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Research Article

IMPROVEMENT OF COOLING SYSTEM OF MINE RECIPROCATING COMPRESSOR UNITS

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ABSTRACT

The research of operational indicators of compressor units shows that undercooling of air in reciprocating compressors for every 5-6 °C increases energy consumption for air compression by 1%, and productivity decreases by 8-10%, which leads to tangible economic losses in compressed air production. The existing cooling systems of compressor units have a number of significant shortcomings due to the peculiarities of their operation, the paper considers various ways to improve the operation of the cooling system, proposed new technical solutions, the implementation of which will reduce the energy consumption of compressor units.

KEYWORDS

Compressor, cooling system, temperature, compressed air, heat transfer, cooling tower, intermediate cooler, heat exchanger, end cooler, productivity, power consumption.

INTRODUCTION

In many industries, pneumatic energy, or compressed air energy, is widely used in addition to electrical energy.

The widespread use of compressed air in the mining industry is due to the fact that pneumatic equipment is safe, especially in gas and dust hazardous mines where the use of electricity in underground mining is dangerous due to sudden gas emissions.Along with this, pneumatic energy has a number of significant disadvantages. The main disadvantage of compressed air as an energy carrier is its high cost relative to electricity due to the large amount of electrical energy consumed by compressors during compressed air production [1].

Mine compressors are energy-consuming installations, the specific weight of which in the consumption of electrical energy by mining enterprises is a significant share. Considering such a wide application of pneumatic energy, it is necessary to reduce operating costs by developing resource-saving technical solutions in the process of compressed air production at industrial enterprises.

Efficient operation of a compressor unit depends to a large extent on cooling. The cooling system of the compressor unit solves three tasks - it reduces the energy consumption of the compression process in the cylinder, eliminates the probability of burning of lubricating oils and contributes to the improvement of the operating conditions of the compressor working units. Violations of the cooling system, as a rule, are associated with forced stoppage of the compressor and increased specific power consumption for the production of compressed air [2].In the majority of industrial enterprises of Uzbekistan the cooling system of stationary compressors is made by circulating open loop scheme. Fig. 1 shows the open circuit cooling system of a two-stage reciprocating compressor.

