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

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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. The "Roots" type lobe blowers have been developed from 2-lobe to 3-lobe blowers, mainly to reduce the pulsation level, but regarding energy efficiency, lobe blowers have not achieved significant improvements.

The step to achieve significant progress in energy efficiency in the low-pressure market, is taken by introducing blowers using internal compression instead of external compression.

This paper will demonstrate from both a theoretical, using a thermodynamic approach, and practical point of view, that 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 favour of the screw thereby proving how drastic energy savings are able to be achieved.

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

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

Introduction

Rotary lobe blowers, also known as "Roots" type 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.

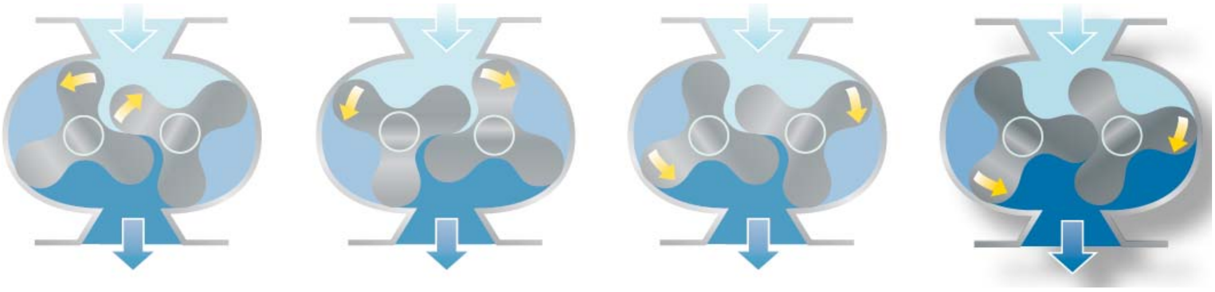


figure 1: working principle of a "Roots" type lobe blower

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.

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

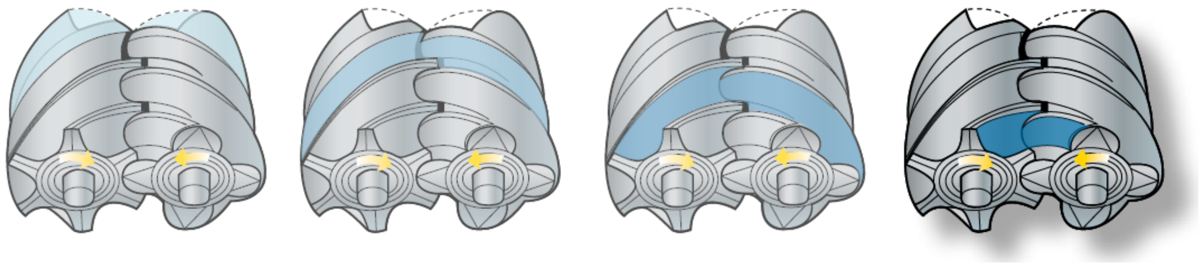
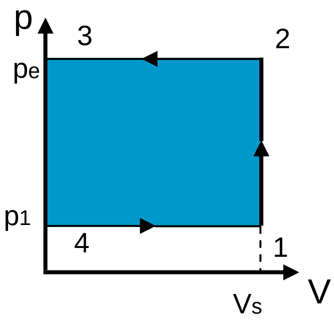


figure 2 : working principle screw blower

Theoretical study

1. p-V diagram "Roots" blower

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



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

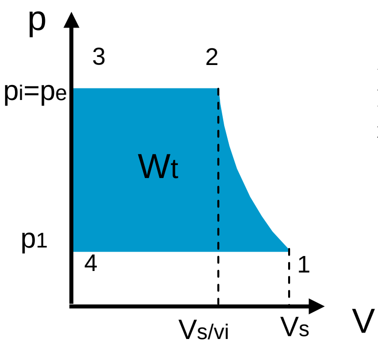
4-1: Air intake; volume increase to Vs
1-2: Compression by back-flow from discharge piping to blower
2-3: Air delivery from blower to discharge piping
Rectangle area 1-2-3-4 represents the compression work Wt
Power consumption is proportional with blue area 4-1-2-3

