eISSN: 2229-3213 pISSN: 2229-3205
The Journal of Applied Science and Social Science
Volume 16,Issue 05 May, 2026

ENHANCING PERFORMANCE OF MINING PISTON COMPRESSORS BY OPTIMIZING COOLING AND LUBRICATION SYSTEMS

Xatamova Dilshoda Normorodovna
Doctor of Technical Sciences (DSc), Professor,Professor of the Mining Engineering Department,
Navoi State Mining and Technology University,Navoi, Republic of Uzbekistan.
Abdikhakimova Malika Amir kizi

Assistant, Department of Natural and Technical Sciences,
"Navoi Innovation University",
Navoi, Republic of Uzbekistan.

https://doi.org/10.5281/zenodo.20241197

Аннотация: Поршневые компрессоры являются одним из важнейших элементов во многих отраслях промышленности и используются для сжатия воздуха или других газов. Эффективность работы таких компрессоров напрямую зависит от поддержания оптимальной температуры сжимаемого газа, что в основном обеспечивается системой охлаждения и от удовлетворительной работы системы смазки, которая уменьшает износ трущихся частей компрессора и снижает расход энергии на трение, повышает герметичность в поршневых кольцах и сальниках, охлаждает трущиеся поверхности механизма движения.

На практике в процессе эксплуатации поршневых компрессоров, возникают различные проблемы, связанные с образованием накипи и слоёв отложений на теплообменных поверхностях воздухоохладителей, поломки клапанов, которые имеют низкую наработку на отказ и интенсивный износ механизмов движения таких как крейцкопф, вал и подшипники, в результате которого увеличивается число аварийных простоев

В данной статье рассматриваются вопросы снижения образования отложений на теплообменных поверхностях воздухоохладителей и совершенствования системы смазки поршневых компрессоров.

Выполнен анализ факторов, снижающих эффективность поршневых компрессоров, приведены результаты экспериментальных работ по эффективному применению акустического устройства для очистки внутренних поверхностей труб воздухоохладителей от накипи, в ходе которых определены оптимальные значения амплитуды, частоты и длительности импульсов колебаний, генерируемых ультразвуковым акустическим устройством, для эффективной очистки от накипи внутренних поверхностей металлических трубок промежуточного и концевого охладителей компрессора. Дано описание экспериментальных исследований предложенной конструкции масляного фильтра, в результате которых определены оптимальные параметры пористого фильтрующего материала позволяющий способность улавливания частиц с размером менее 1 мкм и обеспечивающие оптимальную скорость протекания масла в разработанном масляном фильтре.

Ключевые слова: компрессор, поршень, цилиндр, система охлаждения, воздухоохладитель, температура, сжатый воздух, надежсть, система смазки, масляной фильтр, загрязненность масла.

Abstract: Reciprocating compressors are a vital component across numerous industries, utilized for the compression of air and other gases. The operational efficiency of these compressors depends directly on maintaining optimal compressed gas temperatures—primarily managed by the cooling system—and the effective performance of the lubrication system. The

latter reduces wear on moving parts, minimizes energy losses due to friction, enhances the sealing of piston rings and glands, and cools the friction surfaces of the drive mechanism.

In practice, the operation of reciprocating compressors is hindered by various challenges, including scale and deposit buildup on air cooler heat exchange surfaces, valve failures characterized by low Mean Time Between Failures (MTBF), and intensive wear of drive mechanisms such as crossheads, shafts, and bearings, resulting in increased emergency downtime.

This article examines methods for reducing deposit formation on heat exchange surfaces and advancing the lubrication systems of reciprocating compressors. An analysis of factors limiting compressor efficiency is presented, alongside experimental results regarding the effective application of an acoustic device for cleaning the internal surfaces of air cooler tubes. The study identifies the optimal amplitude, frequency, and pulse duration of oscillations generated by the ultrasonic device to ensure the effective removal of scale from the metal tubes of intercoolers and aftercoolers. Furthermore, the paper describes experimental research on a proposed oil filter design, determining the optimal parameters for a porous filter material capable of capturing particles smaller than 1 micron.while ensuring an optimal oil flow rate within the developed filter.

