

Increasing the operating efficiency of mining compressor installations on the basis of improving the cooling, lubrication and air suction system

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Abstract. Pneumatic or compressed air energy is widely used in the mining industry at the same level as electrical energy. In the technological processes of mining, compressed air, acting as an energy carrier, has a significant impact on the performance of mining machines and other pneumatic energy consumers. The operating efficiency of a compressor depends to a large extent on the operation of its cooling, lubrication and air intake systems, and improving their performance significantly reduces the cost of producing compressed air. The results of scientific research on improving the efficiency of operation of mine compressor installations based on the improvement of the cooling system, lubrication and air suction are presented.

1 Introduction

Today, 20 - 30% of the energy consumed by the mining industry is spent on the production of compressed air energy, i.e. for compressor units.

The reliability and performance of mining compressor installations during their operation depends on several factors, which leads to a decrease in the technical performance of the compressor. Factors that negatively affect the performance of reciprocating compressor units during their operation, as well as their numerical values, are shown in the form of a diagram in Figure 1.

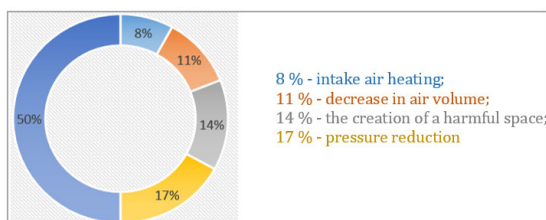


Fig. 1. Factors that reduce the efficiency of a reciprocating compressor.

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An analytical study of the operational efficiency of mining compressor units shows that most of the compressor units operated at mining enterprises operate with low productivity and higher energy intensity compared to those given in the technical data sheet. A decrease in the productivity of mining compressor installations and losses in the network lead to a decrease in compressed air pressure, as a result, the actual power of pneumatic energy consumers is reduced by 25-45% relative to the nominal one [1].

The objective of this study is to increase the operational performance of mining compressor installations based on improving the design of the intake air filtration device, improving the operation of the cooling system, as well as improving the oil filters of the lubrication system.

Study of factors that reduce the efficiency of mine compressor installations. The composition of the water used to cool the compressor contains a large amount of salts and various impurities. In most cases, water hardness reaches 20°J mg-eq/l, which is three times more than the permissible values according to the rules for the design and safe operation of stationary compressor units, air and gas pipelines. An increase in water hardness leads to the formation of scale on the heat exchange surfaces of the compressor air coolers. For example, the experience of operating compressors in the mines of Uzbekistan shows that the intensity of scale formation is 8-10 mm/year or more. Due to scale growth, the intensity of thermal conductivity, the efficiency and safety of compressor units are reduced [2].

Pollution of compressed air has a negative physical and chemical effect on pneumatic equipment and reduces their wear resistance up to 3-7 times. 80% of failures in pneumatic networks are related to poor air quality.

An increase in the contamination of the intake air, or an excess of the permissible content of abrasive dust particles in the air entering the installation, leads to mechanical wear of the compressor parts [3].

Thus, as a result of excessive pollution of the intake air in the compressors, there was a decrease in compressor performance, heating of the unit, premature wear of the piston, piston rings, cylinder, wear and clogging of the suction and discharge valves, oil clogging, clogging of the air filter in the suction tract. The proportion of downtime due to these faults is shown in Figure 2.

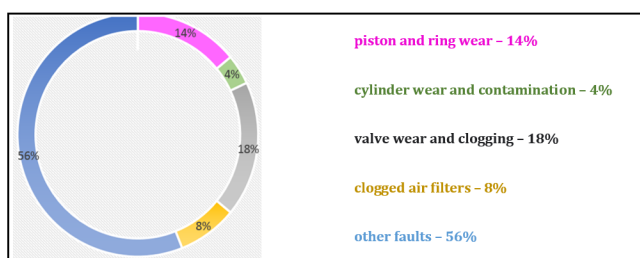


Fig. 2. Types and proportion of downtimes resulting from contamination of the air sucked in by the compressor.

Oil contamination causes wear of the shaft body, cam joint part, bending and premature failure of the shaft.

