

Rational use of energy and waste heat at compressor plants in the wood processing industry of Serbia

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Abstract: Obtaining pressurized air represents a significant expenditure of energy for every branch of industry, and today it is simply unthinkable to exist industrial plants without the production, distribution and use of pressurized air. This is particularly representative in the wood processing industry where it has been shown that there is a low awareness of the savings that can be made with the produced air under pressure, starting from its proper use to the use of waste heat through recovery. Bearing the above in mind, research was carried out in companies of the wood industry in Serbia in order to analyze the economics of obtaining and adequate use of pressurized air. Also, solutions were suggested for the recovery of waste heat in screw and reciprocating compressor plants, which are most present in the wood processing industry, as shown by the survey. The conclusions were drawn in the form of guidelines for the rational use of pressurized air, which can bring significant savings in energy consumption and increase efficiency and productivity in work.

Keywords: compressors, energy savings, heat recovery, wood industry.

1. Introduction

Pneumatic plants are widely used in many branches of industry. They are also present to a large extent in the wood industry, so today it is unthinkable existence even a micro-enterprise without having at least one compressor with a tank and the use of pressurized air. The application of pressurized air in the wood industry involves various purposes, such as [2]:

- the main movement of machines (pneumatic tools, presses, staplers, etc.)
- auxiliary movements of machine tools (drills, grinders, canting, etc.)
- cleaning workplaces and surfaces from waste (sawdust)
- painting and varnishing (pneumatic guns for applying varnish)
- creation of overpressure in the painting cabins
- pneumatic transport

As the production of pressurized air is a significant consumer of energy, the idea was to conduct research on the state and use of pneumatic systems in the wood processing industry on the territory of Serbia [3]. This research involved a detailed analysis of pneumatic systems from the aspects of: energy efficiency, its proper use, maintenance, etc. In order to obtain reliable data on the actual state of pneumatic equipment and gain insight into the proper exploitation and maintenance of pneumatic systems, a survey was compiled in the form of a questionnaire, which will later be processed and analyzed. Participants in the survey were asked to give their answers as conscientiously and honestly as possible, so that the importance of the survey would make sense. The goal of this research is to assess how much attention companies actually pay to pneumatic equipment: choosing its quality, proper maintenance and economical use; as well as the utilization of the waste heat generated by the compressors. Also, the research will show: the age of the pneumatic equipment, the types of compressors used and whether the capacities of the tanks used are commensurate with the needs.

2. Research results with analysis

The following participated in the research: micro, small, medium, and in the smallest percentage 7.69% large companies. The classification was made according to the literature of internet sources [8], supported by the law on accounting [6].

In the sample on which the research was conducted, according to the mentioned classification of companies, the largest percentage share includes micro-enterprises with even more than 80%, which according to [9] depicts the state of the timber industry in Serbia. This confirms that the sample of the 15 mentioned company was representative.

The analysis of the research results was carried out for the questions from the questionnaire, the survey and the necessary conclusions were drawn.

The results of the age of the equipment are shown in table 1. It was surprising that more than 69% of the companies were dominated by newer equipment up to 5 to 10 years old. If we take into account that according to European research, according to [5], the lifespan of compressors with engine power from 10 to 110 kW is about 13 years, it can be concluded that pneumatic equipment in the territory of Serbia in wood processing companies has not worn out, and that relatively regularly changes in accordance with the average recommended period of use.

About 23% of respondents stated that their equipment is between 10-15 years old. So those companies should replace the equipment to prevent unwanted downtime in production, or pay more attention to maintenance.

Table 1: Age of pneumatic equipment in companies [1]

Age of equipment	Percentage
Under 5 years	7.69 %
From 5 to 10 years	69.24 %
From 10 to 15	23.07 %

Certainly, the presence of new equipment is desirable from the point of view of greater reliability in operation, i.e. less probability of failure. On the other hand, the use of modern equipment under pressure implies a higher level of automation, etc. specificities that require greater training of the personnel who service the equipment during exploitation and, if necessary, carry out its periodic servicing.

