Theoretical and Experimental Study on Energy Efficiency of Twin Screw Blowers Compared to Rotary Lobe Blowers

Mr. Gert Van Leuven

Team leader Product Development

Atlas Copco Airpower n.v., Wilrijk, Belgium

Dr. Stefan Henneberger

Team leader, Engineering Low Pressure Projects

Atlas Copco Airpower n.v., Wilrijk, Belgium

Mr. Conrad Latham

Product Manager – Low Pressure

Atlas Copco Airpower n.v., Wilrijk, Belgium

Abstract

In order to achieve a significant improvement in energy efficiency in the technology of air blowers for small volume flows (300 to 5,000 m³/h), a technology step is needed.

The technical evolution in this blower market for small volume flows has been very poor in the past 50 years. Lobe style blowers have developed from a 2-lobe to 3-lobe design, mainly to reduce the discharge pulsation levels. Regarding energy efficiency, lobe blowers have not seen significant improvements.

The step taken for significant improvement in energy efficiency in the low-pressure market, is made by introducing internal compression instead of external compression.

This paper will demonstrate that both from a theoretical; using a thermodynamic approach and from a practical point of view, external compression is less efficient than internal compression, starting from 0.4 bar(e) and increasing to 1.0 bar(e). It will provide an insight into the improved energy efficiency and the lower air outlet temperatures in favor of the screw technology thereby proving how drastic energy savings are able to be achieved.

By designing compressor screw set for low pressure ratio (0.5 bar(e)), a technological advantage is introduced to the market. The paper will show that besides energy savings, the screw technology has further advantages regarding noise, vibrations and reliability.

Key words: twin screw blower; lobe blower; energy efficiency; positive displacement; internal compression

Introduction

Rotary lobe blowers, are positive displacement machines consisting of a pair of two lobed or three lobed rotors, rotating inside an oval shaped casing.

One rotor is driven by external power while the other rotor is driven by synchronization gears.

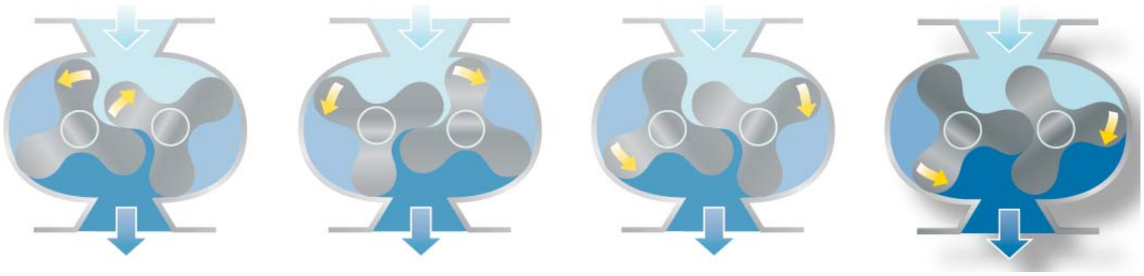


figure 1: working principle of a lobe type blower

As the rotors rotate, air is drawn into inlet side and forced out the outlet side against the system pressure. There is no change in the volume of the air within the machine but it only displaces the air from the suction end to the discharge end against the discharge system resistance.

An *oil free screw blower* is a positive displacement rotary machine, consisting of male and female rotors, which move towards each other while the volume trapped between them and the housing decreases. The rotors don't make contact and are synchronised by timing gears. Each screw blower has a fixed, built-in internal pressure ratio. This means that the outlet port is designed and then manufactured to a certain fixed geometric profile. To obtain the best efficiency, the internal pressure ratio is adapted to the required working pressure.

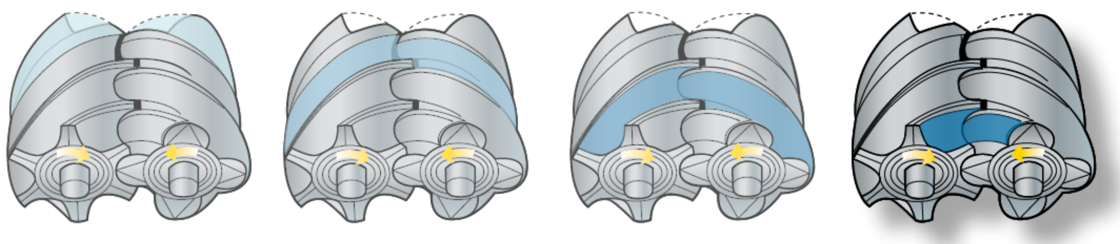
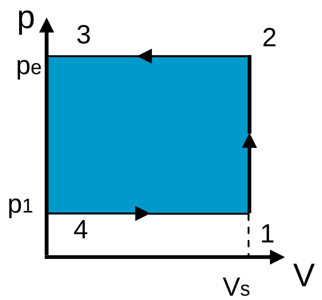


figure 2 : working principle screw blower

Theoretical study

1. p-V diagram Lobe Type blower

At the lobe blower delivery side, air at a higher pressure is present. As the rotor lobes uncovers the exit port, air from the delivery pipeline flows back into the flute space between the rotor and casing. This back flow of air equalizes pressure and compresses the entrapped air externally at constant volume [1-2]. As the rotors continue to turn, the air is pushed into the discharge line against the full system pressure [2-3].



