusers.
- Each tank originally was divided into two zones, no physical separation, just separate diffuser grids fed from separate air control valves.
- Each tank has an 8" motor operated butterfly valve for the front zone and a 6" valve for the rear zone.
- Design was 345 to 3,454 scfm per front zone, 205 to 2,046 scfm per back zone, for a total of 550 to 5,500 scfm per tank, and 1,100 to 11,000 scfm total. (designed to provide maximum air with 2 of 4 aeration tanks out of service).
- Max air to each diffuser, two tanks out of service was 11,000/680 = 16 scfm. Average, with four tanks in service at 5,500 scfm = 5,500/1360 = 4 scfm per diffuser.
- Each air header to each zone included an annubar and a differential pressure transmitter for air flow.
- Each aeration zone included a dissolved oxygen sensor and transmitter.
- Figure 2 is a screen print from the control system showing the display of instrumentation on the aeration tanks including D.O. controls.

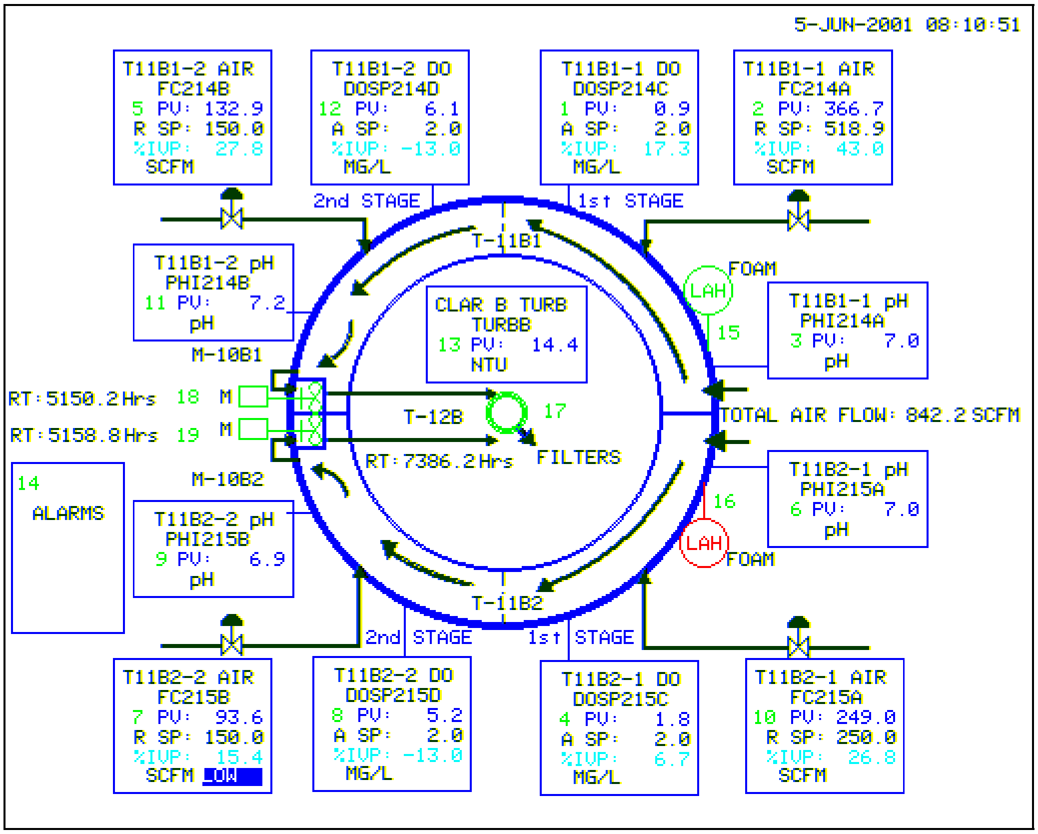

Figure 2 Computer Display of Aeration Tank Instrumentation and Controls

Centrifugal Blowers

- Three 4160 volt , 300 HP, 6 stage centrifugal blowers, each rated at 5,500 scfm (5,875 icfm). at 8.5 psig. Original design was to operation one blower during average conditions and two blowers at maximum design conditions. Each blower was designed to operate efficiently at full load, with some energy savings available by throttling the inlet valve. Figure 3 displays the rapid drop of efficiency when these blowers are operated in the 2,000 to 3,000 scfm range.
- Each blower has a 16” motor operated inlet butterfly valve for flow control and surge and vibration protection. Each blower also has a motor protection and monitoring device which shows amps, volts, power factor, bearing temperature, etc. Blower amps is also an input to DCS. The surge point is currently set at about 2,200 cfm (22 amps).

Positive Displacement Blowers

- Design based on aerating a sludge holding tank of 150,000 gallon capacity.
- Thickened or unthickened sludge.
- Two identical Positive Displacement(P.D.) Blowers designed to provide 750 scfm each at 7 psig, 2161 rpm, 480 volt, 40 HP, constant speed.