The performance of the crosshead, rod and sliders that transmit the movement of the shaft to the piston also depends on the purity and viscosity of the oil. The formation of abrasive particles in the composition of the oil leads to wear of the crosshead and its axis, the surface of the slider, a decrease in the volume of the crosshead and a reduction in working resources [4]. Mathematical modeling of scale formation on heat exchange surfaces of an air cooler

The processes of scale formation on the heat exchange surfaces of reciprocating compressor air coolers are mathematically modeled, where the following expressions are proposed to determine the intensity of scale formation.

$$\varphi_d = \frac{A_t \cdot P_s \cdot T_s^{2/3} \cdot \rho^{2/3} \cdot \mu^{-4/3}}{1 + B_t \cdot P_s \cdot 2\tau_\omega \cdot T_s^{2/3} \cdot \rho^{-4/3} \cdot \mu^{-1/3} \cdot \exp\left(\frac{E}{R \cdot T_s}\right)}, \quad (1)$$

$$P_s = \frac{2 \cdot \tau_\omega^{1-1/1.75}}{\rho} \cdot \left[\frac{2D_e^{0.25}}{0,0791 \cdot \mu^{0.25} \cdot \rho^{0.75}} \right]^{1/1.75}, \quad (2)$$

where T_s - is the surface temperature, K; ρ - is the flux density, kg/m³; μ - is the dynamic viscosity of the fluid, Pa s; R - is the universal gas constant.

Scale surface temperature:

$$T_s = \frac{U}{\theta_2} (T_1 - T_2) + T_2. \quad (3)$$

The heat transfer coefficients are calculated by the correlation equations of pressure drop and heat transfer on the surface of the heat exchanger, depending on the geometry of the pipes and the thermophysical properties of the liquid. In general, these correlations are expressed as follows:

$$\theta_j = \theta_j (v_j, T_j, T_s, d_{e_j}), \quad (4)$$

where v_j – is the flow velocity in the pipe, m/s; d_{e_j} – is the equivalent pipe diameter.

Taking into account the above equations, as a result of the thermal resistance of the scale and its lower thermal conductivity relative to the thermal conductivity of the cooling water, the heat removed from the compressed air is determined from the following expression:

$$Q_c = \sum_1^Z G_c \cdot \alpha_f \cdot (t_1 - t_2) \quad (5)$$

Determination of scale thickness on intercooler pipes during the life of the cooling system is considered difficult. To do this, due to the inability to determine the thickness of scale formation (δ_f), taking into account the change in the temperature of the liquid in the cooler pipe and the concentration of solids in the liquid, taking into account the influence of these parameters, an expression is proposed for the theoretical calculation of the thickness (δ_f)

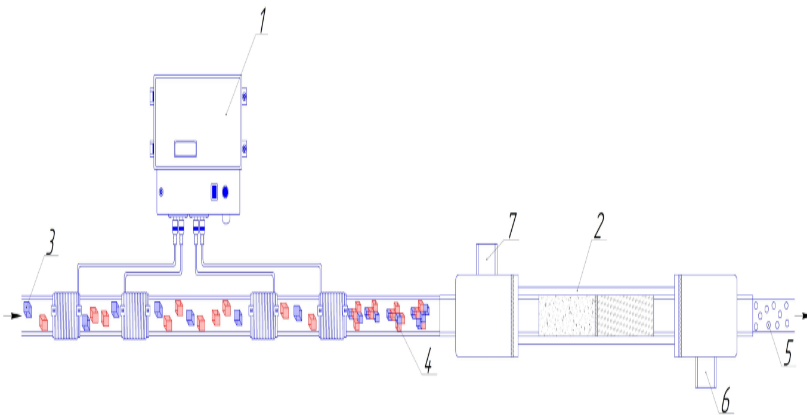
$$\delta_f = R \sqrt{\frac{G \cdot t (1 + \gamma \cdot T_0)}{\pi \cdot \rho_0 \cdot \Sigma l}} \quad (6)$$

where R – is the radius of the pipe, m, t – is the time of passage of water, s; ρ_0 – is the initial density of the liquid, kg/m³, γ – is the coefficient of dependence of density on temperature, 1/C₀, T_0 – is the initial temperature of water, C₀, G – is the concentration of solids in the liquid, mg/kg; l – is the length of the pipe, m.

