

Decrease of the cost of drying compressed air by heat recovery at the compressor station

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Abstract. Compressed air is widely used as an energy carrier. The compressed air production systems are a part of the auxiliary systems of off-site facilities. It is worth noting that the production of compressed air is quite an energy-intensive process, so the potential for energy saving is quite large. There is increasing the efficiency of the compressed air production by developing technology solutions for air preparation in this work. The system of air drying by cooling and the source of cold are considered in this paper. The paper presents a comparison of cooling systems from steam compression and absorption refrigerating machines from the point of view of heat exchange, energy consumption for their own needs, providing cold with required parameters. The economic effect of the proposed circuit solution is given.

1 Introduction

Many modern enterprises have compressed air consumers in their structure. The technological cycle of an industrial enterprise depends on the quality and continuity in the compressed air supply. Compressed air is used for many processes, the pneumatic tool operation, as a transport medium, to ensure the operation of instrumentation and automation systems. As an energy carrier, compressed air is characterized by comparative cheapness, accessibility, harmlessness, safety, elasticity. In some cases, failures of the air supply system may occur, in which the most important production processes stop, and as a result, the enterprise will incur large financial losses, which is associated with underproduction and deterioration of product quality. Despite the cheapness, the production of compressed air is an energy-consuming process. On average, 80-140 kWh of electric energy is spent on the production of 1000 m³ of air, which indicates high reserves of energy saving potential. Thus, improving the efficiency of the air supply system (ASS) of industrial enterprises is an urgent task and it is of great practical importance.

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The air supply system, which is an element of the off-site facilities of an industrial enterprise, is considered as an object of research. The diagram of the air supply system is shown in Figure 1 (main elements are indicated).

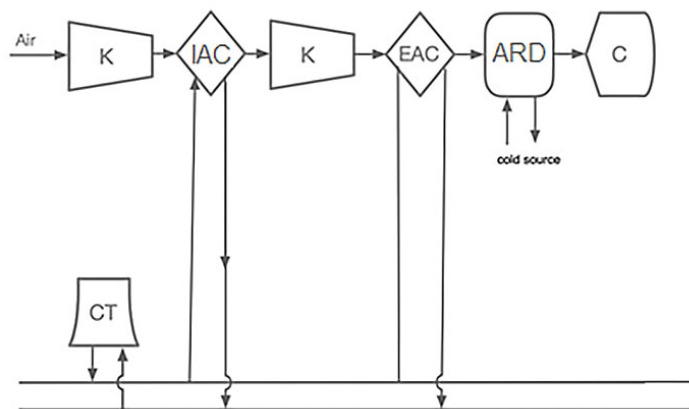


Fig. 1. Diagram of the air supply system. K – compressor stage; IAC – intermediate air cooler; EAC – end air cooler; ARD– air refrigerant dryer; CT – cooling tower; C – compressed air consumer.

In compressed air production systems, unrealized energy saving opportunities include measures to reduce pressure, reduce leaks, optimize the operation of compressor stations, the correct choice of control systems, heat energy recovery, etc. [1].

Regarding energy losses, the proportion of compressed air energy losses in the flow part of the compressor is 40%, due to friction in pipelines - 6%, and during cooling - 54% [2].

2 Materials and methods

Previous studies indicate that the existing methods of designing and selecting the structure of air supply systems do not fully take into account important economic factors of operation, and the use of water-cooled compressors implies the choice of the optimal option from various combinations of centralized air supply schemes and excludes the possibility of considering alternative centralized energy distribution schemes. Methods of increasing the energy efficiency of industrial air supply systems are given [3,4]:

- a method of structural optimization of air supply systems of industrial enterprises based on a rational combination of centralized and local methods of compressed air distribution;
- a method of the comparison of various solutions of the structure of air supply systems based on the generalization of data on equipment and materials used to solve the problem of an integrated approach to the reconstruction of air supply systems.

In some works, the main directions for reducing the energy consumption of the compressor unit are highlighted [5,6]:

- the improvement of the compressor, its drive and control system;
- the improvement of the compressed air preparation system;
- the improvement of the compressed air cooling system.

The methods of improving the compressed gas drying system are analyzed in the works of [6,7,8]. The preparation of air after compressors requires the separation of steam particles from the air so that it does not condense in the network, and the removal of oil as completely

as possible. The presence of water vapor in the atmospheric air leads to a slight decrease in the performance of compressors.

Among the most common energy-saving measures for drying compressed air are [6]:

- the rational installation of air pipes, combined with the correct placement of water separators. Water separators are also installed in front of consumers to dry the air as much as possible. Air intake to consumers should be made from the upper part of the water separators or air pipes after the accumulated water is drained.
- to organize the transfer of the moisture loss zone to the insulated water separators, it is advisable to isolate the air pipe, which makes it possible to preserve the warmth of the air, reduce its consumption and allows to have a sufficiently high air temperature in front of the receivers ($60-80^{\circ}\text{C}$), which ensures their "dry" operation.
- an effective way of drying the air is heating it in front of consumers with pre-cooling and removal of all released moisture. Heating the air, in addition to saving, leads to its dehumidification, as a result of which the air temperature remains high enough, and moisture loss either does not occur, or occurs in small quantities.