p_1 = air intake pressure
pe = working pressure (external system pressure)
Vs = displaced volume

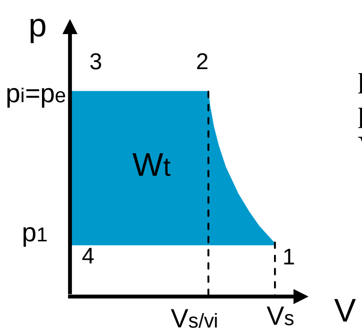
4-1: Air intake; volume increase to Vs
1-2: Compression by back-flow from discharge piping to blower
2-3: Air delivery from blower to discharge piping
Rectangle area 1-2-3-4 represents the compression work Wt
Power consumption is proportional with blue area 4-1-2-3

figure 3 : pV diagram lobe blower

2. p-V diagram screw blower

At the beginning of the compression cycle, gas at suction pressure fills the flute spaces formed by the unmeshed rotors just under the suction flange. Gas continues to fill the flute spaces, until the trailing lobe crosses the inlet port. At that point, the gas is trapped inside the flute space. (= stroke volume V_s) On the underside, the rotors begin to close the trapped space. As the lobe meshes into the flute space, the flute volume is reduced, causing the pressure to increase. Volume reduction and corresponding pressure increase will continue as long as the gas is trapped in the flute space. Gas is discharged from the flute space when the leading lobe crosses the discharge port. (discharge volume = V_s / v_i)

Further rotation and meshing of the rotors forces this gas to the discharge line.



p_1 = air intake pressure
pe = working pressure (external system pressure)
Vs = displaced volume

4-1: Air intake; volume increase to Vs
1-2: internal compression within the screw blower
2-3: Air delivery from blower to discharge piping
Rectangle area 1-2-3-4 represents the compression work Wt
Power consumption is proportional with blue area 4-1-2-3

figure 4 : pV diagram screw blower with p_i=p_e

Due to the internal compression, the energy consumption is reduced as represented in a pV-diagram by the green area in figure 5

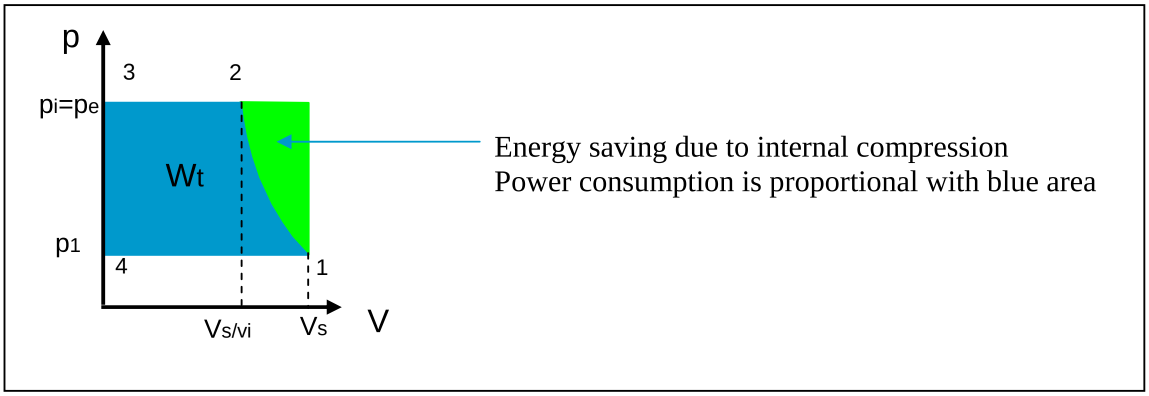


figure 5 : Energy saving screw blower vs lobe blower

For optimal compression efficiency, the volume ratio v_i should be sized so that the internal compression ratio matches the system compression ratio : $p_i = p_e$. If the internal compression ratio does not match the system compression ratio, the gas experiences over or under compression.

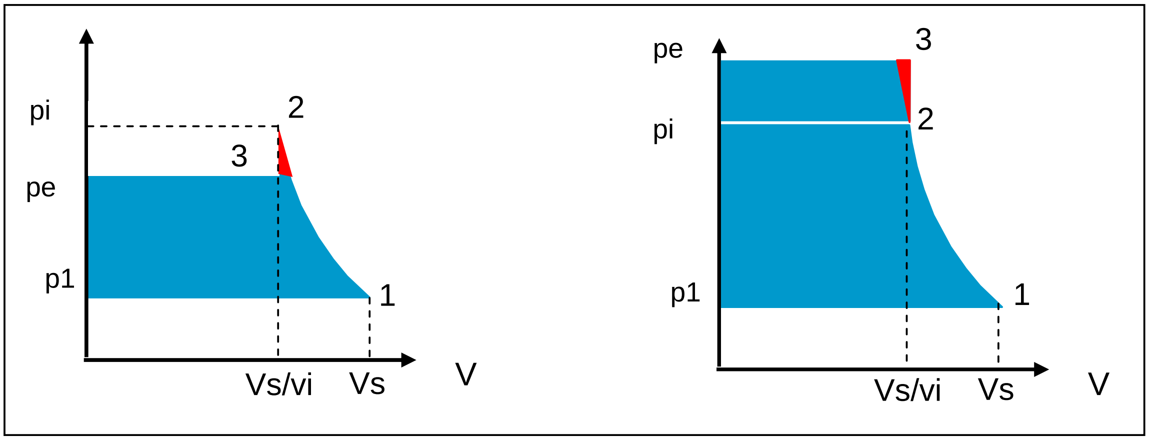


figure 6 : over compression (left); under compression (right)

In case of over compression, the gas is compressed more than the system requires. Gas is compressed internally to a higher pressure and then expands down to external working pressure. Extra work is required to compress the gas to the internal discharge pressure, rather than to the system discharge pressure.

