Evaluating "Wire to Air" Energy Use of Competing Blower Technologies

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The Problem:

Uniform evaluations of energy efficiency between different blower technologies is not readily available, nor encompassed by any available third party referenced specifications to require blower manufacturer's to follow. Owners and consultants cannot evaluate performance in a fair and consistent manner, leading to misinformation and unfair comparisons between technologies. Further, the performance verification process is difficult to prove.

Goals and Objectives:

Offer fair evaluation criteria and a specification for owners and consultants to evaluate which blower technology offers the best energy efficiency for their particular application. The evaluation will be able to look at total energy consumption used in real application conditions of the blower system, which takes into account all potential energy loss.

Identifying the Problem:

There are four basic blower technologies serving the water and wastewater markets: positive displacement, multistage centrifugal, internally geared single stage, and gearless single stage "turbo" technologies. Each has the same basic components such as compressors, motor starters, inlet filters, and some have cooling systems, oil pumps, gears, belts, couplings, and control systems. Whether the components are shipped loose, or pre-assembled the evaluation should include all relevant pieces that consume or affect performance.

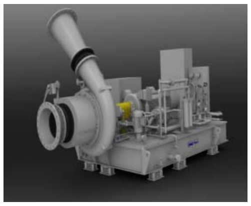
Listed below are some basic packages of the four major blower technologies considered:

- KAESER Omega Com-paK Plus™ DB 236 tri-lobe positive displacement blower package with microprocessor control and integral variable speed drive. Courtesy Kaeser Compressors, Inc

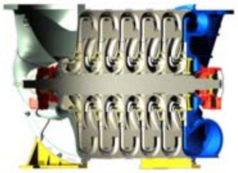
- Aerzen G5 Positive Displacement Blower Package. Courtesy Aerzen, USA.
  Units can be configured in an enclosure with control systems, inlet filter, and motor starter

- HSI Frame 5 Air Bearing Turbo Package includes fused circuit breaker disconnect, PLC controller, variable frequency drive, integral motor/compressor inlet filter, and cooling system.

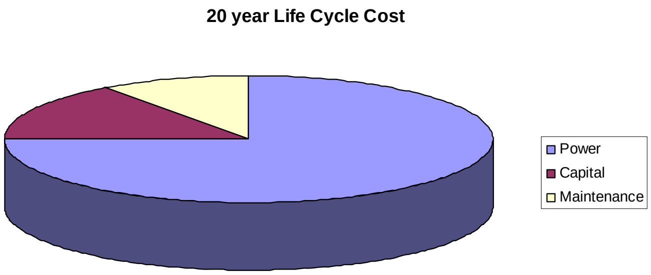
- Dresser Roots Single Stage Internally Geared Blower Package. Courtesy Dresser Roots, Inc. Includes motor, starter, gears, compressor, controller and pressurized oil lube system.



- HSI MC-12606 Multistage Centrifugal Blower Package includes 250 HP motor, VFD drive, direct coupling and control panel.



Each technology offers a potential solution to water and wastewater aeration applications; however, to offer a fair comparison, there needs to be a common evaluation criterion. There is no definite rule of thumb saying one technology is “always” better than another when considering a 20-year life cycle cost that includes power consumption, capital costs, and ongoing maintenance and repair costs. Power is typically 75% of the total cost analysis.



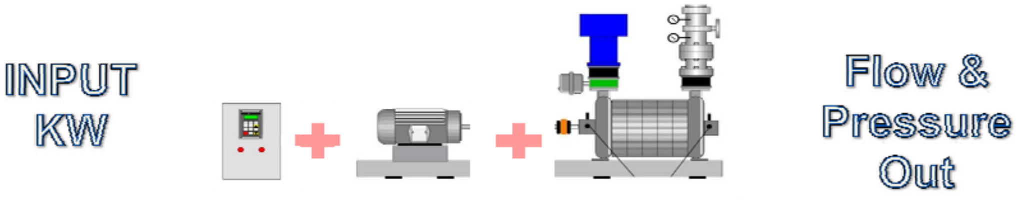
Wire to Air Principal:

“Wire to Air” is a term used to describe the total energy used to produce the required flow and pressure for any particular application.