One of the most effective, from the point of view of energy saving, method of drying compressed air is its cooling in the end cooler installed after the compressor. Drying by cooling the compressed air allows to maintain a satisfactory dew point.

Steam compression refrigerating machines are mainly used as a source of cold. For these machines, the process of obtaining cold is carried out due to the phase transition of the refrigerant, which entails the consumption of electrical energy by the compressor of the refrigerating machine.

In many works, the use of absorption refrigerating machines (ABRM) is proposed instead of vapor compression one. For the production of cold, such machines consume low-potential thermal energy, which is generated in excess at compressor stations. Figure 2 presents an ABRM scheme.

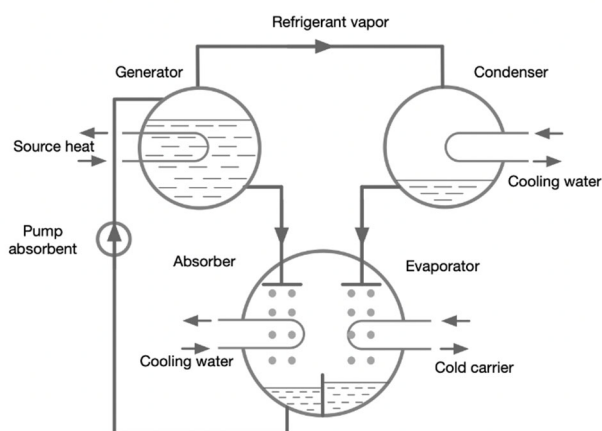


Fig. 2. The main elements of ABRM.

Figure 3 shows the advantages and disadvantages of ABRM in comparison with other types of refrigerating machines that are used at production facilities [9-11].

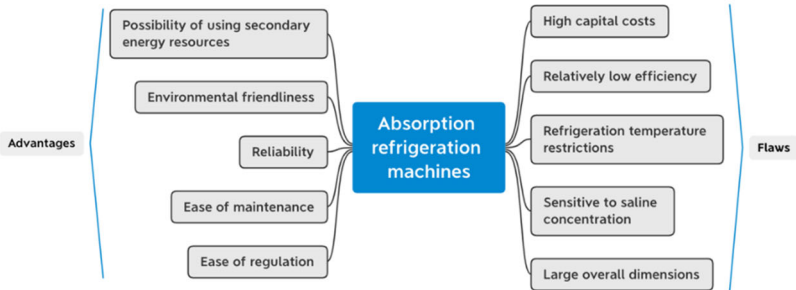


Fig. 3. Advantages and disadvantages of ABRM.

Taking into account the weaknesses and strengths, ABRM have become widespread in the organization of trigeneration systems (joint production of cold, heat and electricity), as well as in systems for the utilization of thermal secondary energy resources.

3 Results

The operation of the air supply system is accompanied by the release of secondary energy resources, which include heat removed in interstage air coolers, compressor jackets, the first stages of the air drying system. Figure 4 shows a schematic diagram of the compressor station with ABRM.

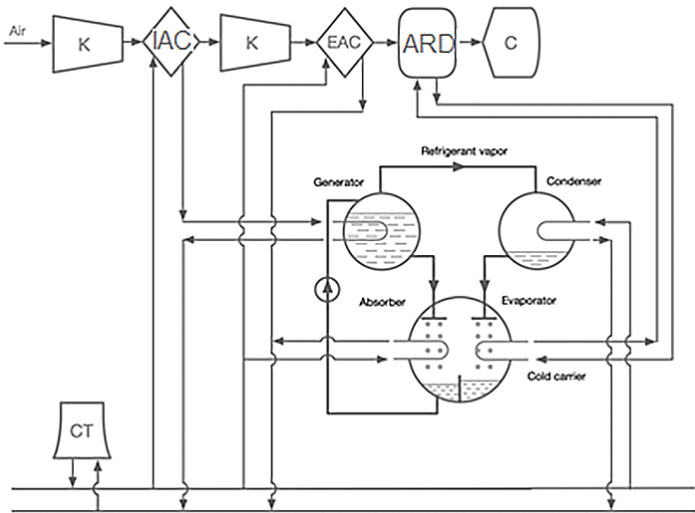


Fig. 4. Schematic diagram of the air supply system with ABRM.

