High Speed Turbo Blowers for Wastewater Treatment Aeration

James S. McMillen, P.E.
Perkins Engineering Consultants, Inc.
6001 Interstate 20 West, Suite 219
Arlington, Texas 76017
jmcmillen@perkinsconsultants.com

Coauthors:
Brian G. Williams, P.E., Director of Wastewater, City of Garland, Texas (ret.)
George R. Luke P.E., Engineering Manager, Gupta & Associates, Dallas, Texas
Jeff Jacobs, I&C Designer, Gupta & Associates, Dallas, Texas

ABSTRACT

In the past year there has been increased interest in using high-speed turbo blowers for wastewater aeration. New manufacturers have appeared on the market, and many manufacturers of multistage centrifugal blowers have developed and begun marketing high-speed turbo (HST) blowers. These blowers potentially have significant advantages over traditional blowers, including higher efficiencies, a wider operating range, lower operating noise, and highly integrated instrumentation and controls.

HST blowers also present significant challenges and unknowns. The technology is new to the United States, and although there are numerous installations there is little long term operating information and little information in the wastewater community on design, installation, operation, and maintenance. Retrofitting HST blowers into an existing facility can also present challenges, particularly when the high speed blowers are integrated into a system with multistage centrifugal (MSC) blowers.

This paper presents a case study of the City of Garland, Texas Rowlett Creek Wastewater Treatment Plant. In 2009 the City began designing an upgrade to the aeration system at the plant. During design, high-speed turbo blowers were investigated and specified as the preferred technology for the plant. These blowers were integrated with four existing multistage centrifugal blowers. Blowers were installed and started in 2011. Discussions on technology, specifications, controls, instrumentation, startup and operational experiences will be included in the paper.

KEYWORDS

Aeration; blower; turbo; wastewater; efficiency; centrifugal; rehabilitation; retrofit

INTRODUCTION

The City of Garland owns and operates two wastewater treatment plants (Rowlett Creek WWTP and Duck Creek WWTP) serving customers in the Dallas-Fort Worth Metroplex. The Rowlett Creek Treatment Plant serves the east side of Garland including the cities of

Rowlett and Sachse. Rowlett Creek WWTP (RCWWTP) is a Trickling Filter/Activated Sludge (TF/AS) plant and is permitted for an annual average daily flow of 24 MGD and peak two-hour flow of 43 MGD. All biosolids from the Duck Creek and Rowlett Creek plants are processed at the Rowlett Creek Plant with ultimate disposal in the City of Garlands' landfill.

In 1991 four multistage centrifugal blowers were installed in a new blower building at RCWWTP. New aeration diffusers and piping were installed at the same time. Provisions were made for installation of two more blowers when flows increased and additional aeration capacity was needed. Since 1991, hydraulic flows have not increased to the point that an additional aeration basin was needed. However, a combination of increased oxygen demand, aging equipment, and problems with blower surge led the City to replace the existing ceramic diffusers, upgrade air piping, and add aeration capacity with new blowers.

PROJECT DESCRIPTION AND BACKGROUND

The RCWWTP 2009 Aeration System and Other Improvements project initially included two new multistage centrifugal blowers, replacement of ceramic diffusers with membrane diffusers, and increasing the size of the aeration system piping. Blower replacement was needed due to the age and maintenance demands of the blowers. In addition only two of the 2,900 cfm blowers could be used simultaneously; attempting to use a third blower would overpressure the discharge air piping and force the running blowers to surge. It was thought that a combination of ceramic diffuser fouling and the size of the air piping caused surge problems. Replacement of diffusers and air piping alleviated this problem.

At the time the project was in the design stage, several manufacturers began marketing HST blowers in the United States. HST blowers have several advantages over centrifugal blowers, including a wider operating range, higher efficiencies, smaller motors and simplified maintenance. HST blowers do have a significantly higher purchase cost that must be balanced against potential long-term savings.

HIGH SPEED TURBO BLOWERS

HST blowers are significantly different from MSC blowers, both in how they are designed and constructed and in how they operate. For the HST blowers at Garland, the blower system was a packaged unit, consisting of the blower (impeller and housing), liquid cooling system, variable frequency drive controller, inverter duty & permanent magnet synchronous motor, PLC control system and blow off valve. All parts of the system were housed in a noise insulated housing that could be uncrated and set in place in a few hours. Figure 1 below shows the installed blower.

Figure 1 - High Speed Turbo Blower

Although the blowers at Garland were installed inside an existing building, these units can be specified for indoor or outdoor installation.

HST blowers utilize a compressor or turbine impeller, similar to that on a jet engine, that spins at 20,000 to 40,000 rpm. By varying the speed of the impeller using the VFD, changes in airflow can be made. Speed changes are made by the onboard PLC, which can receive a speed command from other PLC's or from SCADA. At Garland, the blower speed is controlled by the pressure in the discharge header. If only HST blowers are used the blower speed can be controlled directly by the aeration system dissolved oxygen level; this was not possible operating in conjunction with MSC blowers.

The impeller shaft spins on a non-contact air bearing. After starting, the blower pressurizes the air bearing allowing the shaft to "float" on a layer of air. By using air, there is no need for oil lubrication. The air bearing is coated with PTFE to reduce friction during startup and shutdown. Depending on the size of the unit and the installation location, additional cooling may be required beyond the air cooling provided by the system. At Garland, a liquid cooling system was needed to cool the motor. Maintenance is limited to periodically changing air filters and checking the liquid coolant level.

