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Don't Blow This One Off

By Robert B. Anderson

The use of air within a plant has been referred to as the fourth utility in addition to electricity, water, and gas. Blow-off or drying air is commonly produced by one of several types of centrifugal blowers. Air generated by new generation, more efficient centrifugal blowers can result in considerable savings in operating costs, close to 50 percent in extreme cases, below current "industry standard" systems. Therefore improved blower efficiency will aid the facility engineer or plant manager seeking to improve overall system efficiency and can provide a significant payback by reducing annual operating costs.

One approach to energy efficiency has been to install premium efficient motors on compact centrifugal blower systems. But this does not address compressor efficiency, the primary measure of the ability to convert electrical power to airflow and pressure. Turbomachinery designers invest tremendous effort to develop equipment with the sole objective to deliver flow at a particular design pressure, and maximum attainable efficiency. In fact, efficiency improvement is where the bulk of the design effort is invested. A minimum performance point of 75 percent efficiency at best operating conditions is an achievable target. The various commonly used low-pressure high-flow blowers in operation today – scroll, regenerative, and single stage centrifugal – do not deliver this degree of efficiency. In most cases, maximum achievable isentropic efficiencies range from 55 to 58 percent. This, unfortunately, constitutes the current industry standard.

Vortron (Channel Islands, CA) engineers have developed a line of new generation blowers having efficiencies of 75 to 79 percent. As tested in accordance with SAE Standard J-1723, these high efficiency blowers operating at 18,000 RPM can deliver 1000 CFM at 75 in-H_2O Wc. This same blower operating in a typical air blow-off process condition requires 7.25 less horsepower to deliver 900 CFM at 45 in-H_2O. In real dollars, this represents an annual electric cost savings of over $5,400, depending on local energy costs, for a 24/7 operation.

On the Subject of Blower Efficiency

Owners of centrifugal blowers (or compressors) should be concerned about compressor efficiency, as this measure of performance has a direct and in many cases quite significant effect on operating cost. It can be shown that even moderate improvements in efficiency can result in literally thousands of dollars of annual energy cost savings. SAE Standard J-1723 outlines accepted practices for testing and reporting centrifugal compressor (blower) performance. As for efficiency, blower performance may be evaluated from the following equation:

$$T_2 - T_1 = \frac{T_1}{n_c}\left[\left(\frac{P_2}{P_1}\right)^{\frac{(k-1)}{k}} - 1\right]$$

Equation 1: Compressor Efficiency

The term n_c is the blower efficiency, assuming an adiabatic process. The term k is the ratio of specific heats, c_p/c_v, which for air is commonly taken at 1.40. The temperature and pressure terms represent the conditions at the inlet and discharge of the blower, and may further be characterized by static or total measurements. For example, it is customary to present pressure ratio as a static-to-total measurement, or total-to-total, etc., with corresponding total or static temperature measurements. Note also that compressor efficiency can be evaluated directly from the pressure and temperature rise across the compressor stage.

Equation 1 is well known to turbomachinery designers, is found in many texts, and is accepted as the standard for evaluating compressor efficiency. Since an adiabatic process is assumed, a comparison against an ideal (isentropic) process can be made, the difference between the two being influenced by the "isentropic efficiency", n_c.

Blower Power

Total shaft power required to drive a compressor will be influenced by n_c in addition to other mechanical losses. In general, for any thermodynamic process, $\dot{W}=\dot{m}c_p\Delta T$ where the $c_p\Delta T$ product is the change in enthalpies. For compressors, ΔT is available from Equation 1; the compressor power, then, results from the following equation:

$$HP = \dot{m}c_p \frac{T_1}{n_c}\left[\left(\frac{P_2}{P_1}\right)^{\frac{(k-1)}{k}} - 1\right] \times \frac{60}{2546}$$

Equation 2: Compressor Power with Known Efficiency.

where the latter term is used to convert BTU/hour to horsepower.

