BLOWER TECHNOLOGIES AND ENERGY EFFICIENCY OPPORTUNITIES

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ABSTRACT

The operating principles of today's wastewater treatment plants (WWTP) are permanently under review against world best practices. Not only does the right treatment selection play a vital role, but the energy efficiency is also of utmost importance with energy consumption a major cost factor during the lifetime cycle of installed equipment. It is no longer good enough to purchase individual components. Plant managers, design engineers and consultants must work together to find world best practice system solutions for today's needs that flexibility cater for future requirements. With ever increasing energy costs, it is vital to understand the importance of the working principles of compressed air equipment, and its influence on the overall plant performance and lifecycle cost. Knowing that energy is the single highest operating cost in a WWTP, where blowers for aeration play a crucial role, knowledge of the different blower operating principles is important.

This paper outlines; the traditional approach to WWTP design and its associated efficiency problems, system solutions and an alternate design approach with key efficiency gains, guidance on how to calculate specific power for an individual unit and an entire system.

KEYWORDS

Blowers, low pressure compressed air, energy efficiency, wastewater treatment plants, aeration

PRESENTER PROFILE

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1 INTRODUCTION

The needs of WWTP's for commercial as well as municipals vary substantially in size and projected period of planned operation cycle. It is not unusual that the design for municipals are based on projected populations and demand 10 to 30 years in the future. As project funding is available now and may not be there later on, system engineers must build a system that will continue to serve the community's growing needs, in the most cost-effective, energy-efficient way possible. This is no simple task. Although the volume of air and pressure changes seasonally, each day, even hour to hour, the general practice is to design the plant's capacity for the worst case, maximum future load, resulting in oversizing the blowers. However, oversized blowers do not operate at their most efficient design point and spend as much as 90% of their operating time wasting costly energy.

2 DISCUSSION

2.1 BLOWER OPERATING PRINCIPLE EFFICIENCY

There are two main groups of compression principles known, compression by dynamic and displacement design. Figure 1, shows an overview of the different operating designs available. Standard for all applications with pressure requirements below 1000 mbar$_{(g)}$ is roots type blowers - a robust design where the compression process happens in the associated pipework. Displacement rotary blowers are of oil free design and so require clearance between blower housing and both rotating rotors. This results in slip (backflow) of air, resulting in reduced efficiency.

Figure 2 illustrates the differences between external and internal compression. With increased pressure influence, system engineers do their best to combat wasted energy by selecting energy efficient equipment. This has led to an increased focus on energy and has helped spur innovations in blower technology. It is therefore important to make the right decision on the blower package and its operating principle.

Figure 1: The various designs on compression principles for gaseous mediums

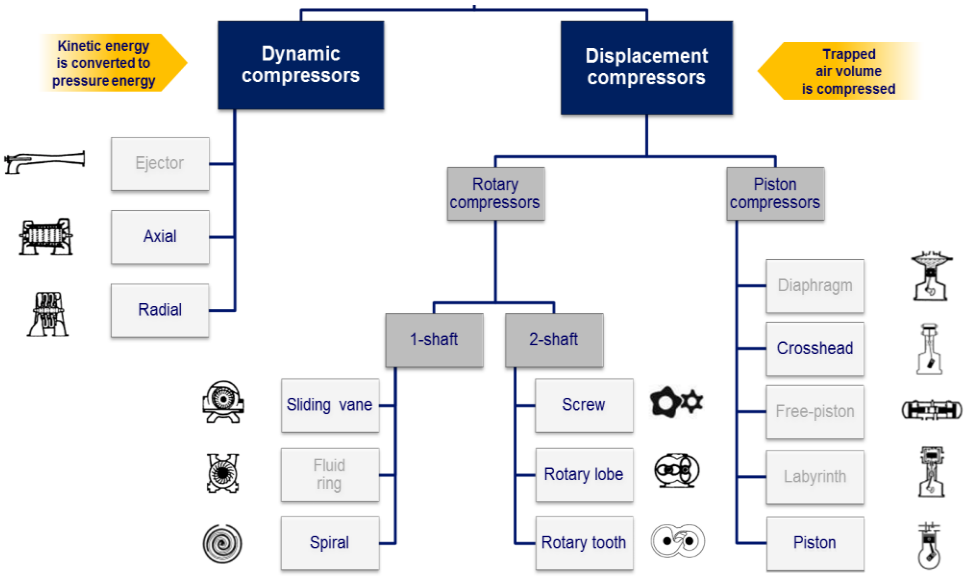
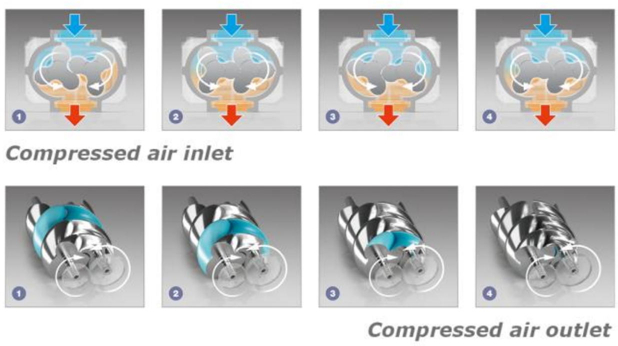