2 Improving the cooling system of reciprocating compressors Introduction

In order to prevent the formation of scale on the intercoolers of compressor units, an electromagnetic water treatment device was developed, with a long-term observation of the effect of electromagnetic waves on water during the experimental study, after a certain period of time, a decrease in the efficiency of electromagnetic treatment was observed. In particular, under the influence of electromagnetic treatment of water circulating in the pipes of the compressor cooling system, the formation of scale is prevented, however, after a certain time, there is a counteraction resulting from getting used to the effects of electromagnetic waves with a frequency of 18 kHz, the separation of calcium (Ca) and magnesium salts decreases (Mg), i.e. for a certain period of time, electromagnetic waves prevent the salts from combining, and then accelerate the process of their connection.

Using the property of electromagnetic waves to connect the salts that are part of the circulating water, for their effective retention, a water softening device has been developed, shown in Figure 3.

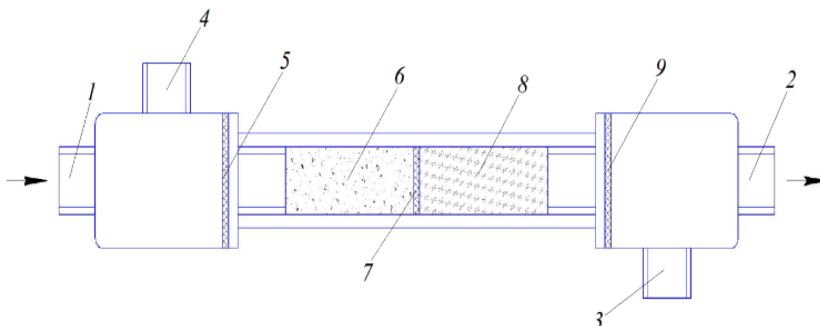


1-electromagnetic water treatment device; 2-line filter; 3-salts of water; 4-compound salts; 5-softened water; 6,7-connecting tubes for filter regeneration

Fig. 3. Water softener.

The use of filters for softening the circulating water of the cooling system of compressor units is limited by filter clogging due to increased water contamination; to solve this problem, a filter design for water softening has been developed (Figure 4), which has the ability of multiple regeneration, eliminating the need for dismantling and installation work.

The design of the developed filter consists of a porous filtration material and a carbon sorbent. Porous carbon consists of ammonium bicarbonate (NH_4HCO_3), polyorganosiloxanes (P_2SiO), acrylic emulsion, polymers and vinyl chloride. The coal sorbent consists of a mixture of brown coal and bentonite.



1-side for water inflow; 2- side for water flow; 3- tubes for filter regeneration; 5,9 mesh; 6-pore filter; 7-hard porosity filter; 8-octagonal sorbent

Fig. 4. Structural view of the filter for water softening.

To determine the effectiveness of the proposed filter for the recirculating water of the compressor cooling system, a physical model of the installation was developed and experimental tests were carried out.

During experimental tests, water samples with a hardness of 0.15; 0.21 and 0.27 L mg-eq/l were subjected to electromagnetic treatment, the effect of electromagnetic waves gradually increased from 2 kHz to 20 kHz, in steps of 2 kHz. Filtered water was taken under

the influence of each magnitude of electromagnetic waves and its hardness was determined. The result of experimental tests is presented in graphical form in Figure 5.

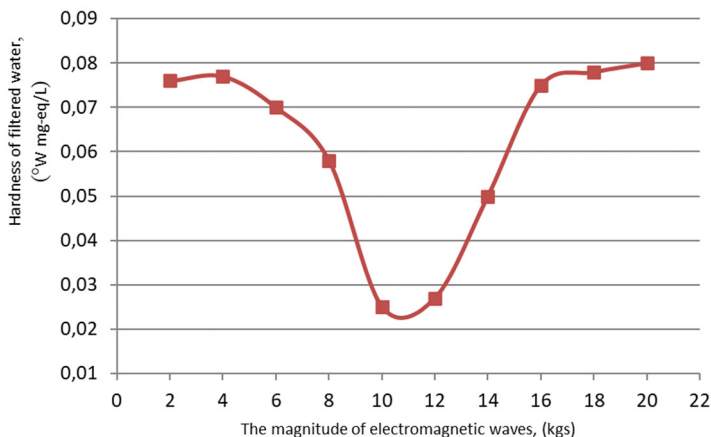


Fig. 5. The influence of electromagnetic waves on the reduction of the hardness of filtered water, with a hardness of 0.27 L mg-eq/l.