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 as the rotors unmesh 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 mesh. As the lobe meshes into the flute space, the flute volume is reduced, causing the pressure to increase. The volume reduction and subsequent 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

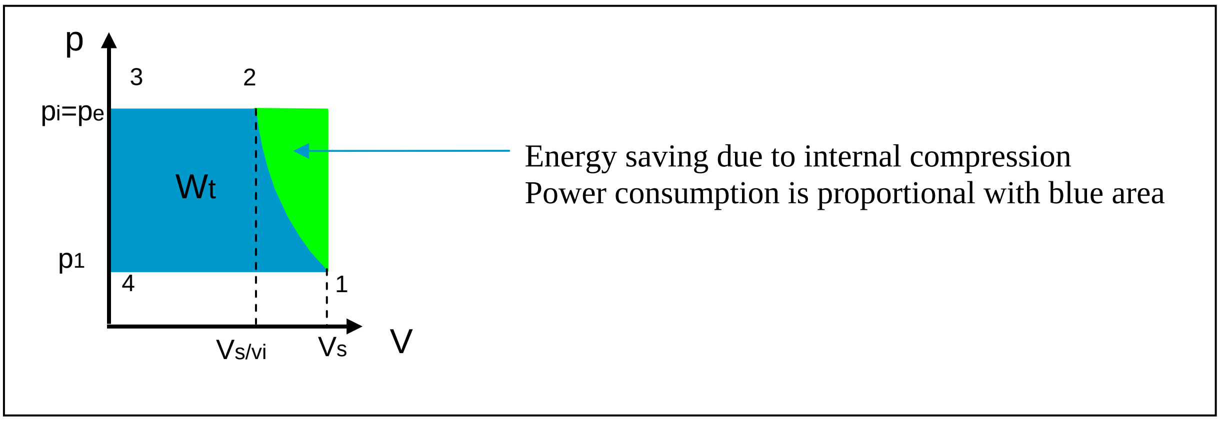


figure 5 : Energy saving screw blower vs lobe blower

For the best 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 result is either over compression or under compression.

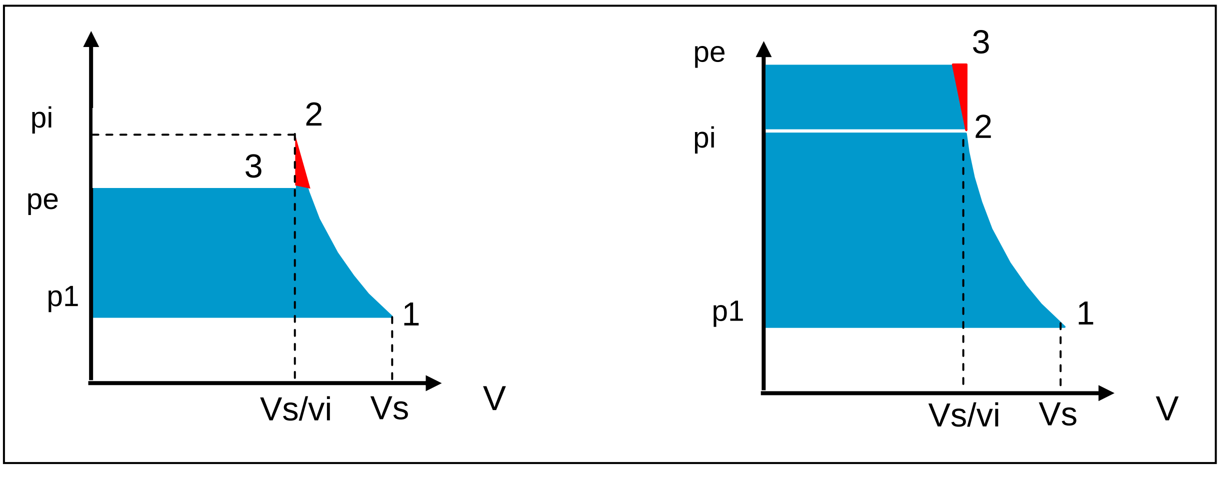


figure 6 : overcompression (left); undercompression (right)

In 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 required.

