ENERGY EFFICIENCY OF SCREW COMPRESSOR

EFICIENȚA ENERGETICĂ A COMPRESOARELOR CU ȘURUB

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Abstract: *The energy efficiency of the screw compressor is a measure of its ability to efficiently use electrical energy in the process of compressing air or gas. High energy efficiency is particularly important in order to minimize energy consumption and associated costs. The lower the specific power, the higher the energy efficiency. This article will look at the theoretical energy efficiency compared to the actual energy efficiency of a screw compressor. A compressor with a rotor spacing of 180mm was chosen, as this was the first product in the new range of screw compressors manufactured by I.N.C.D.T Comoti.*

Keywords: energy efficiency, screw compressor

Rezumat: *Eficiența energetică a compresorului cu șurub reprezintă o măsură a capacității acestuia de a utiliza eficient energia electrică în procesul de comprimare a aerului sau gazului. O eficiență energetică ridicată este deosebit de importantă în scopul minimizării consumului de energie și a costurilor asociate. Cu cât puterea specifică este mai mică, cu atât eficiența energetică este mai ridicată. În acest articol se va analiza eficiența energetică teoretică în comparație cu eficiența energetică reală a unui compresor cu șurub. A fost ales un compresor cu distanța între rotori de 180mm, deoarece acesta a fost primul produs din noua gamă de compresoare cu șurub fabricate de I.N.C.D.T Comoti.*

Cuvinte cheie: eficiență energetică, compresor cu șurub

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1. Introduction

Oil-injected screw compressors were invented in the 1930s by German engineer Heinrich Krigar. Initially, they were used in industrial applications to compress natural gas, but in the 1950s, they began to be used to compress air as well. Over time, these compressors were improved by adding oil injection into the compression chamber, which helped reduce wear and prevent the compressors from overheating. Thus, they have become increasingly popular in industrial and commercial applications as they are known for their reliability and efficiency.

In Romania, National Research and Development Institute for Gas Turbines COMOTI is the sole manufacturer of natural gas screw compressors and compression groups equipped with oil-injected screw compressors and an important competitor on the market of such equipment. It is specialized in improving, diversifying and continuously modernizing its products in order to meet the requirements of the various requested applications and to raise the technical level of the products from other partners on the market and in the research and development niche.

2. Power consumption calculation

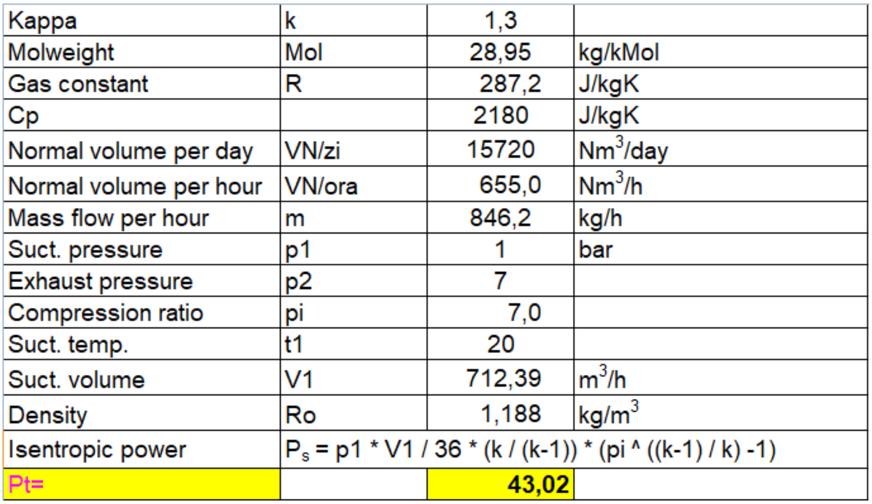
Notations:

P_t - theoretical power
m - mass flow [kg/s]
R - universal gas constant [J/kg/K]
K - adiabatic transformation coefficient [-]
$T1$ - suction temperature
p_1 - suction pressure [bara]
p_2 - discharge pressure [bara]

The theoretical power P_t used to compress the gas is defined by the formula:

$$P_{t.} = mRT_1 \frac{k}{k-1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} - 1\right][\text{kW}] \qquad (1)$$

With the help of a COMOTI developed software we can simulate the parameters of the compression process of a screw compressor:



Kappa	k	1,3	
Molweight	Mol	28,95	kg/kMol
Gas constant	R	287,2	J/kgK
Cp		2180	J/kgK
Normal volume per day	VN/zi	15720	Nm^3/day
Normal volume per hour	VN/ora	655,0	Nm^3/h
Mass flow per hour	m	846,2	kg/h
Suct. pressure	p1	1	bar
Exhaust pressure	p2	7	
Compression ratio	pi	7,0	
Suct. temp.	t1	20	
Suct. volume	V1	712,39	m^3/h
Density	Ro	1,188	kg/m^3
Isentropic power	P_s = p1 * V1 / 36 * (k / (k-1)) * (pi ^ ((k-1) / k) -1)		
Pt=		43,02	

Figure 1. Simulated parameters of the compression process

3. Compression efficiency

According to the leakages that occur between the compression chambers in the screw compressor, in figure 2 the volumetric efficiency is plotted against the peak speed of the compressor rotors for the screw compressor without oil injection and for the screw compressor with oil injection.