An analysis of the test results allows us to conclude that the treatment of filtered water with electromagnetic waves of 10-12 kHz provides a combination of calcium (Ca) and magnesium (Mg) salts, an increased volume of interconnected salts improves their capture, as a result of which effective water softening is achieved.

In addition, the temperature of the air coming from the first stage cylinder to the second stage cylinder was measured at various compressor pressures both with and without the developed filtering device, the measurement results are shown in Figure 6.

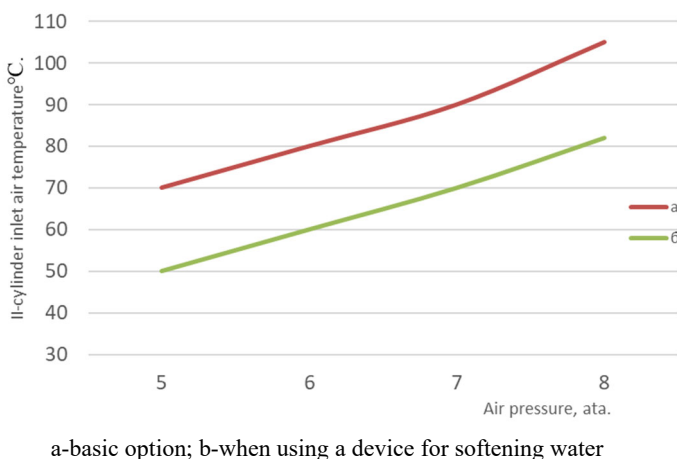
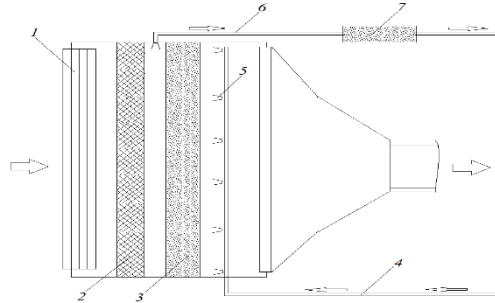


Fig. 6. Graph of the temperature of the air supplied to the second compressor cylinder on pressure (P).

Improving the design of the air and oil filter of reciprocating compressors.

Particles smaller than 3-4 microns in the air sucked by the compressor are not captured by the air filter, which leads to a decrease in the life of the compressor parts.

To increase the service life and resistance to aggressive media of the filter material, to ensure the possibility of its re-cleaning, a fibrous-porous filter material based on polymeric materials was created.



1-guide element, 2- mesh, 3 - porous filter, 4 - compressed air pipe coming from the compressor, 5-air spray nozzle, 6-intake air pipe, 7-filter

Fig. 7. Filtration device of the air sucked in by the compressor.

In order to improve the efficiency of the air filter device, the design of the filter device has been developed, which is capable of self-cleaning and trapping dust particles of 2-3 microns in the intake air. On Figure 7 shows a schematic view of this filter.

To carry out experimental tests of the filter for cleaning the air sucked into the compressor, its experimental model was assembled and tested in laboratory conditions. Figure 8 shows a microscopic image of dust particles in the air purified in the developed and basic filter.

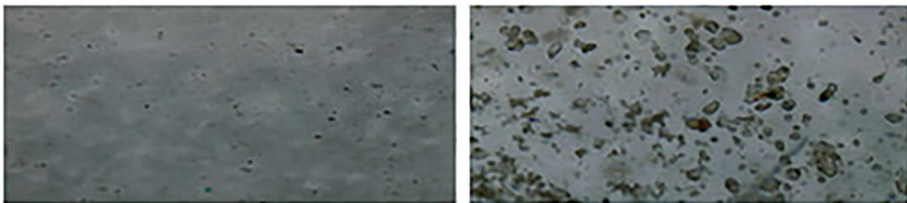


Fig. 8. Microscopic image of dust particles in the air, purified in the developed (a) and basic (b) filter.

When examining dust particles contained in the air that passed through the developed porous (Figure 8.a) and basic paper-fiber filter (Figure 8.b), under a microscope, it was found that when using the proposed filter, the maximum size of dust particles trapped into the glass of a vacuum cleaner, was 0.3-0.4 microns, and the size of dust particles when using the basic filter was 1-1.5 microns.

It has been experimentally established that the proposed fibrous-porous filter material has the ability to retain dust particles in the air sucked in by the compressor by an average of 40% more compared to the base air filter.