With under compression, the internal discharge pressure is lower than the system discharge pressure and gas from the discharge line flows back into the flute space and equalizes pressure at constant volume, resulting in extra work from ideal compression.

3. Adiabatic efficiency

The ideal compression process from p_1 to p_e is a reversible adiabatic (i.e. isentropic) process.

The isentropic work required is $p_1 V_s \frac{\kappa}{\kappa-1}\left(\pi^{\frac{\kappa-1}{\kappa}}-1\right) = C_p T_1\left(\pi^{\frac{\kappa-1}{\kappa}}-1\right)$

For a lobe, the theoretical actual work done is $V_s(p_e - p_1)$

In general the theoretical actual work done can be written as $p_1 V_s\left[\frac{\pi}{v_i}+\frac{\kappa}{\kappa-1}\left(\frac{1}{\kappa}\cdot v_i^{\kappa-1}-1\right)\right]$

With :

v_i = built in volume ratio (v_i = 1 for a lobe blower)
π = external pressure ratio p_e/p_1
κ = 1.4 (air)
p_1 = inlet pressure
V_s = displaced volume
C_p = constant pressure specific heat for air ~1004 J/kgK

$$\eta_{ad} = \frac{work\ done\ isentropically}{Actual\ work\ done}$$

The theoretically maximum achievable adiabatic efficiency

$$\eta_{ad,\max} = \frac{p_1 V_s\left[\frac{\kappa}{\kappa-1}\left(\pi^{\frac{\kappa-1}{\kappa}}-1\right)\right]}{p_1 V_s\left[\frac{\pi}{v_i}+\frac{\kappa}{\kappa-1}\left(\frac{1}{\kappa}\cdot v_i^{\kappa-1}-1\right)\right]}$$

If the results of the above formula are plotted in a graphical format and different values of v_i are used, the resulting representation is shown below in Figure 7.

