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Optimization of WWTP aeration process upgrades for energy efficiency

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Abstract

The volatility of energy prices, desire to improve sustainability, recently proposed legislation, and energy-efficiency project funding have created big opportunities to improve energy and operation efficiency at most water and wastewater facilities. One mechanism of developing these opportunities is through energy management planning. Focusing on wastewater treatment, the majority of electrical energy demand is required for the delivery of air to provide oxygen for biological treatment of waste streams and mixing to suspend solids within process units. Aeration processes can account for 60 percent or more of the overall power consumption at a wastewater treatment plant. Consequently, the recent introduction of direct-drive, high-speed, turbo blowers to the wastewater market has been of great interest with respect to potential energy savings, as well as other ancillary benefits.

Given the significant power consumption required by aeration systems at wastewater treatment facilities, demonstration investigations have been conducted to identify the magnitude of energy savings that wastewater treatment facilities could expect. These studies have shown that energy savings in excess of 35 percent can easily be achieved by replacing existing conventional blower technology with direct-drive turbo blowers. Even greater energy savings are anticipated if other process upgrades, such as automatic dissolved oxygen control, is implemented. This paper provides background information on turbo-blower technology and specific findings from demonstration studies in the United States (U.S.).

Keywords: biologically enhanced high-rate clarification, return activated sludge, wet-weather flow

INTRODUCTION

Energy consumption at a typical municipality in the U.S. is distributed throughout departments with the majority of energy consumption being accounted for at the water and wastewater utilities. Based on the volatility of energy prices, desire to improve sustainability, recently proposed legislation, and energy-efficiency project funding there are big opportunities to improve energy and operation efficiency at most water and wastewater facilities. One mechanism of developing these opportunities is through energy management planning. Focusing on wastewater treatment, the majority of electrical energy demand is delivery of air to provide oxygen for biological treatment of waste streams and mixing to suspend solids within process units. Aeration processes can account for 60 percent or more of the overall power consumption at a wastewater treatment plant (WEF, 1997; EMC Engineers, 2007). Consequently, focusing a demand-side energy management plan on increasing energy efficiency of aeration processes can make the single most significant impact on energy consumption and cost. This recommendation is consistent with AwwaRF (Carlson and Walburger, 2007), concluding that aeration is the single largest energy user at wastewater treatment plants and every energy audit should review the aeration process and options for upgrades. While there are a number of aeration system improvement alternatives that can be implemented, blowers are frequently a source of excessive...
power consumption. As a result, blower replacement is often identified in energy audits as high priority projects for improving a facility’s energy efficiency.

**STATE OF AERATION TECHNOLOGY**

At a wastewater treatment plant (WWTP), conventional blower equipment is typically selected to provide a narrow range of air flows over relatively narrow pressure ranges, meeting only a particular set of operating conditions efficiently. Until the last decade, the choices for energy-efficient blowers were limited to positive displacement (PD) units running on variable frequency drives (VFDs) or integrally geared single-stage centrifugal units equipped with inlet and outlet vanes.

Generally, PD blowers are used at lower air flow requirements than single-stage centrifugals. As a general rule, PD applications are typically used for capacities up to 170 cubic meters per minute (m$^3$/min) [6,000 cubic feet per minute (cfm)], beyond which centrifugal blowers tend to be selected (Firmin et al., 2009). PD blowers provide constant capacity with variable pressures and are typically used for higher discharge pressure applications $>$ 156 kiloPascals (kPa) $>$ 8 pounds per square inch gage (psig) and capacities smaller than 170 m$^3$/min [6,000 cfm]. PD blowers are also used where significant water level variations are expected. Because of the mode of operation, PD blowers are often noisy, and rugged inlet and discharge silencers are essential.

Centrifugal blowers are characterized by an adiabatic process that can develop a specific pressure for a given flow rate and rotating speed. These machines are sized to meet the worst-case scenario under operating conditions with lowest air density and highest compression ratio. Their efficiency is optimized at the design point and is affected by changes in flow requirements, discharge pressure, and relative humidity (Aerzen, 2009). Therefore, the efficiency will change as the operating point moves within the allowable range and turndown capabilities with VFD, which allows the blower to operate in either a constant pressure or constant flow mode. Centrifugal blowers typically emit a high-pitched whine, unless inlet and outlet silencers are installed. At lower air capacities, the ability to regulate centrifugal blowers should be checked to ensure air requirements can be met at low flow conditions that might be encountered in a WWTP, and provisions must be included in the blower design to regulate or turn down the blowers. Methods to achieve blower turndown include inlet throttling, adjustable discharge diffusers, and parallel operation of multiple units. Rated discharge pressures range normally from 150–163 kPa [7–9 psig] for single stage blowers, with multi-stage blowers being able to reach significantly higher discharge pressures. Centrifugal blowers are typically very noisy and often emit a high-pitched whine, unless inlet and outlet silencers are installed.