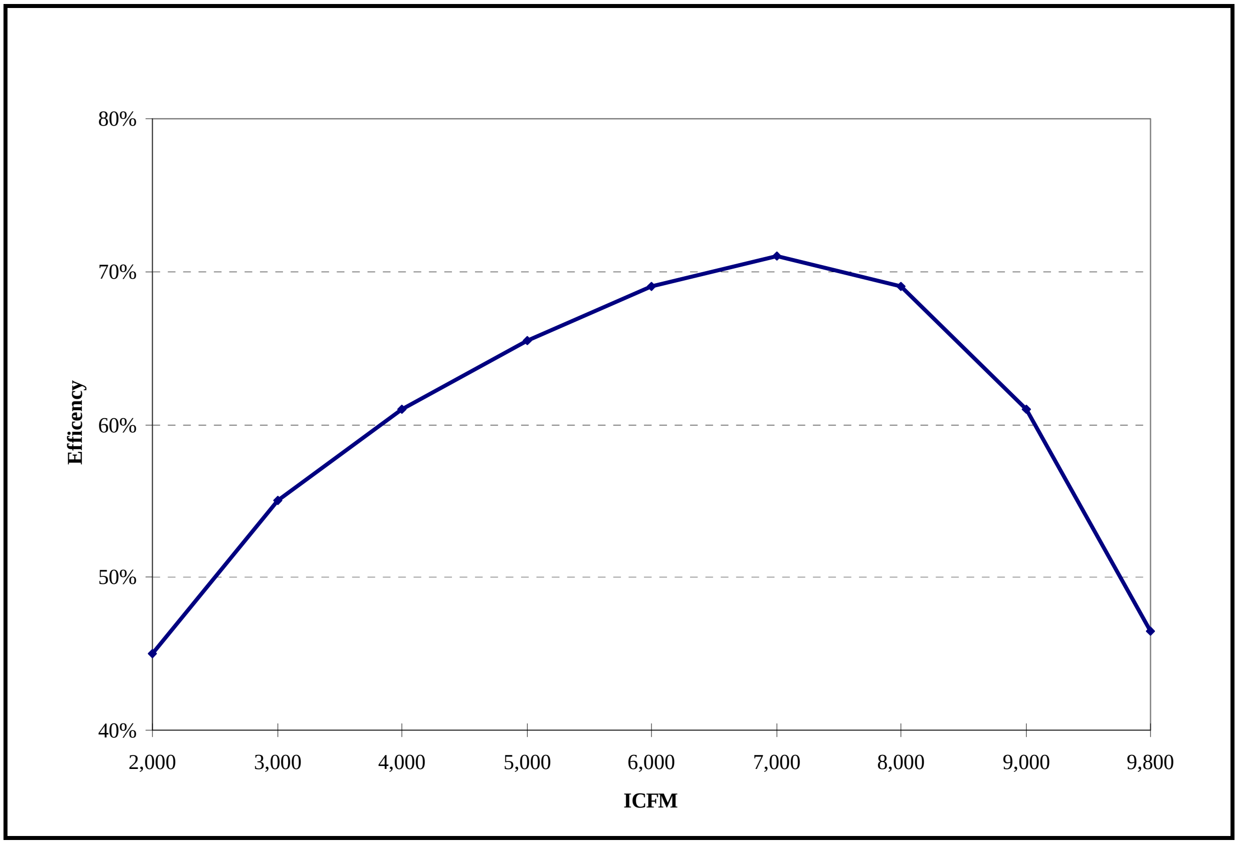

Figure 3 Graph of Mechanical Efficiency of 300 HP Blower

Distributed Control System (DCS)

- All I/O (inputs and outputs) wired back to central control room.
- About 500 I/O points.
- Discrete inputs- blowers running.
- Analog Inputs- pressure, temperature, air flow, D.O. blower amps, sludge tank level.
- Discrete Outputs- start/stop blowers.
- Analog Outputs- adjust valves.
- Graphic Screens and Keyboards.
- Plant divided into 29 Process Control Units, each has graphic screen.
- Screens for Aeration Tanks (2), Centrifugal Blowers, P.D. Blowers and Sludge Storage Tank.

QUESTIONS AND ANSWERS

In order to optimize the Aeration System, the following questions were posed and answered:

Question: How much air is really required for the process?

Answer: Rohm and Haas had a good idea the aeration blowers were oversized because they only had to run one of the three blowers at minimum and the dissolved oxygen levels in the aeration tanks were still very high (5 to 8 mg/l typically). However, what was not known was how much air was really required to successfully operate the plant without wasting energy because the blowers were operating just above their low current shutoff protection. Furthermore, there was no confidence in the existing air flow devices (particularly at low air flows) and D.O. meters. In addition, the operators were not comfortable operating the blowers through the computer control system.

In order to determine how much air was required, Rohm and Haas decide to look at 1) the original basis of design, 2) typical "textbook" values for activated sludge systems, and 3) the data available from their own plant's computer system (after improving the air flow and D.O. measurement's reliability).

1) Original Design

The original design was based on the following:

- A mathematical model of the activated sludge process with kinetics from an actual pilot plant with the Rohm and Haas wastewater
- 8,870 lbs oxygen required per day, average
- 17,513 lbs oxygen required per day, maximum (SOR= Standard Oxygen Transfer Rate= 44,080 lbs/day)
- Alpha factor of 0.5
- Beta factor of 0.99
- Fine bubble diffusers with an oxygen transfer of 22% in a 15 foot deep tank
- 1.25 scfm per square foot of floor area and 12 scfm per diffuser maximum

These design parameters resulted in 1,360 fine bubble diffusers and design air flows of 4,000 scfm average and 8,000 scfm maximum. A peer review of the concept design (by another chemical company) increased the air requirements to **5,500 scfm** average and **11,000 scfm** maximum. Therefore, the designers selected three identical centrifugal blowers, each sized for 5,500 scfm - one operating at average conditions, two at peak, and one spare.