This relationship between total input power and the amount of flow and pressure produced replaces a straight efficiency percentage as a meaningful comparison. Efficiency as a percentage can be defined many ways including isentropic, polytropic, and others, but it does not necessarily correlate to useful energy. Higher discharge heat can increase efficiency as a percentage, but is not a useful state of energy for the process and can be a misleading indicator of true energy usage. Efficiency is further explained later in this paper.

With the introduction of high speed “Turbo” type blowers, the only way to evaluate this technology is a “wire to air” approach, as the motor and compressor are combined into one unit which comes in a pre-packaged system with drive, controller, and cooler. Traditional evaluations only take into account shaft brake horsepower (power to rotate the compressor excluding motor and all other drive losses). Other technologies need to add in all the drive losses of the complete system including motor, starter, variable frequency drive, inlet filters, gears, belts, guide vanes, valves, cooling system etc. to compare in an equivalent manner.

The average user will not fully understand all the inter-workings and design features of the different technologies available, so a wire to air type specification will fully assemble the entire blower system for testing as it will be used on location. What will not be allowed is the use of nominal or nameplate efficiencies of the various components. Wire to air puts the onus on manufacturer to design and build complete blower systems where all losses are accounted for in real life testing with the actual equipment used in the process.



Dynamic performance should also be used to give an evaluated power usage over a range of operation instead of relying on one particular flow and pressure to compare energy usage.

The table below gives an example of a simple evaluation that lists performance points and gives each a weighted average for real process conditions. The basic premise is to evaluate how the blower will work over the entire range of expected operation. The variable flow or pressure and the power that different blower technologies consume over a range of performance will also have a large impact. Air densities are also accounted for, as centrifugal type blowers are more sensitive to temperature, humidity and elevation.

Design Point	Use Factor	Capacity	PSIA	Flow SCFM	Temperature	Relative Humidity	PSIG	Guaranteed KW	Weighted KW
1	0.25	100	14.7	6650	89	48%	8.40	210	53.75
2	0.3	90	14.7	5985	83	54%	8.40	186	56.7
3	0.25	80	14.7	5320	70	50%	8.40	168	42.5
4	0.2	50	14.7	3325	20	39%	8.40	107	23
						Weighted Average			175.95

In conclusion, the definition of “wire to air” will include all the actual components required and supplied on the particular application and will be tested as a working system over a range of operating conditions. Verification will be made by measuring kW into the system and measuring mass flow rate at the discharge of the system. These are two easy points to independently verify using a 3 phase kW meter measuring power at the wall, and a fixed orifice plate flow meter where the delta pressure and temperature can be measured on either side to determine the mass flow rate produced. The blower system can be regulated to produce exact points of flow and pressure during the verification testing, and the corresponding kW reading can be recorded to substantiate any specified kW points offered by the manufacturer.

Existing Testing Codes:

Performance test codes currently in use are not suited for a wire to air scenario. These codes do not address power measurement adequately and do not address specifically where to measure mass flow.

ASME PTC-10 is a commonly prescribed test code for centrifugal blowers. This code allows the measurement of the flow at the inlet to the blower instead of at the outlet.

What this allows, specifically, is a table for permissible deviations from specified operating conditions. Parameters are also translating the data to the calculated performance for a simulation of actual site conditions. Take ASME PTC 10 Tables 3.1 and 3.2 respectively. For instance, Table 3.1 only allows a 2% deviation in speed, and therefore does not take into account variable speed applications. Table 3.2 has a permissive deviation on specific volume ration from 95 to 105% of design values. It also has a flow coefficient from 96 to 104%. This is the reason the machine Mach number allows further deviations. These are all translated to a calculated prediction with a significant amount of error per code that is allowed to be determined by the manufacturer while testing the unit.

The reality is the translations are not in fact linear. Making these assumptions is not a true representation of the actual performance of the blower using this test code. These allowable deviances can be used to overstate a blower’s true performance by as much as 10%.

