Evaluation of Potential Operational Cost Savings Associated With Automated Blower Control

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Abstract

With the forecast of increasing power costs, the Cinco Municipal Utility District (MUD) No. 1 Board of Directors expressed concerns regarding the potential power cost required to operate their wastewater treatment plants. In response to these concerns, TCB conducted a study of the aeration system at the Cinco MUD 1 Wastewater Treatment Plant (WWTP). The focus of this study was to determine the magnitude of potential cost savings associated with the installation of more efficient blowers, minimization of back pressure created by manually throttling the air flow, and installation of automated blower controls to match blower output with system process demands.

The existing aeration system consists of five constant speed, multi-stage centrifugal blowers. During the field test, no changes to routine operations were requested or performed. The WWTP was operating at approximately 1.6 MGD (roughly 50 percent of its design capacity) and two blowers were operated continuously but in a throttled condition. For the field test, instrumentation was provided by Aeration Control Technology, which also collected the field data that was used in the study. Turblex Inc. performed a separate and independent analysis of the data and provided consultation services during and subsequent to the field test. Air flow, dissolved oxygen (DO) concentration, motor amperage, ambient and blower discharge air temperature, and blower discharge pressure were collected at 10-minute increments, 24 hours per day throughout the three-week test period.

Activated sludge treatment systems require a minimum amount of air to be introduced into the system in order to maintain a thoroughly mixed system and the necessary DO concentration for biological activity. Any air introduced into the system beyond what is needed to maintain these two parameters is considered excessive and may be eliminated to reduce power consumption. As in most WWTPs of this size, no method of precise or automated control is available to the operator at the plant. Throughout the day, blower output is set to meet the peak daily oxygen demand and then partially throttled at night to conserve energy. All throttling on the blowers is performed using valves on the discharge side of the blowers.

For the tested conditions, diurnal process demand curves based on the 10-minute incremental DO data points were developed and excess air flow to the system was determined. The amount of excess air flow was determined by comparing measured air flow to the air flow required to maintain a 2.0 mg/l DO concentration. The wire to water efficiency of the existing blowers was determined from the motor amperage, air flow measurements, and pressure readings. Additionally, the amount of energy wasted through the discharge throttling operations was identified. Theoretical optimum process demand curves were compared to actual daily blower output to determine the degree of potential cost savings. The data was extrapolated for annual increments up to full build-out conditions expected in 10 years. Operational costs were projected over a 20-year life cycle for the proposed equipment.

An evaluation of available blower and control technologies was performed. Appropriate blower technologies and optimal blower sizes were selected for this particular application. Three potential areas of savings were identified. The results of the study show that the most significant savings, approximately 35 percent of the aeration energy consumed, is available through controlling blower output to match process demands. Other areas of savings are related to using more efficient blowers (10 percent) and minimizing discharge valve throttling.

Introduction

At the request of the Cinco Municipal Utility District (MUD) No. 1 Board of Directors, TCB determined the degree of potential cost savings that could result from improvements to the existing blower system at the Cinco MUD No. 1 Central Wastewater Treatment Plant (WWTP). Currently the WWTP has a rated treatment capacity of 3.3 million gallons per day (MGD), but currently receives only 1.6 MGD on average. The plant services a primarily residential community with only a small portion of commercial development. The waste stream is typical of a primarily residential service area.

Preliminary treatment at the plant consists of coarse bar screens and grit removal. There is no primary treatment. The secondary treatment system consists of a conventional complete mix activated sludge system, which is followed by granular media filtration and ultraviolet disinfection. The plant's current discharge permit requires an effluent quality of 10/15/3 (BOD_5/TSS/ammonia nitrogen).

The existing blower system consists of five, 100-HP constant speed, multi-stage blowers. Two of the blowers were installed as part of the first phase of construction in 1997. The other three blowers were installed in 2001 as part of a plant expansion. Blower output and air distribution between basins is manually controlled with butterfly valves. On a typical day, two blowers, each rated at 1,400 scfm at 8.5 psi, operate continuously. The blowers are typically throttled to reduce the combined output to match the peak daily oxygen demand that occurs between 9:30 a.m. and 11:30 a.m. weekday mornings. During this brief diurnal peak oxygen demand period, the dissolved oxygen (DO) in the aeration basin varies between 1.5 and 2 mg/l. The relatively constant air flow to the aeration system results in high DO levels that can reach as high as 6 mg/l overnight.