The next question was about the type of compressor or plant used. The research results indicate that 38.46% of companies use only reciprocating compressors and 23.07% of companies have screw compressors, while 38.46% have both types. It is interesting that the companies that participated in the research do not use other types of compressors, such as: diaphragm compressors, turbo compressors, Ruts compressors, etc. All this points to the fact that these compressors are slowly going out of use, at least when they are in question in wood industry companies. This especially applies to membrane compressors, which have a larger capacity, so they are not needed in the micro-enterprises that dominate in Serbia.

The fact that reciprocating compressors are more present in the companies that participated in the research. Their purchase price is lower than screw-type ones of the same capacity, they are simpler and cheaper to maintain, and this is probably a decisive factor for slightly smaller companies in these areas.

The range of power values that would be generated at the maximum operating pressure of the compressor would be, which is impressive. If we adopt, according to [4], that 80% of this power is generated as heat due to increased pressure, including the present losses in heat transfer in order to bring it to the user, we obtain significant values of (17.6÷134.4) kW

If the cooling of the compressor is air, which is mostly present in older reciprocating compressors of smaller capacities, the recommendation for using that waste heat would be heating the rooms near the location of the compressor. When it comes to cooling the compressor through: water, oil or some other cooling agent, adaptation and the introduction of additional heat exchangers and a secondary circuit that would bring the generated heat to the place of application, along with the present transmission losses, is required. Of course, this heat would be constantly generated and recuperated because the need for compressor operation in the company is non-stop. Therefore, it would ideally serve for consumers who work all year round, such as: painting and varnishing rooms, dryers, etc.

The next question related to the possibility of separating parts of the system (executive bodies) from the central system (installation) if they are not currently working via valves. It was concluded that 76.92% of users have the ability to separate parts of the system from the central system. This is a very satisfactory percentage and is a pleasant surprise. It speaks of the awareness of our colleagues that by installing only

one valve, i.e. with insignificant costs, they achieve significant savings because potential air leakage and pressure drop in the pneumatic installation are eliminated.

The causes of pressure drop and loss of air flow in a pneumatic system are covered in the following question. The purpose was to see if the maintenance service is realistically looking at the causes of problems with the functioning of the pneumatic installation. The biggest problem of air loss in the pneumatic system is air leakage from the installation. Even up to 77% of respondents confirmed that statement. The results are shown in Figure 1.

For the maintenance survey (Figure 2), users were asked for precise and honest answers, for procedures they regularly perform. However, the analysis, to a negative surprise, says that companies absolutely do not attach so much importance to the maintenance of pneumatic equipment.