Depending on the technology of the blower that is tested, there will be other performance losses that are not accounted for. By measuring inlet flow volume, you are making the assumption that the translation to discharge flow is linear (as mentioned above), and that there is no performance loss of flow and pressure across the blower. For instance, a single-stage centrifugal blower can lose flow from behind the impeller seal, allowing it to get credit for the flow measurement on the inlet, but will be not penalized for the flow it actually delivers to the process. This can overstate efficiencies significantly depending on the seal capability. Again, the performance is assumed to be linear when measuring the mass flow on the inlet, then calculating what the discharge mass flow will be.

With changing densities of gas, and by measuring the discharge of the blower, it is conclusive that the calculated method is not as accurate as the measurement of the same blower on the discharge pressure side where there are no deviations allowed.

When discussing motor efficiency, different methods and associated dissimilar accuracies are often interchanged. Most manufacturers use a torque meter between the motor and blower; however, many manufacturers rely on ASME PTC-10 section 4.12, which allows the use of electrical measurement as agreed upon between manufacturer and owner. In practice, this equates to the use of the motor manufacturer's published efficiency. NEMA provides motor efficiency guidelines, and these guidelines are rather lenient with what they allow for published data. The NEMA standards specify two different efficiency values for motors, a "nominal" efficiency that must appear on the nameplate, and an associated "minimum" efficiency that "may" also appear on the nameplate, but is not required (Ref. MG1 1998 Section 12.58 - "The average efficiency of a large population of motors of the same design."). The NEMA standards elaborate on this definition by explaining that variations in materials, manufacturing processes, and tests inevitably result in “motor-to-motor efficiency variations”. Hence, the efficiency for a large population of motors is not a unique value but a “band of efficiency”. These efficiencies can easily vary by 3-4%. Further complicating matters is the fact that motor efficiency changes with loading.

ISO 1216 and PTC 9 are published specifications, typically for positive displacement blowers. Similar to ASME PTC 10, they do not address measuring power in a wire-to-air format, and have the same inadequacies as other specifications.

A test code should take into account the entire blower system to make sure every item is maximized for energy use, and therefore, give a much more realistic estimate of what power savings will actually be observed in the application.

The Fallacy of Efficiency:

Efficiency as a percentage measurement of how effectively the blower transforms input power is often misunderstood and is not a good indicator for comparison. This is primarily due to the wide variety of definitions of efficiency used in the industry. Analyzing efficiency does not always give you a measure of useful power.

There are typically two thermodynamic processes used to approximate the physical work done on the gas as it is compressed. It is important to understand the difference between the two processes since the assumptions are used define the usefulness of the results. The two processes used are adiabatic (Isentropic) and polytropic. We will start by defining the two processes and some common terms.

Adiabatic Process:

An adiabatic process is defined as a process in which no heat transfer takes place. This does not mean that the temperature is constant, rather that no heat is transferred into or out of the system. In blower theory, the terms adiabatic (no heat transfer) and isentropic (constant entropy) are used interchangeably. Anyone who has stood next to a blower in operation will attest to the error of assuming a blower transfers no heat from its surface. Adiabatic process was used before the early 1980’s and is mostly used as a legacy form of approximation (The actual definition of an isentropic process is an adiabatic, reversible process).

$$c_v dT = -P dv$$

And

$$c_p dT = v dp$$

Combined,

$$\frac{dP}{P} = -\frac{c_p}{c_v} \qquad \frac{dv}{v} = -k\frac{dv}{v}$$

For k = Constant,

$$\ln \mathrm{P} = \ln\, v^{-k} + \ln \text{constant}$$

$$Pv^k = \text{constant}, \qquad k = \frac{c_p}{c_v}$$

Or

$$\frac{P_1}{P_2} = \left(\frac{v_2}{v_1}\right)^k$$

Combining this with the equation of state for a perfect gas,

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1}$$

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

$$\frac{v_1}{v_2} = \left(\frac{P_2}{P_1}\right)^{1/k}$$

Polytropic Process:

When a gas follows a reversible process that includes heat transfer, the process generally proceeds such that a plot of log P versus the log v is a straight line, as shown in Figure 1.