As part of a previous study, the blowers in the aeration system were identified as being the largest consumer of power within the WWTP and also presented the highest potential for improvements in energy consumption. As part of this phase of the study, several areas affecting blower performance were reviewed, and methods of improving the blower system efficiency were analyzed.

To initiate the study, a comprehensive field investigation was implemented to monitor existing blower performance and process demands. Aeration Control Technology was employed to perform the field investigations and record existing blower performance data. The field test was conducted between May 3, 2006, and May 23, 2006. Eighteen days of data was obtained in ten-minute increments, 24 hours per day. Motor current, DO, barometric pressure, inlet temperature, blower discharge pressure, combined blower output, header pressure, and ambient temperature were all recorded during 18 days of testing.

From this data, the mechanical and electrical efficiency of the existing blower system was determined. Additionally, through field DO measurements, the amount of excess air provided to the system could be estimated for each ten-minute increment in a typical day. The data was then compared to guaranteed blower performance curves from several manufacturers to determine if mechanical and electrical efficiencies could be achieved with other blower technologies, specifically single-stage blowers. Potential savings as a result of automating blower controls to match process demands were also estimated.

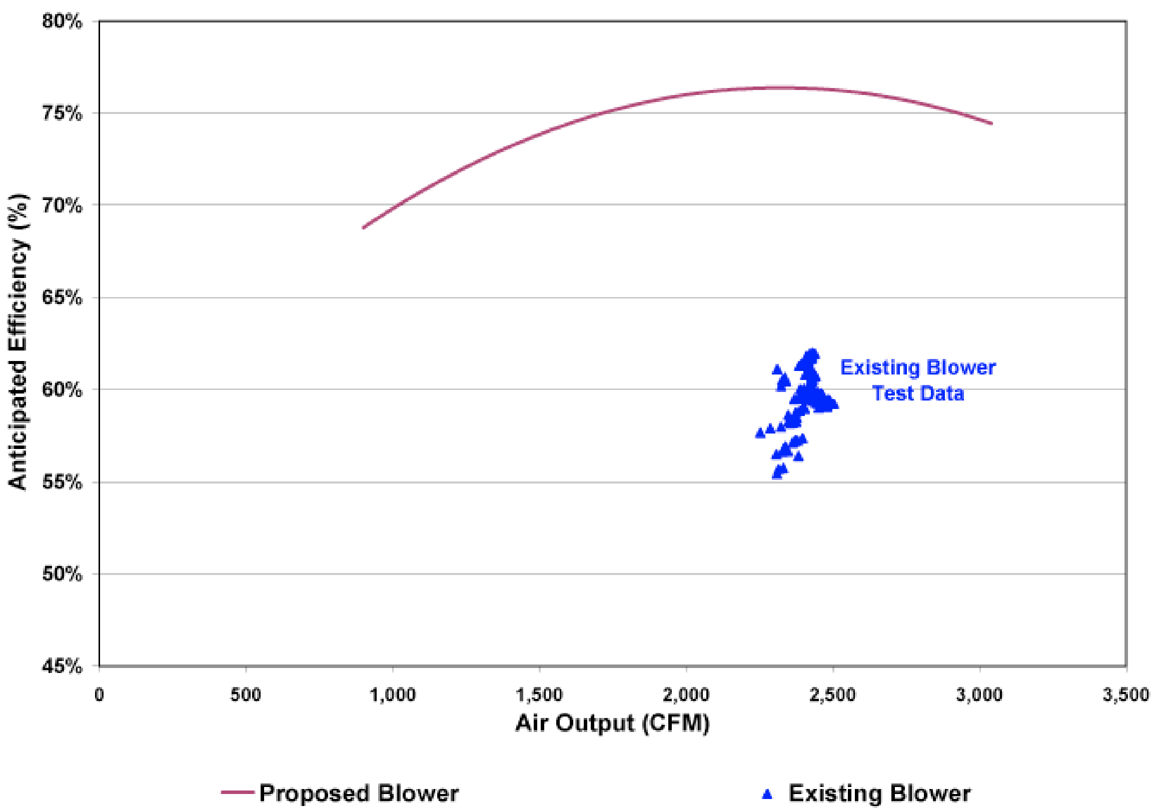
Evaluation of Potential Energy Consumption Reductions

Proposed modifications of the current blower system would result in savings in three areas. First, savings can be realized through installation of more efficient blowers. Second, savings can be realized by optimizing the amount of air produced to more closely match the oxygen demand within the treatment system. The third area of savings is the minimization or elimination of the additional back pressure against which the blowers operate. The targeted excess back pressure is that which is caused by throttling the air distribution valves. These three methods of reducing energy consumption are discussed in more detail below.

