Evaluating Innovative Blower Technologies With "Low-Speed" Turbo Units

Lucas Botero, John Paul Castro, Julie Gass, Hector Torres, and Olena Lytvyn

The City of Key West (city) owns the Richard A. Heyman Environmental Protection Facility (facility), where all of the city's wastewater is treated. The city was interested in increasing redundancy at the facility as part of an initiative to improve resiliency, which requires increasing the air delivery capacity at the plant.

The existing aeration system is comprised of two multistage centrifugal blowers with inlet throttling control. An evaluation of different blower technologies for increasing the plant capacity was made, with the goals of optimizing energy consumption and providing sufficient firm capacity in case of mechanical breakdown of any of the blower units. A total of five different alternatives were evaluated for the facility:

1. Additional multistage blower with inlet valve throttling
2. Additional multistage blower with variable frequency drive (VFD)
3. Integrally geared single-stage blowers with variable vanes
4. Integrally geared single-stage VFD (referred also as low-speed turbo blowers)
5. Dry screw blowers

Integrally Geared Single-Stage Turbo Blowers With Variable Frequency Drives and "Low-Speed" Turbo

The integrally geared single-stage turbo blower is comprised of a turbo blower volute, with its high-efficiency impeller and integral gearbox unit that is coupled to a standard-speed motor to drive the impeller with VFD for capacity control. Figure 1 shows the main components of this technology in a direct-driven application.

The units are also available with belt drives that allow the stacking of the blower and motor, reducing overall footprint, as can be seen in Figure 2.

The combination of the increasing speed gears or belt drives with a standard VFD is probably the most important element of the low-speed blower. The shaft speed of the motor driver is connected to an increasing speed gearbox (and, in some cases, a belt assembly as well) to achieve high-speed output to drive the blower impeller and achieve high-speed turbo efficiencies when compressing air. This results in the simplification of the design by not requiring inlet guide vanes and diffuser vanes for flow control, as is the case with traditional integrally geared blowers, and allowing the use of standard motors, unlike gearless turbo blowers with noncontact bearings. The main components of the gearbox are depicted in Figure 3.

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The units are typically in an enclosure that's assembled at the factory and are ready for installation upon arrival. Figure 4 shows typical enclosures for direct-driven low-speed turbo blowers.

Main Technology Features

The low-speed turbo units combine the more robust elements of two technologies: a

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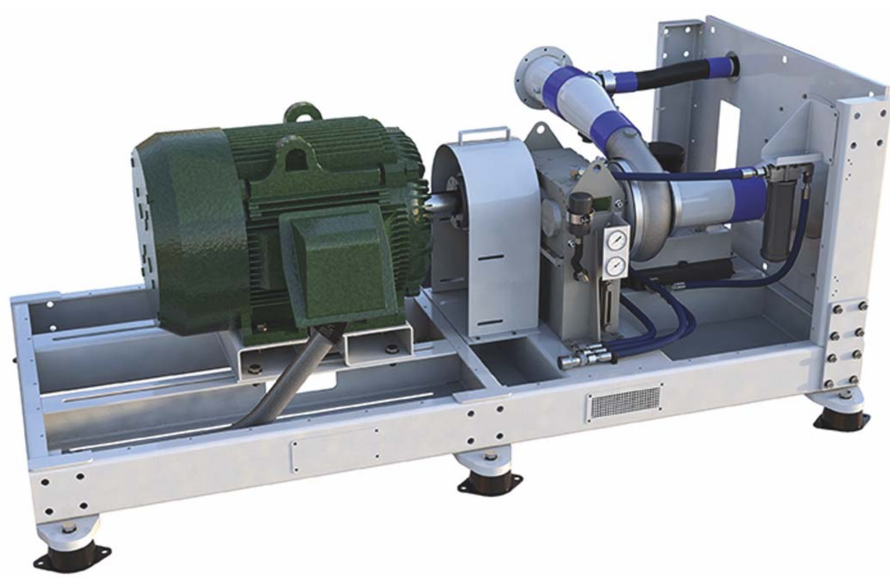