BLOWER EVALUATION AND SYSTEM DESCRIPTION

Early in the design, addition of two new multistage centrifugal blowers was considered. However, the emergence of HST blowers led the City to evaluate this new (to the U.S.) technology. These blowers potentially have significant advantages over traditional blowers, including higher efficiencies, a wider operating range, lower operating noise, and highly integrated instrumentation and controls.

A typical MSC blower operates at best efficiency at a single point, ideally the operating point specified. For example, Figure 2 below shows a MSC blower for 5,800 cfm air at 8 psig requiring a 276 HP to operate (a 350 HP motor). However, throttling the blower airflow (usually accomplished by modulating the inlet valve) causes a rapid decrease in efficiency. Contrast this with Figure 3, a HST blower curve, at the same duty point requires only 235 HP (a 250 HP motor). Modulating an HST blower is done by changing the blower speed using a variable frequency drive. Reducing the blower output also reduces the blower horsepower requirement, using less electrical energy.

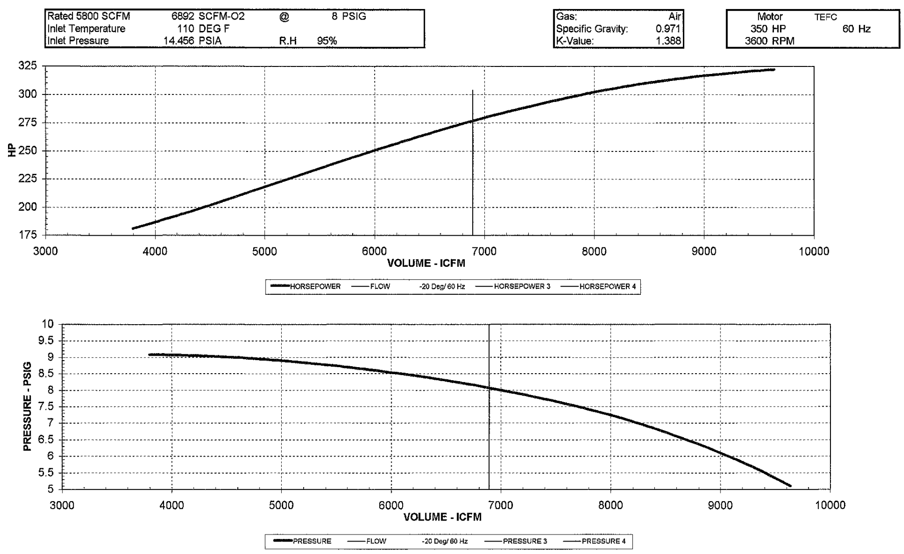

Figure 2 – Multistage Centrifugal Blower Performance Curve

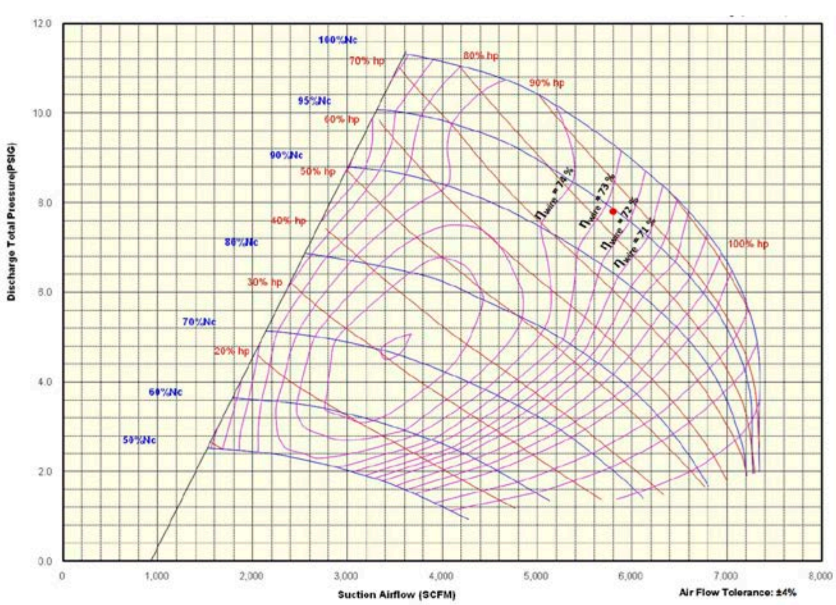

Figure 3 – High Speed Turbo Blower Performance Curve

Figure 4 below shows a typical turndown range for an HST blower. These blowers can operate anywhere in the range from the 100% HP curve (on the right of Figure 4) to the surge line (on the left of Figure 4). This gives the owner a wide range of operation so that dissolved oxygen demand can be matched to the blower output.