Potential Energy Savings Due to Blower Efficiency

Data was gathered during the field study to determine the mechanical efficiency of the existing multi-stage blowers that are currently in use at the WWTP. Only two of the five blowers were in use and monitored during the field study. The overall efficiency of the existing blowers was calculated based on the data collected in the field. As shown on *Figure 1*, the two existing blowers were operating at an overall efficiency of approximately 60 percent during the study. The efficiency of the existing blowers was compared to the efficiency of the proposed blowers as listed in the guaranteed performance data for a single-stage blower. Electrical motor efficiency of 93 percent was applied to the manufacturer's listed mechanical efficiency. The resulting blower efficiencies are illustrated on *Figure 1*.

Figure 1 - Blower Efficiency Comparisons



The average annual savings over a ten-year period due to the use of a more efficient single-stage blower was calculated based on an initial power cost of $0.08 per kW/hr and an annual inflation rate of 5 percent. The calculated average annual savings over a ten-year period is $10,488. These savings are the result of increased blower efficiency only, and not due to any modifications to blower control or operations, which were determined separately. If energy costs rise at a greater rate than the assumed 5 percent inflation rate, more significant savings and a more immediate recovery of capital investment costs would be realized.

Potential Energy Savings Due to Improved Blower Control

Oxygen demand within the aeration basins varies throughout the day. The current system does not allow the degree of control necessary to closely match the blower output to the oxygen demand within the system. The result is the consumption of energy to produce air that is not needed within the system. On average, WWTPs that employ activated sludge treatment with nitrification are operated at an average goal DO concentration of 2.0 mg/l. Plants also require a minimum rate of air introduction for the purpose of mixing. The industry standard for the minimum air supply is 0.12 cfm/ft^2 for fine bubble systems. Any air introduced into the system beyond what is needed to maintain the desired DO concentration and a thoroughly mixed system is excessive and can be eliminated to reduce power consumption. For the purpose of this report, a DO setpoint of 2.0 mg/l is assumed. The minimum air introduction rate necessary for mixing is 1,000 scfm under the current conditions.

Figure 2 illustrates the incremental DO concentrations and air production rates over the course of an average day, as determined by the 18-day field study. The values shown for each ten-minute interval are the average result for each interval during the 18-day field study. As shown in the graph, the current regime of air production results in extended periods of time in which the DO concentration is above 2.0 mg/l. This is indicative of excessive, unnecessary air production, which can be eliminated. This is primarily due to the current blower system not allowing a precise level of control or a straightforward method for synching blower output to real-time oxygen demand.