2) Textbook Values

Textbook values (Metcalf & Eddy) for typical (municipal) activated sludge plants were found to be:

- Based on organic loading: 1,500 cu ft per pound BOD applied = **2,440 scfm average** (does not include requirements for nitrification)
- Based on mixing only: 20-30 scfm/1,00 cubic feet = **2,504 to 3,756 scfm**

3) Operating Data

The plant's own operating data, extracted from the computer system using a data acquisition system, reveals an air flow of approximately **1,300 scfm** is required to the aeration tanks to maintain the D.O. at 2 mg/l. This air flow will meet the process requirements at least 95% of the time. Figure 4 contains summary information for the WWTP operations from February through May. This chart displays the variation of temperature in the aeration basins from winter conditions to late spring (12^oC to 27^oC), and the corresponding change in DO saturation levels. The data collected during late April and early May indicates an apparent increase in air requirements, however, examination of the D. O. instrumentation indicated that the meters were fouling extremely quickly. The fouling appears to have been related to the seasonal change from winter to summer operation. Data for about ten days was excluded from the analysis as well as data which was incomplete due to data acquisition problems.

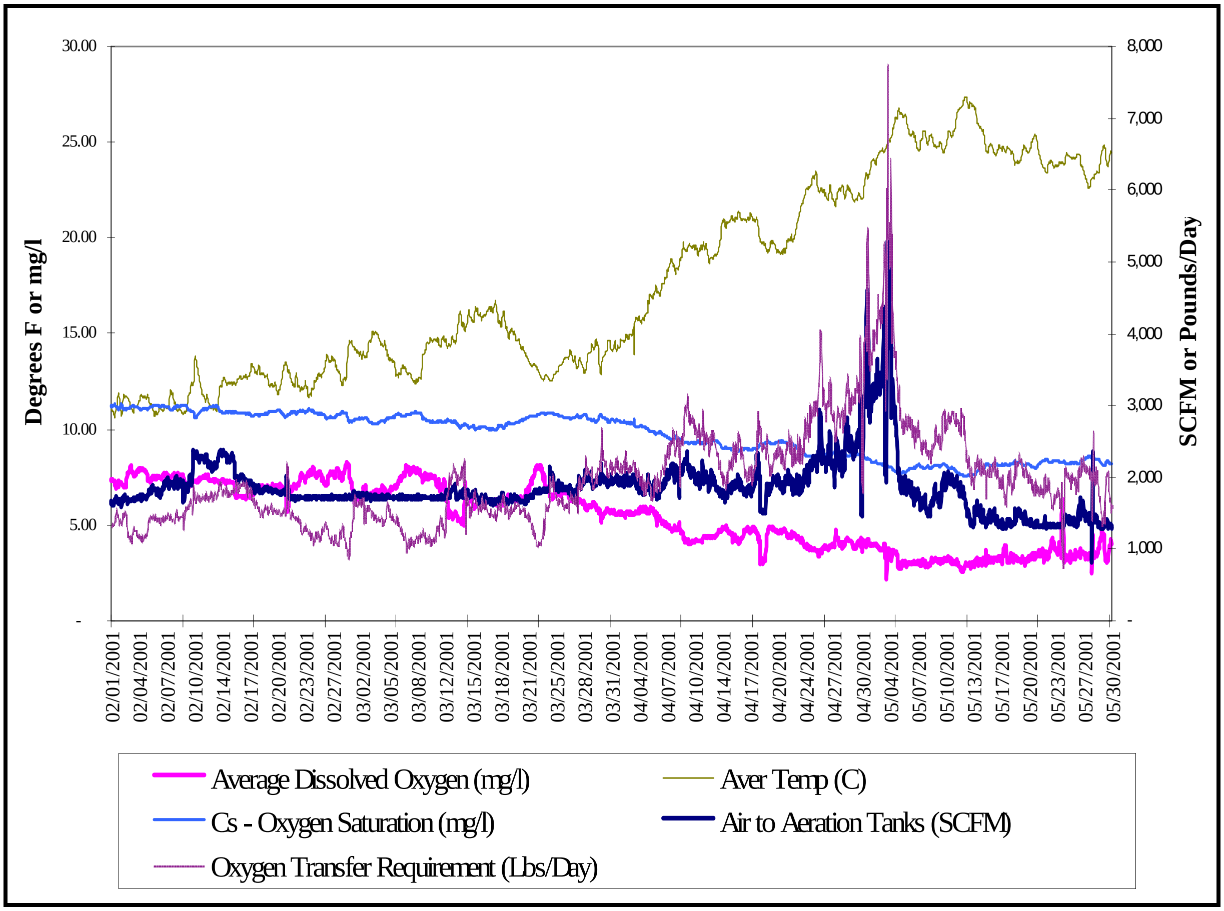

Figure 4 **Hourly Average Data on Aeration System Performance collected between May and June 2001**

Analysis of the operational data revealed that oxygen requirements had little variability, and temperature variations across the year had little impact. Calculated values of the hourly oxygen transfer requirements are displayed on Figure 4 as well. To complete the analysis of target oxygen requirements for optimizing the aeration system, Parretto analysis was completed and is displayed in Figure 5.