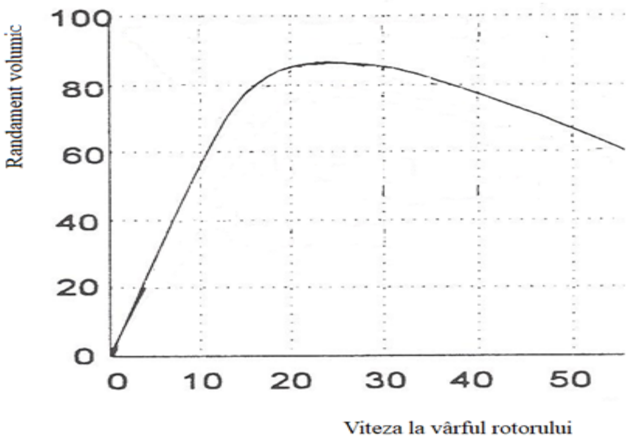


Figure 2. Volumetric efficiency of oil-injected screw compressor (O'Neill, 1993)

3. Volumetric efficiency

Notations:

V_a - real volume [m3/min]
V_t - theoretical volume [m3/min]

The volume of air intake into the cavity created by the lobes largely depends on the profile characteristics of the rotors and their number. It is important to note that the profile formed between the rotors and the housing is uniform along its entire length. More precisely, the amount of air drawn in during rotation can be determined using the following formula: Va = free airfoil area x rotor length. It is essential to consider that this formula is based on the specific shape of the airfoil and the geometric properties of the rotor, which influence the volume of air drawn in. Therefore, a clear understanding of these aspects can help optimize system performance.

Figure 3 shows how the volume in the compression chamber varies during the suction and discharge processes.

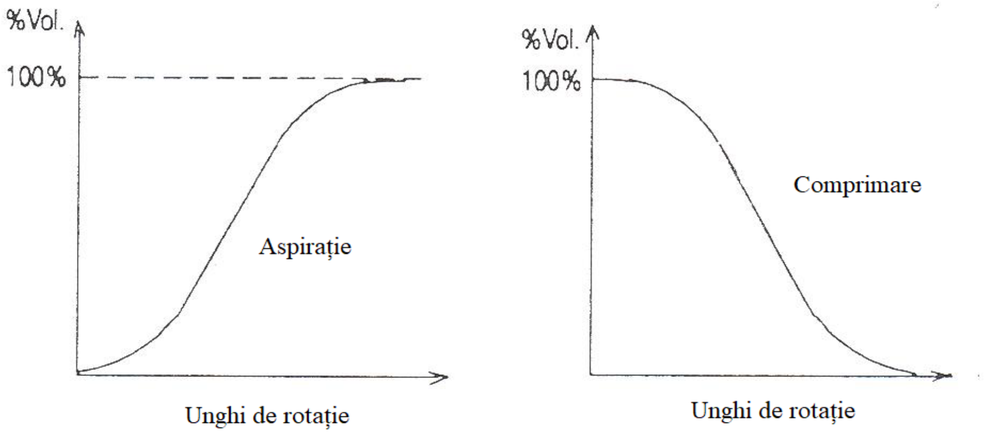


Figure 3. Volume characteristic depending on the angle of rotation

The airfoil wrap angle determines when the compression process starts depending on the rotor position. When a wrap angle is small, compression does not begin until the suction volume is completely filled, resulting in a reduced volumetric efficiency of the compressor. On the other hand, a large winding angle leads to a significant overlap of the rotors and the return of gas back into the suction chamber, but ensures a high volumetric efficiency. [1]

The winding angle is defined exclusively for the main (male) rotor, which has a value between 250 and 350 degrees. The winding angle for the secondary (mother) rotor is determined by defining the winding angle of the main rotor. [2].

A typical value of the profile twist angle is 300° which allows only a small re-engagement of the rotors (figure 4).