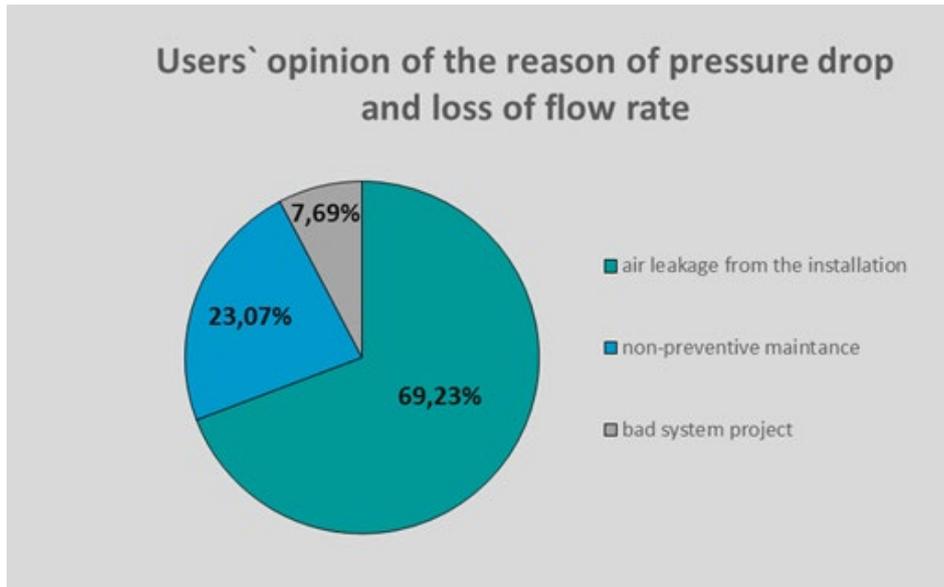


Figure 1: Losses in the pneumatic system

Unfortunately, some users pointed out that the pneumatic equipment is serviced and inspected only when it breaks down and stops working.

Regular maintenance of the pressurized air system ensures the stable development of production without unforeseen interruptions and the achievement of the set goals in the management of pressurized air, the most important of which are the continuous operation of the system and adequate supply of the end user with pressurized air. It is best to follow the manufacturer's recommendations because different systems and components have different maintenance intervals and types.

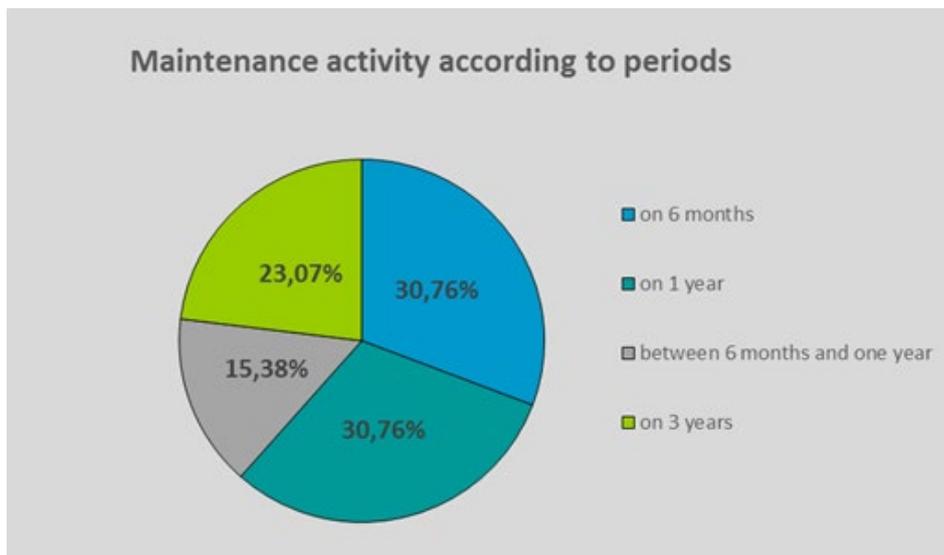


Figure 2: Periodicity of pneumatic equipment maintenance

The last question from the survey asked companies to answer whether they evaluate the efficiency of the system.

From the diagram in Figure 3, it can be seen that even 77% of the surveyed companies engaged in wood processing do not evaluate the efficiency of the system, i.e. measurement and monitoring of system performance.

Merely measuring the performance of the system will not improve energy efficiency, but it would be the first step in improving energy efficiency for two basic reasons:

- Measuring air and energy consumption is essential for determining whether changes in maintenance practices or investments in equipment are cost-justified or not.
- By monitoring the performance, negative changes are observed, as well as changes in the quantity and quality of the use of pressurized air.

As already mentioned in the introduction, the three basic parameters that are monitored are: air flow, air pressure and electricity consumption. An ultrasonic gun helps to facilitate the measurement, to help detect the location of the leak.