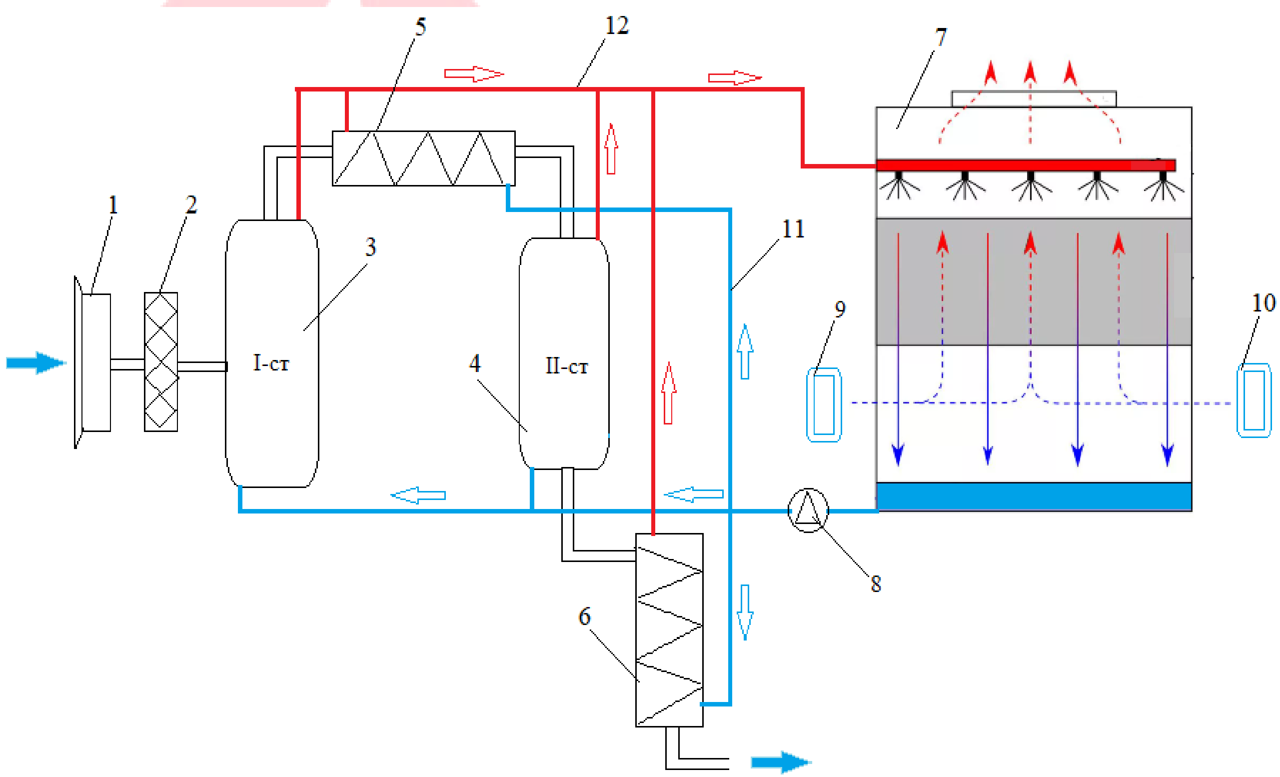

Fig.1. Schematic diagram of the open-circuit cooling system of a two-stage reciprocating compressor.

1-air intake, 2-filter, 3-first compressor stage, 4-second compressor stage, 5-intermediate cooler, 6-end cooler, 7-cooler, 8-pump, 9,10-fans, 11-pipeline of chilled water, 12-pipeline of heated water.

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Analysis of compressor units operation shows that undercooling of air in intercoolers of reciprocating compressor for every 5-6°C increases energy consumption for air compression by 1% [3].

The existing cooling systems of compressor machines have significant disadvantages caused by the peculiarities of their operation. Water used for cooling has a high content of salts and various impurities. In most cases the total water hardness, reaching more than 20 mg-eq/l, is almost 3 times higher than the permissible values, which is the main reason for rapid contamination of heat exchange surfaces. Decrease in intensity of heat exchange processes, due to the growth of deposits in the form of scale, contributes to the reduction of safety and efficiency of compressor equipment.

Presence of scale layer 0,1 mm thick leads to decrease of air cooling in the refrigerator by 10-15 %. The scale layer reduces the heat transfer coefficient by adding additional thermal resistance [4].

At the outlet of the intermediate cooler, the normal temperature of compressed air should not exceed the inlet cooling water temperature by more than 5-10 °C. If the temperature difference increases up to 20 °C, the power consumption may increase by 14 %, all other things being equal. Scale on the inner walls of the tubes sharply reduces heat transfer to the cooling water, Fig. 2 shows the graphical dependence of the heat transfer coefficient on the thickness of the scale layer [4].