Introduction of the single-stage centrifugal units in the early 1980s was the last major improvement in blower technology for wastewater treatment until 2003, when single-stage, oil-free, direct-drive turbo blowers with airfoil bearings were introduced to the wastewater market. Since that time, more than 2000 units have been installed worldwide, but in the U.S. and European Union (EU), less than a few hundred units have been installed. The advantages of direct-drive, high-speed, turbo blowers include energy savings, higher surge margins, greater durability, higher reliability, minimum maintenance, soft failure (if a bearing failure occurs, the bearing foils restrain the shaft assembly), environmental durability, ease of installation, compactness, light weight, and reduced noise (Edwards, 2007). When compared to traditional blowers, direct-drive turbo blowers have demonstrated significant savings in power consumption (Bell et al., 2010; Firmin et al., 2009) and a comparison of typical blower efficiencies is provided in Table 1.
Table 1 | Typical Blower Efficiency Ranges

<table>
<thead>
<tr>
<th>Blower Type</th>
<th>Typical Efficiency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-stage Centrifugal Blowers</td>
<td>65% to 80%</td>
</tr>
<tr>
<td>Multi-stage Centrifugal Blowers</td>
<td>60% to 75%</td>
</tr>
<tr>
<td>Positive Displacement Blowers</td>
<td>45% to 60%</td>
</tr>
<tr>
<td>Turbo Blowers</td>
<td>70% to 85%</td>
</tr>
</tbody>
</table>

Maintenance is limited to periodic cleaning or replacement of the inlet air filter that is provided as part of the blower package. There are no lubrication requirements. Moving parts in the blower are limited to the impeller shaft with motor rotor, cooling fan, and air bearings. Required building footprints can be reduced by at least 25 percent compared to conventional blower technologies (Edwards, 2007).

A typical, complete turbo blower package is shown in Figure 1, although configurations will vary slightly from manufacturer to manufacturer. Typical space requirements for a complete 200-horsepower (hp) turbo blower package are approximately 2.0 meters (m) × 0.91 m × 1.7 m high [6.5 feet (ft) × 3 ft × 5.5 ft high], excluding the blow-off silencer.

![Figure 1 | Turbo blower package system (courtesy of APG-Neuros).](image_url)

The turbo blower package system integrates a controller, VFD, motor, and blower in a single unit. These compact blowers operate over a range of pressures and flow rates. Air bearing technology has the benefit of lower discharge temperatures, which can result in higher air transfer efficiencies than those provided by either centrifugal or PD blowers. These operational benefits of using this type of blower can result in additional reduced energy costs. The key to the high-speed turbo blowers is the air foil bearing. Turbo blowers operate at high speeds, 20,000 rotations per minute (rpm) to more than 40,000 rpm, which results in efficiency improvements, because dynamic efficiencies of compressors increase with increasing speed. Air foil bearings were first developed in the 1960s for airplane ventilation systems and this technology has been further developed and applied for wastewater blower
applications. A more detailed summary of the history, application, and theory of air foil bearings is provided in work by Agrawal (1997), Valco and DellaCorte (2002), and DellaCorte and Valco (2000). A schematic of a turbo blower core is provided in Figure 2.

![Turbo blower core](image)

**Figure 2** | Turbo blower core (courtesy of APG-Neuros).

With the emergence of this technology has come a number of demonstration projects comparing turbo blower units to similarly sized PD and centrifugal blowers. These demonstrations have shown that energy savings in excess of 35 percent can easily be achieved by replacing existing blowers with direct-drive turbo blowers (Firmin *et al.*, 2009).

**DEMONSTRATION STUDIES**

Pilot tests conducted at various WWTPs suggest that replacing conventional blowers with turbo blowers can result in a reduction in power consumption and operating costs. Because turbo blowers require no oil, liquid, or belts to change, operation and maintenance can also be significantly reduced. Demonstration tests were performed at the Franklin WWTP in New Hampshire (Firmin *et al.*, 2009) and at the Central Advanced WWTP in Fort Myers, Florida (Bell *et al.*, 2010). A summary of the testing at Franklin WWTP is provided and details of the demonstration in Fort Myers are provided herein.