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 “Roots”, 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 “Roots” 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.

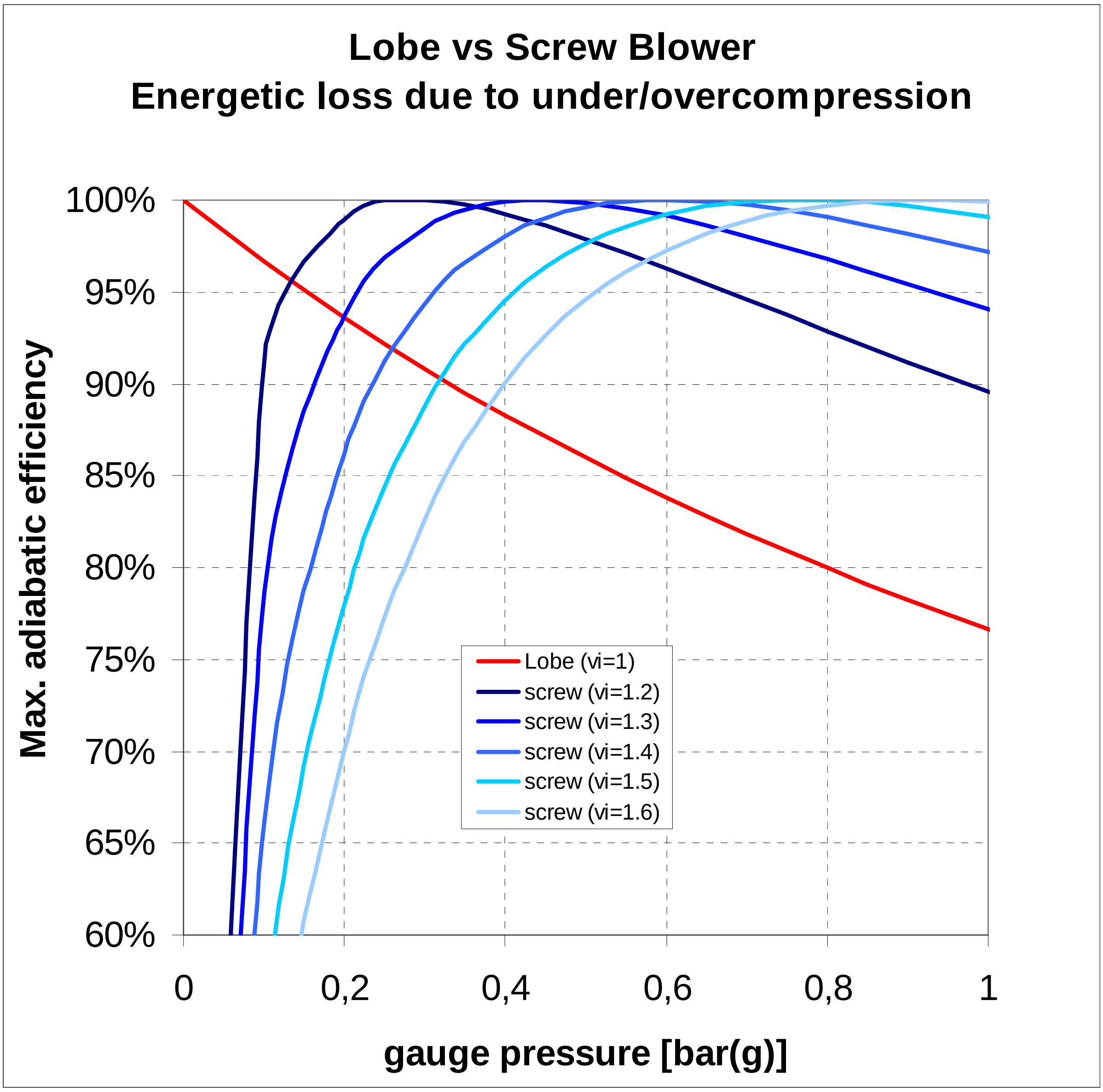


figure 7: maximum adiabatic efficiency screw vs lobe

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

Due to dynamic losses at inlet and discharge side, leakages and friction, the real compression work is increased, and subsequently the adiabatic efficiency will be reduced. These effects can be taken into account by definition of an energetic efficiency.