Calculating Blower Efficiency

As can be seen in Equation 2 power depends on: (1) Flow; (2) Pressure; and (3) Efficiency. If thorough testing is conducted on a suitable gas compressor test stand, in other words, in accordance with SAE Standard J-1723, performance "maps" can be developed which explicitly define performance, including efficiency. Commonplace, however, is to see blower "power" plotted against flowrate, or other means for relating motor power to a flow and pressure operating point. Knowing efficiency makes calculating required motor power easy. Recasting Equation 2 in the form of familiar units:

$$HP = CFM \times 528 \times \left[\left(\frac{P + 407}{407}\right)^{.286} - 1\right] \frac{1}{n_c} \times .000425$$

Equation 3: Calculating Motor Power

Where P is the blower discharge pressure, in inches-H_2O. This equation also assumes inlet air at 68˚F, 14.7 psia standard atmospheric pressure. Knowing horsepower, on the other hand, you can calculate efficiency by simply rearranging Equation 3:

$$n_c = CFM \times 528 \times \left[\left(\frac{P + 407}{407}\right)^{.286} - 1\right] \frac{1}{HP} \times .000425$$

Equation 4: Efficiency with Known Power

In this fashion, a direct performance comparison can be drawn between blower products; or in other words, available industry standard products vs. new generation, high efficiency designs.

Example 1: Blower Power

For 1,000 CFM at 80 in-H_2O, calculate the blower power needed if the efficiency is known to be 70 percent. Use Equation 3 as follows:

$$HP = 1{,}000 \times 528 \times \left[\left(\frac{80.0 + 407}{407}\right)^{.286} - 1\right] \frac{1}{.70} \times .000425$$

or, HP = 16.9

Example 2: Efficiency

Say, a manufacturer claims his blower will deliver 45 in-H_2O at 900 CFM, at 15 HP. What's the efficiency? Use Equation 4:

$$n_c = 900 \times 528 \times \left[\left(\frac{45.0 + 407}{407}\right)^{.286} - 1\right] \frac{1}{15.0} \times .000425$$

or, $n_c = 0.41$ (41 percent)

This means that 59 percent of the input power is carried away as waste heat in the compressed air stream.

High Efficiency Blower Performance

Armed with some basic tools, plant engineers can now begin to draw some comparisons between available blower products, and the more modern, new-generation blower designs. By comparison, the new-generation blowers typically deliver well in excess of 70 percent efficiency, over the majority of its useful flow range. In addition, these blower designs can deliver much greater pressure at the more useful higher flowrates. One way of comparing is to look at pressure/flow performance at a constant speed, say, 18,000 impeller RPM. Figure 1 depicts such a comparison. The new-generation unit can deliver about twice the airflow at 75 in-H_2O than the industry standard. But, is this necessarily better?

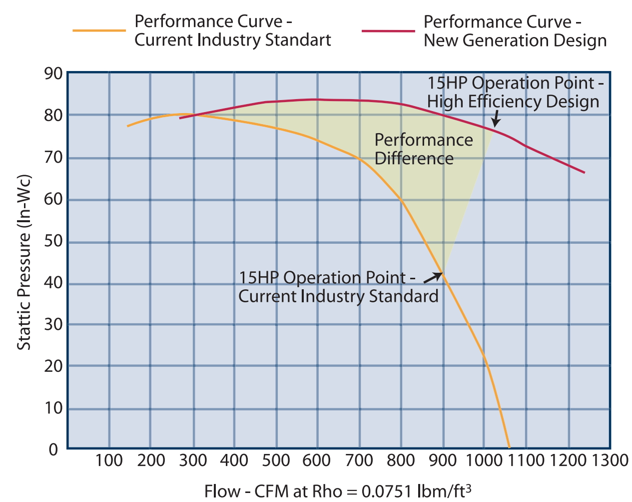

Figure 1: Direct Performance Comparison, units at constant 18,000 RPM impeller speed, with 15HP operating point defined for both. New-generation unit also delivers far greater performance for the same 15HP energy cost.