**Summary of Demonstration Testing at the Franklin WWTP, New Hampshire**

The Franklin WWTP in New Hampshire was built in the 1970s and has a design average capacity of 30.2 cubic meters per minute (m$^3$/min) [11.5 million gallons per day (mgd)] with current average flows of 17.3 m$^3$/min [6.6 mgd]. The activated sludge aeration system at the facility consists of fine bubble diffusers; dissolved oxygen (DO) controls; and 125-hp, VFD driven rotary lobe, PD blowers. Aeration accounts for approximately 36 percent of the total electrical consumption, which is in line with typical values at plants this size. The blowers were inefficient and required excessive
maintenance. As a result, during a plant evaluation in 2008, replacement of the blowers was identified as a high priority project, and arrangements were made to install a full-scale demonstration turbo blower at the plant.

The demonstration test was conducted for a period of nine weeks, during which power draw, pressure, airflow, and DO concentration data were collected. Power and airflow rates were normalized to standard cubic feet per minute per kilowatt (scfm/kW) for comparison with the existing PD units. The efficiency of the turbo blowers was demonstrated to be essentially constant, while the PD blowers showed constant decreasing efficiencies with decreasing airflow rates. Additionally, due to vibrations, the existing PD blowers were limited to a maximum output of about 59 m$^3$/min [2,100 cfm] per unit.

The demonstration high-speed, direct-drive turbo blower used approximately 38 kW or 35 percent of the power used by the existing PD blowers for aeration in the activated sludge system. With the permanent magnetic motor, there was no power surge at startup; the startup power is nearly the same as the operating power. With regard to the low noise and vibration levels claimed by the manufacturer, only modest sound levels were generated by the demonstration blower, especially compared to the existing PD blowers. While operating at a speed of 18,400 rpm and a 147 kPa [6.6 psig] discharge pressure, noise levels at 0.91 m [3 ft] from the demonstration blower package were measured between 69 to 75 dBA. There were no noticeable vibrations in the demonstration blower or the discharge piping. Instrumentation furnished with the unit indicated blower vibration ranging from 0.2 to 0.8 mm.

Because of the results obtained during the demonstration period, the plant is replacing the existing PD blowers with four high-speed turbo blowers (two 100 hp and two 150 hp). Overall projected savings are estimated to be 32 percent reduction in power consumption on a direct wire-to-water comparison. Accounting for optimization of the blower sizing, the energy savings could be as much as 35 percent (Firmin et al., 2009).

**Demonstration Testing at the Fort Myers Central AWWTP**

Because of rising energy costs and their interest in sustainable operations, the city of Fort Myers was interested in investigating ways to reduce their energy consumption. Because Fort Myers understands that wastewater operations account for significant energy use opportunities for energy savings at both of their wastewater treatment plants were identified. The city has two advanced wastewater treatment plants (AWWTP) designed to meet effluent limits of 5 milligrams per liter (mg/L) of biochemical oxygen demand (BOD), 5 mg/L of total suspended solids (TSS), 3 mg/L of total nitrogen (TN), and 1 mg/L of total phosphorus (TP). The Central AWWTP is designed for an annual average capacity of 11 million gallons per day (mgd) and the South AWWTP is designed for an average annual capacity of 12 mgd. Both facilities use aerobic digestion for biosolids stabilization.

At the Central AWWTP, the biosolids processing facility includes an aerobic digestion system that provides aeration using one of three multistage centrifugal blower that were installed in 1994. The conditions and design criteria used to select the original blowers is shown in Table 2. Each blower has a 250-hp motor that is rated for 3575 revolutions per minute (rpm). There are two circular and four rectangular sludge holding tanks, which are part of the aerobic digestion system; the maximum surface water depth in the tanks is 17 feet with coarse bubble diffusers mounted one foot off the tank floor. The blower and tank configuration results in a maximum pressure drop of 151 kPa [7.2 psig],
including the losses from the diffusers, drop legs, friction losses, and submergence. Tanks are aerated 24 hours per day and 7 days per week using one multistage centrifugal blower that discharges approximately 113 m$^3$/min [4000 cfm], with the exception that on Sunday, facility staff turn off the blower and decant for 6 hours. During the decant process, the level of the solids holding tank is lowered by 1.2–1.5 m [4–5 ft].

The blower for the sludge holding tank was identified as an ideal process to pilot a turbo blower to confirm estimated energy savings through installation of this technology at both WWTPs. Thus, in consultation with one of the turbo blower manufacturers, the optimum blower for the design conditions at the city’s Central AWWTP sludge holding tank was identified and initial calculations, based on the blower curve, indicated that approximately 40 percent energy savings could be realized. While the desire of the city was to install a specific unit for pilot testing, the optimum model was not available; a similar unit with a slightly different impeller trim was available and was offered to the city for testing. While this unit was adequate to meet design conditions, it was not optimized for maximum energy efficiency. Although the unit would not provide the city a precise estimate of cost savings, the unit would yield data to provide an approximation of the cost savings along with hands-on experience of operating a turbo blower unit. A blower curve for the demonstration unit is provided in Figure 3.