Figure 2: Compression principle three lube rotary blowers with pre-inlet channel design and screw blower

External compression: air is pushed out against the pressure losses in the process and therefore compressed air in the piping between blower and application

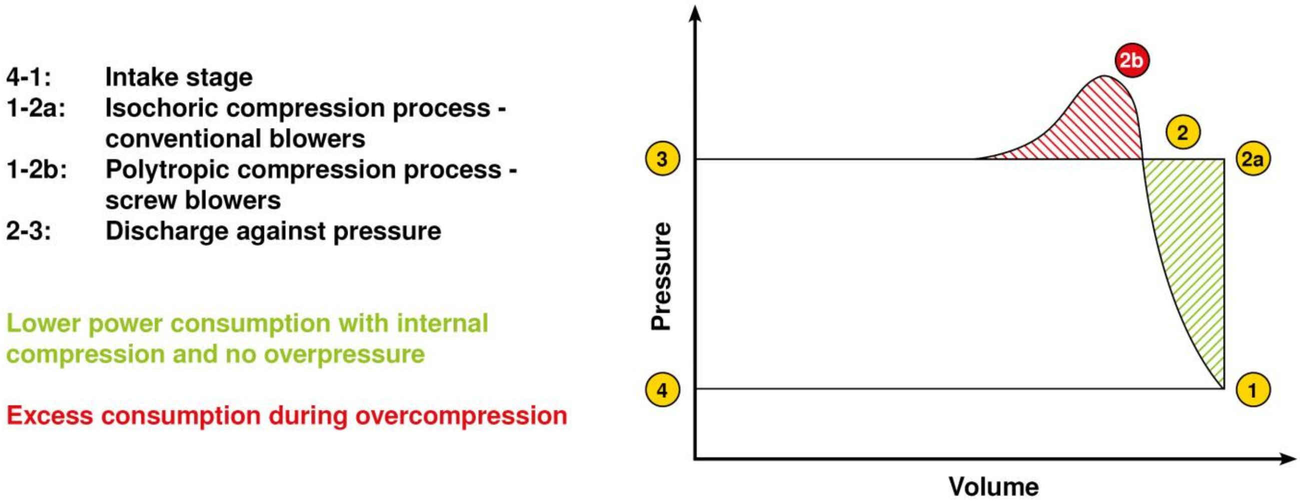
Internal compression: a certain pressure is always built up, independent of the process requirements



Blower manufacturers are taking advantage of the increasing interest in energy savings and offer low pressure equipment in the form of Roots Type Three Lobe Blowers, as well as Screw Type Blowers. The question therefore becomes, 'what blower type for what application?'