Efficiency Compared…

Another way to compare is to look directly at blower, or compressor efficiency. Recall that we defined a way to calculate compressor efficiency, knowing motor power and a flow/pressure operating point. Figure 2 depicts such an efficiency comparison for the same two units operating, again, at 18,000 impeller RPM. Here, the advantage of the New-generation unit is clearly shown, particularly at the higher flowrates.

Motor Power Compared…

We now have a way to contrast motor power requirements, and hence begin to formulate potential energy or operating cost impact. Figure 3 shows such a comparison. Again, assumed operation is 18,000 RPM for both units. Interestingly, the high-efficiency design draws less motor power, but the performance difference at the higher flowrates does not seem as dramatic as depicted in Figures 1 and 2. What's wrong here? The answer lies in the differences in blower performance. Remember, power depends on flow, pressure, and efficiency. Even though the two blowers are running at the same 18,000 RPM speed, they are not delivering the same performance, as is shown in Figure 1.

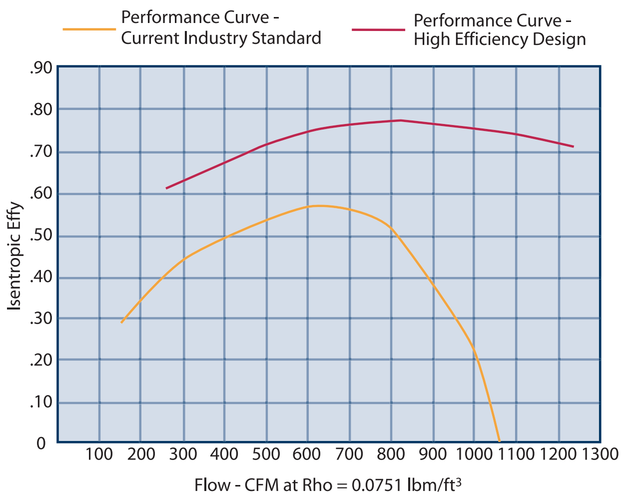

Figure 2 – Efficiency Comparison, units at constant 18,000 RPM impeller speed. Typical unit is at "0" Efficiency at 1,050 CFM because its discharge pressure is also 0 (see Equation 4 and Figure 1).

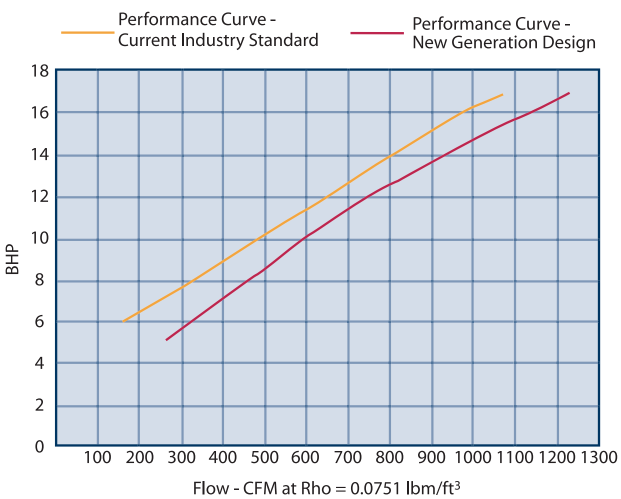

Figure 3 – Motor Power Comparison, units at constant 18,000 RPM impeller speed. Even though blower speed is the same, this comparison is misleading because pressure delivery, i.e., performance is not equivalent, as was shown in Figure 1.