Figure 2 - Field Measured Test Data:
Average Dissolved Oxygen and Air Production

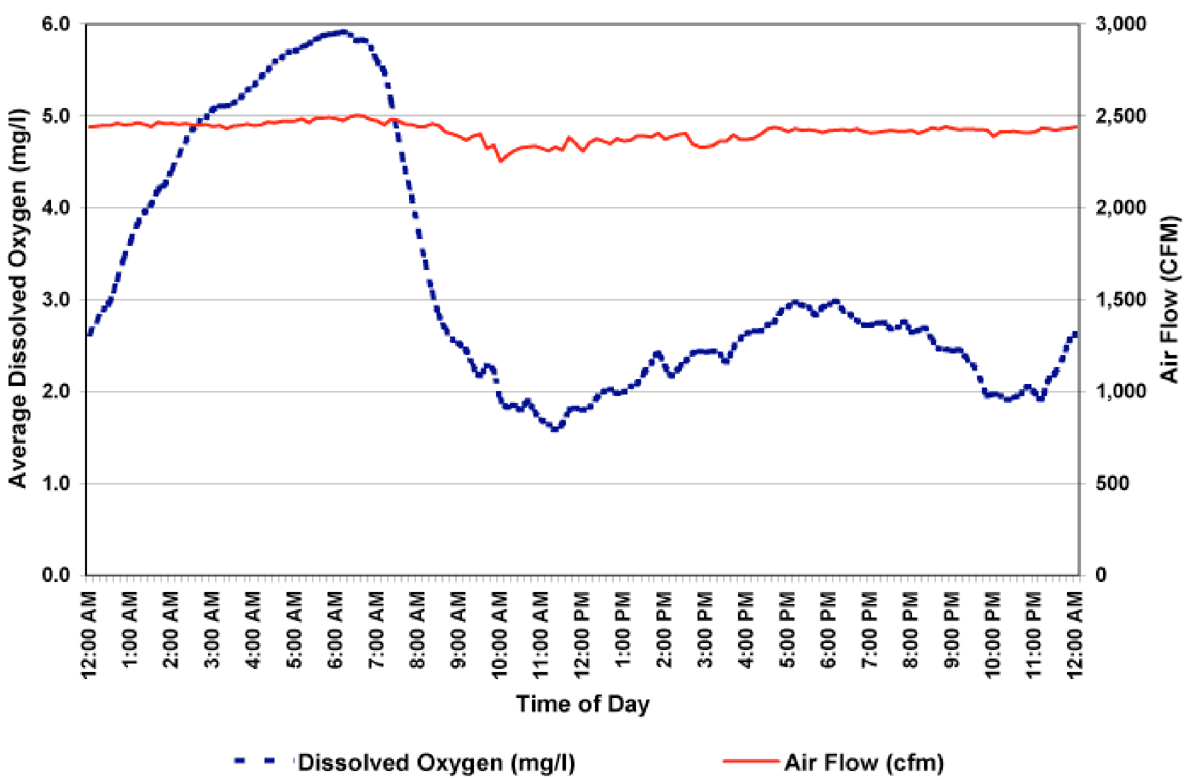


Figure 3 shows the optimum air production rate to maintain a DO setpoint of 2.0 mg/l and a thoroughly mixed system. In the theoretical cycle shown, blower output is continuously adjusted

throughout the day in proportion to oxygen demand within the system in order to maintain a DO concentration of 2.0 mg/l. Theoretically, this is the most efficient daily cycle of air production for the WWTP. The figure was generated from data collected during the field study. A point of interest displayed by *Figure 3* is that at night the DO concentration rises above 2.0 mg/l. This is not indicative of overproduction, but is instead indicative of the amount of air needed to maintain an adequate DO concentration being less than the amount of air needed to maintain a completely mixed system.