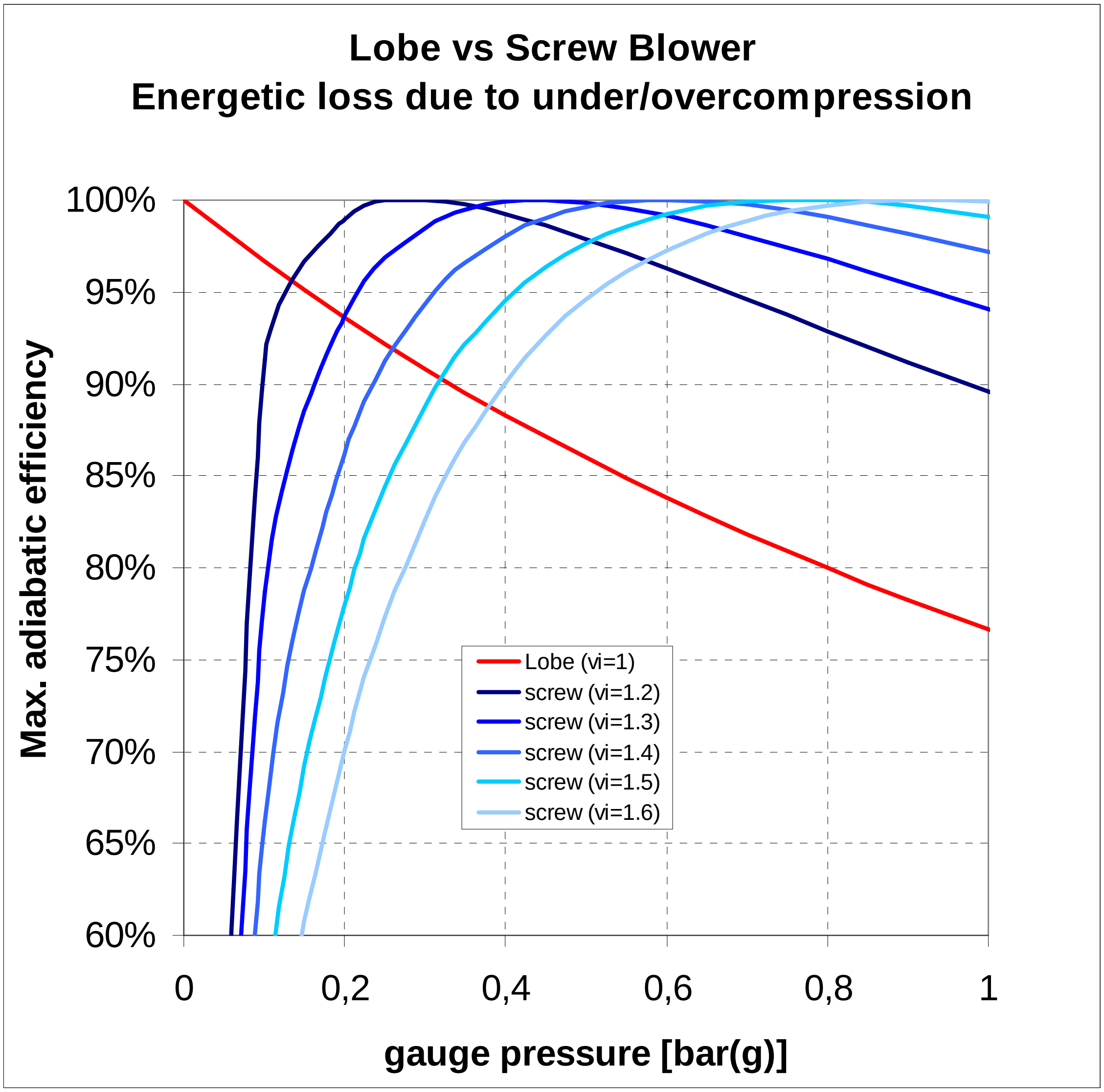


figure 7: maximum adiabatic efficiency screw vs lobe

From figure 7 can be seen that the theoretical maximum efficiency in case of lobe type blowers is 76.5% at a pressure ratio of 2, while a tuned rotary screw blower could reach 100%.

Due to dynamic losses at inlet and discharge side, leakages and friction, the real compression work is higher, and subsequently the adiabatic efficiency is reduced. These effects can be taken into account by defining and 'energetic efficiency'.

The more realistic and actual adiabatic efficiencies are given in figure 8.

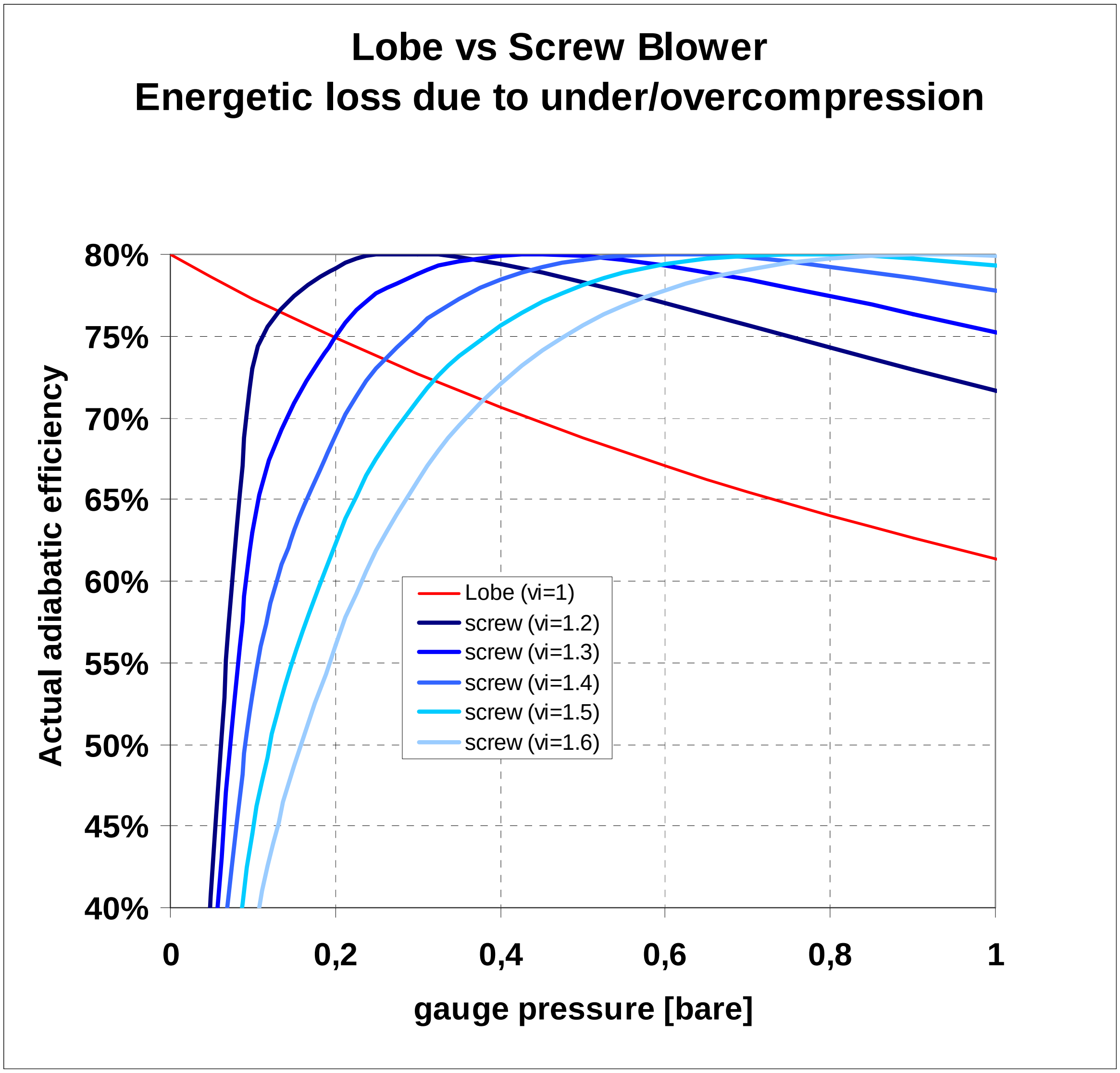


figure 8 : actual adiabatic efficiency screw vs lobe

4. Air outlet temperature

The extra compression work for a lobe blower, compared to a screw blower, results in extra heat dissipation (= power loss) and consequently a higher outlet temperature. (cfr figure 9)

