Analysis of opportunities for energy savings in reciprocating and screw compressors depending on the operating mode

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Analysis of opportunities for energy savings in reciprocating and screw compressors depending on the operation mode: *Many types of industrial processes accomplishes by the means of compressed air. The energy needed for the production of compressed air accounts as much as 10% of the industrial electricity consumption. In Bulgarian industry the most commonly used compressor are screw and reciprocating type. In a relation with a huge amount of electricity needed for running of those machines in current article are presented the ways of increasing their energy efficiency during operation.*

Key words: *Screw compressors, Reciprocating compressors, Energy efficiency.*

INTRODUCTION

Compressed air is an energy carrier widely used in many types of industrial processes but it is the most expensive utility in a plant. It accounts for as much as 10% of industrial electricity consumption. The advantages of air are that it is clean, safe, non-toxic and it can be stored.

There are three different types of compressed air:

- active compressed air is used for transporting e.g. goods, raw materials;
- process compressed air is needed for the production processes e.g. drying, ventilation;
- vacuum air is used for packaging, positioning.

The compressed air systems consist of following major components - intake air filters, inter-stage coolers, after coolers, air dryers, moisture drain traps, receivers, piping network, filters, regulators and lubricators (see Figure 1).

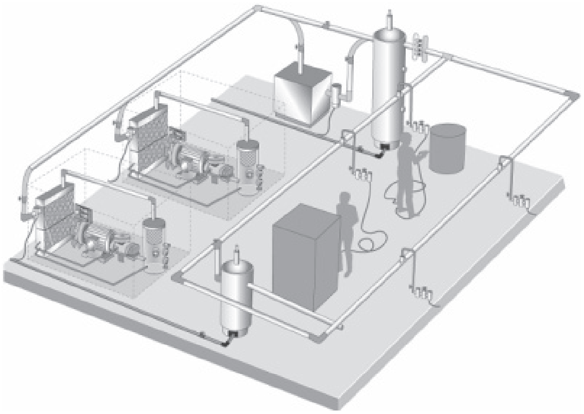


Fig.1. General view of the industrial compressed air system with major components [1]

The compressors that are commonly used in the industry are reciprocating, vane, screw and centrifugal. Table 1 gives information about the specifics in the abovementioned types of compressors.

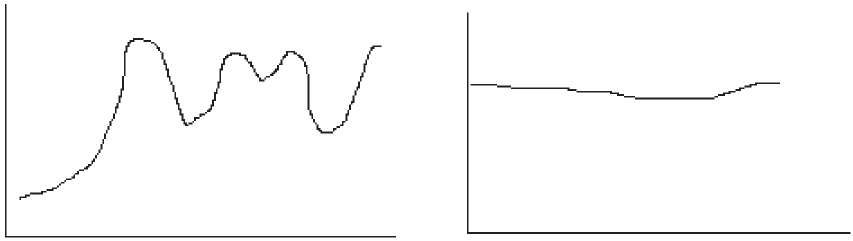
The focus in this article is about the reciprocating and screw compressors because they are most commonly found in Bulgarian industry. What type of compressor should be used? Of course there is no general answer to this question. Each compressor type has its particular advantages, depending on the specifics of the operating conditions. The energy consumption strongly depends on state of the compressor, operating conditions, load of the system and etc.

Table 1. Specifics for different types of compressors

Compressor type	Specifics
Reciprocating	Oscillating forces High end temperatures High maintenance Noisy Relatively expensive
Vane	Limited capacity range Oil residues in the air
Screw	Oil residues in the air
Centrifugal	Sensitive to dirt in air Relatively high cost Energy efficient

Reciprocating compressors are by far the best choice in small flow rates in situations where operation is short-term or intermittent, and load is fluctuating (figure 2a).

Screw compressors are best used where you need a relatively constant "base load" air supply (figure 2b).



a) b)

Fig.2. Load characteristics in operation of a) reciprocating and b) screw compressors

APPROACH TO IMPROVING THE ENERGY EFFICIENCY

There are different measures of compressor efficiency – volumetric, adiabatic, isothermal and mechanical efficiency [3].