The influence of the use of the device for filtering the air sucked into the compressor on the service life of the compressor parts is analyzed. At the same time, it was found that the indicator of the purity of the air sucked into the compressor significantly affects the life of the air filter, the suction and delivery valves of I and II cylinders, and the life of the piston rings. Below is a diagram of the change in the working life of the compressor parts as a result of using the intake air filtering device in Figure 9.

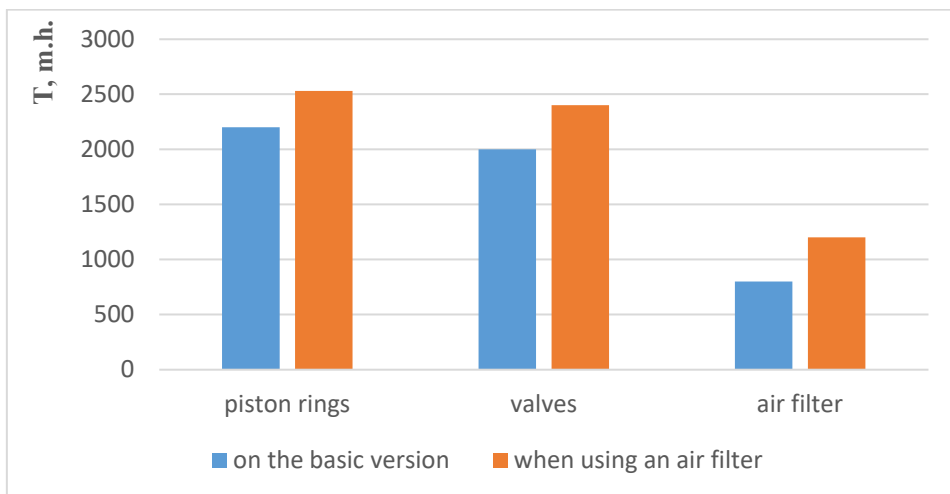
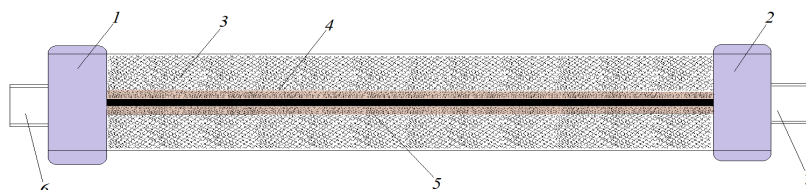


Fig. 9. Changes in the operating life of the compressor parts without and with the use of an intake air filter device.

The design of an oil filter based on a porous filter material has been developed, which makes it possible to qualitatively purify the circulating oil of the compressor lubrication system, that is, to trap abrasive metal particles up to 0.5 mm in size in its composition, and also to use the filter material for repeated regeneration.

A distinctive feature of the developed filter design from other similar porous filters is that the filter material is made in the form of a cylinder, in the center of which a magnetic rod is installed, the filter material itself is two-layer, the pore sizes of the layer above the magnetic rod are 0.5-1.0 mm, the pore sizes of the second layer are 3-5 microns. The design diagram of the developed filter is shown in Figure10.



1, 2-removable covers; 3-filter material with pore sizes of 3-5 microns;
 4-filter material with pore sizes 0.5-1.0 microns; 5-permanent magnet; 6, 7-connecting parts.
Fig. 10. Magnetic oil filter design.

In order to study the movement of metal particles during oil filtration, a mathematical model of the movement of particles in the magnetic oil filter presented above was developed, and based on this model, the following theoretical expressions were developed, taking into account a number of factors that determine the total mass of particles.

The mass of polluting particles captured by the magnetic filter can be determined by several parameters. Depending on the time of passage through the filter, the mass of trapped particles is determined by the following expression [5]:

$$m_z = m_o(K_t - 1) + \frac{2F_n t}{v_z}, \tag{7}$$

where m_o – is the total mass of liquid passing through the filter, kg; K_t – speed coefficient; F_n – is the effective force acting on the pollutant particle retained in the filter, N; v_z – is the speed of particles passing through the filter, m/s; t – the time of passage of polluting parts through the filter.