Required additional power for a lobe compared to a screw blower = mass flow x c_p ($T_{out,\ lobe}$– $T_{out,\ screw}$)

Assuming the compression process takes place very quickly, heat transmission can be ignored and the process is approximately adiabatic.

Actual specific work $W_t = c_p\,(T_{out} - T_{in})$ [J/kg]

Based on the actual work done, the air outlet temperature can be calculated.

Air outlet temperature $T_{out} = T_{in} + \dfrac{W_t}{c_p}$

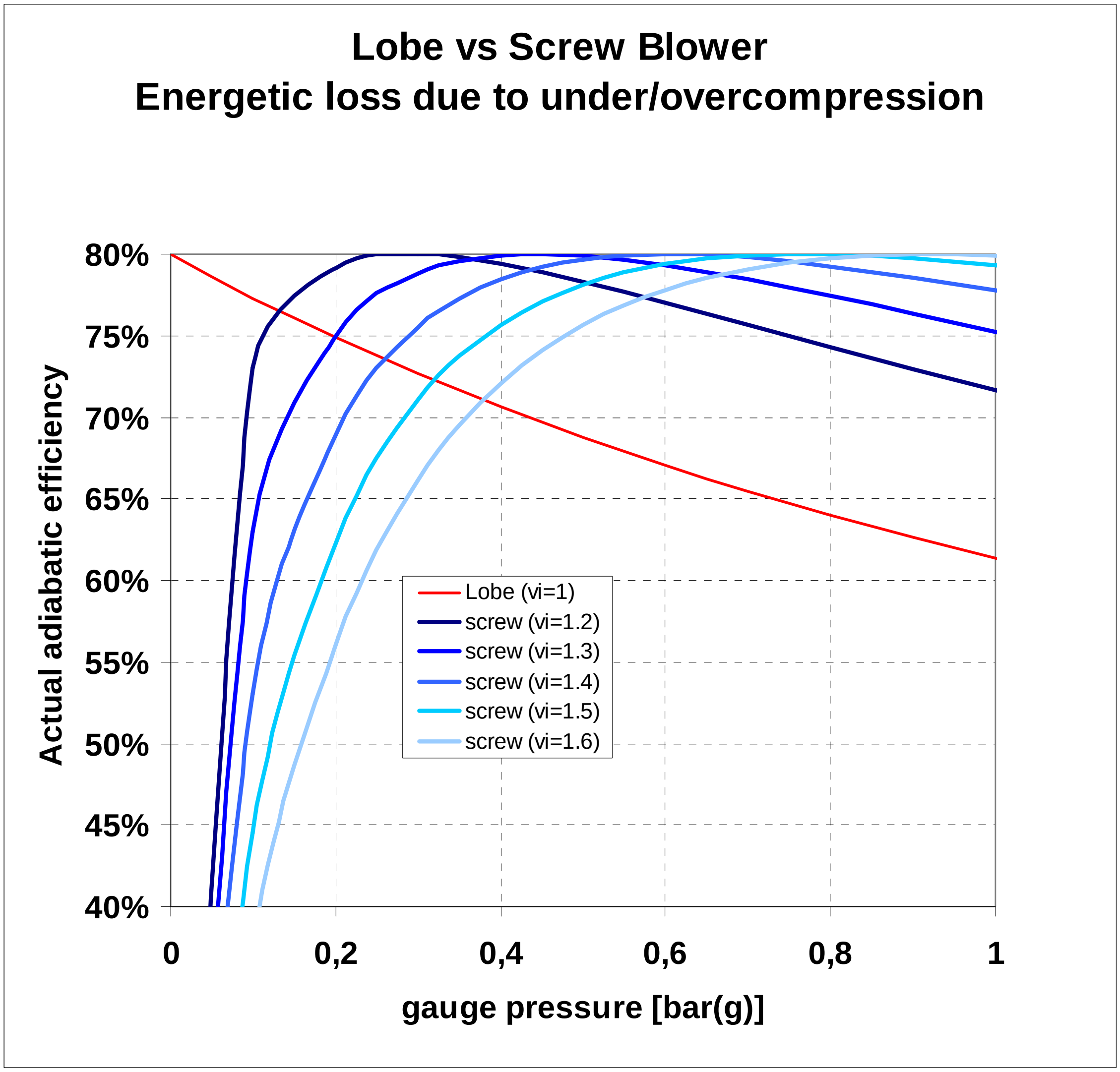
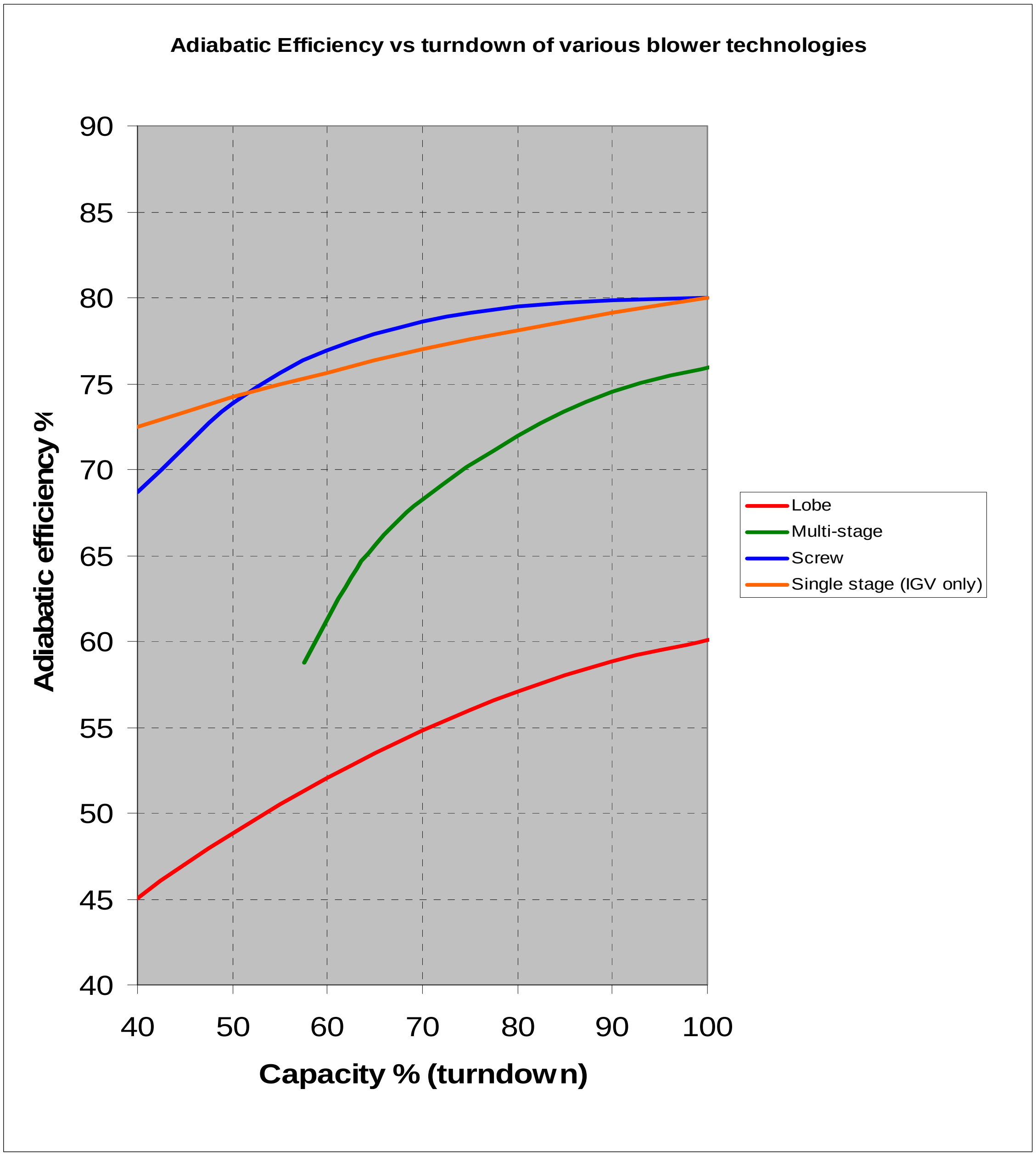