Figure 1. Integrally Driven Single-Stage Turbo Blowers With Low-Speed Turbo *(photo: Inovair)*

Figure 2. Vertically Mounted Low-Speed Turbo *(photo: Inovair)*

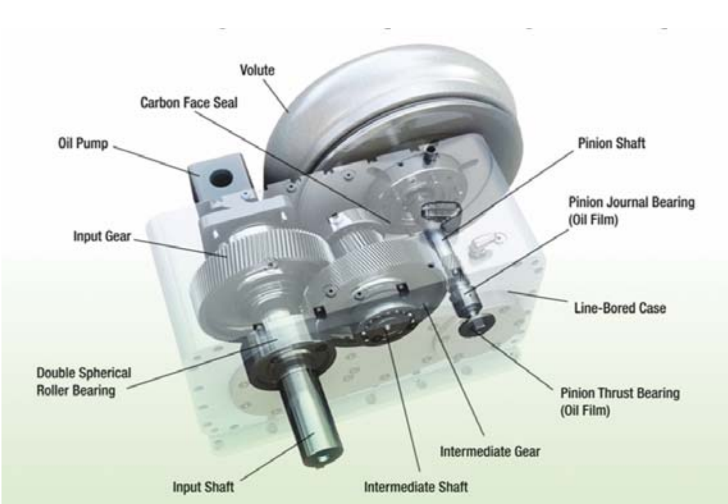

Figure 3. Gearbox Components of Low-Speed Blower *(photo: Inovair)*

Figure 4. Direct-Driven Unit Enclosures *(photo: Inovair)*

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centrifugal turbo volute impeller, and a speed-increasing gearbox with a standard VFD for flow control instead of variable vanes. As mentioned, the main differences are that they are not driven by ultra-high speed motors with sophisticated VFDs and controls (as is the case with high-speed turbo blowers), which don't have the complexities of a dual-point control system that uses two sets of variable vanes, as is the case with traditional integrally geared units. Variable vane linkages need periodic cleaning and can be difficult to access, so eliminating the vanes removes this maintenance task. A regular 1800-revolutions-per-minute (rpm) or 3600-rpm motor drives the low-speed blowers, allowing the installation of common VFDs to achieve flow/pressure control. Conventional programmable logic controllers (PLCs) are also used to control the units.

Another important feature of the low-speed blowers is that they use a mass airflow-based control system, which adjusts the blower speed as required to maintain the required mass flow of air as the temperature changes. This helps minimize excess power consumption for wastewater aeration, where mass flow is key for the process.

Another key and unique advantage to these units is that two blowers can be stacked for small-footprint installations.

City of Key West Blower Evaluation

The city has forward-thinking views regarding its assets. At the facility, the city was interested in adding redundancy to its existing aeration system. Due to this, Black & Veatch performed an investigation of the blower and air distribution system at the plant, with the goal of exploring sustainable options for the city.

Blower Selection

The existing blower system at the facility has enough capacity to meet system demands from the main process train; however, plant staff felt that, in the event when the existing equalization basin required aeration during the high-load season, the existing two multistage blowers did not have sufficient firm capacity. Therefore, an extensive airflow evaluation was conducted and it was found that a blower, with a capacity of 4,600 standard cu ft per minute (scfm), will cover the required flows for approximately 88 percent of the time, while the existing blower could provide the balance of the air flows 12 percent of the time. This combination minimizes the capital expenditures of adding a new redundant unit and provides an excellent opportunity for energy savings.

The blowers were evaluated at a discharge pressure of 9.2 pounds per sq in. gauge (psig) and a suction pressure loss between 0.3-0.4 psi (from dirty inlet filters and inlet piping). Any variation in discharge pressure should have a relative impact on rankings of the alternatives.