The mass of polluting particles captured by the magnetic filter, depending on its length, is determined by the following expression:

$$m_z = m_o(K_t - 1) + \frac{2F_n \Delta l}{v^2}, \quad (8)$$

where Δl – is the filter magnet length, m.

The mass of pollutants captured by the magnetic filter, depending on the amount of liquid passing through the filter, is determined by the following expression:

$$m_z = m_o(K_t - 1) + \frac{2F_n V}{Q\vartheta}, \quad (9)$$

where Q – is the amount of liquid passing through the filter, m³/kg; V – is the volume of liquid passing through the filter, m³.

The mass of polluting particles captured by the magnetic filter, depending on the diameter of the magnet, is determined by the following expression:

$$m_z = m_o(K_t - 1) + \frac{\pi F_n l (d_k^2 - d_m^2)}{2Q\vartheta} \quad (10)$$

where d_k – is the internal diameter of the structure, m; d_m – is the diameter of the magnetic filter, m.

The mass of polluting particles captured by the magnetic filter, according to the degree of contamination of the liquid, is determined by the following expression:

$$m_z = m_o(K_t - 1) + \frac{2F_n (1 + G_m) V_m}{Q\vartheta} \quad (11)$$

where G_m – is the degree of contamination of the liquid, mg/kg.

Based on the above expression (11), software was created in the Delphi programming language, which makes it possible to calculate the mass of polluting particles trapped by the magnetic filter of the reciprocating compressor lubrication system.

To determine the effectiveness of the developed oil filter, two-stage experimental tests were carried out. At the first stage, compressor oil KS-19 with a volume of 5 liters, which has worked for 2500 hours, with a content of metal particles in the amount of 880-900 mg/kg with a particle size of 0.5 to 25 microns, was filtered through a conventional porous filter with a porosity of 40%, 50%, 60 % and 70% at a pressure of 4 bar. The results of the experimental test are shown in Figure 11 and Figure 12.

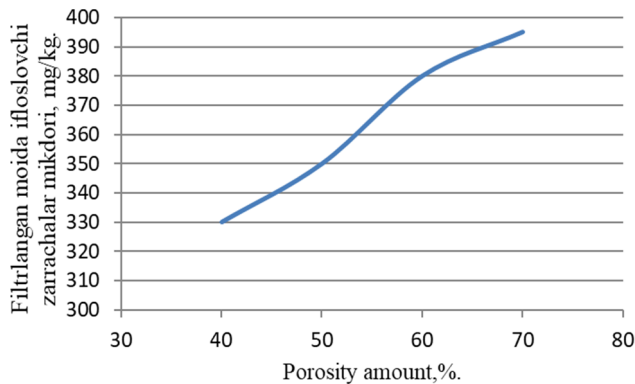


Fig. 11. The dependence of the degree of contamination of the oil passing through a conventional porous filter on porosity.

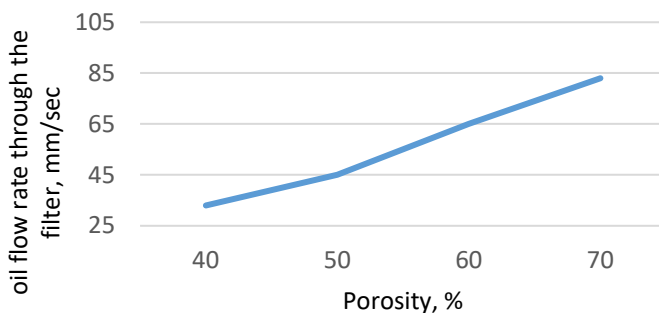


Fig. 12. The dependence of the speed of oil passage through a conventional porous filter on porosity.

At the second stage of experimental work, the proposed magnetic oil filter was tested. In this case, the experiments were carried out with a thickness of 5 mm, 10 mm and 15 mm of filter material placed around a magnet installed in the filter, with a porosity of 40%, 50%, 60% and 70%. The results of experimental tests are presented in Figures 13, 14, 15 and 16.

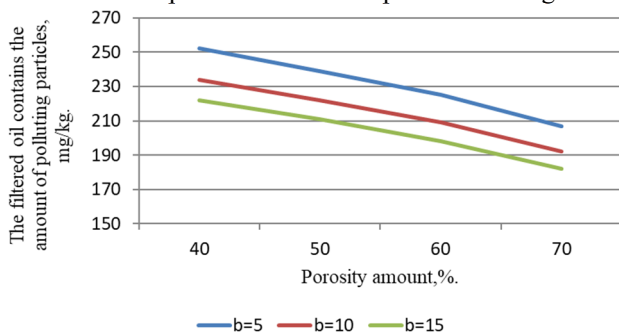


Fig. 13. The dependence of the degree of contamination of the oil passing through the magnetic filter on porosity (with the porosity of the main filter 60%).