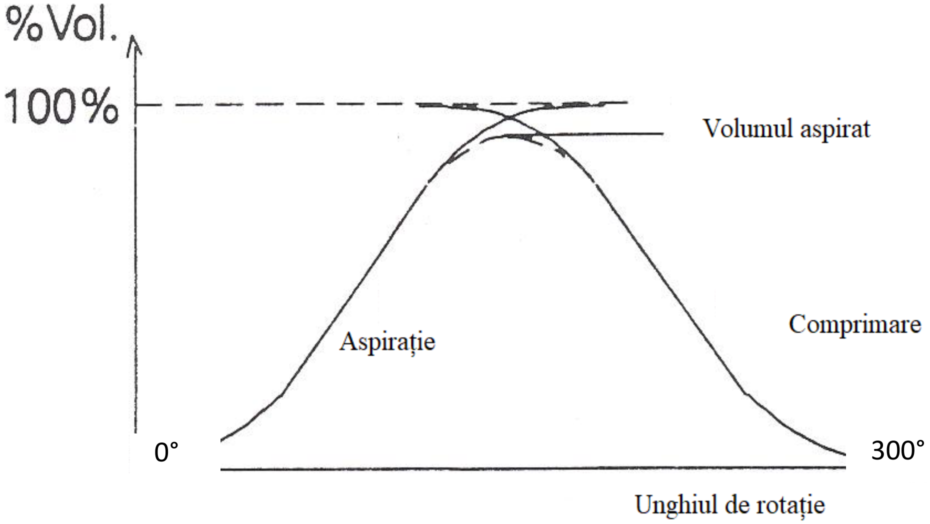


Figura 4. Suction cycle – discharge for a twist angle of 300°(O'Neill, 1993)

The volumetric efficiency of a screw compressor is determined by dividing the actual volume of compressed air or gas, considering the operating conditions of the compressor (pressure and temperature), by the theoretical volume of compressed air or gas. [4] The theoretical volume is obtained through 3D modeling of the chamber compression after the suction process is completed.

The calculation formula for the volumetric efficiency of a screw compressor is as follows:

$$\eta_v = \frac{V_a}{V_t} \cdot 100\% \qquad (2)$$

The theoretical volume (figure 5) is calculated based on the geometric dimensions (3D modeling) of the compression chamber and the speed of rotation of the rotors. To obtain the actual volume, the flow of compressed air or gas must be measured and the temperature and pressure at the inlet and outlet of the compressor must be taken into account.

Volumetric efficiency plays a crucial role in assessing the efficiency of a compressor and can be utilized to calculate the specific energy consumption (kW/m3/min or kW/cfm) of the compressor. Enhancing the volumetric efficiency of the compressor can be achieved through alterations in the compression chamber geometry, increasing the rotation speed, or utilizing higher-performing materials to minimize pressure and energy losses. [3]

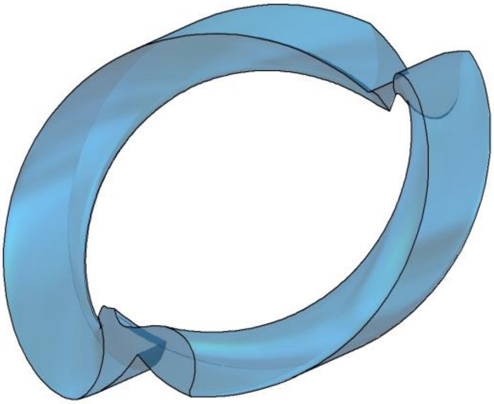


Figure 5. 3D model of compression chamber volume

4. Experimental tests

In this table, the various parameters are listed, including the speed of the system in revolutions per minute (RPM), the discharge pressure in bar, the measured mass flow rate in normal cubic meters per hour (Nm^3/h), the calculated mass flow rate in Nm3/h, the measured power consumption in kilowatts (kW), the calculated power consumption in kW, the measured specific power in kW/Nm^3*min, and the theoretical specific power in kW/Nm^3*min.

Table 1. **Measured and calculated values of a compressor with a distance between rotors of 180mm**

Speed (rpm)	Discharge pressure (bar)	Measured mass flow (Nm^3/h)	Calculated mass flow (Nm^3/h)	Measured Power (kW)	Calculated power (kW)	Measured specific power (kW/Nm^3*min)	Theoretical specific power (kW/Nm^3*min)
1116.03	5.98	730.48	841.15	70.73	43.02	6.39	3.76
1680.36	5.98	1118.67	1266.47	106.49	69.39	6.18	4.03
2219.45	6.09	1488.82	1672.79	140.65	99.07	5.65	4.35
2786.92	5.96	1855.34	2100.48	176.61	121.57	5.71	4.25
3344.93	6.04	2189.37	2521.06	211.98	144.83	6.02	4.22
1109.73	7.54	723.10	836.39	80.52	49.85	7.31	4.38
1674.05	7.56	1103.33	1261.72	121.47	80.23	7.08	4.67
2232.07	7.54	1493.48	1682.29	161.96	114.88	6.46	5.02
2790.08	7.54	1838.88	2102.87	202.45	141.45	6.59	4.94
3357.55	7.48	2187.79	2530.56	243.62	167.42	6.85	4.86
1122.34	9.06	725.06	845.90	91.48	56.02	8.29	4.87
1674.05	8.94	1088.21	1261.72	136.46	88.73	7.91	5.17
2232.07	9	1460.54	1682.29	181.94	125.64	7.34	5.49
2793.22	9.02	1815.72	2105.24	227.68	156.40	7.50	5.46
3360.71	9	2171.10	2532.95	273.94	186.76	7.69	5.42
1116.03	10.59	723.56	841.15	97.28	60.79	9.29	5.31
1677.19	10.54	1088.14	1264.09	146.19	96.95	8.94	5.64
2232.07	10.46	1450.39	1682.29	194.56	136.51	8.15	5.96
2793.22	10.46	1812.20	2105.24	243.47	170.56	8.26	5.95