figure 9

5. Efficiency during turndown

Most compressed air applications that use blowers in industrial and wastewater markets require that the blower adjust it's delivered air flow with the process.
This can be accomplished in general terms by cycling the blowers on and off, throttling the inlet suction, adjusting outlet diffuser vanes, or using adjustable speed drives. In most low flow blowers, it is the latter method that is the preferred choice.
The change in overall efficiency related to delivered airflow is a very important issue in the overall economics of blower operation.
The below chart demonstrates how the adiabatic efficiency changes with respect to turndown in capacity for various compression technologies. As can be seen the screw blower maintains a more stable efficiency compared to a lobe blower at part load flows.



6. Pressure pulsations

Traditionally, Lobe blowers were designed around a two lobed rotor concept. Manufacturers have put a lot of effort in trying to reduce the pressure pulsations levels inherent in this two-lobe design.

As the pressure in the pocket is below discharge pressure when the pocket opens to the discharge line, a sudden backflow will occur, accentuating gas pulsations. [1]

Tri-lobe rotors partially address this as their lower levels of pulsations do provide for smoother flow pulsations than their two-lobe cousins. For additional pressure pulsation reduction, helical rotors and special channels have been designed into blower casing. These advances have brought reduction in pulsations levels by pre-filling the reverse chamber.