The isothermal efficiency of such types of machines can be obtained by using the following relation (Eq. 1) [4, 5]:

$$\eta_{isoth} = P_{input}/P_{isothermal} \quad (1)$$

$$P_{isothermal} = P_1.Q.\log_e r/36.7 \quad (2)$$

where:

$P_1 - absolute\ intake\ pressure, Pa;$ $P_2 - compressed\ air\ pressure, Pa;$ $Q - delivered\ air, m^3/h; r - presure\ ratio, P_2/P_1.$

In this way calculated compressor isothermal power does not include power needed to overcome friction and generally gives an efficiency that is lower than adiabatic efficiency. The reported value of efficiency is usually the isothermal efficiency. This is an important consideration when selecting compressors based on reported values of efficiency.

The volumetric efficiency of the compressors is the ration of air delivered to compressor displacement. Below is presented the respective relation (Eq. 4):

$$\eta_{vol} = Q_{delivered}/L_{displ} \quad (3)$$

$$L_{displ} = N.(D^2/4).L.S.N.n \quad (4)$$

where:

$D - cylinder\ bore, m; L - cilynder\ stroke, m; S\ compressor\ speed, min^{-1};$
$N\ is\ 1\ (single\ acting), and\ 2\ (double\ acting\ cylinders), n - number\ of\ cylinders.$

Concerning practical applications the most effective way of comparing the compressor efficiencies is the specific power consumption or kW per volume flow rate (kW/m^3/h).

Concerning improving the efficiency in **screw compressors** the following measures can be taken into account:

- *Reducing the pressure system*

It is important to ensure that the air pressure at the compressor is the minimum required to do the job. As a general rule, for every 1 bar reduction in operating pressure resulting in about 6-7% energy savings. Table 2a presented the energy and cost savings as a result of reduction of pressure in the system with 1 bar.

- *Air leakages*

Leakage levels at facilities are typically between 20-25%, but still 50% are not unusual for the systems. Well operating systems has the leakage percent below 10%.

Approximately leakage losses can be calculated with the following relationship (Eq. 5):

$$Q_{leaks} = \frac{Time\ on\ load.100}{(Time\ on\ load + Time\ off\ load)}, l/s \qquad (5)$$

Table 2b presented the energy and cost savings as a result of air leakages reduction in the amount of 25%.

- *Implementation of high energy efficient motors*

High efficient motor will be within about 1.5 to 2% more efficient than the standard compressor. The efficiency (energy and costs) because of the implementation of efficient motors is presented in Table 2c.

- *Implementation of multistage compressors*

Multistage screw compressors are between 10 and 13 % more efficient than the single stage. An example of energy efficiency in implementation of multistage compressor is presented in Table 2d.

- *Implementation of VSD*

VSD compressors are designed to control discharge pressure within a very accurate range while within the compressor's variable speed range. However, VSD compressors can only slow down so much, with the minimum speed point often depending on the characteristics of the compressor. Below the minimum speed point, the compressor acts like a load/unload (or start/stop) controlled compressor with the compressor operating between two set pressure settings.

Implementation of VSD compressor control (rather than inlet modulation) leads to an energy savings in the amount of up to 70%. Example of reaching the efficiency with the implementation of VSD compressors is presented in Table 2e.

- *Variable inlet volume*

As a result of using variable inlet volume compressor than inlet modulation leads to the energy savings in the amount of up to 45%. An example is presented in Table 2f.

In Figure 3 is presented the energy balance for typical reciprocating compressors.