Figure 3 - Theoretical Optimum Blower Operation

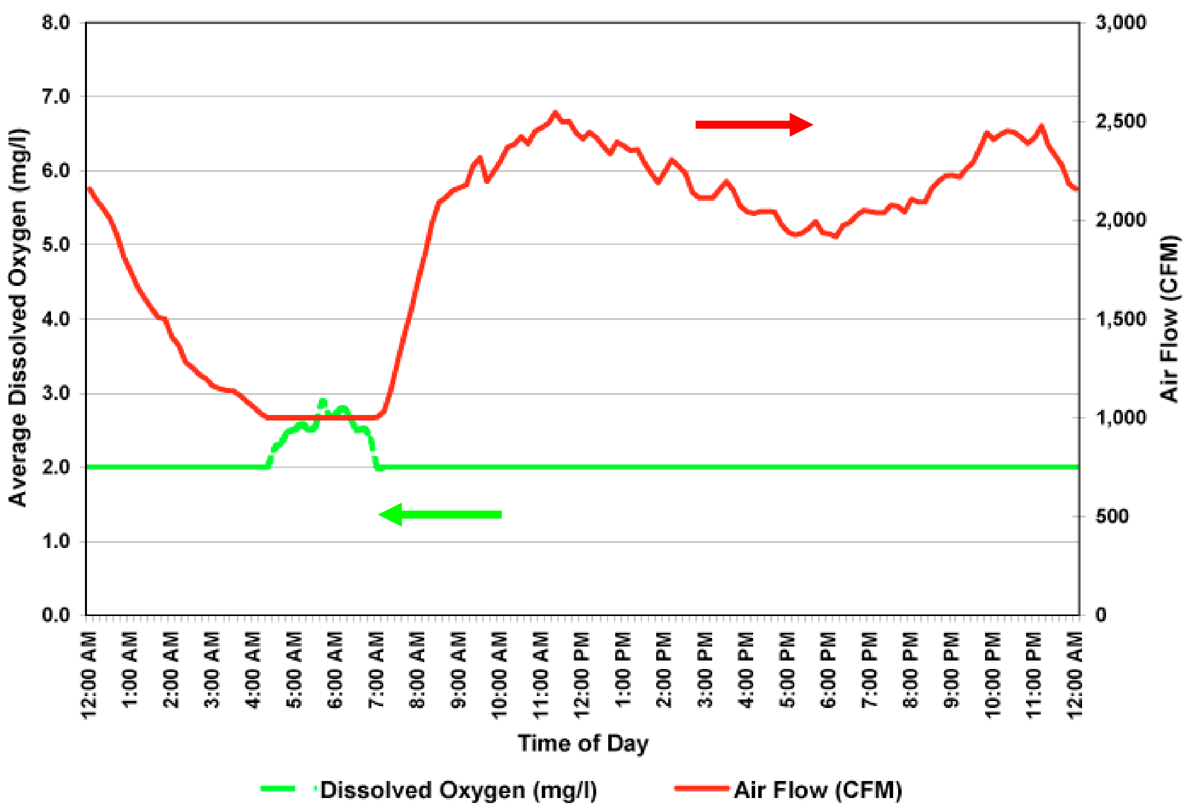
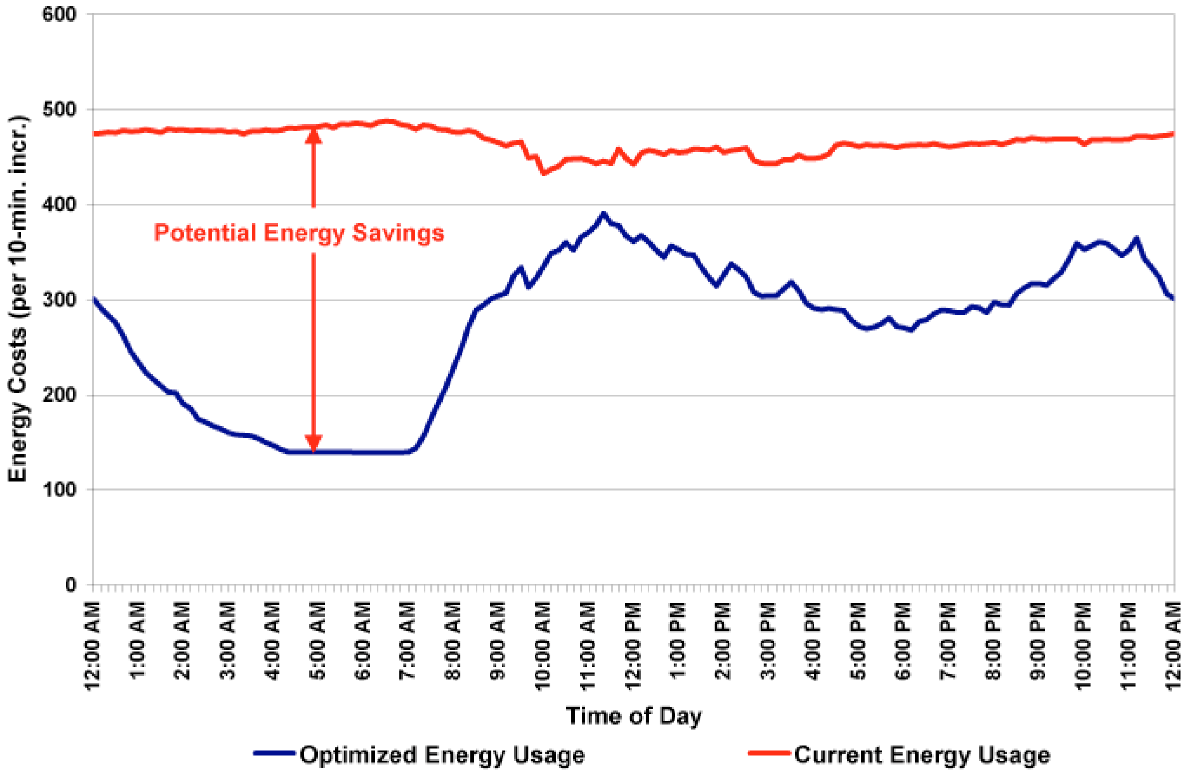


Figure 4 shows a comparison between existing daily blower output and the theoretical optimal daily blower output in terms of the operational costs of each. The curves were generated by converting blower output (scfm) to power consumption rates (kw/hr) and then to operational cost by applying the cost of power, $0.08 kW/hr. Annual potential savings can be determined by calculating the difference between the two data sets. Total savings is subject to change based on alterations to the cost of power and the DO setpoint selected by the operator. The total theoretical savings associated with improved blower control is summarized in the following section along with the savings attained by a reduction of system back pressure.