Figure 3 shows the trade off on work required to compress a gas, using internal or external compression principle: an energy advantage of internal compression at precise adjustment of the screw geometry (green area), compared to additional consumption at over-compression (red area).

Figure 3: Comparison on required work associated with blower using internal and external compression



Energy savings are achieved as long as the area enclosed by 4-1-2b-3-4 is less than the area 4-1-2a-3-4. When choosing a blower with internal compression (helical rotors), the operating point must exactly comply with the by design (geometrically) determined optimum design pressure or else this will lead to over-compression and unnecessary energy consumption. The internal compression of screw blowers operating in idle load, is always connected to higher power consumption. Pressure requirements of 500 $mbar_{(g)}$ and above should be considered as a base line where screw blowers can be more efficient.

2.2 PLUG AND PLAY SOLUTIONS

The next step is "Wire-To-Air" efficiency. Here, the drive system, motor and starter, are carefully matched, ensuring minimum mechanical and electrical losses. A basic tool for the plant operation and system design engineer is simply total energy used to provide the specified flow and pressure and is expressed as a ratio of the power to the flow. While this metric is relatively new to the blower market, it is widely used for industrial compressors and compressed air systems and is often referred to as *specific power*.

Whether using the term plug & play, wire-to-air or specific power, it is important to differentiate between each individual piece of equipment's efficiency and the overall *system* efficiency. The traditional system design approach for WWTP's focuses on individual blowers instead of considering how each piece will work with one another.

However, even if the most energy efficient blowers are selected, if they are not properly applied and controlled, they will not yield the anticipated energy savings. This is why system specific power is crucial in system design.

2.3 SPECIFIC POWER EXPLAINED

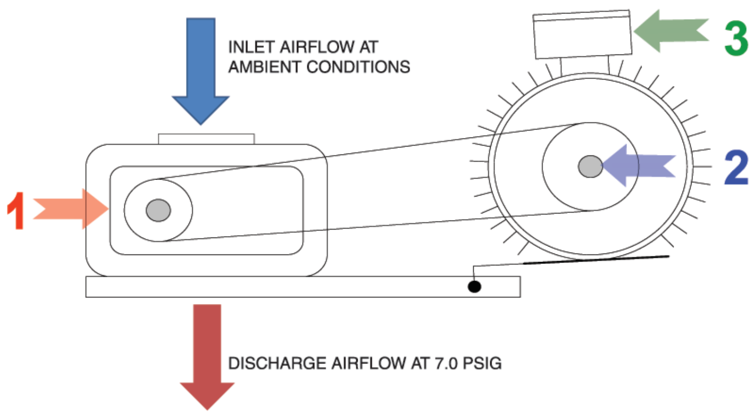
In its most basic form, specific power is a product of input kilowatt to the machine divided by cubic metre per minute of air at standard conditions.

$$\text{Specific Power} = \frac{\text{Input kW}}{m^3/\text{min}} \qquad (1)$$

While the equation is relatively simple, the process for calculating the value is not, no unified testing standard currently available to serve as a baseline for the calculations. There are a number of international standards manufacturers can use for determining equipment efficiency, depending on the compression principle of the equipment. Most commonly used is ISO1217-2008 annex C for compressors, operating on displacement principle. Furthermore, these international standards don't use a common baseline, or unified protocol for manufacturers to publish their performance on datasheets. Because the testing procedures aren't standardised, end-users aren't able to make true 'apples-to-apples' comparisons when considering different equipment to purchase.

As there is currently no testing standard and no published datasheets for blowers, the burden of making uniform calculations is on the user. To calculate specific power, it is possible to measure the input kW at the package control panel and install a flow meter at the outlet of the package to determine flow. However, when specifying equipment, this is not possible as the equipment is not on hand. This necessitates understanding how to calculate specific power for the entire package and how each component will affect the overall efficiency. Looking at the specific power of only a blower block from one manufacturer versus that of an entire package from another will not give a true efficiency comparison.