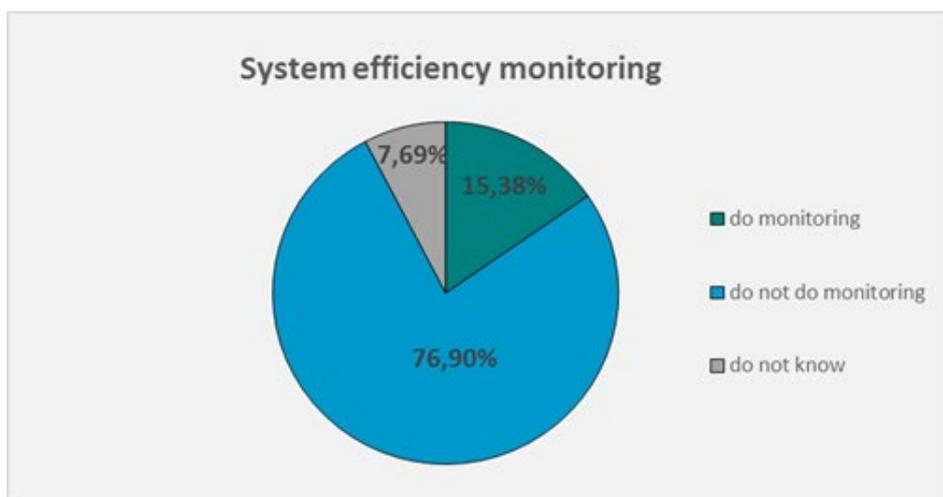


Figure 3: Evaluation of system efficiency by the company

3. Recovery of waste heat

In theory, any amount of heat that can be recovered from an industrial refrigeration system offers the possibility of improving the system's efficiency ([10], [11], [12]). Practically, the amount of recovered heat must be large enough to justify the investment in the main equipment, as well as any additional operating cost (e.g. maintenance) or complexity of the installation requires additional utilization of waste heat [7].

Locations within the industrial cooling system where it is possible to take waste heat, which is suitable for recovery, are:

- oil cooling (oil cooling with fluid in screw compressors);
- cooling of cylinder heads (piston compressors);
- high pressure gas flow:
- reciprocating compressors,
- screw compressors;
- low pressure of gas flow (minimum capabilities).

Modern screw compressors use oil for lubrication, regulated actuation and rotor sealing to maintain volumetric efficiency during the compression process. The consequence of using oil in these machines is that when the oil passes through the compressor, it absorbs part of the "heat of compression" from the cooling fluid. That is why the oil at the outlet of the compressor will be at a temperature approximately equal to the temperature of the cooling fluid on the thrust. Excluding various versions of liquid injection oil cooling, maintaining proper compressor operation requires oil cooling after compression to limit oil temperature rise. With thermo-syphon oil cooling and oil cooling with water (or glycol), heat exchangers are located in the compressor units, which cool the oil from the pressure temperature to an acceptable temperature at the compressor inlet (e.g. 54°C). Therefore, the heat removed by cooling the oil is a potential source of heat recovery.

Reciprocating compressors operating at moderate or high compression ratios require a supply of water, glycol or coolant to cool the cylinder heads. The fluid used to cool the heads (water or glycol) is another potential source of heat suitable for recuperation.

Heat recovery from the refrigerant leaving the compressor under pressure is the next obvious possibility in industrial refrigeration systems. The quality of the heat, which is available for recovery, will depend on the type of compressor (piston or screw), the operating pressures on the suction and discharge of the compressor and the load. With screw compressors, the heat quality will also vary depending on whether the oil is cooled internally (e.g. by coolant injection) or externally. By their very nature, compressors equipped with an oil cooling system by injecting a cooling fluid have lower pressure temperatures, and therefore a lower quality or energy level of heat available for recovery. Machines with coolant injection have a higher mass flow of steam under pressure, so the amount of heat that can be recovered is usually higher than in units with thermo-siphon or external oil cooling. Let's see how much heat can be recovered and what is the quality of the heat available to us from these sources. Figure 4 shows the savings in heating costs due to heat recovery for different primary fuel prices and water flow rates. The recovered heat could replace the operation of a boiler with an efficiency of 80% that would normally be used to provide heating needs.