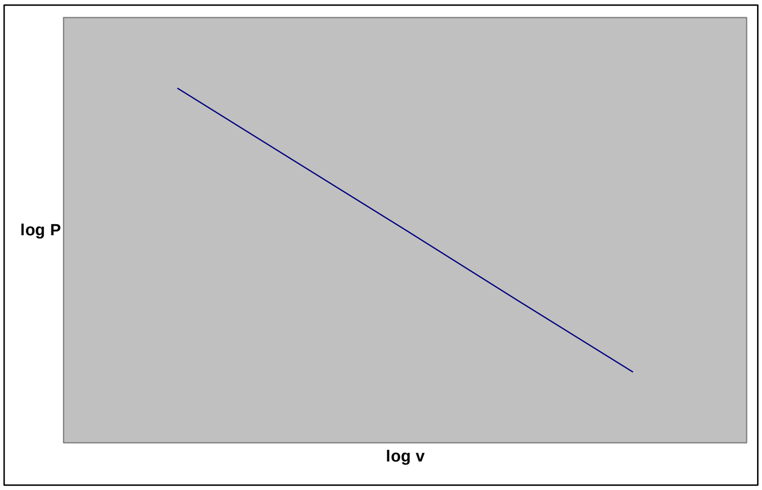


Figure 1. Polytropic Process.

From this can be written

$$\frac{d\ln P}{d\ln v} = -n$$
$$d\ln P + nd\ln v = 0$$

Or

$$Pv^n = \text{constant}$$

Where

$$n = \frac{\ln(P_2 / P_1)}{\ln(v_1 / v_2)}$$

With this, the governing relationships can be written:

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2} \right)^n$$

$$\frac{T_2}{T_1} = \left(\frac{P_1}{P_2} \right)^{(n-1)/n} = \left(\frac{v_1}{v_2} \right)^{n-1}$$

The selection of a blower for a specified operating condition requires an understanding of the properties of gases, the thermodynamic laws governing the behavior of gases and the principles of compression equipment. This will explain the basics required to select a blower for optimum performance and efficiency and explain the meaning of the values typically called “efficiency”.

Thermodynamics of Gas Compression in Centrifugal Type Blowers:

Gas is considered, in the broadest sense, the physical-chemical definition. The movement of gas requires three properties to be defined. This is in contrast to the handling of an incompressible fluid, which has only pressure and volume to be considered. The third dimension, which gives depth and perspective to the compressible fluid, is the density of the gas. Temperature is thus added to the basic state parameters. Furthermore, in order to define the gas being moved, all components must be included typically by volumetric percentage. This is in exception of water vapor content, which is expressed as a relative humidity percentage.

Since gas is an aeriform fluid having neither definite shape nor volume, and tends to expand infinitely, the absence of form makes it necessary to establish a unit of measure by definition. The unit of measurement is standard cubic feet (SCF). Amid the various definitions, the most widely accepted values for these two standards are the following:

- SCF – The gas contained in a cubic foot of space at 68°F (519.7°R) and 14.696 psia (760mm or 29.92 inches of mercury). A standard cubic foot of dry air is assigned a specific gravity of 1.000, and weighs 0.0763 lb/ft3 at standard conditions.

Conclusion: Adiabatic versus Polytropic Process:

The following can be concluded by analyzing the relationship shown above. It is beyond the scope of this paper to independently show how each one is derived. (However, HSI engineering can validate any individual result listed within the conclusion section of this paper.) Traditionally, compressor vendors have used polytropic as opposed to isentropic efficiency when quoting blower performance. This is because polytropic efficiency is essentially independent of the compression of ratio and gas composition. Thus, for centrifugal compressor machines, polytropic efficiency is more accurate than adiabatic efficiency. This is also true since polytropic efficiency does not change within press ratio.

It can be seen that by examining the effects as the exponent, n, increases, the amount of power required by a compressor for any given inlet and outlet pressure and any given flow rate also increases. The extra energy goes into the gas as an increase in temperature.

For values of n *less than* k, there is heat being removed during the compression process. Note that an isentropic process is not the most efficient process in terms of the power required.