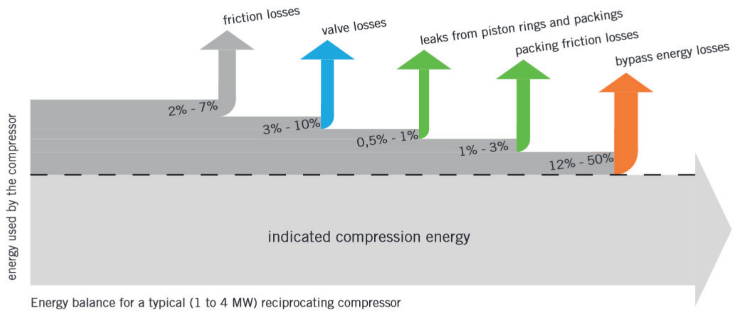


Fig.3. Energy balances for reciprocating compressors

Table. 2. Energy and costs savings as a result of a) reducing pressure system, b) reducing air leakages, c) implementation of high energy efficient motors, d) implementation of multistage compressors, e) implementation of VSD, f) variable inlet volume [2]

a)

Parameter	Your Data	Unit
Motor Power :	55.00	[kW]
Motor Efficiency :	90%	[%]
% Full Load :	65%	[%]
Annual Operation Hours :	8 000	[h/y]
Pressure Reduction :	1.00	[bar]
Annual Energy Consumption :	317 778	[kWh/y]
% Savings :	6.5%	[%]
Annual Energy Savings :	20 656	[kWh/y]
Average Electricity Price :	€0.097	[€/kWh]
Annual Cost Savings :	**€2 007**	[€/y]

b)

Parameter	Your Data	Unit
Rated Free Air Delivery (FAD) :	160	[l/s]
Time on Load	5	[min]
Time off Load	15	[min]
% Air Leaks :	25%	[%]
Air Leakage rate :	40	[l/s]
Approximate Energy Wasted :	28 000	[kWh/y]
Average Electricity Price :	€0.097	[€/kWh]
Approximate Energy Cost of Leakage :	**€2 716.00**	[€/y]

c)

Parameter	Your Data	Unit
Motor Power :	55.00	[kW]
Motor Efficiency :	92%	[%]
% Full Load :	65%	[%]
Annual Operation Hours :	8 000	[h/y]
Annual Energy Savings :	4 987	[kWh/y]
Average Electricity Price :	€0.097	[€/kWh]
Annual Cost Savings :	**€484**	[€]

d)

Parameter	Your Data	Unit
Motor Power :	55.00	[kW]
Motor Efficiency :	92%	[%]
% Full Load :	65%	[%]
Annual Operation Hours :	8 000	[h/y]
% Savings over Single- stage:	12%	[%]
Annual Energy Savings :	37 304	[kWh/y]
Average Electricity Price :	€0.097	[€/kWh]
Annual Cost Savings :	**€3 619**	[€]

e)

Parameter	Your Data	Unit
Motor Power :	55.00	[kW]
Motor Efficiency :	90%	[%]
VSD Efficiency :	95%	[%]
Average Part Load Condition :	65%	[%]
Annual Operation Hours :	6 000	[h/y]
Average Power Saving :	14.22	[kW]
Annual Energy Savings :	85 342	[kWh/y]
Average Electricity Price :	€0.097	[€/kWh]
Annual Cost Savings :	**€8 278**	[€/y]

f)

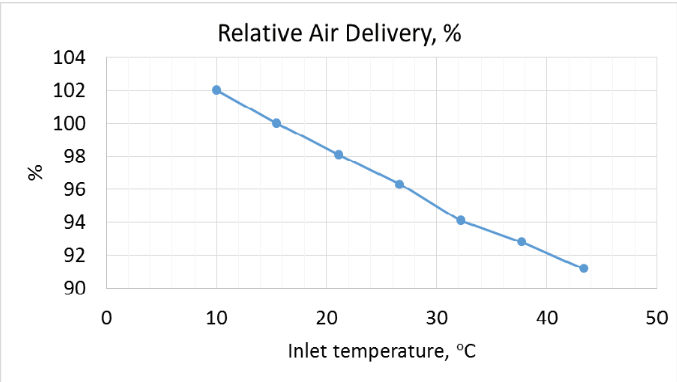
Parameter	Your Data	Unit
Motor Power :	55.00	[kW]
Motor Efficiency :	90%	[%]
Average Part Load Condition :	75%	[%]
Annual Operation Hours :	6 000	[h/y]
Average Power Saving :	6.88	[kW]
Annual Energy Savings :	41 250	[kWh/y]
Average Electricity Price :	€0.097	[€/kWh]
Annual Cost Savings :	**€4 001**	[€/y]

The location of air compressors and the quality of air drawn by the compressors will have a significant influence on the amount of energy consumed. Compressor performance as a breathing machine improves with cool, clean, dry air at intake.