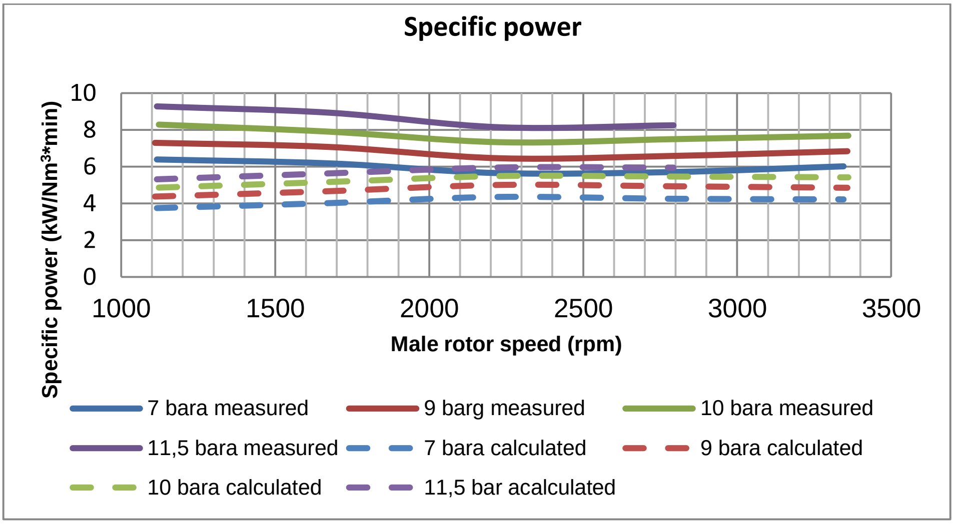


Diagram 1. Measured and calculated specific power
X-axis: The x-axis represents the male rotor.
Y-axis: The y-axis represents the specific power.

Theoretical Specific Power: This line represents the ideal or calculated specific power based on equations presented above. It demonstrates the expected or optimum specific power under ideal conditions.

Measured Specific Power: These points are obtained from experimental data. They indicate the specific power values observed or measured in real-world conditions.

By plotting the measured specific power data points and comparing them to the theoretical specific power line, it is possible to analyze the performance of the screw compressor.

The measured specific power at different pressures exhibits an ideal speed range between 2200 and 2400. This observation suggests that within this speed range, the system or component achieves a desirable level of efficiency and performance in terms of power consumption or output per unit of the specific parameter being analyzed.

5. Conclusions

In conclusion, this scientific article underscores the crucial role of energy efficiency in screw compressors and emphasizes the significance of specific power as a key metric for assessing their efficiency. The specific power of a screw compressor represents the power consumption or output per unit of a specific parameter, such as mass flow rate or displacement.

The findings of this study demonstrate that a lower specific power corresponds to a more efficient screw compressor. This implies that by achieving a lower specific power, the compressor is able to deliver a greater output or achieve the desired compression with reduced energy consumption. Consequently, this leads to substantial energy savings and cost reduction in various industrial applications.

The importance of energy efficiency in screw compressors cannot be overstated, considering the widespread use of these machines in various sectors such as manufacturing, refrigeration, and air conditioning. The significant energy requirements of compressors necessitate a focus on optimizing their efficiency to minimize environmental impact and enhance sustainability.

By understanding and evaluating the specific power of screw compressors, engineers and manufacturers can make informed decisions to enhance the overall performance and efficiency of these systems. Advancements in compressor design, operating strategies, and maintenance practices can be employed to achieve lower specific power values, leading to more energy-efficient operations and reduced carbon footprints.

In summary, this research highlights the paramount importance of energy efficiency in screw compressors, emphasizing the critical role of specific power as a key indicator. By striving for lower specific power, it is possible to achieve higher levels of efficiency, resulting in substantial energy savings and contributing to a greener and more sustainable future.

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