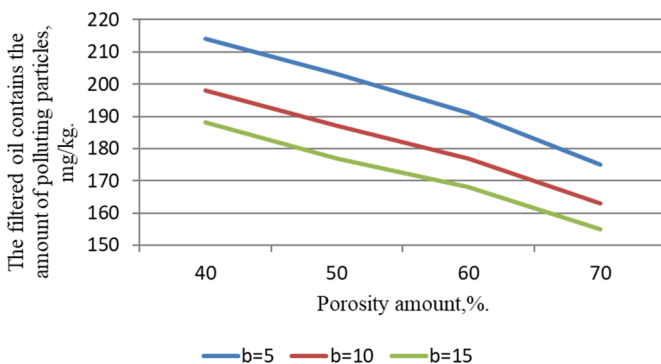


Fig. 14. The dependence of the degree of contamination of the oil passing through the magnetic filter on porosity (with the porosity of the main filter 70%).

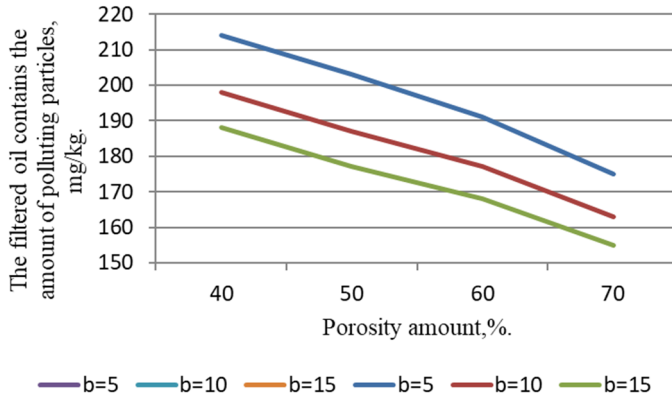


Fig. 15. The dependence of the rate of passage of oil through the magnetic filter, on porosity (with the porosity of the main filter 60%).

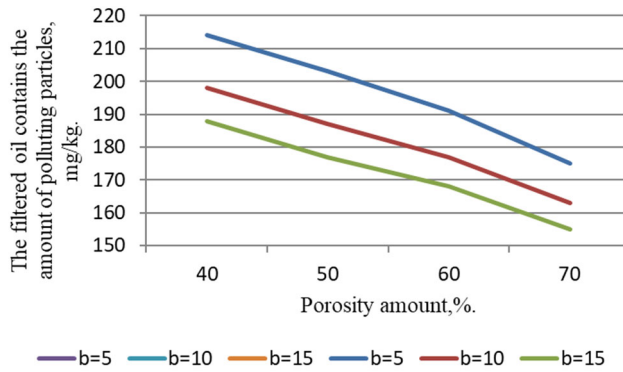


Fig. 16. The dependence of the speed of oil passage through the magnetic filter, on porosity (with the porosity of the main filter 70%).

As can be seen from the above graphs, the installation of a magnetic rod in a porous filter material reduces the oil flow rate, the oil flow rate through a conventional filter with 70% porosity is 55 mm/s, the oil flow rate through a magnetic filter with 70% porosity and a magnetic surface filter thickness of 5 mm is 50 mm/sec. The oil flow rate is also affected by the thickness and porosity of the magnetic surface filter. The decrease in the oil flow rate in the magnetic filter is compensated by an increase in the cleaning capacity of the filter.

The optimal parameters of the proposed magnetic filter are 70% porosity and 10 mm thickness. With these parameters, the maximum purity of the oil and the highest speed through the filter are ensured, as well as the ability to retain particles smaller than 1 micron contained in the oil.

The oil cleaning capacity of the proposed and basic magnetic filters were tested on the 2VM10-63/10 compressor for 2500 hours, while oil samples were taken every 500 hours. The results of the experiments are presented in Figures 17 and 18.