The design still results in strong pulsating forces levels on the rotors by the gas forces. These can lead to intermittent noise and vibration problems (rattle) in the gearing mechanism.

Screw blowers deliver a more stable flow and thanks to a better matching of the internal pressure to the external pressure, pressure pulsation levels are reduced to levels not achievable with rotary lobe technology.

The higher rotational speed and the higher number of lobes results in a higher pulsation frequency with lower pulsation levels. In generally, pulsations with higher frequencies are easier to dampen and will result in lower overall noise and pulsation levels in the system discharge piping.

This design improvement prolongs the lifetime of the flexible elements of aerating systems and protects conveyor systems against undesirable pulsations.

Inside the blower, the reduction in pulsations also results that lower gas pulsation amplitude levels (vibrations) are transmitted to the bearings; increasing the bearing lifetime.

Experimental comparison

7. Rotary Lobe vs screw technology

From a customer point of view, it’s often difficult to compare the energy efficiency of machines using different technologies if the available data is not presented in a comparable manner.

Lobe type blower data is commonly offered by providing the air theoretical intake volume flow and the shaft power required of the bare compression element. Low pressure compressors on the other hand are quoted by listing the FAD (free air delivered) at the unit outlet and the power consumption at the terminals of the power supply. This means that air-flow path losses as well as electrical and mechanical transmission losses are considered for the rotary screw, but not for lobe blowers. In order to make the comparison of the technologies, the efficiencies and losses of the other blower components have to be evaluated.

The air flow path before and after the blower element includes air-inlet filter, air inlet silencer, air-outlet silencer and the check valve. The pressure drop over these components has to be added to the performance data of the lobe blower element.

The transmission losses from the terminals of the power supply to the shaft power of the blower element, consists of the losses of the electric motor and the transmission losses (belt drive) from motor shaft to the element.

These losses vary generally as a function of the blower size and the operating point. The following table lists typical values for a small lobe type blower (1000 m³/h) operated at 0.7 bar(e) and medium sized blower (5000 m³/h) operated at 0.5 bar(e).

Air flow path losses		small lobe type blower 1000 m³/h, 0.7 bar(e)	medium lobe type blower 5000 m³/h, 0.5 bar(e)
Inlet filter pressure drop	[mbar]	20	40
Outlet silencer pressure drop	[mbar]	15	25
Check valve pressure drop	[mbar]	10	15

Additional energy consumption	[%]	6	9.4

Mechanical and electrical transmission losses		small lobe type blower 1000 m³/h, 0.7 bar(e) 30 kW	medium lobe type blower 5000 m³/h, 0.5 bar(e) 150 kW
Belt losses	[%]	4	5
Motor efficiency	[%]	90	95
Total transmission losses	[%]	14	10

Of course, screw blowers also have air flow path and transmission losses, but they are already taken into account when listing the system data, measuring at the power supplies and the compressed air outlet.

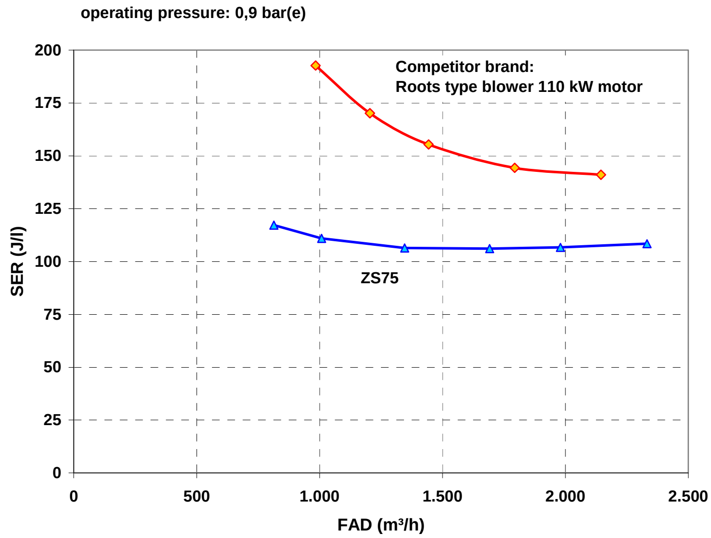
8. Laboratory test: Lobes vs screw technology

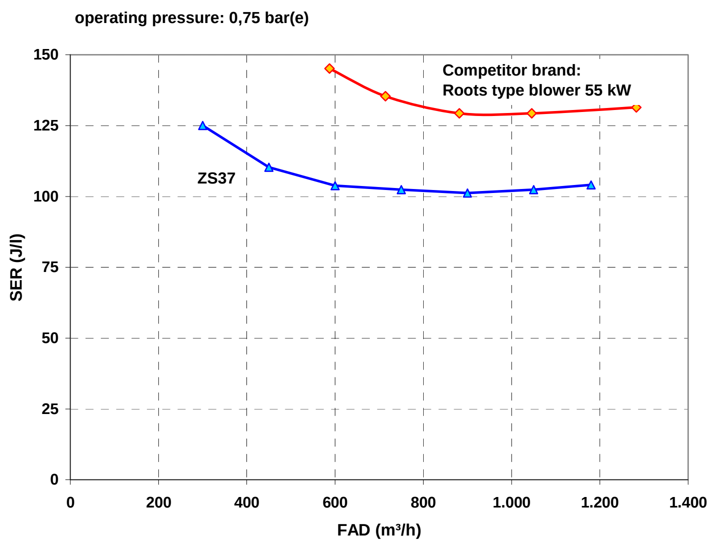
It has been shown that neither leaflet data nor test data from different suppliers using different technologies can be used to analyze package energy efficiency. The best way to compare the performance of machines is in a laboratory test where the different technologies work in the same environment under equal operating conditions and their performance is measured using the same measurement equipment.