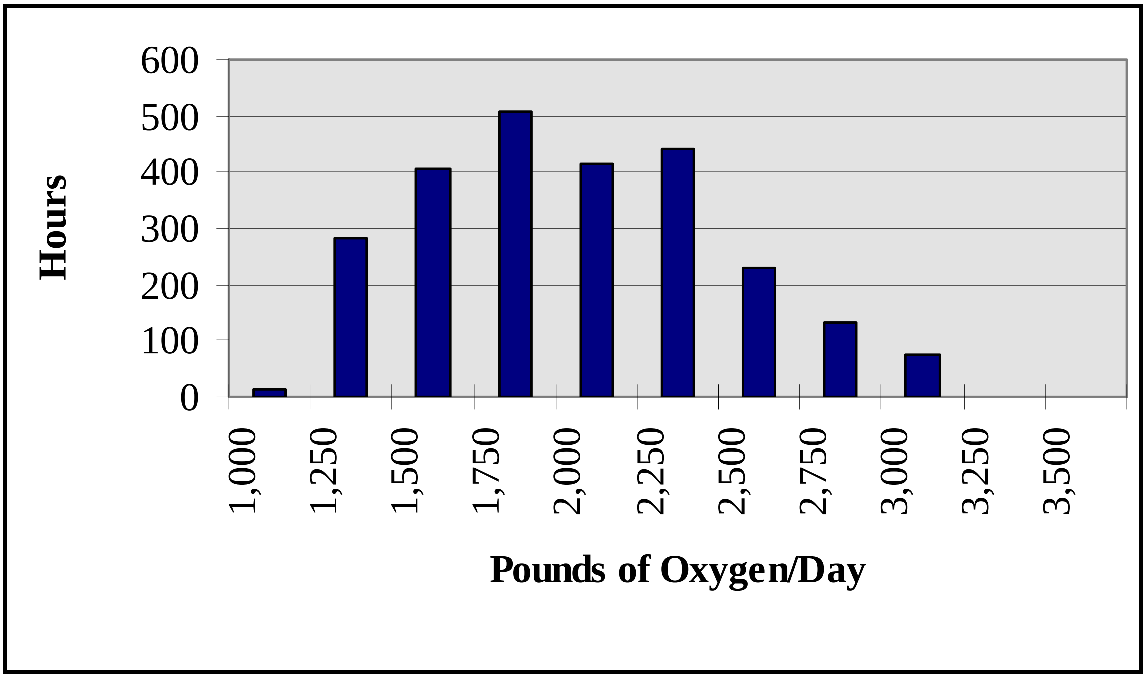

Figure 5 **Paretto Analysis of Hourly Average Oxygen Transfer Data collected between May and June 2001**

Further analysis showed that the average oxygen transfer requirements was about 1,900 pounds/day, and the 99% value of this data was about 3,200 pounds/day. Table 1 displays an analysis of air flow requirements for a variety of conditions, including winter and summer process temperatures, and range of target D. O. levels for the biological reactors, and the average and maximum expected oxygen requirements. Considerations included low target DO levels of .5 and 1.0 mg/l to understand the impact of a temporary sag in D.O. on the oxygen transfer rate, such as could occur from a slug discharge from a production unit.

Temperature (C)	Target DO (mg/l)	OTR (#s/Day)	SCFM (Caculated)
30 Max	4 Max	1900 Average	1250
30 Max	4 Max	3200 Max	2105
12 Min	4 Max	1900 Average	1915
12 Min	4 Max	3200 Max	3225
30 Max	2 Optimal	1900 Average	866
30 Max	2 Optimal	3200 Max	1458
12 Min	2 Optimal	1900 Average	1327
12 Min	2 Optimal	3200 Max	2235
30 Max	1 Min	1900 Average	751
30 Max	1 Min	3200 Max	1264
12 Min	1 Min	1900 Average	1150
12 Min	1 Min	3200 Max	1938
30 Max	0.5 Min	1900 Average	704
30 Max	0.5 Min	3200 Max	1185
12 Min	0.5 Min	1900 Average	1079
12 Min	0.5 Min	3200 Max	1817

Table 1 **Calculated Air Requirements for various WWTP operating conditions**

Thus it was determined that the main biological process required approximately 1,300 scfm to meet normal operating requirements, and that the aerated sludge holding tank consumed another 300-500 scfm for a total plant air req uirement of 1,700 to 1,900 scfm. The existing blowers are operating as close to surge as practical (about 2,300 scfm) in order to minimize operating costs, but are very inefficient at that point (less than 50%).

Question: Are the existing blowers correctly sized and operating efficiently?

Answer: As described above, it became readily apparent that the 300 HP blowers were oversized and inefficient for the plant. Figure 6 demonstrates how data acquired from the operating blowers compared with the design information provided by the blower manufacturer. We have looked at the instrumentation used to collect the data and are convinced that it is representative of the actual performance of the blowers. There are a number of factors that could create some discrepancy from the curve. The data points plotted (The blue diamonds on the figure) are from a variety of operating conditions, including inlet temperatures from 10^{o}F to 80^{o}F, and discharge pressures from 6.5 to 7.1 PSI versus a design operating pressure of 8.5 psi . In addition, the blowers are now 11 years old, and while they are still mechanically sound and appear to be clean, they cannot be expected to perform as efficiently as new equipment. Lastly, the portion of the curve where we normally operate is far from the manufacturer's optimal operating conditions, and the design information available at our conditions is less certain.