Manufacturers' Selections

Table 1 shows the different manufacturers used for the evaluation and the associated technology.

Table 1. Summary of Selections for Blower Evaluation

BLOWER TYPE	NO. OF UNITS	MOTOR SIZE (HP)	DISCHARGE PRESSURE (PSIG)	RATED FLOW (SCFM)	TURNDOWN FLOW SUMMER/ WINTER
Multistage - Inlet Throttling	1	300	9.2	4,600	50/59%
Multistage - AFD	1	300	9.2	4,600	65/75%
Integrally Geared – Inlet Vane	1	250	9.2	4,600	50/50%
Integrally Geared – AFD	3	100	9.2	1,533	50/50%
Dry-Screw - AFD	1	250	9.2	4,600	50/50%

Probabilistic Cost Evaluation

All the proposed alternatives were compared from the financial standpoint of life cycle costs. Given the large number of input variables required to predict total cost, capital expenditures (CAPEX), and operating expenses (OPEX), a probabilistic sensitivity analysis was performed. In this evaluation, each of the main variables affecting the total cost of each alternative (CAPEX + OPEX) was assigned a probability function specific to the variable. Then, a Monte Carlo-type simulation (with over 10,000 iterations) was run for each of the

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Table 2. Evaluation Input Parameters

CAPEX		
Total # of Blowers		Quantity of blowers
Motor Rating	HP	Nameplate motor size per blower
Blower Cost	$	Initial cost of blowers
Installation Cost	$	Installation cost per blower (assumed to be 40% of equipment cost)
CAPEX	$	Total of capital costs (equipment + installation)
OPEX		
Maximum Day, Summer		
Units operating		Quantity of blowers operating, max. day summer
Discharge pressure	psig	Blower discharge pressure, max. day summer
Capacity	scfm	Blower capacity, max. day summer
Power per blower	HP	Blower draw, max. day summer
Power per blower including motor efficiency	HP	Wire power draw, max. day summer
Yearly operation	%	Percent of time per year in use, max. day summer
Average Day, Summer		
Units operating		Quantity of blowers operating, ave. day summer
Discharge pressure	psig	Blower discharge pressure, ave. day summer
Capacity	scfm	Blower capacity, ave. day summer
Power per blower	HP	Blower draw, ave. day summer
Power per blower including motor efficiency	HP	Wire draw including motor efficiency
Yearly operation	%	Percent of time per year in use, ave. day summer
Minimum Day, Summer		
Units operating		Quantity of blowers operating, min. day summer
Discharge pressure	psig	Blower discharge pressure, min. day summer
Capacity	scfm	Blower capacity, min. day summer
Power per blower	HP	Blower draw, min. day summer
Power per blower including motor efficiency	HP	Wire draw including motor efficiency
Yearly operation	%	Percent of time per year in use, min. day summer
Maximum Day, Winter		
Units operating		Quantity of blowers operating, max. day winter
Discharge pressure	psig	Blower discharge pressure, max. day winter
Capacity	scfm	Blower capacity, max. day winter
Power per blower	HP	Blower draw, max. day winter
Power per blower including motor efficiency	HP	Wire draw including motor efficiency
Yearly operation	%	Percent of time per year in use, max. day winter
Average Day, Winter		
Units operating		Quantity of blowers operating, ave. day winter
Discharge pressure	psig	Blower discharge pressure, ave. day winter
Capacity	scfm	Blower capacity, ave. day winter
Power per blower	HP	Blower draw, ave. day winter
Power per blower including motor efficiency	HP	Wire draw including motor efficiency

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alternatives and the probability curve envelopes of the total cost for each alternative were generated.

The Monte Carlo method is a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. The method involves using random values within a certain range to solve for a variety of possible outcomes, and thus provide a realistic statistical evaluation. This is often used in physical and mathematical problems and is most useful when it's difficult or impossible to use other approaches. Monte Carlo methods are mainly used in three problem classes: optimization, numerical integration, and generation of draws from a probability distribution. In this case, each of the evaluated options has multiple variables that make it impossible to predict a specific result without doing multiple iterations of the different variable combinations. Thus, a Monte Carlo simulation is required to combine the different alternatives in a probabilistic distribution.