The consumed energy taken from the terminals at the power supply at the installed blower is measured as well as the volume flow at the outlet flange of the blower system according to ISO1217 ed.3 full acceptance test (Ppack).

The test series has been performed on different power ratings and various brands of lobe blower manufactures. The test results are expressed in the specific energy requirement (SER (in J/l), which shows the relation of the consumed power (in kW) divided by the free air delivery (FAD in m³/h).

In first test set-up, a tri-lobe lobe blower sized with a 110 kW motor and connected to a separately installed frequency converter is compared to a screw blower using a 75 kW motor with integrated frequency drive. The result at maximum volume flow of the lobe blower (2,145 m³/h) shows a 32.1 % higher specific energy consumption (Lobe: 141.0 J/l, screw 106.7 J/l). At minimum volume flow (984 m³/h) the difference in the specific energy requirement is 64.4 % (Lobe: 191.7 J/l, screw 117.2 J/l).





In addition to these tests it was determined that an independent audit to witness the testing of a screw blower against a tri-lobe blower may bring an objectivity otherwise not available . The below certificate shows the results of the independent performance test.

TÜVRheinland®

Certificate

ET 333 2009 C2

The company

Atlas Copco Airpower n.v.

Oil-free division

Boomsesteenweg 957

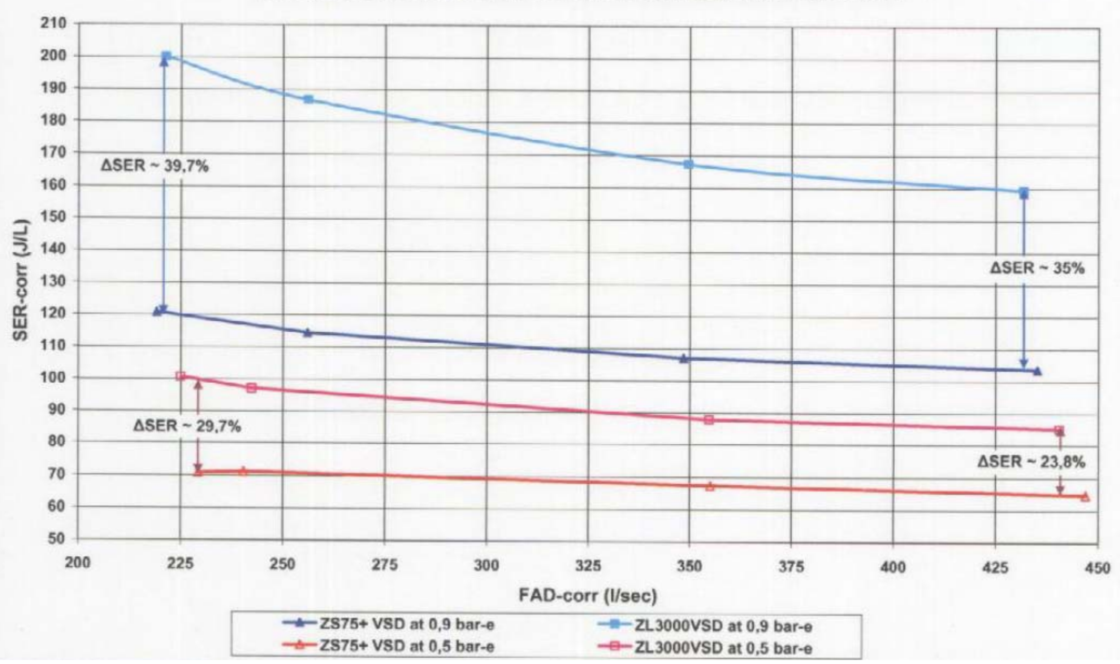
B-2610 Wilrjik (Belgium)

made a comparison investigation of a screw blower and a tri-lobe blower each with variable speed drive under the supervision of TÜV Rheinland based on performance tests according the standard

ISO 1217, 4th. edition - Displacement compressors – Acceptance Tests.

The aim was to compare the performance data of the two blowers

Screw blower *ZS75+VSD* versus tri-lobe blower *ZL3000VSD*



Note: The TÜV, Germany's Technischer ÜberwachungsVerein or Technical Inspection Association, is an independent, international organization that specializes in evaluating the safety and quality of technology. The TÜV is recognized worldwide for its independence, neutrality, professional expertise and strict standards.

9. Conclusions

In this paper we have made a technological evaluation between a traditional lobe type blower and a screw blower. We demonstrate that the rotary lobe technology can be improved with the adoption of rotary screw technology. Up to 50% less energy consumption is available to the industry.

References

[1] W. Soedel, Sound and vibrations of positive displacement compressors, CRC press, 2007, pp. 17-19.