It is clear that there is room for significant improvement to the aeration system's efficiency, therefore, several alternatives were considered:

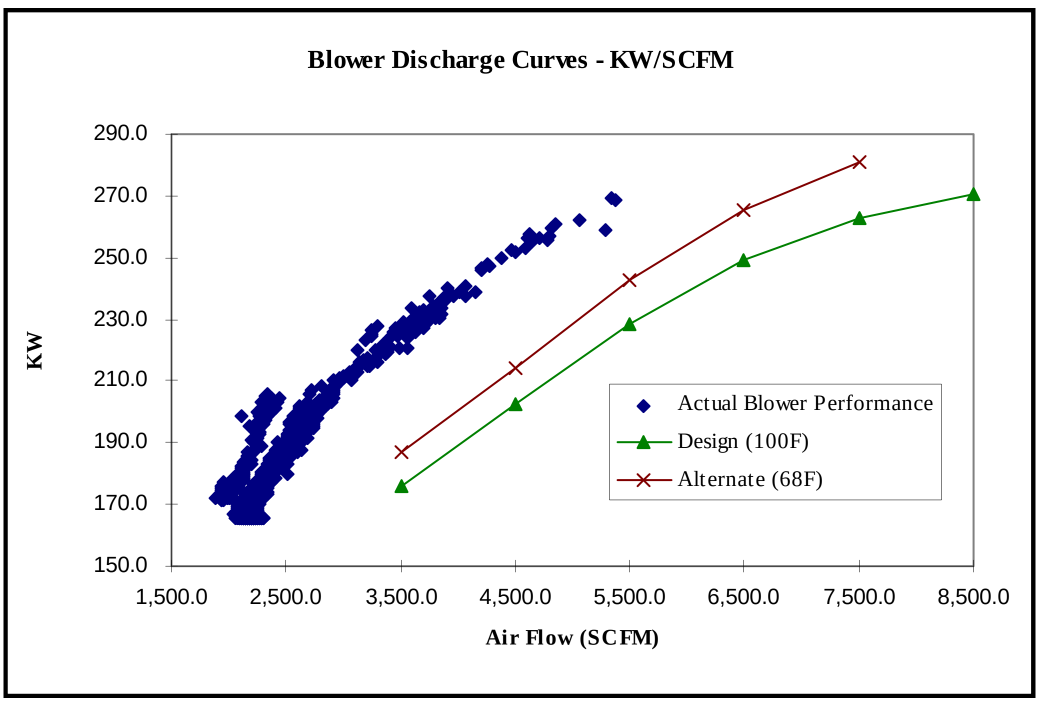

Figure 6 **300 HP Centrifugal Blower Curves, Actual and Two Design Conditions (68F and 100F)**

Change the speed of the existing blowers to lower the air flow
The manufacturer of the blowers provided curves for the blowers with slower speed motors. However, the cost and availability of 300 Hp , 4160 volt, low speed motors made this alternative impractical. Furthermore, lowering the speed of the blower also lowers the discharge pressure, which could be a problem if not enough pressure was available to create bubbles in the aeration tanks.

Install Variable Frequency Drives(VFDs) on the existing blowers
The cost and availability of 4160 volt VFDs also made this idea impractical. In addition, lower the speed of a centrifugal blower also lowers the discharge pressure as discussed above.

Use the centrifugal blowers to aerate the sludge holding tank as well:
This idea was deemed to be very attractive and was therefore implemented. The 20" aeration header was interconnected to the 8" air header feeding the sludge storage tank. Since the level in the sludge storage tank varies, a flow control butterfly valve and mass flow air meter were included. Now the aeration blower aerates the sludge storage tank and the aeration tanks. The two 40 HP P.D. blowers are no longer required, but have been kept as backup. Since one, and sometimes both 40 HP blowers ran all the time, this project has saved considerable energy. Figure 7 depicts the new cross connect between the main aeration header and the sludge storage tank aeration system. Included in this control algorithm is a current control for the 300 HP blowers to keep current above the blowers'low current shut-off.