Motor Power Matched to Performance…

We can finally make a true motor power comparison if we match flow and pressure performance of each blower, and then look at motor power required to operate each. After all, two units operating at identical flow and pressure delivery will provide the most direct "apples-to-apples" comparison of which consumes less power. Figure 4 provides such comparison. Notice how the typical unit shows increasing power with flow, while the new-generation unit exhibits a drooping power draw at higher flow. How can this be? The answer is because the new-generation unit is performance matched (via turn-down) to keep pace with the falling pressure characteristic of the industry standard unit. Knowing also the efficiency, we can compute the power requirement. In short, the new-generation product, operating at 900 CFM and 45 in-H_2O consumes ~8HP, while the current industry standard unit is running at ~15HP – an 88 percent power increase.

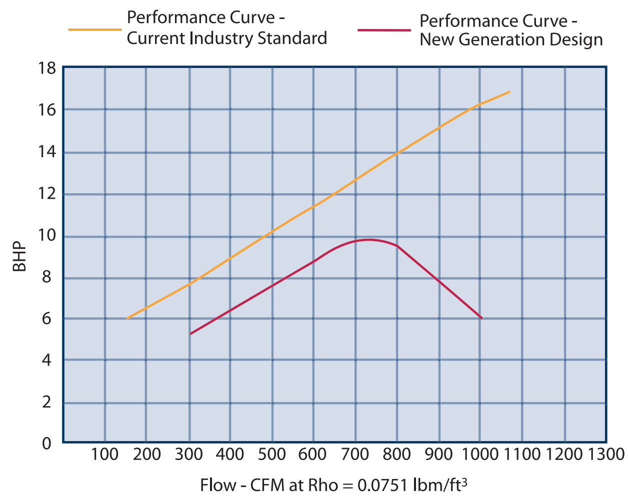

Figure 4 – Motor Power Comparison, units are matched in flow/pressure performance; new-generation product is matched to current industry standard performance curve via turn-down.

The Bottom Line

A simple energy calculation reveals the annual operating cost difference between these two units is significant. Take a nominal high-performance operating point, such as 900 CFM at 45 in-H_2O, which is roughly equivalent to a typical 15HP blower application. The motor power difference is 7.25HP. For a typical manufacturing, 8-hour per day, 365 day-per-year operation, we have:

$$7.25HP \times .746\ {}^{kW}/_{HP} \times 1.15pf \times .10\ {}^{\$}/_{kWhr} \times 8hr \times 365\ {}^{d}/_{yr} = \$1,816$$

Since we are calculating the energy difference, this represents annual operating cost saved. For a 24-hour, 365 day/yr operation, this equates to over $5,400 depending on local energy cost. ■

About the Author

Robert B. Anderson, MSME is the Director of Industrial Products for Vortron. Rob has over 20 years of experience ranging from aerospace system test and evaluation, pump and compressor design and development, to automotive product development including traction control systems and superchargers.

For the past 12 years, Vortech Engineering, LLC has been a leader in developing, manufacturing, and testing automotive supercharging systems. Vortron Industrial is the industrial product division of Vortech, specializing in the design, development, manufacture and test of high-efficiency centrifugal blower products and drying systems.

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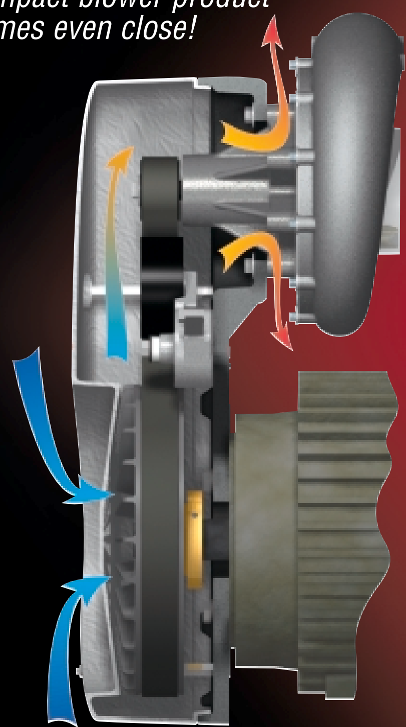

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