More realistic, 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 ($T_{out, “Roots”}$ – $T_{out, screw}$)

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 $T_{out} = T_{in} + \frac{W_t}{c_p}$

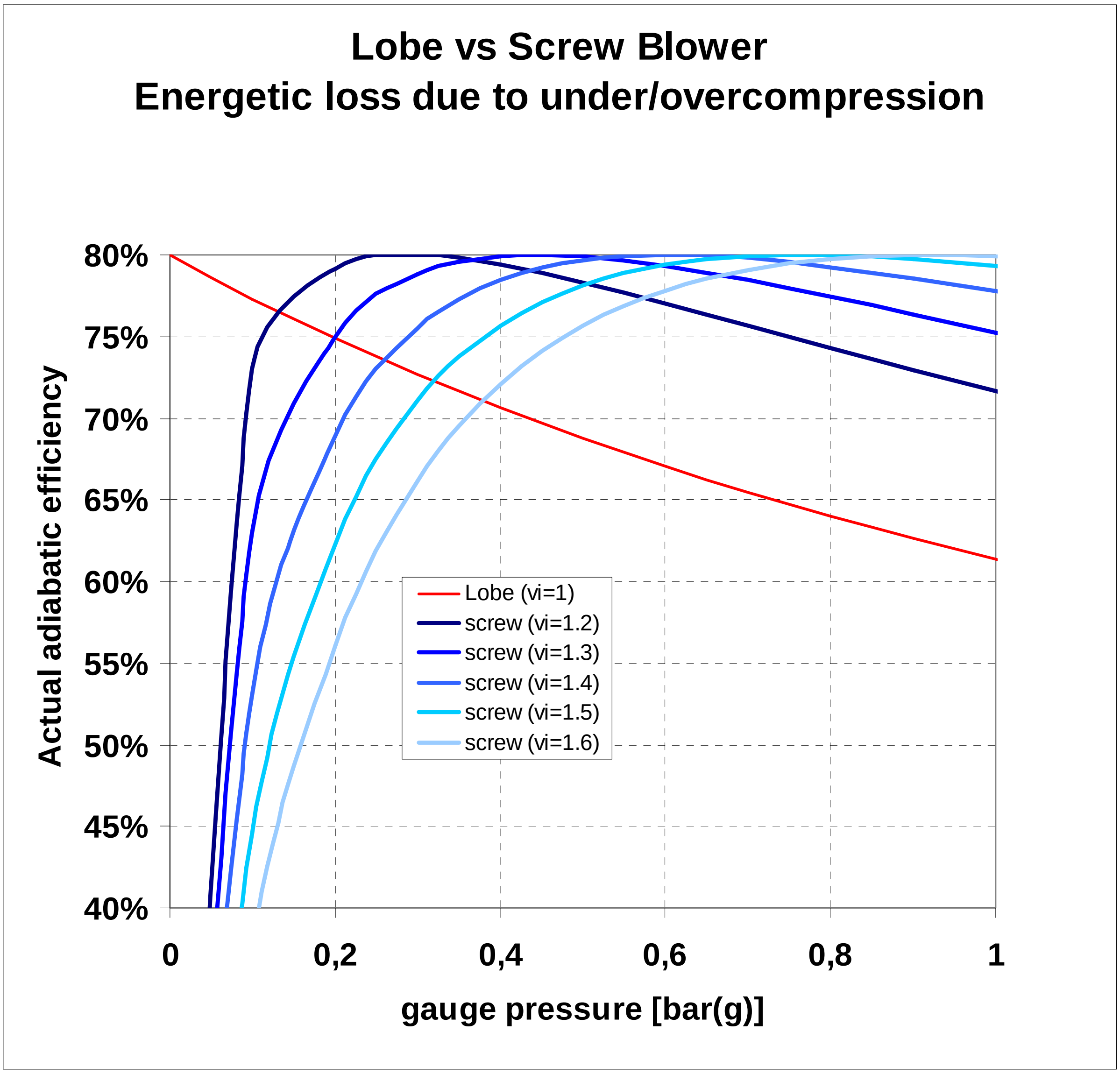