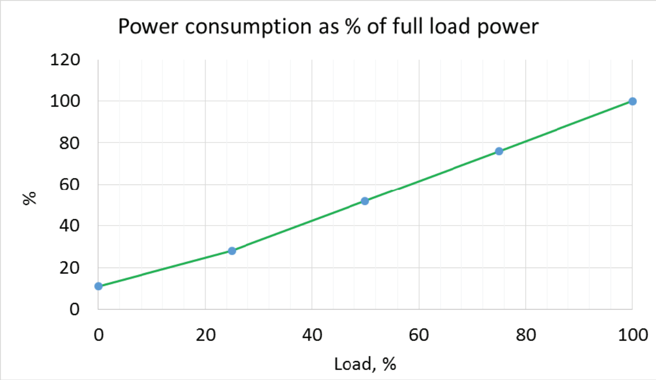
As a rule, "Every 4°C rise in inlet air temperature results in a higher energy consumption by 1% to achieve equivalent output".

In figure 4 a) and b) is presented the relation between inlet temperature and relative air delivery (in %) and power consumption as a % of full load power.

It should be considered here that the effective operational mode of the machines is closely related with characteristic of the pipe network [6, 7, 8].



a)



b)

Fig.4. a) Relative air delivered as a function of inlet temperature, b) power consumed as a % of full load power

In addition fhe following rules should be considered in determination of energy efficiency in reciprocating compressors:

- Clean air-inlet filters regularly. Compressor efficiency will be reduced by 2 percent for every 250 mm H_20 pressure drop across the filter.
- Keep compressor valves in good condition by removing and inspecting once every six months. Worn-out valves can reduce compressor efficiency by as much as 50%.
- Minimize low-load compressor operation; if air demand is less than 50 percent of compressor capacity, consider change over to a smaller compressor or reduce compressor speed appropriately (by reducing motor pulley size) in case of belt driven compressors.
- Retrofit with variable speed drives in big compressors, say over 100 kW, to eliminate the “unloaded” running condition altogether.

CONCLUSION

In the paper are presented the options for the improving the efficiency in screw and reciprocating compressors. As the most efficient measures that can be applied in the screw compressor are reducing the operating pressure in the system, reducing the air leakages and implementation of multistage compressors. In reciprocating compressors reducing the end temperature, losses in the valves and bypasses can be indicated as important energy efficiency measures.

REFERENCES

[1] http://www.uzngi.uz/en/energo

[2] http://www.seai.ie/

[3] Confederation of Indian Industries. Manual on Compressors and Compressed Air Systems.http://greenbusinesscentre.com/documents/compressor.pdf

[4] Kostov B., G. Popov, K. Klimentov, Effective regulation of the flow rate of parallel working pumps, „Machines, Technologies, Materials“, Sofia, Bulgaria 2013 (International Virtual Journal), (p.p. 57-59).

[5] Energy Efficiency Guide for Industry in Asia –www.energyefficiencyasia.org

[6] Попов Г., Б. Костов, К. Климентов, Изследване на енергийно-ефективните работните полета на помпени агрегати“ - „Топлотехника“, 2013, бр. 5, стр. 40-43.

[7] Popov G., Klimentov Kl., Kostov B. “Investigation of the energy consumption in regulating the flow rate of pump systems” – “DEMI2011”, Banja Luka (Bosnia), 2011, pp. 481-487.

[8] Popov G., Klimentov Kl., Kostov B. “Methods to estimate the energy consumption in regulating the flow rate of pump systems” – “DEMI2011”, Banja Luka (Bosnia), 2011, pp. 495-500.

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