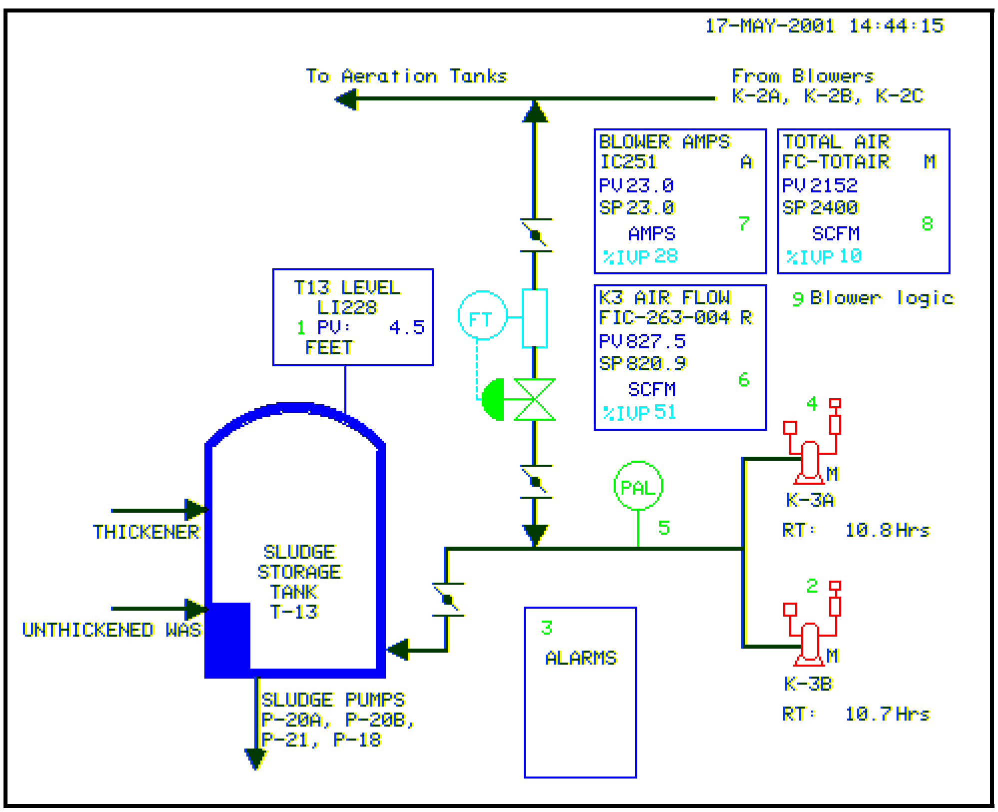

Figure 7 Computer Display of Sludge Holding Tank with new Connection to Main Aeration Blowers and Current Controls

Purchase one or more smaller blowers

Since the existing blowers are operating at about 50% efficiency or less, a smaller blower operating more efficiently would obviously save considerable energy. Therefore, quotes for centrifugal and P.D. blowers were solicited. The quotes revealed that a new 100 HP blower would meet the aeration requirements 95% of the time, run at about 75 to 80 efficiency and save at least $40,000 per year. The payback period for the project would be just over a year; therefore, Rohm and Haas is planning on implementing this project in the near future.

Figure 8 displays the operating scenarios possible with one 100 HP centrifugal blower, two 40 HP PD blowers, and one 300 HP centrifugal blower. A new 100 HP centrifugal blower should be able to meet the plants normal aeration needs (1,700-1,900 scfm) well over 95% of the time. Our two 40 horsepower blowers can augment this blower very efficiently up to about 3,500 scfm. For the infrequent periods of very high air demand, one or two 300 HP blowers can be operated. Thus, the aeration system would be able to supply from roughly 1,000 scfm to 11,000 scfm with good operating efficiency - in effect a 11:1 turndown ratio. This is a significant improvement over the current configuation which has a turndown ratio of about 4:1.

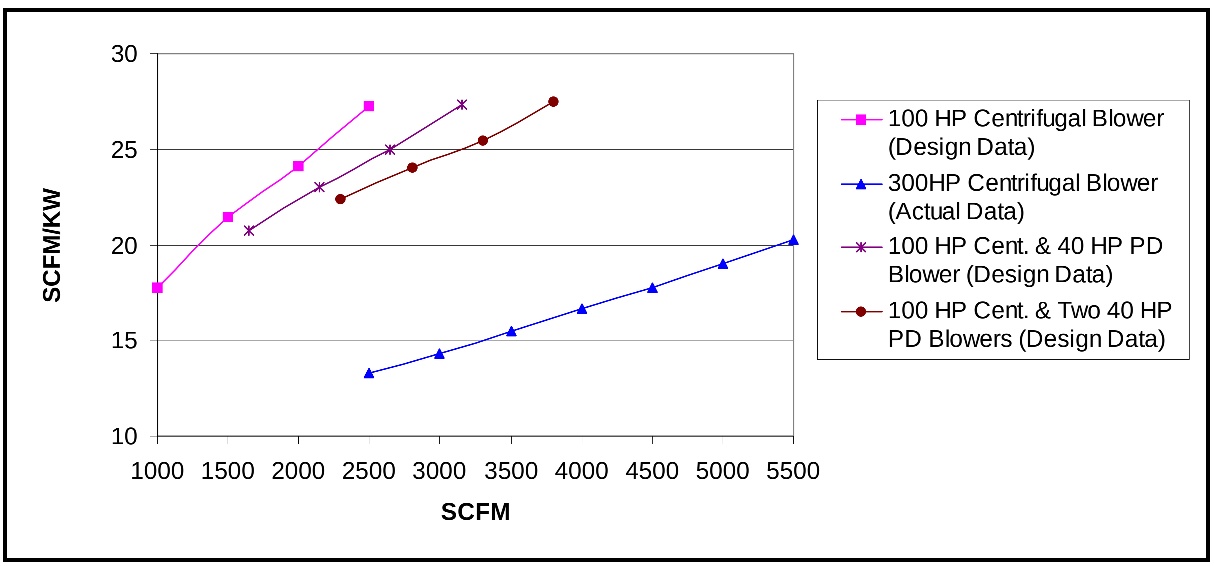

Figure 8 **Operational Scenarios possible with One 100 HP Centrifugal Blower, Two 40 HP PD Blowers, and One 300 HP Centrifugal Blower**

Question: Do we have accurate data for D.O., air flow, blower amps and other key parameters? If not, should we install any new instruments?

Answer: In conjunction with studying the blowers, the existing instrumentation was also examined. The findings were as follows:

- The existing D.O. meters were unreliable, difficult to calibrate and required considerable effort to maintain and rebuild.

- The existing air flow measurements were unreliable at the low air flow ranges (anything less than about 400 scfm was unreliable) because they were measuring very low differential pressures (less than 1" of water column). In addition, the annubars were subject to moisture problems in the tubing.
- Blower amps were wired as an input to the DCS, but had never been setup or displayed in the system.