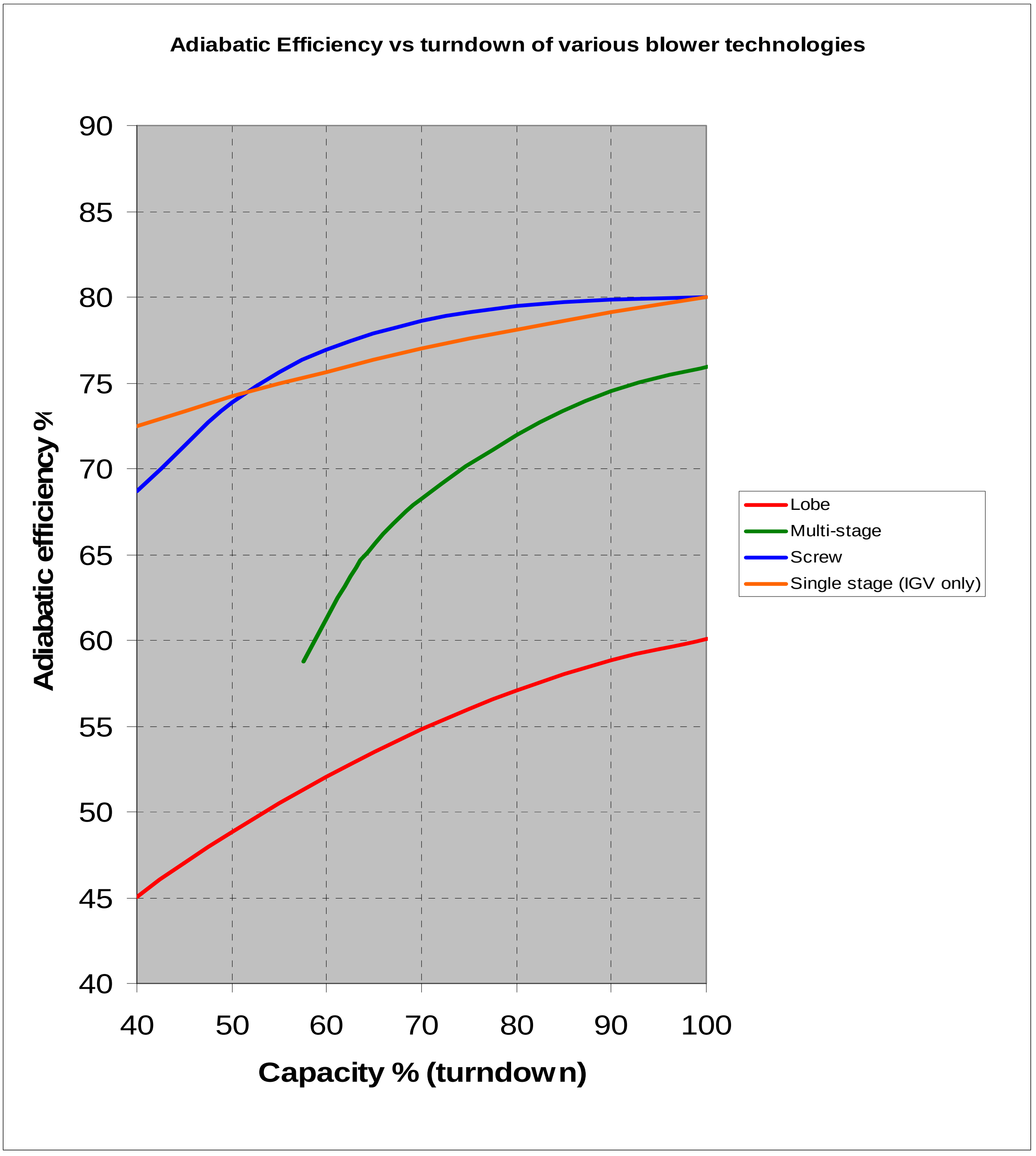


figure 9

5. Efficiency during turndown

Most compressed air applications that use blowers in both industrial and wastewater markets, require a blower that is able to change the delivered air flow.