The principle of operation shown in Figure 4 is that the water heated in the intercooler (PO) enters the ABRM generator, where it heats a mixture of absorbent and refrigerant. Under the influence of heat, the refrigerant passes into a vapor state and it is sent to the condenser, and the absorbent in the form of a liquid enters the absorber for irrigation. After

the condenser, the refrigerant enters the evaporator, where it absorbs the heat of the coolant and, evaporating, is fed into the absorber. In the absorber, the refrigerant vapour is absorbed by the absorbent, while thermal energy is released, which is removed by water from the circulating water supply system. The mixture of absorbent and refrigerant after the absorber is sent to the generator and the cycle repeats again.

Such a scheme of the air compressor station refrigeration allows to reduce the cost of electrical energy, since the production of cold in the ABRM is carried out due to the chemical reactions.

As a criterion of the technical and economic efficiency of a scheme with a compression refrigerating machine and a scheme with an absorption refrigerating machine, an indicator of the cost of 1 GJ of produced cold according to the expression (1) is adopted.

$$\Delta S = C_f \cdot \left(\frac{b_{CHP}}{\varepsilon \cdot \eta_k} - \frac{b_f}{\zeta_t \cdot \eta_f} \cdot \omega_f \right) + (P_a - P_p) \cdot \Delta K + S_p \quad (1)$$

where C_f is the fuel costs, rub/t; b_f is the specific fuel consumption for the released heat from the CHP plant or boiler house for heating the ABRM generator; η_f is the loss coefficient of ABRM, which takes into account heat losses in heat and cold in refrigeration networks, as well as additional electricity consumption for the drive of auxiliary mechanisms (pumps, instrumentation, etc.); ζ_t is the thermal coefficient of ABRM; ω_f is the coefficient that takes into account the energy consumption for the drive of mechanisms that are part of the ABRM; P_a , P_r are the share of deductions for depreciation and maintenance; ΔK is the difference in capital costs when switching to an alternative option, rub/GJ; S_p is a constant part of annual costs, rub/GJ.

When using renewable energy resources heat technology to heat the generator, formula (2) is converted to the following form:

$$\Delta S = 3_f \cdot b_{CHP} \cdot \left(\frac{1}{\varepsilon \cdot \eta_c} - \frac{\omega_{RER}}{\eta_{RER}} \right) + (P_a - P_p) \cdot \Delta K + S_p \quad (2)$$

Since the mode of operation of the thermal transformers CRM and ABRM changes during the year, the calculation of energy and technical and economic indicators must be carried out according to the average annual indicators, for which the ratio (3) can be used.

$$X^{year} = \frac{X_i \cdot \Delta \tau_i}{\tau_{year}} \quad (3)$$

where X^{year} is the average value of the parameter X for the year; τ_{year} - the number of hours of equipment operation per year, hour/year; i is the number of modes under consideration; $\Delta \tau_i$ is the duration of i - mode, hour/year; X_i is the value of the parameter X observed during the period $\Delta \tau_i$.

The volume of recycled water use in the ABRM increases significantly compared to steam compression plants, and therefore the volume of make-up water in the recycled water supply system also increases. The change in operating costs for recycled water is calculated according to the formula (4), rub/year:

$$\Delta S_w = C_w \cdot (G_{make-up}^{CRM} - G_{make-up}^{ABRM}) \cdot \tau_{year} \quad (4)$$

where C_w is the cost of recycled water, rub./m³; $G_{make-up}^{CRM}$ - the volume of make-up water in the circulating water supply system CRM, m³/year; $G_{make-up}^{ABRM}$ - the volume of make-up water in the circulating water supply system ABRM, m³/year; τ_{year} - the number of hours of operation of the installation per year, h/year.

To calculate the change in the cost of 1 GJ of produced cold, the resulting savings in annual operating costs should be divided by the annual cooling capacity of the system in accordance with the expression (5):

$$\Delta \Pi_w = \frac{\Delta S}{Q_o^{year}} \quad (5)$$

The calculation results are shown in Table 1.

Table 1. Technical and economic comparison of options at the cost of 1 GJ of the released cold.

Indicator	Option number	
	1	2
Type of refrigerating machine	CRM	ABRM
Refrigeration capacity, kW	2000	2000
annual, GJ/year	$5.76 \cdot 10^4$	$5.76 \cdot 10^4$
Operating time of the refrigerating machine, h/year	8000	8000
Thermal load of the generator: per unit of time, kW	-	4844.6
annual, GJ/year	-	139524.4
Electric power consumption, kW	320	107.7
Annual electricity consumption, kW·h	$2.56 \cdot 10^6$	$0.86 \cdot 10^6$
Conventional fuel economy: per year, t/year	0	4761.9
Cost change 1 GJ of cold, %	0	-37.7%

4 Conclusion

Reduction of electric energy consumption is the main advantage of ABCM, which allows to reduce the specific energy consumption of the compressor station, as well as to increase the share of the useful use of energy resources.

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