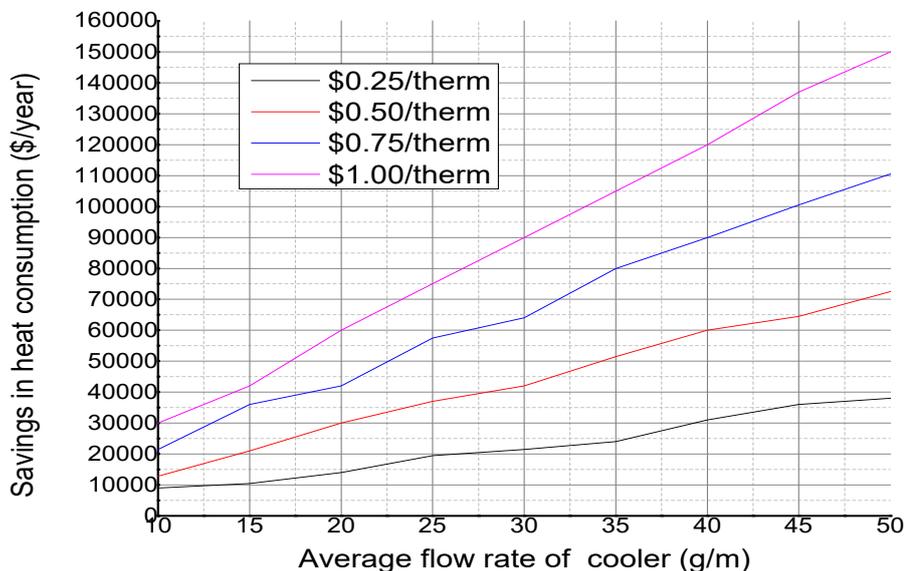


Figure 4: Annual savings in energy costs for heating at a temperature of 30°C waste water [4]

3.1. Heat recovery at oil-free compressor

1) within an air-cooled

Oil Free VSD Air Compressor with Heat Recovery as an option is the only Oil Free Air Cooled Compressor on the market today with Heat Recovery as an option.

This eliminates the need for an external cooling water system i.e. cooling water pumps, Blast Coolers, pipe work, etc. associated with water-cooled compressors. In the new Ingersoll Rand E Series Compressor, the heat exchangers, pump and controls are all within the compressor enclosure and you get usable water temperatures of up to 80°C (Figure 5).

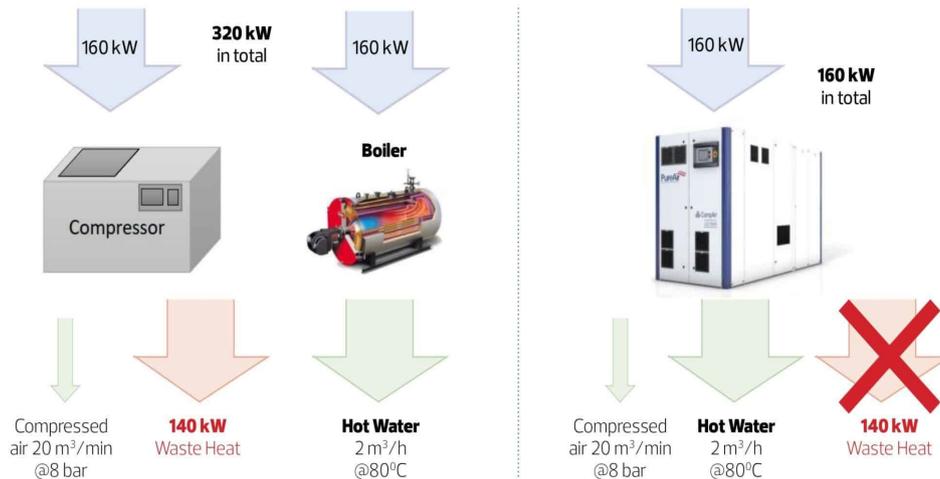


Figure 5: Oil-free compressor: a) within a water-cooled, b) within an air-cooled [16]

Thousands of savings are achievable each year as not only does the Heat Recovery element reduce energy bills, the E-Series has the lowest specific power of any Oil Free, VSD, Rotary Screw Compressor (between 75kw & 160kw) in the market today – thereby, amplifying the ability to reduce operating costs. The potential energy savings can mean a return of investment in just two to three years.