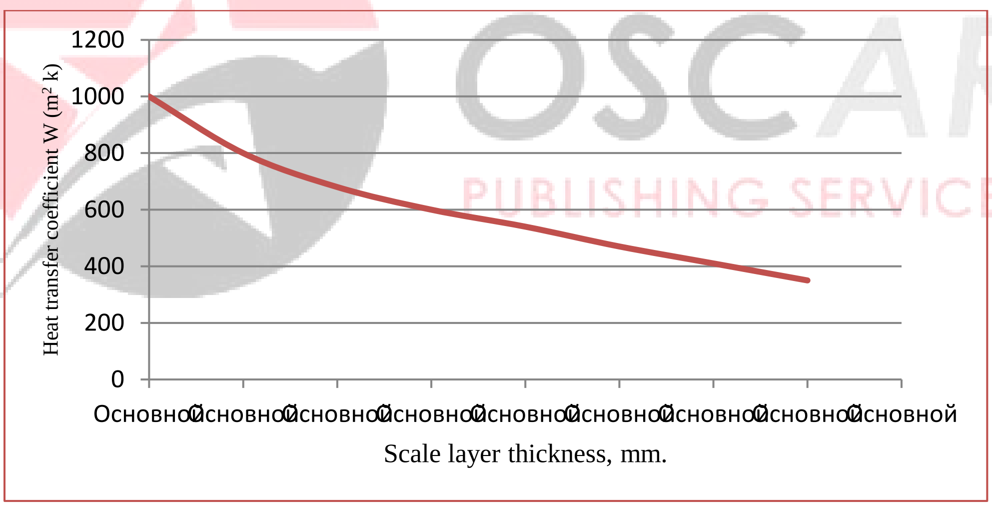

Fig.**2. Variation of heat transfer coefficient as a function of scale layer thickness.**

From the graph in Fig. 2, it is observed that the heat transfer coefficient deteriorates as the thickness of scale layer increases. Exceeding the compressed air temperature of 150 °C can lead to spontaneous combustion of carbon-oil deposits in air communications, which is the cause of detonation explosions. Analysis of the operation of compressor units operating at industrial enterprises of Uzbekistan shows that the temperature of compressed air at the compressor outlet reaches 170-180 °C and higher.

Another important factor affecting the efficient operation of compressor units is air heating in the suction process, due to the resistance of the suction path and heat exchange with heated components of the equipment. Decrease in mass capacity and compressor volumetric delivery, reduced to normal atmospheric conditions, is due to the lower density of heated air, relative to normal atmospheric air.

The influence of air heating on compressor performance is estimated by its temperature coefficient, the value of which is tentatively equal to the ratio of normal atmospheric temperature T_0 to the air temperature T_1 in the cylinder at the end of suction [5]:

$$\lambda_T \cong \frac{T_0}{T_1}; \qquad (1)$$

It should be emphasized that an increase in atmospheric temperature leads to an increase in T_1 temperature and a decrease in the compressor unit capacity.

In Uzbekistan, during the hot period of the year, especially from May to September, the air temperature can reach 40-45°C and higher, which leads to significant heating of the compressor suction air. The increase in temperature and decrease in air density contributes to an 8-10% decrease in compressor performance, resulting in tangible economic losses in compressed air production [6].

The efficiency of the cooling system of compressor units also depends on the operation of the cooling tower. In a circulating chiller water supply system, cooling water from the compressor enters the cooling tower for cooling. For the optimal operation of the compressor, the temperature difference of the cooling water between the inlet and outlet should not be more than 15°C. The water temperature should not exceed +25°C at the inlet and +40°C at the outlet of the cooling system [7].

Most of the cooling towers in use at compressor stations were built according to the designs of 70-80s of the last century, most of them are in unsatisfactory condition, and the technical solutions incorporated in the designs of these cooling towers are outdated [8]. As a result, the recycled water is undercooled, especially in the warm period of the year, which leads to overconsumption of energy resources and other negative consequences.

Research conducted on compressor cooling systems has revealed the following major factors that lead to reduced plant efficiency. These include:- increased temperature of atmospheric air at the inlet to the compressor unit, which leads to increased electrical energy consumption for compression and reduced productivity;

-unsatisfactory operation of cooling tower coolers, especially during the hot period of the year, the cooling towers currently used in the enterprises do not cope with the cooling of circulating water, as the water spray nozzles used in most cooling towers do not provide the required atomization of water, which leads to undercooling of circulating water. Frequent formation of contaminants on heat exchange surfaces, reduction of heat exchange intensity due to scaling layer formation on the walls of intermediate and end coolers.

In order to increase the energy efficiency of reciprocating compressor units operation, based on the above-mentioned factors leading to the decrease of compressor units efficiency, we propose the following technical solutions.

Artificial cooling of the air at the inlet to the compressor. It is obvious that lowering the temperature of the intake air leads to an increase in the weight capacity, artificial cooling can always achieve an increase in capacity.