This can be accomplished by cycling the blowers, throttling the suction, adjusting outlet diffuser vanes, or using adjustable speed drives. In most small flow blowers it is the latter that is the preferred choice.
The change in efficiency is a very important issue to understand as most applications do not always need the exact amount of air that is produced when a blower is running at it's maximum flow.
The below chart shows how adiabatic efficiency changes with respect to turndown in capacity. As can be seen the screw blower maintains a more stable efficiency compared to a lobe blower.



6. Pressure pulsations

Traditionally, “Roots” blowers were designed around two lobed rotors. Lobe blower manufacturers put a lot of effort in trying to reduce the pressure pulsations from 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 offer a smoother flow and for further reduction of pressure pulsations, helical rotors and special canals are milled in the blower casing to pre-fill the reverse chamber.

The strong pulsating torque 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.

The higher rotational speed and the higher number of lobes results in a higher pulsation frequency. Pulsations with higher frequencies are easier to dampen and result in lower noise levels and lower pulsation levels in the system discharge line.

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

Inside the blower, the reduction in pulsations results in fewer vibrations transmitted to the bearings, increasing the bearing lifetime.

Experimental comparison

7. “Roots” 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.

“Roots” blower data is commonly offered by giving the air intake flow volume and the shaft power of the bare element. Low pressure compressors 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 not considered in the data of lobe blowers while they are taken into account in the low-pressure compressor data. In order to make the available “Roots” blower data comparable to other technologies, the efficiencies and losses of the other blower components have to be determined.

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 “Roots” 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 “Roots” 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 “Roots” type blower 1000 m³/h, 0.7 bar(e)	medium “Roots” 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 “Roots” type blower 1000 m³/h, 0.7 bar(e) 30 kW	medium “Roots” 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.

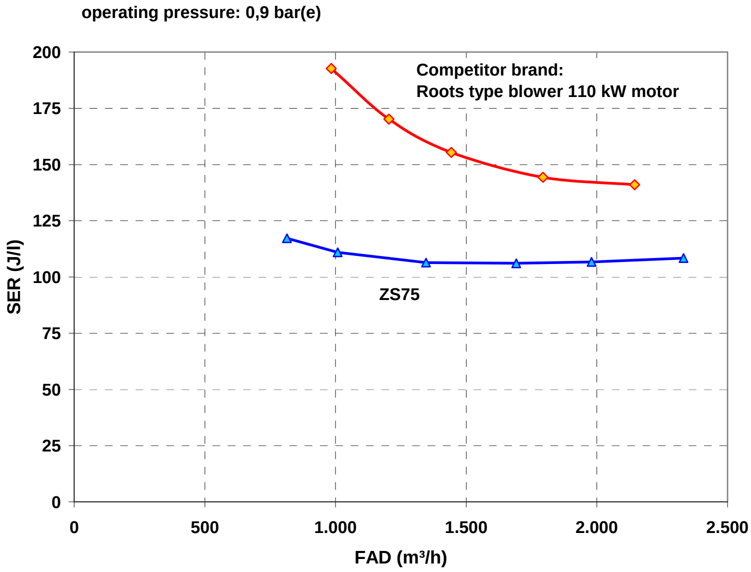
8. Laboratory test: “Roots” vs screw technology