Since air flow and D.O. were regarded as critical process information in order to operate and optimize the plant, the decision was made to replace these instruments. First, the annubars and differential pressure transmitters were replaced with new insertion style thermal mass flow meters. After soliciting quotes and technical information from three vendors, one meter was selected and installed as a test case. When this meter proved to be very reliable and easy to operate, seven more were installed. The new units have a range of 30 to 3000 scfm and are very stable and able to measure the low ranges very accurately.

Next a new D.O. meter was installed in one of the aeration tanks as a trial. The manufacturer was selected based on very favorable results at other WWTPs. When this unit proved to be easy to calibrate and reliable, seven more were installed.

In addition to new air flow and D.O. instruments, blower amps were added to the DCS. This information allowed the implementation of a control scheme to operate the blowers at a minimum air flow rate without surging.

Question: Should we modify the Aeration System Controls?

Answer: Yes, the DCS system was initially setup to provide automatic control of the entire aeration system through:

- Automatic inlet valve positioning when starting and stopping the centrifugal blowers
- Automatic control of the operating blower's inlet valve to maintain a the desired header discharge pressure setpoint.
- Automatic control of the air flow valves based on D.O. in the associated zone

The operators were not using the capabilities of the DCS system because of lack of confidence in the instrumentation and lack of understanding of how the control system was supposed to work. Therefore the following items were implemented to optimize the DCS control of the system and gain the operator's confidence:

- Trained the operators on blower start/stop and inlet valve control through the DCS and documented the procedure.
- Added more information to the graphics screen including blower amps, total air flow and time until a blower was permitted to be restarted (the system prevents restarts until 30 minutes after a blower is stopped).
- Overhauled eight motor operated air zone control valves and three blower control valves to ensure reliability.
- Added air flow control and valve position indication for the sludge storage tank
- Trained the operators on automatic control of the air flow valves based on D.O.

- Implemented blower amps and total air flow control schemes

Through the aggregate of the above projects, the turndown of the aeration system was increased to allow more efficient operation at much lower than design conditions, but still allow easy restoration of design capacity.

Question: What else can we do to improve the operability of the system?

Answer: In conjunction with blowers that were too large, it became apparent that there were too many fine bubble diffusers in the aeration tanks. Through discussions with the diffuser manufacturer and a trial in one tank, it was decided to eliminate half the diffusers in the system. This change has resulted in more air flow per diffuser which should result in less fouling and sliming. Furthermore, less diffusers will mean less maintenance cost when units need to be repaired or replaced.

Furthermore, the Eight Motor Operated Valves For Aeration Tanks were also repaired and optimized as follows:

- Restored operation through the DCS
- Overhauled all valve actuators
- Upgraded select components to latest specifications- for example, plastic gears were replaced with brass
- Replaced faulty components-for example a burned out transformer
- Adjusted limit switches and torque switches to make the valves more reliable.
- Adjusted DCS outputs to prevent valves from being driven into their mechanical stops.

Question: Most data collection efforts result in unexpected understandings and opportunities, what else can we do with the data?

Answer: The ability of our real time data acquisition system to view reliable dissolved oxygen measurements, coupled with derating of the air supply system to allow dissolved oxygen control has given us the ability to better see what is happening in our process. Operation of the plant with significant excess air resulted in high, near saturation, levels of oxygen throughout the biological reactors. Since dissolved oxygen levels were always high, increases in load, or inhibition could occur with no indication to the operation. In a plant with an appropriately sized aeration system, dissolved oxygen levels can be maintained at a setpoint, and significant deviations from the setpoint would reflect a special cause.

Figure 9 shows the impact of an inhibitory substance on the aeration basins. The dissolved oxygen levels elevated as a significant slug discharge entered the plant. This discharge contained significant organic load, however inhibition of the biomass resulted in oxygen uptake dropping to low levels, and dissolved oxygen levels approaching saturation. This incident occurred after we had upgraded 6 of our 8 Dissolved Oxygen instruments, and we believe that the incident would not have been characterized by the old dissolved oxygen measurement system. We have trained our operators to monitor the real time trends and displays for any dramatic change in dissolved oxygen levels, and our considering establishing alarms to warn of potentially inhibitory or toxic influents.