However, the used special refrigeration units for artificial cooling of the suction air are quite expensive and energy-consuming, the use of which is not always economically feasible.

Therefore, we propose to cool the air before the compressor with the use of a tubular heat exchanger, using as a cooler circulating water from the cooling tower. In this case, the heat exchanger is made in such a way that it does not create hydraulic resistance to the movement of the intake air. By cooling the suction air before the compressor by 5-6°C, the compression energy saving is 1-2%.

Modernization of cooling tower chillers based on improving the design of water spray nozzles. As mentioned above, the existing water spray nozzles do not provide efficient water atomization. Application of new design of ejection water-splashing nozzles with swirler allows to intensify heat exchange, thus improving cooling of circulating cooling water. Figure 3 shows a general view of our proposed ejection spray nozzle.

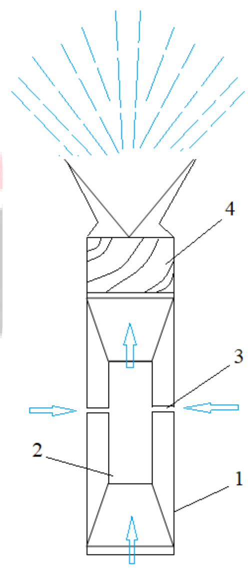

Figure 3. General view of the proposed induction water spray nozzle.

1-outer tube, 2-nozzle displacement chamber, 3-air inlet hole, 4-vortex atomizer.

Prevention of scale layer formation on the walls of intermediate and end coolers. Increasing the efficiency of compressor unit cooling system operation is possible due to intensification of heat exchange between the cooled (compressed air) and cooling (water) coolants. This is primarily realized by preventing scale and sludge deposits in the coolers. Today, water hardness softening is achieved chemically. Chemical method of scale prevention is effective, however, it requires constant expenses, pollutes the environment and harms the health of service personnel. Prevention of scale formation is possible due to electromagnetic treatment of circulating cooling water [9].

We have developed in laboratory conditions the installation for electromagnetic treatment of circulating water. In order to determine the effectiveness of the developed installation of electromagnetic treatment of circulating water, we conducted experimental tests. Schematic view of the experimental unit is shown in Figure 4.

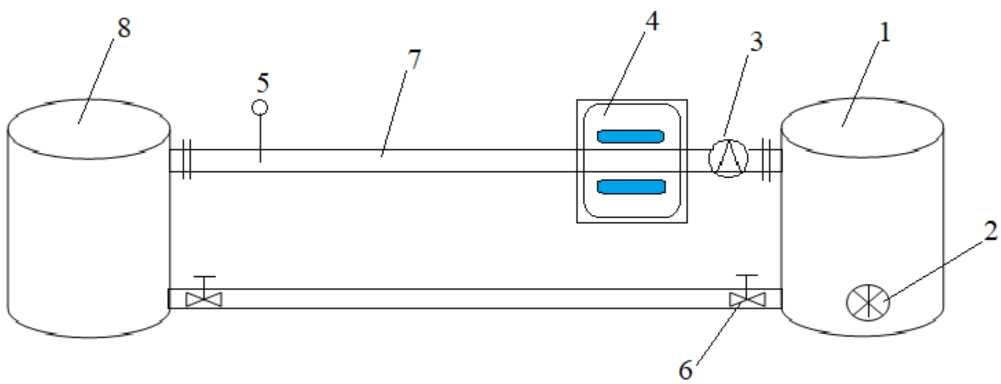

Fig. 4. Schematic view of the experimental setup when testing the device for electromagnetic water treatment.

1-capacity with electric heater, 2-temperature regulator, 3-circulation pump, 4-device for electromagnetic water treatment, 5-point of water temperature measurement, 6-valve, 7-metal pipe, 8-capacity with water.