2) within a water-cooled

With water-cooled oil-free compressors, the Heat Recovery Solution requires the installation of a control unit between the compressor and the customers’ cooling and heating circuit. The compressor operates independently from the customers’ process.

3.2 Oil-lubricated compressors

Considerable savings can be achieved with oil-lubricated compressors. In fact, of the 100 percent of the electrical energy consumed, some 94 percent is converted to heat, that can be put to good use after it has been recovered (Figure 6).

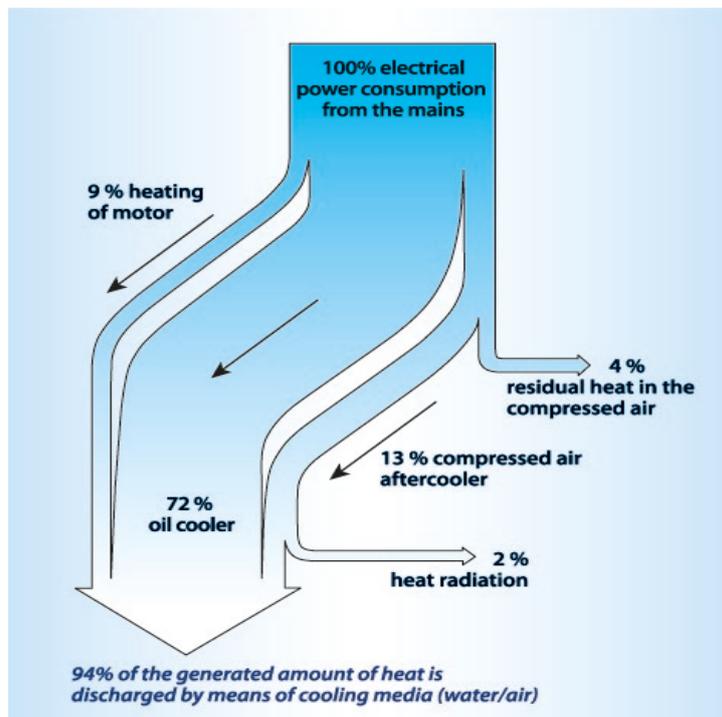


Figure 6: Exegetic diagram of utility of invested electric energy [14]

There are two ways of cooling oil-lubricated compressors:

VI. Energy efficiency in industry, civil engineering, communal systems, and traffic

1) *Thermo-siphon cooling*, the most modern solution for oil cooling in screw compressor aggregates [13]. In thermo-siphon oil cooling, saturated liquid coolant is used as a coolant in the coolant-oil heat exchanger, which is integrated into the compressor unit. The coolant liquid in the heat exchanger is at a lower temperature and therefore absorbs heat from the hotter oil and evaporates. The refrigerant vapor is then led to the condenser(s) where it condenses again, allowing it to be further used to cool the oil or meet the cooling needs of the cooling system. Thermo-siphon oil coolers are flooded evaporators with gravity circulation.

Thanks to its working principle, thermosiphon oil cooling requires a minimum amount of energy for heat exchange – only additional energy is needed to drive the condenser fans and pumps. Thermo-siphon oil cooling is particularly effective when properly constructed; however, it is also a technology that has not been satisfactory in exploitation in many plants. Improperly dimensioned thermosiphon receiver, equalization lines, return or distribution lines can individually or together cause numerous problems in installations. In addition, systems with thermos-siphon oil cooling are not particularly suitable for expansions. When problems arise in thermos-siphon systems (which happens quite often), solving and eliminating them is difficult and frustrating.