Budget equipment costs were obtained from the blower manufacturers based on the design requirements listed in Table 1. Installation cost is assumed to be 40 percent of the equipment cost; maintenance costs and electrical infrastructure costs to provide the required power to the blowers are not included in the evaluation of alternatives. The five blower alternatives were evaluated assuming the blowers operate for 100 percent of the year over a 20-year evaluation period and have a varying power cost rate. All alternatives were compared with the net present worth method within the Monte Carlo analysis. Note that the results provided by the analysis are comparative costs for purposes of equipment selection only and do not represent total project costs for aeration system modifications.

Aeration system controls were not specifically included in this evaluation; system control capabilities are similar across the alternatives. Anticipated controls would consist of a new master control panel to control sequencing and capacity of the blowers.

Table 2 includes the input parameters considered in the evaluation. For additional information about the different input variables used in the probabilistic model developed use the QR Code provided.

The representative plots from the analysis showing the CAPEX, OPEX, and total expenditures (TOTEX) for each of the alternatives are shown in Figures 5, 6, and 7, respectively. In the plots the alternatives are numbered in accordance with Table 3.

Results

A summary of the results from the analysis is shown in Table 4, which shows the minimum, maximum, and mean values from the analysis. The percent difference for each option is compared to the multistage centrifugal with inlet throttling, as that is the technology currently used in the plant. This comparison is shown as a negative percent difference to indicate that the alternative is more expensive than the base alternative, and a positive number indicating the savings with the specified alternative.

The capital cost of the multistage centrifugal with inlet throttling is the second-least expensive option at $169,051-$404,189, with a mean value of $282,937. The capital cost of the dry screw technology is the least-expensive option at $145,981-$336,873, with a mean value of $238,001, which represents a savings of 14 to 17 percent (16 percent). The other three alternatives all have higher capital costs than dry screw and multistage with inlet throttling.

In contrast to the lower capital cost, and as expected, the power consumption from the multistage blowers with inlet throttling is the greatest of all the technologies, with an annual operating present worth of $91,815-$358,297, with a mean value of $182,554, or $1,836,300-$7,165,940, with a mean value of $3,651,080 over a 20-year period. The most-efficient alternative was the integrally geared turbo with adjustable frequency drive (AFD), with an annual operating present worth of $71,183-$274,904, with a mean value of $141,235, or $1,423,660-$5,498,080, with a mean value of $2,824,700 over a 20-year period, which represents a 22 to 24 percent (23 percent) savings (over a 20-year period) compared to the existing blowers.

Overall, the blower alternative with the lowest total present worth (capital cost + operating cost) is the integrally geared turbo with AFD, with a total present worth of $1,350,489-$4,232,682, with a mean value of $2,332,649 over a 20-year period, for a savings of 14 to 22 percent (19 percent), followed by the dry screw blower, with a total operating present worth of $1,302,014-$4,333,168, with a mean value of $2,341,288 over a 20-year period at 17 to 20 percent (19 percent). Total savings over a 20-year period for the integrally geared with AFD and dry screw versus multistage with inlet

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Table 2. Evaluation Input Parameters (continued)

Yearly operation	%	Percent of time per year in use, ave. day winter
Minimum Day, Winter		
Units operating		Quantity of blowers operating, min. day winter
Discharge pressure	psig	Blower discharge pressure, min. day winter
Capacity	scfm	Blower capacity, min. day winter
Power per blower	HP	Blower draw, min. day winter
Power per blower including motor efficiency	HP	Wire draw including motor efficiency
Yearly operation	%	Percent of time per year in use, min. day winter
Summer		100°F, 95% relative humidity
Winter		40°F, 50% relative humidity
Power Cost	$ / Kw h	Electricity rate
Annual Cost	$	Annual cost of operating blowers
n	20 years	Evaluation period
i	3.5%	Discount rate
OPEX	$	Present worth of annual cost of operating blowers
TOTEX		
TOTEX	$	Total present worth of each alternative (CAPEX + present worth annual cost)