Figure 4: Comparison on required work associated with blower using internal and external compression



To calculate specific power, first the flow rate needs to be determined. For positive displacement blowers, this is a function of the blower's displacement per revolution, blower slip, operating RPM, ambient conditions, and operating pressure.

$$\dot{V}_1 = V_0 \left(n - n_{slip} \cdot \sqrt{0.0371 \cdot \frac{T_1 \cdot \Delta p}{p_1 \cdot 1K}} \right) \quad (2)$$

V_1 =	Suction Volume	n_{slip} =	Slip Speed (basis 100mbar)	p1 = Inlet Pressure
V_0 =	Displacement/Revolution	T1 =	Inlet Temperature in Kelvin [K]	
n =	Block Speed	Δp =	Pressure Differential	

Next, we need the required blower power (1) which is a function of mechanical design and pressure differential. As ambient conditions are the same as normal conditions in this example, Nm^3/min and m^3/min are equal. Now we have blower power (1), but this is not what the user is paying for. The user is paying for electrical input at the motor (3).

To calculate motor input power (2), we need to determine the losses associated with the drive. For most v-belt slide base designs where the motor can be moved to adjust centre distance and apply tension, we can expect a 5% loss. For more advanced tension systems, these losses can be reduced to 2-3%. Finally, we need the rated motor efficiency as given on the motor nameplate. Therefore, input kilowatt (3) is given by;

$$\frac{\text{Blower Horsepower} \times (1 + \text{Drive Efficiency}) \times 0.746}{\text{Motor Efficiency}} \quad (3)$$

Once input power is calculated the specific power can be obtained.

$$\text{Specific Power} = \frac{\text{Input kW}}{m^3/\text{min}} \quad (4)$$

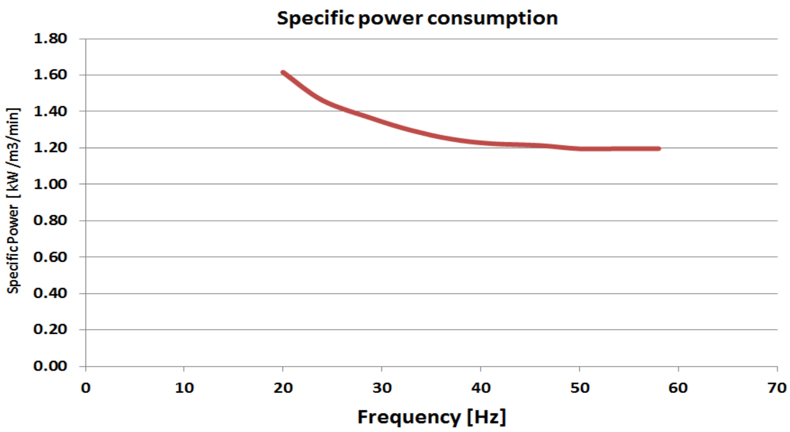
The lower the specific power value, the more efficient the blower is. Here we only evaluated the blower, belt drive, and motor, and we assumed ambient conditions to be the same as standard conditions, which helped simplify the flow values and calculations. In reality, most blower systems include accessory components such as silencers, filters, and valves, which all present flow restrictions. Flow restrictions result in a greater pressure differential across the blower and result in more power consumption. In addition, other package designs utilise cooling fans (shaft or separate), pumps for cooling, or some other electrical or mechanical device, which add to the power requirements of the machine. We also need to consider the different internal pressure between rotary lobe and screw blowers. For the best accuracy, input kilowatt should be measured at the input of the machine’s control panel. This takes into account all losses associated with the package as well as other relevant components. In addition to system losses and power consumers inside the package, power consumers in the control panel also need to be considered. The sum of each of these gives the total package input kilowatt consumption.

So far we have evaluated the elements of a blower package, power transmission, and accessory power consumers to represent the performance of the physical package. For a fixed speed machine, the specific performance of the machine is mostly constant (excluding the effects of ambient conditions). However, the vast majority of modern wastewater systems utilise variable frequency drives and the demand is split between the units enabling handling flow and pressure requirement at constantly changing needs.