2) *Water (or glycol) oil cooling in heat exchangers* is a less commonly applied cooling technology [15]. In this method, water or a glycol solution is used as a secondary cooling fluid that receives the heat of the oil. In this case, the glycol is passed through an oil cooler, receiving heat from the oil, and then cooled, i.e. giving up heat, in a closed-type liquid cooler, which is located outside. This heat can be recovered and used to meet the relatively moderate heating needs of the plant. Typically, oil cooling heat exchangers accept hot oil from the screw compressor separator at a temperature close to the pressure steam temperature, which is in the range of 71°C to 85°C, and cool it to the temperature at which it is returned to the compressor, which most often it is 54°C. With oil in this operating temperature range we clearly have a heat source of acceptable quality (temperature). Now the question is, "What amount of oil cooling heat is available to us?" The amount of heat that can be used from the oil cooler depends on several factors, including: - compressor size (capacity); - suction pressure; - thrust pressure and - degree of partial load.

4. Conclusion

After a detailed analysis of the survey, one gets the impression that the participants in the survey answered most of the questions credibly. From all that has been stated so far, it can be concluded that pneumatic equipment on the territory of Serbia in wood processing companies:

- 1) has a wide range of uses, and is mostly used in the implementation of: main and auxiliary movement of machines, painting and varnishing;
- 2) it has not worn out, and that it is changed relatively regularly in accordance with the average recommended period of use (as many as 70% of companies own equipment between 5 and 10 years old);
- 3) it mostly uses reciprocating compressors (around 70%), while in addition to them only screw compressors are present, the use of which is gradually increasing;
- 4) generates a considerable amount of heat in the process of air compression in the compressor, which should be adequately utilized through recuperation;
- 5) it has insufficient automation of the plant, which is mainly reduced to on-off regulation of the operation of the compressor coupled to the tank; while manual and mechanical (68%) dominate the distributor activation methods;
- 6) the majority have the ability to separate parts of the system from the central system (77% of users)

What is still definitely a problem:

- that the presence of leakage is not considered, and there is no awareness of what losses are involved through the increased consumption of electricity to compensate for the losses;
- non-preventive maintenance and a small number of workers servicing pneumatic equipment (over 60% of respondents claim that there is no need to spend resources on maintenance in the service center for their equipment, but they maintain their equipment independently)

With the increase in the price of fuel used for heating, there are greater opportunities to economically recover heat from industrial cooling systems. Classical approaches to heat recovery focus on heat recovery from the steam stream at the thrust of a high-pressure compressor (superheated steam cooler). Another possibility, which should not be overlooked, is the recovery of heat from the oil coolers of screw compressor aggregates. The advantages of this solution include:

- the possibility of heat recovery from the oil cooler, both with low and high pressure compressors;
- recovery of relatively high-quality waste heat is enabled;
- the result of an oil cooling approach that is less prone to problems compared to thermosiphon oil cooling;
- the use of a fluid that receives sensible heat and a pump allows greater control over oil cooling (removes the influence of "mother nature" from the classic thermosiphon circuit);
- it is easier to adapt to the addition of new compressors when expanding the plant compared to systems with thermos-syphon cooling;
- great possibilities for modification of compressors with oil cooling by injection of cooling fluid liquid;
- makes the cooling of the oil independent of the pressures in the system, which enables easier commissioning; and
- enables the use of plate heat exchangers without fear of pressure drop on the coolant side.

Although the advantages are attractive, other factors must be considered when applying this method of heat recovery. First, each compressor unit must be equipped (or modified) with a suitable oil cooler. Second, the heating needs should match the cooling heat of the oil. If there is a mismatch between heating needs and supplied heat, additional infrastructure is needed to accommodate this mismatch. Finally, the economy of heat recovery from the oil cooler needs to be evaluated on a case-by-case basis.

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