Table 3. Alternative Numbering in Analysis Plots

Alternative 1	Multistage - Inlet Throttling
Alternative 2	Multistage - VFD
Alternative 3	Integrally Geared – Inlet and Diffuser Vane
Alternative 4	Integrally Geared –VFD
Alternative 5	Dry-Screw - VFD

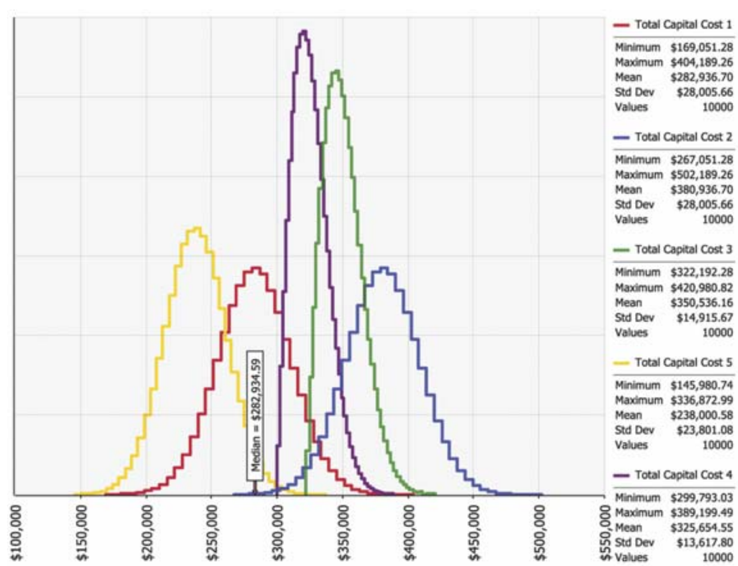

Figure 5. Capital Expenditures for the Evaluated Alternatives

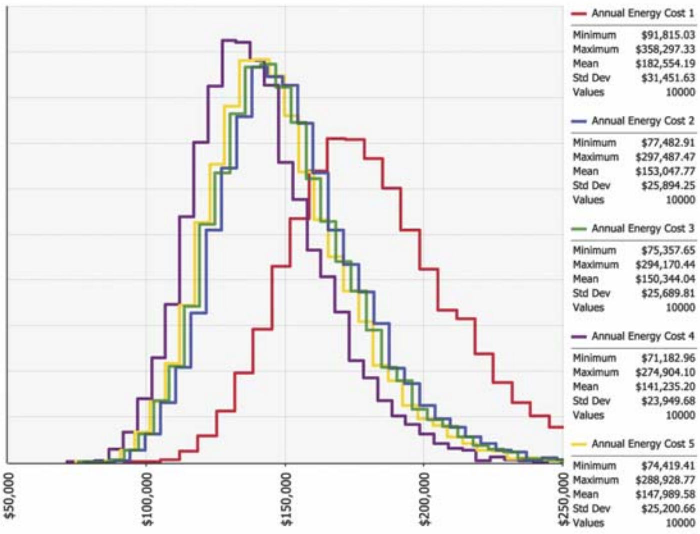

Figure 6. Annual Value of Operational Expenditures for the Evaluated Alternatives