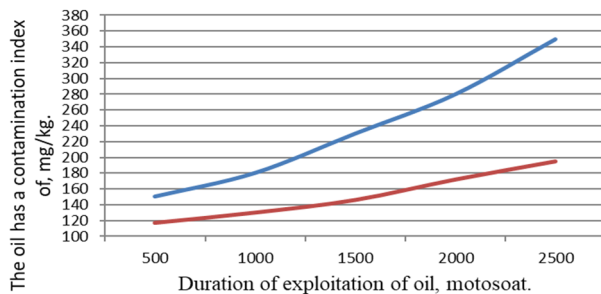


Fig. 17. Oil cleaning capacity of the basic and developed oil filter.

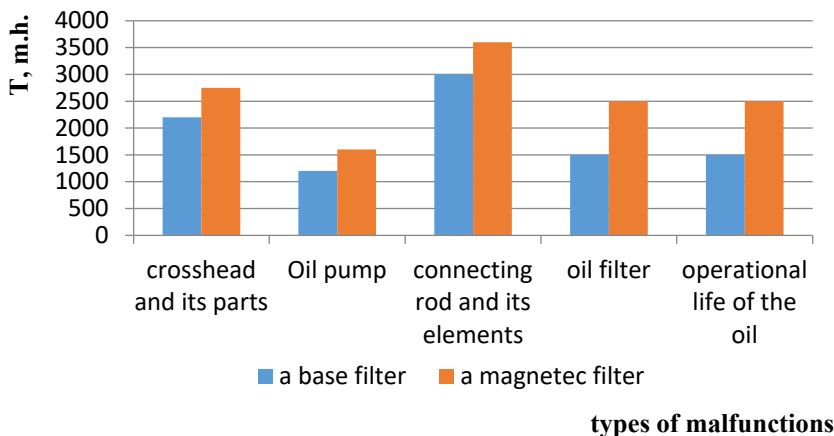


Fig. 18. Service life of compressor parts when using a basic and magnetic filter.

Research results show that the use of a magnetic filter in the compressor lubrication system can increase the life of the crosshead (user) by 20%, the oil pump by 25%, the connecting rod by 6%, oil filter and oil by 40%.

3 Conclusion

Exposure of filtered water to electromagnetic waves with an amplitude of 10-12 kHz ensures the combination of calcium (Ca) and magnesium (Mg) salts in water. As a result of an increase in the volume of interconnected salts, their trapping in the filter improves, which results in effective water softening.

A filter for softening the circulating water of the compressor cooling system has been developed, which makes it possible to reduce the formation of scale on the heat exchange surfaces of the intermediate and aftercoolers by 85-95%.

By using a device for softening the recirculating water of the cooling system, the formation of scale on the intercoolers of the compressor is prevented, thereby the temperature of the air entering from the I-stage cylinder to the II-stage cylinder is reduced to an average of 18-20 °C.

A design has been developed for filtering the air sucked in by the compressor, the use of which will increase the service life of the compressor piston rings by 300 hours, i.e. by 15%, valves - by 350 hours, i.e. by 20%, the air filter - by 400 hours, or 50%.

The optimal parameters of the improved design of the compressor lubrication system filter have been developed and determined. With a porosity of 70% and a filter thickness over the magnet of 10 mm, the maximum oil purity and the fastest passage through the filter are achieved, as well as the ability to retain particles smaller than 1 micron contained in the oil.

References

1. D.N. Khatamova, N.A. Abduazizov, R.U. Juraev, *Innovative technologies* **1**, 55-77 (2021)
2. R.U. Juraev, M.V. Merkulov, V.A. Kosyanov, A.M. Limitovsky, *Mining Journal* **12**, 71-73 (2020)
3. M.V. Merkulov, R.U. Djuraev, O.B. Leontyeva, G.Y. Makarova, Y.B. Tarasova, *IJETER* **8**, 4383-4389 (2020)
4. R.U. Juraev, B.Kh. Shomurodov, D.N. Khatamova, Yu.F. Tagirova, Modernization of the cooling system for reciprocating compressor units, *Proceedings of the IX International Scientific and Technical Conference on the topic «Achievements, problems and modern trends in the development of the mining and metallurgical complex»* (Navoi, 2017)
5. D.N. Khatamova, N.A. Abduazizov, R.U. Juraev, *Mining Bulletin of Uzbekistan* **4**, 91-94 (2021)