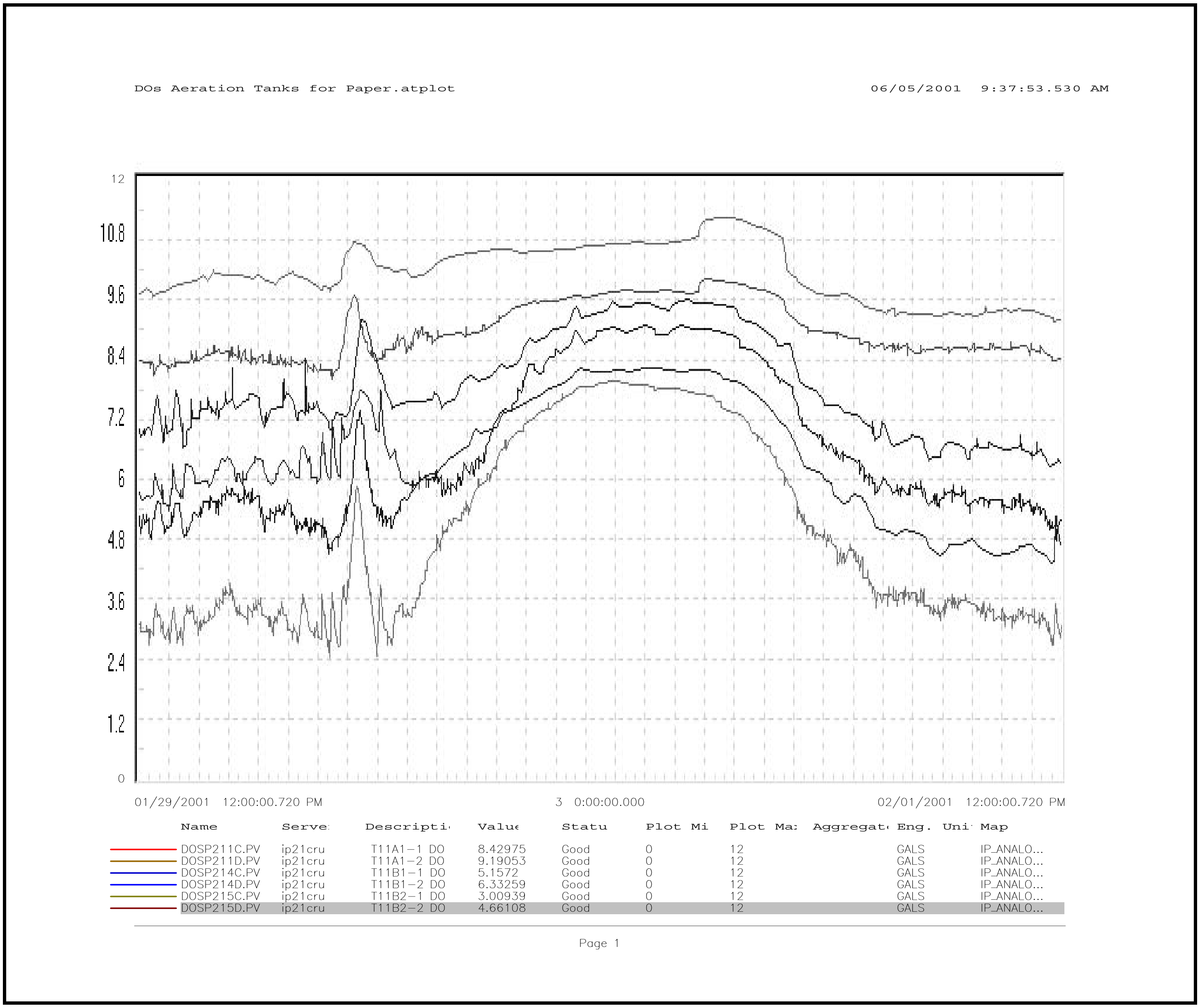

Figure 9: Dissolved Oxygen (mg/l) versus Time demonstrating Inhibitory Substance elevating Dissolved Oxygen Levels (Screen Print from Data Acquisition System)

The ability to collect data on the operation of the system also allowed Rohm and Haas to understand how inefficient the 300 HP blowers were at approximately 50% of rated capacity. The ability to capture motor amperage data directly, and relate it to blower output also facilitated our understanding of how different our operation conditions were than the plant design conditions. The specific cost (CFM/KW) to deliver air to the biological process was much greater than the operators believed based on design and normal operating information.

The ability to gather data in real time has also facilitated routine activities including process and equipment troubleshooting, loop tuning, and tracking problematic influents back to the sources.

RESULTS

The results of the Reliability work are as follows:

- Reduced O&M costs by approximately $40,000 per year projected for 2001 and beyond including parts, labor and electricity.
- Better attitude among the plant operators because many of the nagging problems with the Aeration System have been eliminated
- More time for the operators to focus on process optimization at the plant.
- Support from upper management to invest in small projects to improve operational efficiency and save significant dollars. Payback of total project is approximately one year.
- A much higher level of awareness of optimization and reliability for everyone involved with the WWTP (Upper Management, WWTP Management, Operators, Mechanics, etc.).
- Provides opportunities to better utilize data from process instrumentation to create real-time windows into the process/operations. Possibilities include relating load (Using on-line Influent Load Monitoring) to oxygen uptake to determine inhibition, toxicity, and impact of high loadings and deliver alarm indications to operators.
- Shared ideas with other Rohm and Haas WWTPs, both domestic and abroad.

CONCLUSIONS

Rohm and Haas Company was able to drastically reduce O&M costs for their Aeration System by focusing on Reliability Engineering and Optimization at their WWTP. The costs reductions were a team effort and have resulted in a wide variety of benefits for Rohm and Haas and for the people associated with the WWTP. This initiate also revealed several interesting points relating to the design and operation of WWTPs:

- Good data, particularly D.O., air flow and blower amps can help optimize operations and reduce energy costs. Without this data, plants may be wasting energy unnecessarily by adding to much air.
- Existing blowers may be operating very inefficiently even if they are throttled or controlled to maintain D.O. setpoints.
- If plants are designed for conservatively high present or future peaks loadings, the result will be an inefficient operation with oversized components unless good turndown is incorporated into the design. If designing for peak conditions, the use of different size blowers is strongly recommended.

SIGNIFICANCE

The successful Aeration System Reliability Engineering Initiative at the Rohm and Haas Plant can serve as an example for other WWTPs who would like to reduce O&M costs, but are unable or unwilling (or lack upper management or community support) to spend the time, money and effort to experience the savings. In particular, there are probably hundreds or thousands of activated sludge plants that could be run more efficiently if the data was available to optimize the system. Specifically, good air flow and D.O data could result in the ability to minimize air requirements and save energy. Furthermore, the data may reveal that blowers are very inefficient, even if they are meeting the process demands.