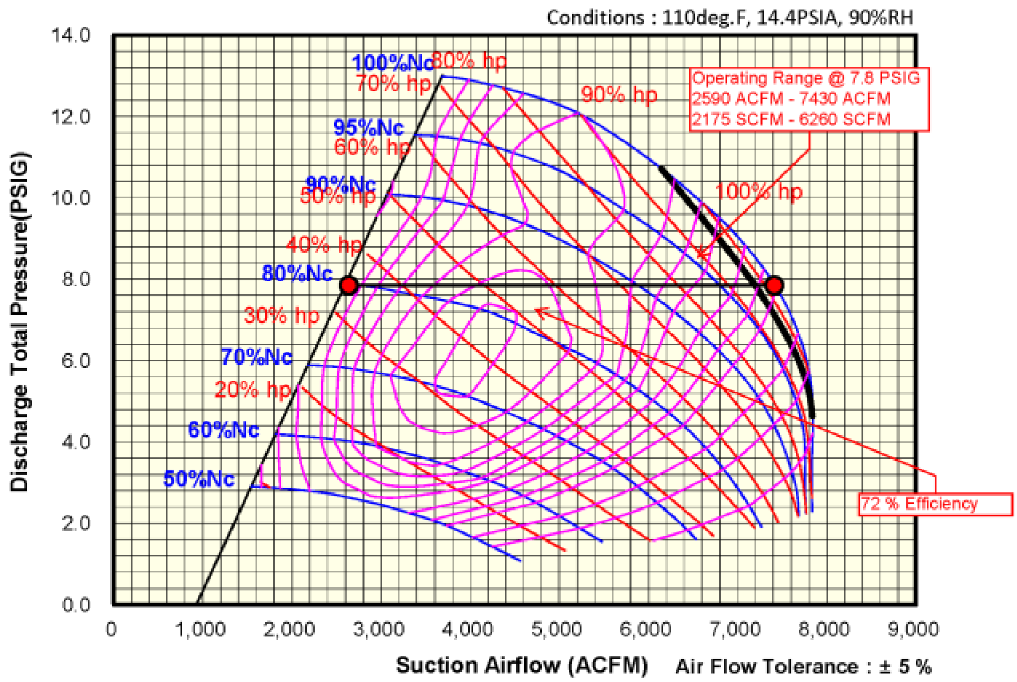

Figure 4- HST Blower Turndown Range

In addition to the operational advantages, an investigation into costs was made. Although the capital purchase costs for HST blowers is about 50% higher than purchase costs for MSC blowers, the higher efficiency/lower energy costs for HST blowers recoup the additional capital costs within 2 years. Figure 5 below shows the long term costs for three different blowers.

	Quantity	Units	Description	Unit Cost	Extended Cost
High Speed Turbo Blowers					
	2	EA	5,800 cfm HST Blowers @ 7.8 psig (250 Hp)	$176,475	$352,950
	1	EA	Electricity, NPV @ 6% annually for 20-yrs @ 9.3¢/kWh	$1,831,486	$1,831,486
				Total 20-Year Cost	$2,184,436
Multistage Centrifugal Blower #1					
	2	EA	5,800 cfm MSC Blowers @ 7.8 psig (350 Hp)	$121,465	$242,930
	1	EA	Electricity, NPV @ 6% annually for 20-yrs @ 9.3¢/kWh	$2,990,181	$2,990,181
				Total 20-Year Cost	$3,233,111
Multistage Centrifugal Blower #2					
	2	EA	5,800 cfm MSC Blowers @ 7.8 psig (350 Hp)	$113,750	$242,930
	1	EA	Electricity, NPV @ 6% annually for 20-yrs @ 9.3¢/kWh	$2,803,295	$2,803,295
				Total 20-Year Cost	$3,030,795

Figure 5 - Long Term Cost Evaluation

Costs were evaluated based on the expected demand of 5,800 cfm. After startup, it was seen that the actual air demand varied throughout the day and was often less than 5,800 cfm. Although not easily quantifiable, the ability to reduce the blower speed (and energy requirements) results in additional savings beyond those seen in Figure 5.

Based on the operational flexibility provided and the long term cost savings, two HST blowers were installed instead of the two MSC blowers originally envisioned.

BLOWER INTEGRATION WITH EXISTING BLOWERS

Although over 20 years old, the four existing blowers had useful life and the City wanted to continue using them. Two of the blowers had been rebuilt recently and all four blowers were in operational condition. To exploit the existing facilities, it was decided that the two new HST blowers would be installed parallel with the existing MSC blowers.

Blower surge was a main design concern. The existing blowers, which were already prone to surge, would be connected to the same air header as the new HST blowers. Operationally, one HST blower would act as the main blower and an existing MSC blower would provide supplemental air. This arrangement led to the requirement that both new HST blowers must have the same maximum discharge pressure as the existing MSC blowers. By operating at the same maximum pressure, the new blowers would not over pressure the air header to and send the existing blowers into surge.

As designed, one HST blower would operate when air demand is between 2,900 cfm and 5,800 cfm (the HST operating range). If aeration demand exceeds 5,800 cfm, the HST blower will turn down to 2,900 cfm and the existing MSC blower will start, providing 2,900 cfm of air. The HST blower can then ramp up to any point between 2,900 cfm and 5,800 cfm to provide up to 8,700 cfm. If air demands exceed 8,700 cfm, the second HST blower or a second MSC blower can be started to provide additional air.

Following startup, one core was replaced on the HST blower. Operators had been unable to adequately turn down the blower speed for cold weather operation and were forced to "waste" air. By replacing only one core, the City had the ability to use one HST blower for cold weather operation and one HST blower for warm weather operation. Since there is a significant overlap in the operating range for the two cores there was no loss in redundancy.