Experimental work was carried out in two stages, the first stage of experimental research was carried out without the use of the device for electromagnetic water treatment. The second stage with application of the device for electromagnetic water treatment. Duration of experimental work for each cycle was 48 hours, average water hardness 25 mg-eq/l.

The main objective of the experimental work was to establish the dependence of scale layer formation on the surface of the metal pipe on the temperature of the circulating water, with the use of a device for electromagnetic water treatment and without its use.

The performed experimental tests allowed to obtain the dependence of scale formation on the metal surface on the temperature of circulating water with and without the use of a device for electromagnetic water treatment, the graphical dependence is presented in Fig. 5.

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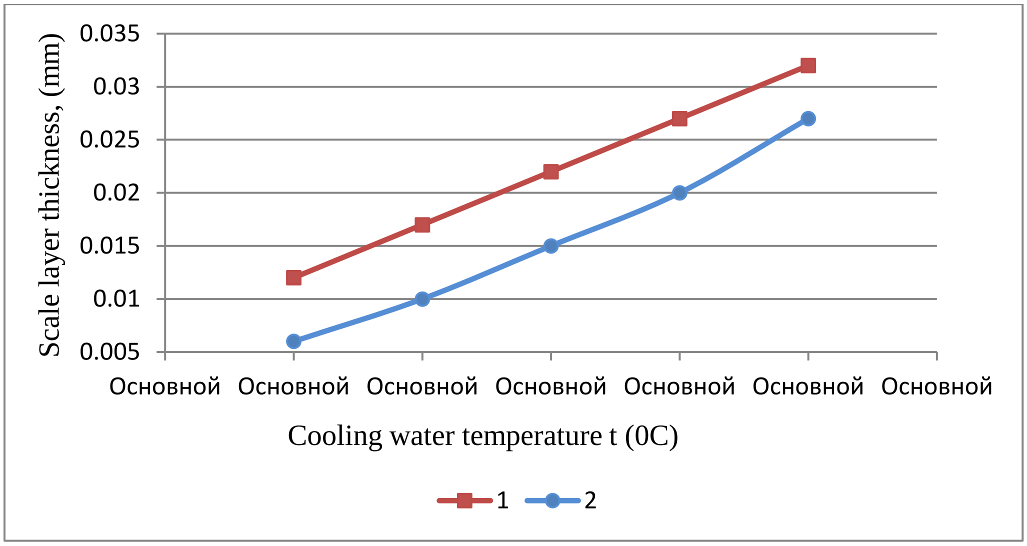

Fig.5. Graphical dependence of scale thickness formation on the temperature of circulating water.

1-without application of the device for electromagnetic water treatment, 2- with application of the device for electromagnetic water treatment.

From the graph in Fig.5 it is observed that electromagnetic treatment of circulating water, contributes to the reduction of scale formation on metal surfaces on average by 70-80%.

Fig.6 shows a microscopic photograph of the wall of the metal pipe after the completion of experimental work. The analysis of microscopic photos shows that the application of electromagnetic treatment reduces the formation of scale layer on the walls of the metal pipe.

a)

b)

Figure 6. Microscopic photograph of a metal pipe wall.

a) operation of the pipe without using the electromagnetic water treatment device, b) using the electromagnetic water treatment device.

From Figure 6 it is observed that the scale layer on the wall of the metal pipe, shown in Figure 6a is much thicker, relative to the one shown in Figure 6b. This makes it possible to conclude that the use of the device for

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electromagnetic treatment of water, contributes to reducing the formation of scale on the surfaces of heat exchangers.

Figure 7 shows a schematic view of the cooling system of a two-stage reciprocating compressor after modernization.