In order to achieve the maximum amount of savings, a blower system must be capable of closely matching the actual oxygen demand within the system. For the Cinco Central WWTP, the optimal blower capacity was determined to be 3,300 scfm. The evaluated technology has a turndown capability of approximately 60 percent. Although the selected design point will not allow the blower to turn down to the minimum initial demand (1,000 scfm), it will be a better match during future phases when flows and oxygen demands are higher. In the initial phase, the single-stage blower will be capable of handling the peak demand without any additional blowers being operated. Additional air production will be needed in the future when peak demand exceeds the proposed blower's capacity. To achieve this, additional single-stage blowers will not be a necessity. Instead, a better approach is to use the existing multi-stage blowers for demands greater than 3,300 scfm. For example, if the demand is 4,000 scfm, one constant speed, multi-stage blower would be activated and will produce its rated production, 1,400 scfm; and the adjustable rate, single-stage blower would produce the remaining portion, 2,600 scfm. The constant speed, multi-stage blowers would only operate when the demand is greater then 3,300 scfm.

Figure 4 - Existing and Theoretical System Operational Cost Comparison



Potential Energy Savings Due to Reduction of System Back Pressure

Another method of optimizing blower system efficiency is to reduce the discharge pressure against which the blowers operate. Discharge pressure increases in relation to the depth of the diffusers, the number of valves and fittings in the system, the degree to which the valves are throttled, and to a lesser extent, the length of discharge piping. Of these factors, the only one that is controllable by the operator is the throttling of valves. Valve throttling decreases the blower output while increasing discharge pressure. Currently, the valves are throttled to control the blower output. According to the operator, operating one blower does not produce enough air, but operating two blowers at full capacity causes problems elsewhere in the WWTP. Therefore, two blowers are operated simultaneously, but their combined capacity is reduced by generating additional pressure through valve throttling. At the time of the field study, many of the valves were throttled by as much as 66 percent, thereby resulting in a discharge pressure of 8.5 psig. During the field study, it was determined that a discharge pressure of 7.55 psig could be achieved by opening all valves between the diffusers and blowers. Theoretically, the proposed blower could be operated at this reduced pressure condition due to the fact that its output is controlled by methods unrelated to adjusting external valves.

As shown and described above, operational cost savings can be realized at the WWTP through the implementation of the control system and reduction of system back pressure. For the WWTP in question, the average annual savings over a ten-year period due to the proposed improvements would be approximately $36,488. This rate of savings is based on a DO setpoint of 2.0 mg/l, the cost of power being $0.08 per kW/hr, and an annual inflation rate of 5 percent applied to the cost of power over the ten-year period examined.

Conclusion

Operational cost savings can be realized at any WWTP at which the owner/operator can increase the mechanical efficiency of the blowers, more closely match blower output to oxygen demand within the system, and reduce back pressure within the air distribution system. Capital investment costs will typically be necessary when addressing the first two of these three items. An evaluation was conducted for Cinco MUD No. 1 to determine if the capital investment would be sufficiently recouped in a timely manner through savings resulting from the proposed improvements. For the WWTP in question, the internal rate of return associated with the recommended modifications was 9.4 percent based on the given assumptions stated within this report and the cost of equipment as quoted by the manufacturers. If Cinco MUD No. 1 sold bonds at an interest rate of 5 percent and the cost of power inflates at a rate of 5 percent per year, the annual savings resulting from the modifications would result in a positive cash flow after 3 years, and Cinco MUD No. 1 would realize more than $350,000 in total savings over the blower's lifetime.

The recommended equipment modifications include the replacement of one of the existing multi-stage blowers with one single-stage blower similar in capability to those investigated as part of this study. To fully realize the identified savings, the selected blower and motor combination must have an efficiency of at least 73 percent, be capable of varying output based on an external signal, have a method of turndown integral to the blower or drive that does not rely on external discharge throttling valves, and have a turndown capability of at least 60 percent. The proposed blower technology that was evaluated as part of the study consists of single-stage blowers.

The recommended improvements in this application consist of installing one single-stage blower equipped with a DO-based control system. In this application, the full range of control could be achieved by installing one single-stage blower and operating it in conjunction with one or more constant output, multi-stage blowers. Installing multiple, single-stage blowers increases the capital costs of the improvements without a corresponding level of energy savings. Redundancy in the variable capacity system was not a significant issue because sufficient capacity is still available from the existing blowers which could be operated in a less efficient mode in the event of a failure until the variable capacity blowers are placed back in service.

Acknowledgements

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