The demonstration blower arrived at the Central WWTP in late August 2009. The equipment manufacturer’s representative, the city’s engineering consultant, and plant staff installed the blower. This quick installation was driven by the schedule for delivery of the demonstration unit to the manufacturer for delivery to a customer. Due to the size and weight of the discharge silencer, and the desire to verify the manufacturer’s claim regarding blower noise, the silencer was not shipped with the unit. A photograph showing the installation of the temporary turbo blower is shown in Figure 4; photographs of the inside of the unit are shown in Figures 5 and 6. The pilot study for the Neuros blower was run from August 26, 2009 to September 21, 2009.

Figure 3 | Blower curve for unit tested at the Central WWTP (courtesy of APG-Neuros).
Because the turbo blower package is provided with a VFD, it is possible to turn down the blower. An experiment was conducted to determine if the aeration to the digesters could be reduced and still achieve dissolved oxygen concentrations that were consistent with normal operation of the digestion process. Thus, during pilot testing, the turbo blower was run at two different air flow conditions. Energy data was collected during the test period using a power logging meter. Power data were collected for the turbo blower for approximately four days at 113 m$^3$/min [4,000 cfm], which was the air flow provided by the existing blower. A reduced flow of 96 m$^3$/min [3,400 cfm], an air flow at
which the dissolved oxygen in the sludge holding tanks were held at concentrations consistent with normal operating conditions, was also tested. Dissolved oxygen readings were collected manually to determine that adequate dissolved oxygen was provided to the digester under the reduced air flows. In order to compare the power draw from the turbo blower to the existing blower, power data was also collected for the multistage centrifugal blower for three and a half days at the normal operating air flow. The power consumption for each blower under the 113 m$^3$/min [4000 cfm] operating conditions is shown in Figure 6 with the power data being shown against time. Where data was available for both blowers at the same time in the digestion cycle, the power draw was averaged so that an estimate of the energy savings could be determined.

As illustrated by the results in Figure 6, installation of turbo blowers at the city's WWTPs has the potential of greatly reducing the energy consumption of the existing blowers. Additionally, the results of the one-day test using the blowers to deliver a reduced airflow to the digestion process, it may be that the amount of air necessary for the process could be reduced and still maintain good process control; however, additional data would be necessary to confirm this. A summary of the power consumption for each operating condition is summarized along with the estimated annual energy cost associated with each condition is provided in Table 2.

![Figure 6 | Power consumption data for blowers under varying air flows.](image-url)
Table 2 | Comparison of Power Consumption

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average Power Draw (kW)</th>
<th>Average Annual Power Consumptiona (kWh/year)</th>
<th>Estimated Annual Power Costb (@ $0.10/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrifugal blower</td>
<td>172</td>
<td>1,500,000</td>
<td>$150,000</td>
</tr>
<tr>
<td>@ 4,000 cfm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbo blower</td>
<td>109</td>
<td>920,000</td>
<td>$92,000</td>
</tr>
<tr>
<td>@ 4,000 cfm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbo blower</td>
<td>89</td>
<td>780,000</td>
<td>$78,000</td>
</tr>
<tr>
<td>@ 3,400 cfm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aThe average annual power consumption is estimated based on the average power consumption and does not account for seasonal fluctuations in aeration demands or for optimization of the turbo blower.
bThe estimated annual cost is based on the average power consumption during the test period and an assumed energy cost of $0.10/kWh.

It is anticipated that even greater energy savings could have been realized with installation of an appropriately sized turbo blower and dissolved oxygen control. The estimated additional reduction in energy consumption using an appropriately sized blower is approximately 17 percent. An additional 15 to 20 percent energy consumption savings could also be achieved with automatic dissolved oxygen control.

CONCLUSIONS

Replacing conventional blowers with turbo blowers can translate into significant power consumption savings. As suggested by the results of the demonstration tests discussed in this paper, more than a third of the power draw associated with plant aeration could be reduced by replacing the existing blowers with turbo blowers. In addition, other benefits can be offered by turbo technology, including reduced maintenance and footprint. Another benefit of turbo blowers is the low noise generated by these machines, making them of particular interest at plants in residential areas, where noise control may require costly sound abatement measures.

Additionally, the experience of installing demonstration turbo blowers in both facilities by operations staff in a very short period of time demonstrates the ease of installation of these blower units.

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