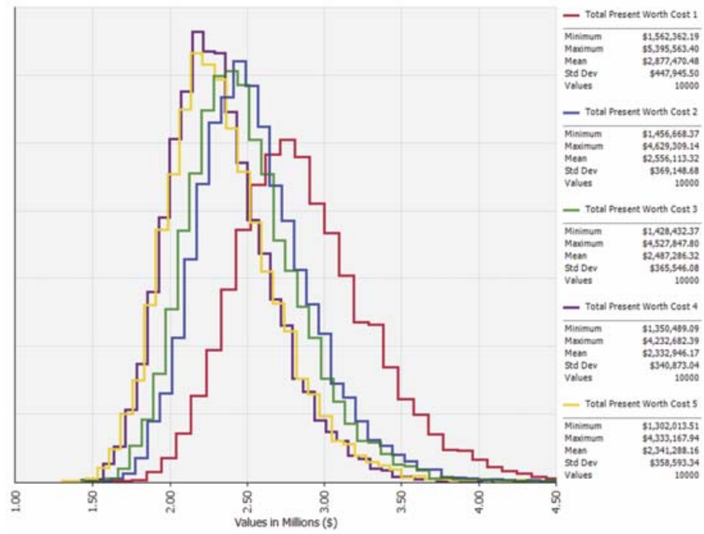

Figure 7. 20-year Present Worth of Total Cost of Ownership for the Total Expenditures

Table 4. Evaluation Summary

	MULTISTAGE INLET THROTTLING	MULTISTAGE VFD	GEARED TURBO INLET GUIDE VANES AND DIFFUSER VANES	GEARED TURBO VFD[1]	DRY-SCREW VFD
Capital Expenditure					
Minimum CAPEX	$169,051	$267,051	$322,193	$299,793	$145,981
Maximum CAPEX	$404,189	$502,189	$420,981	$389,199	$336,873
Mean CAPEX	$282,937	$380,937	$350,536	$325,655	$238,001
Annual OPEX					
Minimum Annual OPEX	$ 91,815	$ 77,483	$75,358	$71,183	$74,419
Maximum Annual OPEX	$ 358,297	$ 297,487	$ 294,170	$ 274,904	$ 288,929
Mean Annual OPEX	$ 182,554	$ 153,048	$ 150,344	$ 141,235	$ 147,990
Total Present Worth					
Minimum Present Worth Cost	$ 1,562,362	$ 1,456,668	$1,428,432	$1,350,489	$1,302,014
Maximum Present Worth Cost	$ 5,395,563	$4,629,309	$4,527,848	$4,232,682	$4,333,168
Mean Present Worth Cost	$ 2,877,470	$2,556,113	$2,487,286	$2,332,649	$2,341,288
Savings Using a New Multistage Blower with Inlet Throttling as the Base Unit					
Mean CAPEX	---	$98,000 35%	$67,599 24%	$42,718 15%	($44,936) 16%
Mean Annual OPEX	---	($29,506) 16%	($32,210) 18%	($41,319) 23%	($34,564) 19%
Mean Present Worth Cost	---	($321,357) 11%	($390,184) 14%	($544,821) 19%	($536,182) 19%

1. Three blowers need to operate at the same time to meet rated flow.

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,othrottling was $571,665 (18 percent savings) and $489,343 (15 percent savings), respectively.

The city evaluated all the information on the different alternatives and performed a survey of existing low-speed turbo units in wastewater treatment plants (WWTPs). The feedback from all of the references provided by the manufacturer was very positive, providing confidence in the product. The other aspect evaluated was the potential increase of power costs. Since the low-speed turbos have better efficiency compared to the dry screw positive displacement (PD) units (closest competitor), then their selection will provide hedging against future power increases. Therefore, the city is implementing the low-speed turbos at the facility.

Conclusion

There are several blower alternatives in the market for WWTP applications. In the case of this facility, additional redundancy was used to also improve energy efficiency in the air delivery system at the plant, leaving the city well-positioned for more sustainable operations at the facility.

The integrally geared single-stage turbo blowers with VFD control have emerged in the market as a viable alternative for certain airflow ranges, using standard components, such as motors, VFDs, etc., which reduces the capital cost and operational complexities of high-speed turbos and allows their installation in less-stringent environmental conditions.