ELECTRICAL, INSTRUMENTATION, CONTROLS

The Process Control System at this Plant is based upon a redundant fiber optic ring that encircles the Plant and connects to a total of 28 programmable logic controllers (PLCs). Primarily, the SCADAPack® PLC from Schneider Electric (formerly Control Microsystems) is used virtually exclusively. Wonderware® InTouch from Invensys® is used as the top end SCADA graphical user interface, however there are individual operator interface terminals (OIT) providing local displays installed on several of the

PLC cabinets throughout the facility. The simplified system architecture is shown in Figure 6:

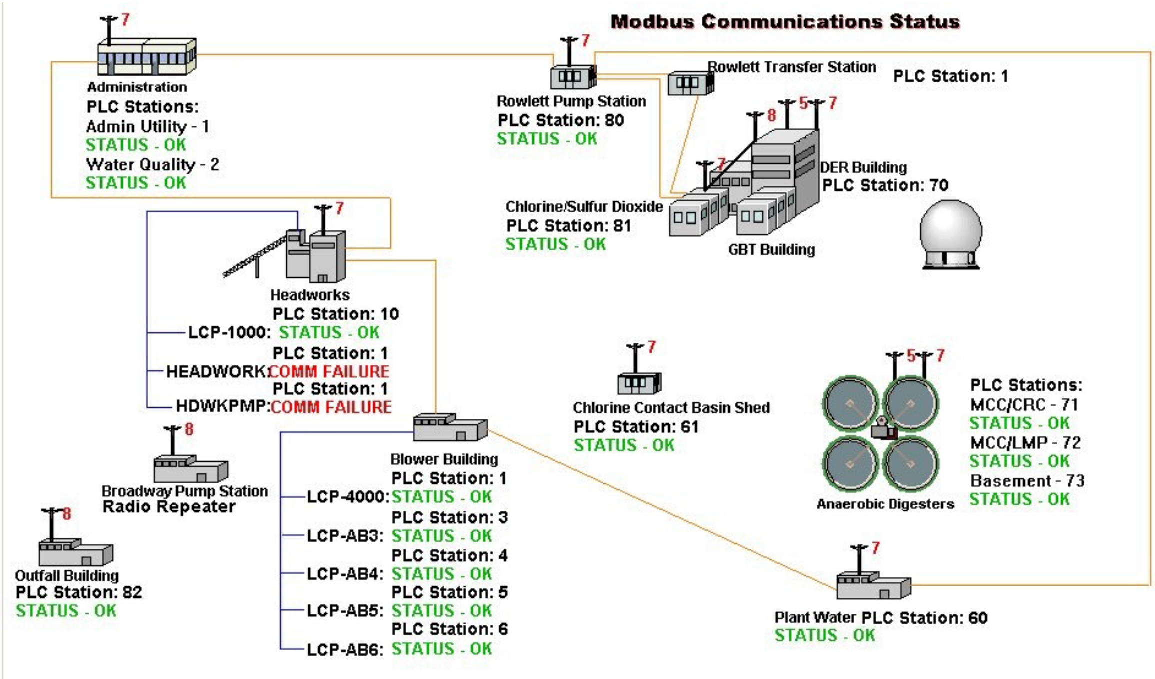

Figure 6 - RCWWTP System Architecture

Early operational philosophy was for the Top End to provide monitoring and alarming capability only. Operator process interaction was limited to these OIT's. The idea was that if the Operators were to make a change to the process, they needed to be at the process and not in the Control Room. As time has progressed, more and more capability has been provided to the Control Room Operator. Now the Control Room Operator can, with proper log-in credentials, start/stop or open/close equipment manually and make process set point changes from the Control Room.

The new HST blowers were procured as a package with individual PLC-based control panels and OIT stations. Also, two of the existing MSC blowers were rebuilt with new PLC-based control panels and OIT stations as well. In order to ensure a balanced and comprehensive control scheme, during the design phase it was decided to install a "master" PLC in the Blower Building. Each of the individual blower PLCs would communicate with the master PLC via peer-to-peer exchange, and the master PLC would communicate with the Control Room top end. But since the individual blower PLCs were Allen-Bradley® from Rockwell Automation the peer-to-peer communication using Modbus TCP with the SCADAPack master PLC required additional initial design considerations.

These individual PLC's were responsible for individual blower surge control as well as other internal control functions. Each individual blower control panel has a local OIT for display and set point adjustment. In addition, the HST blower PLC's were to have the capability of doing complete stand-alone PID speed control based upon integral instrumentation for discharge pressure and air flow. However, since there were to be multiple HST and MSC blowers, it was not practical to rely on the individual controllers to provide total control as there was no means for networking them independently. That functionality was provided by the master PLC. The master PLC controls the starting and stopping of blowers based on air needs. The master PLC also controls DO in the aeration basins by monitoring the basin DO and modulating the air valves to the basin. The P&ID for the Aeration Basin is shown in Figure 7:

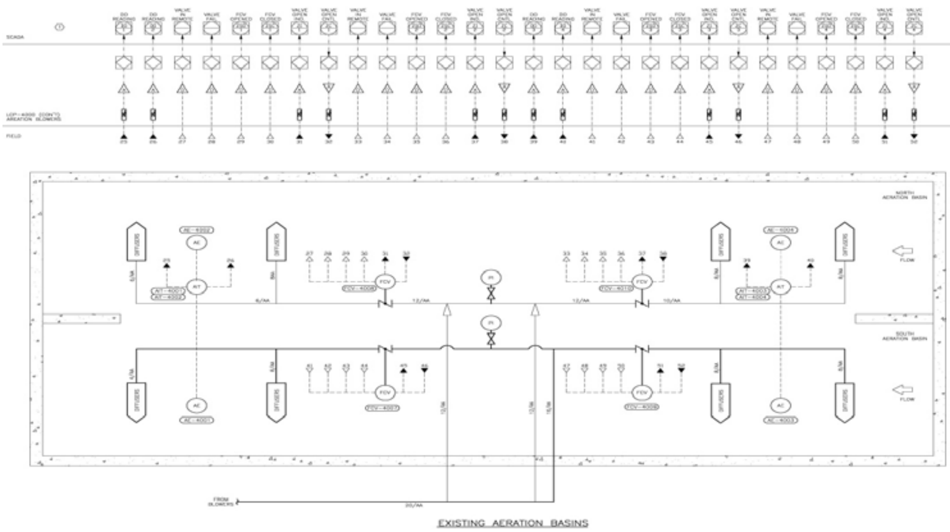

Figure 7- Aeration Basin P&ID

And the P&ID for the Blowers is shown in Figure 8:

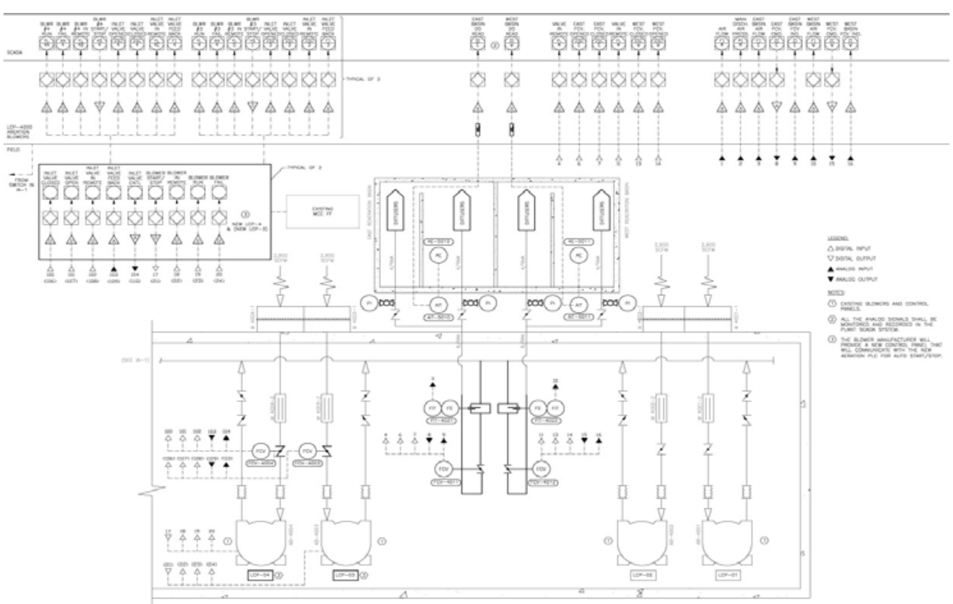

Figure 8- Blower P&ID

Still, it was thought that the master PLC would only need to send either a header pressure set point or flow set point to the HST controller and the individual HST would then do an internal PID calculation for speed control. The master PLC would monitor HST VFD speed and would start additional blowers should the running HST blower speed reach a maximum. This logic is depicted in the following simplified logic flowchart:

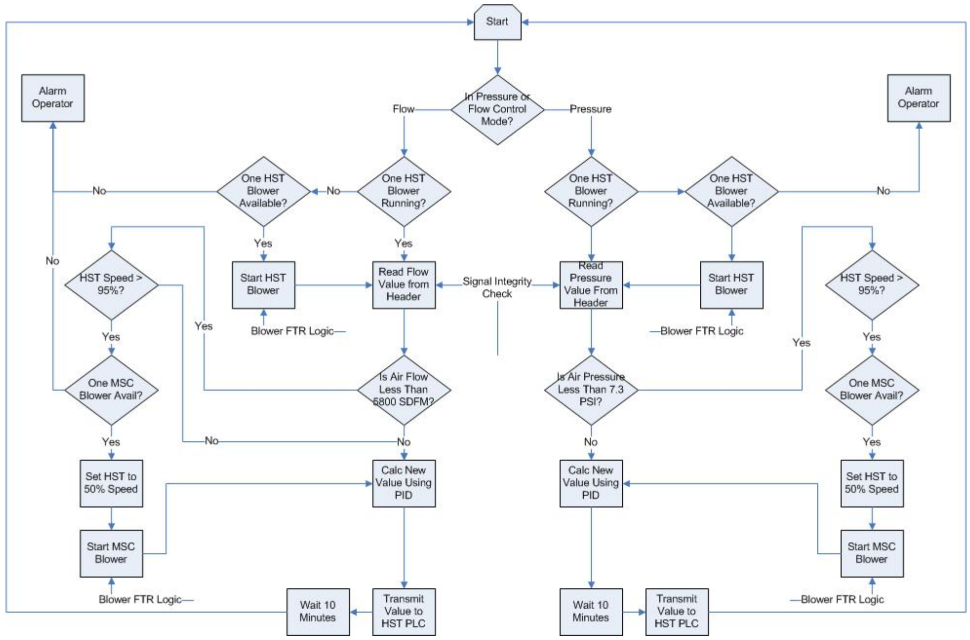

Figure 9 - Blower Control Logic

However, during startup it was learned that this was a misunderstanding of the HST design. The HST could only perform an internal PID calculation for speed control if the pressure set point was entered locally via the local OIT. As this was unacceptable for Plant operations, it was decided to perform the PID calculation for header pressure control inside the master PLC and only send a speed command to the HST blower controller. In this way, the HST blower controller believes it is running in a remote manual mode as opposed to a total automatic mode. Therefore, the master PLC was configured to perform multiple PID calculations:

1. Each of the four individual aeration basin air valves required an individual PID calculation with an individual DO sensor as the process variable and each one with an individual DO set point.
2. The air header pressure was the process variable to a PID for controlling the blowers. The output of this PID loop would control the speed of the HST blower. If the output of this PID loop reached a maximum value for a set period of time, another blower would be started.
3. The reaeration Basins are configured with an individual PID for each of the DO measurements and flow meters with the valves.

From the Control Room, the Operator can, with proper log-in credentials:

1. Make set point changes;
2. Start and stop individual blowers manually;
3. Send a manual fixed speed to an HST blower; and

4. Define the order of which blower would be started automatically.

An example of the graphical user interface screen used in the Control Room is shown below:

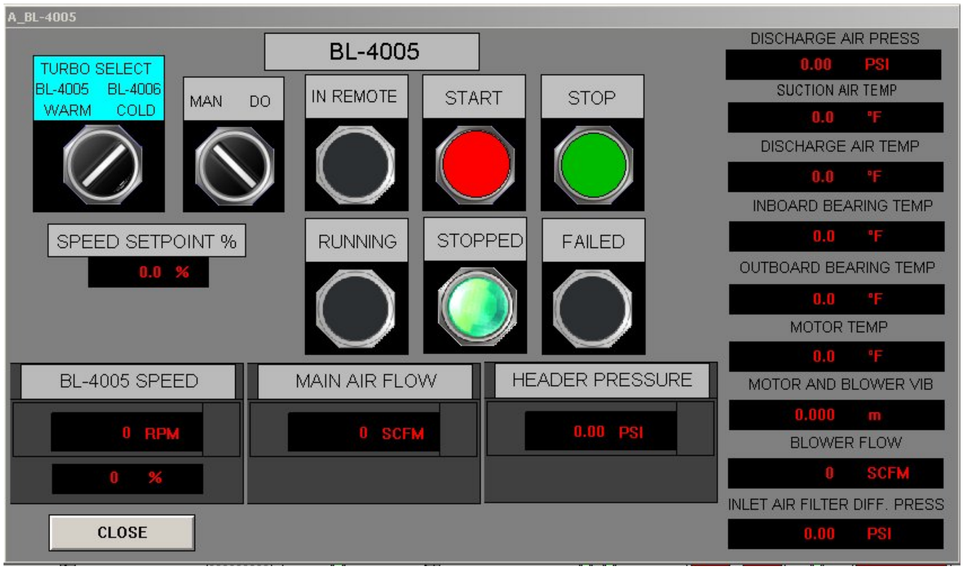

Figure 10 - Control Room Operation Screen

During initial testing and operations, it was noticed that the header air pressure did not change quickly enough to satisfactorily serve as the process variable for controlling HST blower speed. As it turned out, the HST blowers were maintaining header pressure relatively steadily, but the individual aeration basin air valves would modulate until they were 100% full open and the DO would still be below set point. Attempting to speed up the PID loop tuning proved to be problematic in that it caused overshooting the set point and sending the system into wild fluctuations.

An alternate approach was implemented where the attempt was to ensure the DO readings remained close to their set points. The master PLC no longer considers header pressure directly. Rather:

1. When three or more of the four individual DO PID loops are below their individual set point for three minutes, the master PLC increases the VFD speed command by 1.25%.
2. When three or more of the four individual DO PIC loops are above their individual set point for three minutes, the master PLC decreases the VFD speed command by 1.25%.

This ensures there is adequate air pressure supply to the modulating valves that they can maintain set point.

As described above, the two HST blowers do not have the same core units. This means they have different rated air supply capacities. This was required since during colder weather the required amount of air changes in order to satisfy the DO levels is much lower than during the warm summer months. This allows for two operating modes:

Mode	Lead (Primary) Blower	Lag 1 (Secondary) Blower	Lag 2 (Next) Blower	Lag 3 (Final) Blower
Warm	Higher Capacity HST	First Available MSC	Last Available MSC	N/A
Cold	Lower Capacity HST	Higher Capacity HST	First Available MSC	Last Available MSC

Figure 11 - Operational Modes

In determining the order of blowers started, the following points are considered:

1. The Control Room Operator chooses to operate the system in Warm Mode or Cold Mode based on weather conditions and plant experience.
2. The two HST blowers are not to run at the same time.
3. In Cold Mode, there are still days when the air capacity is greater than what the single lower capacity HST blower can deliver. In that case, the higher capacity HST blower will start and the lower capacity blower will stop if the lower capacity HST blower cannot keep up with air demands.
4. Whenever the higher capacity HST is unable to keep up with air demands, the two MSC blowers are started in a sequence set by the Control Room Operator and run in parallel with the HST.