For values of n *greater than* k, there is heat being added during the compression process. This heat is generally due to inefficiencies (friction) and results in higher levels of power being required for compression as compared to isentropic.

In the isentropic case, one substitutes k for n, where $k = C_p/C_v$ the ratio of the specific heat at a constant pressure to the specific heat at a constant volume.

All blower processes fall between isentropic ($n = k$) and isometric ($n = \infty$).

For many years, the blower industry, (as opposed to the compressor and the single stage manufacturers) used adiabatic equations as an accepted practice. Since most machines tend to work along a polytropic path nearing the adiabatic, most compressor estimations are done based on an adiabatic curve; however, when comparing across different platforms, true efficiency should be used. This will be investigated further in the next section. The most important thing to remember is that polytropic assumptions cannot be compared to isentropic assumptions and that neither leads to the correct result in all cases.

Conclusion – The Real Effects of Efficiency:

Through the process of calculating the path a compression has proceeded on, two values are of the utmost importance. One is the entering Enthalpy and the other the exiting Enthalpy.

The preceding discussion concentrated on the differences due to assumptions of the theoretical path followed by the compression process. This portion of the discussion will focus on the real-world effects of efficiency. Since it will shortly become important, enthalpy (H) is defined as the amount of energy contained in a piece of matter, in this case the process gas.

$h = (U + PV)$

U=internal energy
P=Pressure
V=Volume

The second term requiring definition at this point is efficiency as commonly used:

There are two errors that enter the logic if using thermodynamic efficiency to define the actual real-world results. First is path assumption. The values that are calculated for exit enthalpy are dependent on your assumption of path. This has already been covered in the previous discussion.

The second error is the most critical one made by most users when comparing any two machines. Since the energy leaving the blower is based on enthalpy, and enthalpy is made up of essentially two components, one “PV” is very valuable to most users; however, the other internal energy is useless to most applications. Internal energy is mostly dependent on the temperature of the process gas, which does not provide real benefit and in many cases is detrimental to the customer.

Therefore, in conclusion, one should choose any blower based on a comparison of the actual volume of gas supplied and the pressure at which it is supplied vs. the work (energy) required by the blower to supply this desired volume and pressure. These values are typically reported to users separately from thermodynamic efficiencies. In simple terms, it’s a ratio of input (KW) and what mass flow is delivered to the process that should be compared.

The Solution:

ASME PTC-13

The industry is already aware of the need for a new power evaluation and there are several efforts underway to present a wire-to-air specification to meet this need. The ASME (American Society of Mechanical Engineers – www.asme.org) has formed a new committee to write a new power test code.

ASME PTC 13 is to encompass a strict procedure to be used for all blower technologies on a simple wire-to-air principal that tests the entire blower system including motor, drive, gears, belts, filters, cooling systems, etc., and measures the flow and pressure of the discharge of the system proposed. This code is still being written at the time of this paper, but should be approved and available in the latter part of 2011 for general use.

The CEE (Consortium of Energy Efficiency - www.cee1.org), is a nonprofit public benefits corporation that develops initiatives for its North American members to promote the manufacture and purchase of energy efficient products and services. The CEE has also put forward an initiative to establish a wire-to-air specification to be used by owners, consultants, and its constituents to make a fair and knowledgeable tool, and to make an energy efficiency evaluation of blowers in the water and wastewater industry and beyond.

Illustrating, writing, and evaluating a wire-to-air specification that can be uniformly applied to all blower technologies in a fair and unbiased way will be a useful tool in evaluating energy usage. Furthermore, this evaluation can be done and the performance guaranteed by the blower manufacturer in a way that can be easily verified and can include financial penalties should the kW guarantees not be met. Such a specification would allow a customer to fairly and accurately compare the power consumption of two different pieces of equipment with different technologies. They could do this while not having to be a rotating equipment engineer, who would understand each of the technologies intimately. While not all consumers are completely versed in all types of technologies, a test code running the entire blower system proposed in a wire-to-air format can assure all losses are accounted for. A simple concept of measuring the input kW to the whole blower system and measuring the mass flow and pressure on the discharge is both easy to understand and easy to verify.