2.4 VARIABLE FREQUENCY DRIVE

Variable frequency drives (VFDs) allow equipment to operate at different speeds by adjusting the voltage and frequency delivered to the motor. This gives the machine versatility by varying blower performance to match system demand; however, this comes at a price. Most variable frequency drives have an efficiency rating just like motors. The 97% VFD and 95% motor efficiency do not apply when the unit is running at ¼ or ½ speed. At these reduced speeds, the efficiency is decreased; therefore, VFD usage should be limited to applications where the demand actually fluctuates.

Figure 5: Running at reduced capacity greatly impacts the energy efficiency of a variable frequency drive unit



VFD's are beneficial in handling fluctuations in demand, especially when compared to blowing off excess air to atmosphere. What should be avoided, however, is using a VFD on an oversized machine.

2.5 FOCUS ON THE SYSTEM

For a multiple blower system, the focus must be on system efficiency. It is not enough to simply use the most efficient blowers. Well-designed blowers are a great start but to operate as an efficient system, they must be applied correctly and controlled properly.

Now that we have examined the efficiency for individual units, we can apply those concepts to understanding the overall efficiency of the entire system and how sizing and selection affects the efficiency of the system. This means, system design engineers should actively investigate the possibility of using rotary lobe- and screw- blowers in one system. Conventional aeration system designs include two large blowers. This needs to be critically reviewed, knowing that WWTP's are designed for the future, and that for a long time blowers are underutilised and operating most of the time in part load. Also the impact of large variable speed blowers with an identically sized back up unit are the main reason for the high energy consumption. In-house basic control systems are set to share the demand and the units cost more to purchase, their drive losses must be factored into the unit's efficiency. Flexibility and energy efficiency can be achieved by an alternate method of system design, so called system splitting. With system splitting, the maximum load is split among several cycling online/offline fixed speed machines to cover the large portion of the demand and a variable frequency drive (VFD) machine to cover the trim load. This method of system design allows much more efficient control without sacrificing the ability to meet the occasional periods of higher demand. Simulation programs can assist working out the best combination on rotary lobe blowers, screw blower and which one should be driven by variable speed drive.

2.6 ADAPTIVE CONTROL

For system splitting, only one or two machines are VFD units. If there are two VFDs in the system, only one runs at a time, with the second acting as back-up. The remaining blowers are fixed speed units. By limiting the number of VFD units in the system, initial investment costs are considerably lowered. The final component of system splitting is controls. Adding an adaptive master controller makes it possible to find the best combination of units to meet the current demand. Since the fixed speed units run on auto-dual control, the units can run idle for a defined period of time before shutting down. This gives the adaptive master controller enough time to observe the system's response and signal the units to reload if needed. The VFD is sized no larger than required, reducing the initial investment cost while covering the supply gaps that occur when the fixed speed machines are offline.

Table 1: Adaptive master controller; key criteria to consider when selecting a controller

Adaptability: A master controller that learns the system and adapts to fluctuating demand can better respond and choose the most efficient unit combination to meet the demand and improve pressure stability. **Integration:** Chances are you have a plant SCADA system for monitoring. Look for a master controller with communications capabilities that will easily integrate into what you already have. **Back-up:** The right controller can help reduce maintenance costs, with some able to rotate like-sized machines to equalise run times and spread out maintenance intervals. Some will also let you specify the units to run as back up only, ideal where you want older/less efficient units to only operate if a unit fails.

3 CONCLUSIONS

Wastewater treatment is a critical utility and the system must be designed to reliably meet its highest expected load. When it comes to the blower system, bigger is not always better. The best air system design is a holistic one that takes into account the range of demand, future growth, the entire system's specific power, and optimised energy efficiency. System splitting, using rotary lobe and screw blowers, and using an adaptive control scheme can provide reliable supply without unnecessarily burdening the community with higher energy costs. Understanding system dynamics can save initial costs as well as maintenance and power costs for many years to come.

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