The final control scheme described above was developed over a period of time as the Plant Operating Staff became more familiar with the HST blowers, their controllability, and the unique characteristics of this process. In order for the Plant Operations Staff to gain the experience necessary to have confidence in the system while maintaining operational needs, additional flexibility was built into the system from the beginning. This included the ability for the Control Room Operator to place the blowers into a remote (computer) manual mode such that they could be manually started, stopped, and the HST blower speed set to a fixed value from the Control Room. This proved to be a critical function. The Plant Staff worked closely with the Control System Programmer to bring the system on line in the following manner:

1. Initially, the blowers were run totally manually from the local individual control panels to gain run time experience with the blowers.
2. Next, the remote (computer) manual mode was used to gain experience with the remote controllability of the system.
3. Next, the system was placed into a full automatic mode where the master PLC took control. But the Operator had the ability to return to remote (computer) manual mode when the system was at risk of getting out of control.
4. Finally, while the remote (computer) manual mode is still an option, the system is left in full automatic as much as possible with the Control System Programmer available to witness the specific idiosyncrasies being experienced.

This is probably the greatest lesson learned regarding the control system. Regardless of the amount of engineering design, there are still unexpected consequences and system demands to which only experienced Plant Operators can react. Providing the flexibility to allow the Operators to revert back to manual control was critical to their acceptance. In this case, this Plant Operations Staff was also very willing to accept the challenge of making something so new and different to them work successfully. This cooperative effort is the reason the control system was tailored successfully to the final state.

OWNER'S PERSPECTIVE

The major expectations for the HST blowers that Garland had from an Operations and Maintenance perspective were threefold:

1. Provide the required dissolved oxygen (DO) content to the aeration process
2. Reduce electrical consumption/operating cost
3. Preserve the same level of maintenance that was required of the current multi-stage blowers (current levels were negligible)

The HST blower system lends itself well to fully automatic operation. Previously with the MSC blower system, plant operators received no DO information feedback to the operations control room. Adjustments to the blowers were only made if a process upset was noted due to excessive DO concentrations in the aeration basin. Therefore, there was essentially no adjustments being made at the aeration system and when they were made, an operator had to go out and manually adjust blower intake valves or start up an additional blower and try to manage blower surge concerns that were onerous. With the current control operation, automatic adjustments are being made continuously and the plant operators can easily view the aeration system operating parameters such as DO, system pressure, valve position and HST blower speed and the system will automatically start and stop HST and MSC blowers and take into account surge concerns. Plant operators have been very pleased with the operation of the HST blower operation and are becoming more comfortable with the automatic operation as the instrumentation control loop is being fine-tuned. Figure 6 demonstrates the variation in blower output (cfm) for a 24 hour period that is automatically being adjusted to meet DO requirements.