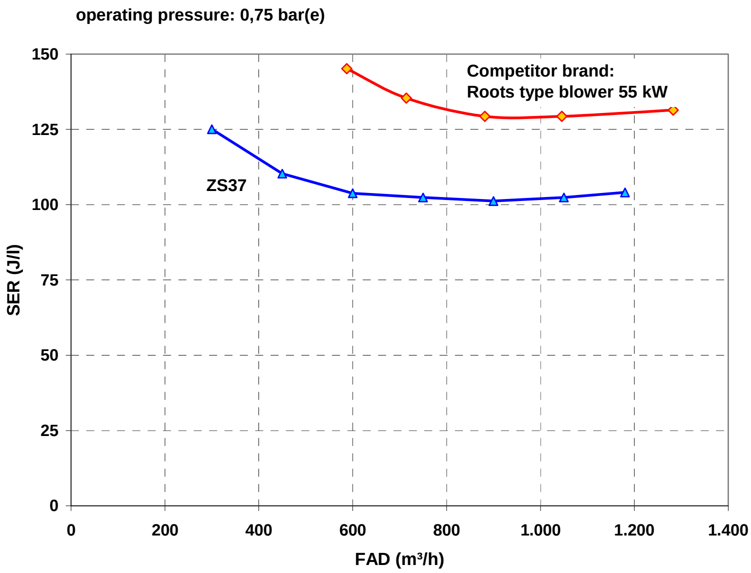
It has been shown that neither leaflet data nor test data from different suppliers using different technologies can be used in order to analyze the energy efficiency. The only way to compare the performance of machines is a laboratory test in which different technologies work in the same environment under equal operating conditions, while 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 “Roots” 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 “Roots” 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 “Roots” blower (2,145 m³/h) shows a 32.1 % higher specific energy consumption (“Roots”: 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 % (“Roots”: 191.7 J/l, screw 117.2 J/l).





In addition to these tests it was decided to allow TÜV Rheinland to witness the testing of a screw blower against a tri-lobe blower. 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

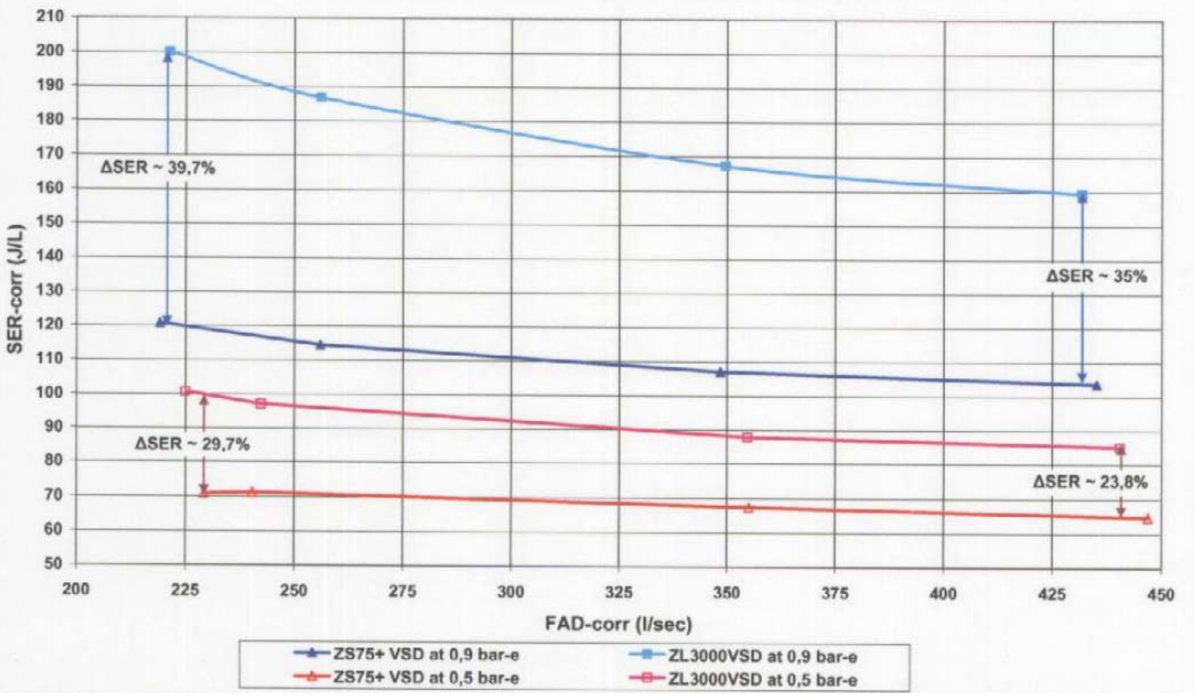
B-2610 Wilrjik (Belgium)

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 considered an energetic study between a traditional “Roots” blower and a screw blower. The experimental results show a strong correlation with the basic thermodynamic laws and present a screw blower as a more efficient machine, even up to 50% less energy consumption.

References

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