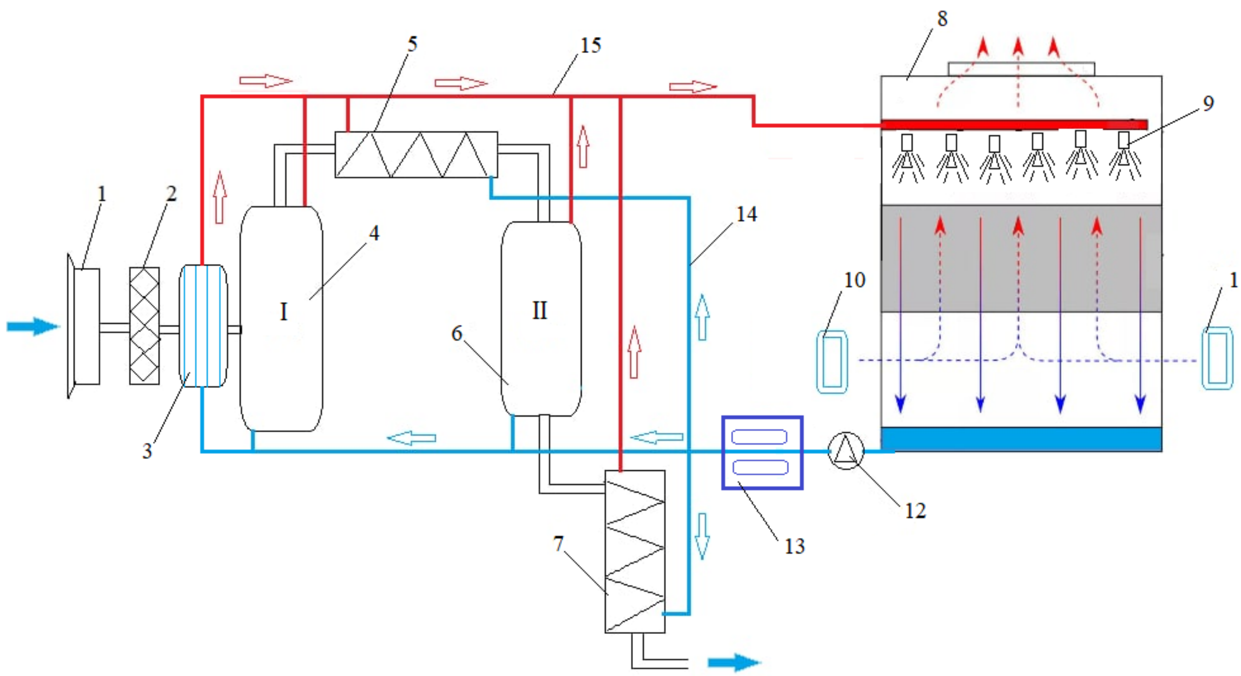

Fig.7. Schematic diagram of the open-circuit cooling system of a two-stage reciprocating compressor after modernization.

1-Air intake, 2-Filter, 3-Air cooler before the compressor,4-First compressor stage, 5-Intermediate cooler, 6-Second compressor stage, 7-End cooler, 8-Cooler, 9-New design of water atomizer, 10 and 11-Fans, 12-Pump, 13-Electromagnetic water treatment device, 14-Chilled water pipeline, 15-Heated water pipeline.

Application of our proposed technical solutions to improve the efficiency of compressor units, based on the improvement of the cooling system can increase productivity and reduce the specific cost of electrical energy of the compressor for the production of compressed air. But in this case changes will be made in the current scheme of the cooling system (Fig. 7).

Realization of our proposed technical solution, provides the following changes in the current scheme of the cooling system of compressor units:

- between the filter and the first stage of the compressor will be installed air cooling chamber in the form of a heat exchanger, cooling medium will be cooled water from the cooling tower;
- the cooling tower water spray nozzles will be replaced with a new design of ejection water spray nozzle;
- an electromagnetic water treatment device will be installed on the chilled water pipeline exiting the cooling tower.

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From analytical studies revealed that the implementation of our proposed technical solutions at compressor plants of mining enterprises contribute to reducing energy costs of air compression process in the cylinder on average by 4-5%, to increase compressor performance to 8%, depending on operating conditions. And also to exclude emergency situations and to increase operational indicators of working units of the compressor, due to which the cost price of compressed air production will be reduced.

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