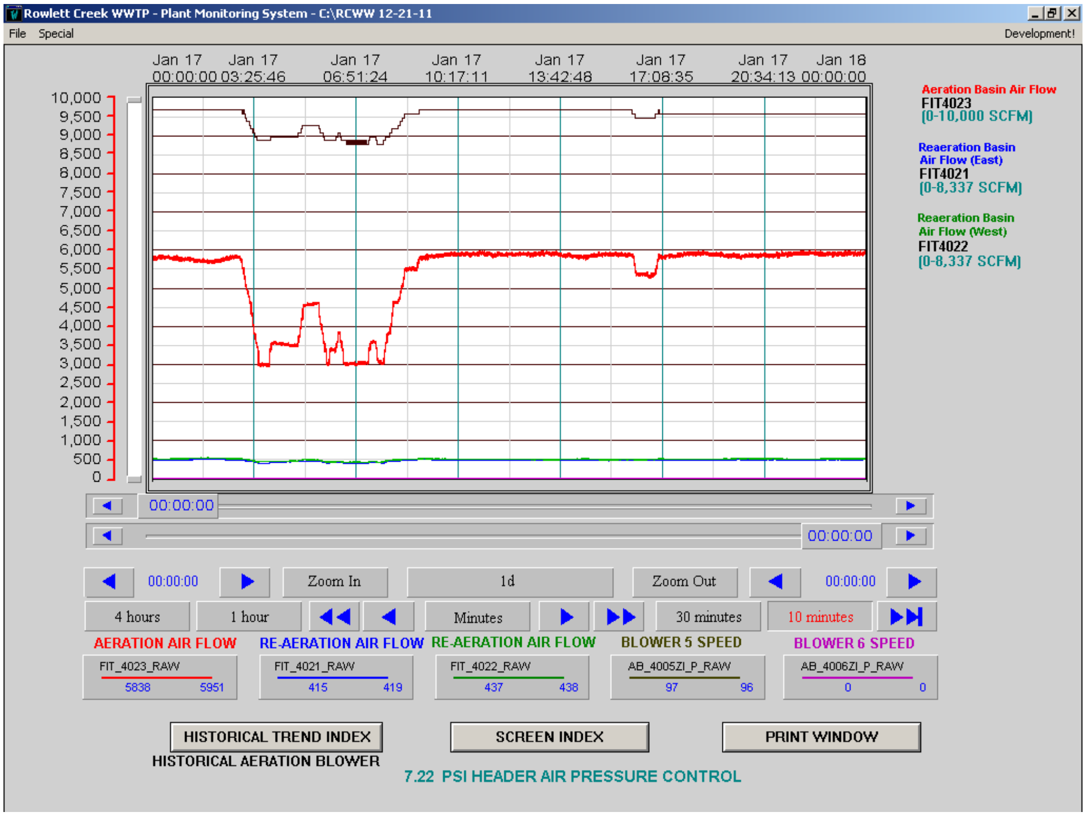

Figure 12 - HST Blower Operation

Early in the operation of the new aeration system, it was determined that the process had operated at less than optimum DO concentrations. Prior to the installation of the HST blowers, automated DO sensors had been installed at the blower basins but they were not tied into the plant SCADA system. Consequently, the aeration basin DO content was not tracked throughout the day. Also the process was limited to operating a maximum of two MSC blowers with a combined nameplate output of 5,800 cfm. The City is now convinced that periodic low DO concentrations were occurring frequently and impacting ammonia removal. Now that the system is able to track the DO and real time adjustments are being made to air volume (at times above the previous limit of 5,800 cfm), the treatment plant has not experienced any ammonia upsets. The ability to provide more than 5,800 cfm is primarily due to the replacement of the aeration piping and diffuser system; however, the HST blower control system and blowers now provide a greater operating range of air requirements in a more economical manner.

A comparison of electrical operating costs of HST blowers versus MSC blowers has not been performed. Several significant variables were changed by the project, so it would not be valid to compare operating costs and attribute the savings to the HST blower. As mentioned, the aeration piping and diffuser system were changed out in the project to a more efficient system and the previous air system did not always provide sufficient air to meet system demands. The City is in the planning stages to develop a test procedure that will compare the electrical consumption, under similar operation, of one 5,800 cfm HST blower and two older 2,900 cfm MSC blowers. The outcome (with appropriate interpretation, since it would be comparing relatively new HST blowers to twenty year old MSC blowers) would provide insight to the potential savings for blower upgrades.

The maintenance of the blowers has met expectations and very little maintenance has been required. Routine maintenance has entailed changing out two air filters – one for the air intake to the blower and one filtering ambient air for the variable frequency drive. The filters are changed after about one week of blower operation. A filter set is removed and replaced with another set. The set of filters that is removed is blown clean with compressed air and is set aside to be reused. It is anticipated that a set of filters will provide approximately 2000 hours of operation or about three months. The filter sets have a replacement cost of $110 (2011$). No other routine maintenance is required other than checking glycol levels on the liquid cooling system for the blower core.

The system has experienced one unforeseen maintenance issue. A 1.02 MM diameter airline that is attached to a diaphragm valve has clogged on two occasions and forced the shutdown of a blower. This valve operates to allow air to escape into the atmosphere during blower startup. Without the proper operation of the diaphragm valve, the air blow-off valve remains open and will not allow the process air to pass through to the aeration piping. This has only caused a minor inconvenience; the airline was quickly cleared and the blower was returned to service.

Other benefits to the HST blowers include the quiet operation. The HST blower/motor core is housed in a sound dampening enclosure and it was found that the unit does operate at a very low noise level.   However, as the large volume of air passes through the piping and appurtenances, it produces some excessive noise but is still quieter than the MSC blower operation. Future design considerations should possibly consider a noise performance specification not only on the HST blower but on the entire installed package.

Another operation and maintenance issue occurred that was not anticipated. During the start-up operation it was noticed that the two HST blower units produced more air than was specified. However, the units were not meeting the lower end of the specified operating range. In order to meet the lower end, which proved to be a necessary operating requirement, it was decided to replace one of the core units. The new unit was rated at the same horsepower but with a different impeller that produced different operating characteristics. This change allowed the units to meet the operating range. The entire change-out procedure was accomplished within a six hour work period. The work was performed by mechanics trained by the manufacturer and went very well. This process provided a good insight concerning the ease to replace a core unit, if necessary, in the future.

LESSONS LEARNED

As with any new technology, some aspects of the equipment, design and installation can only be improved upon after its initial installation. In the case of the HST blowers at

RCWWTP, several aspects of the project came to the forefront during construction and startup. Some of the lessons learned include:

- Close coordination with the manufacturer during the design phase is needed. HST blowers operate in a significantly different manner than MSC blowers. Coordination early in the design phase is critical for a smooth installation and startup.
- Close coordination with the Operator during startup and initial operations is crucial. Integration of the HST blowers with the existing MSC blowers and plant control system was a process that required experienced personnel from both the City and the system integrator. Moving to the point where operators are comfortable with new equipment takes time and effort from all parties.
- Control logic in a hybrid system can take unexpected paths. The initial system was intended to operate similar to a typical MSC system where a DO probes controlled modulating valves and the subsequent pressure change operated MSC blowers. In the end, the system operates where DO controls the majority of the blower operation. If only HST blowers are used in a system, this would be the preferred control strategy.

CONCLUSION

High Speed Turbo blowers potentially have significant advantages over traditional blowers, including higher efficiencies, a wider operating range, lower operating noise, and highly integrated instrumentation and controls. Retrofitting HST blowers into an existing facility can also present challenges, particularly when the high speed blowers are integrated into a system with multistage centrifugal blowers. However, the long term cost and energy savings that are possible with HST blowers, coupled with the ease of installation and integrated control system, make HST blowers an attractive alternative to traditional aeration blowers.