Keywords: compressor, piston, cylinder, cooling system, air cooler, temperature, compressed air, reliability, lubrication system, oil filter, oil contamination.

Introduction

The operation of mining compressors is one of the most energy-intensive processes in the mining industry, necessitating effective resource conservation. In the overall energy balance of mining enterprises in Uzbekistan, the proportion of compressor equipment generating compressed air for pneumatic energy accounts for 20–25%. Therefore, its further improvement significantly impacts the performance indicators of subsequent technological processes. The widespread application of compressed air dictates the need to reduce operating costs through the development of efficient technical solutions for industrial compressed air production, as well as the enhancement of the overall energy efficiency of compressor unit operations [1].The cooling system has the most significant impact on the reduction of productivity and the increase in specific energy consumption of mining compressor units. Consequently, the efficiency of reciprocating compressor units can be improved by upgrading the cooling system, as energy losses due to insufficient cooling (undercooling) in reciprocating compressor units reach up to 20%.

Furthermore, the failure-free and reliable operation of reciprocating compressors heavily depends on the lubrication system of the compressor's drive mechanisms. Special attention must be paid to the lubricating oil parameters and its purity, as the degradation of the initial oil characteristics and its contamination lead to the wear of moving friction components, thereby increasing the frequency of emergency shutdowns. Oil contamination causes wear on the shaft journal and its sections connected to the crank webs, leading to shaft deflection and premature failure. The operational performance of the crosshead, piston rod, and sliding blocks, which transmit the motion from the shaft to the piston, also depends on the purity and viscosity of the oil. The presence of abrasive particles in the lubricating oil leads to the wear of the crosshead, its slider surfaces, and the crosshead pin, resulting in a reduction of their dimensional tolerances and a decrease in their overall service life.

Analysis of Factors Reducing the Efficiency of Reciprocating Compressors

During the operation of mining compressor equipment, various factors influence its efficiency and productivity, leading to a degradation of the compressor's rated technical performance indicators.

eISSN: 2229-3213 pISSN: 2229-3205
The Journal of Applied Science and Social Science
Volume 16,Issue 05 May, 2026

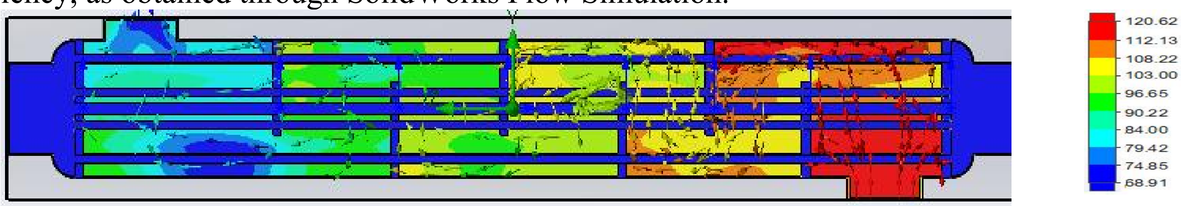
A significant portion of a reciprocating compressor's operational efficiency depends on the performance of its cooling system, and optimizing its parameters substantially enhances the overall efficiency of compressed air production. One of the primary causes for a reduction in compressor unit productivity by up to 25% and an increase in specific energy consumption by 12–15% is the use of low-quality water with high total dissolved solids (TDS). This leads to scale formation and fouling of the heat exchanger surfaces within the air coolers [2, 3].

Currently, one of the primary challenges identified in the cooling systems of multi-stage reciprocating compressors is the inadequate cooling of air within the intercoolers and aftercoolers. The discharge pressure of the compressed air exiting the first stage of a reciprocating compressor typically ranges from 0.3 to 0.4 MPa, with temperatures reaching approximately 110–130 °C. It is necessary to reduce the temperature of the air being transferred from the first-stage cylinder to the second stage by roughly 70 °C. If the air temperature is not cooled to the specified requirement before entering the second stage, it may lead to emergency conditions. Moreover, a degradation in intercooler performance—where the air temperature remains 6–8 °C above the target—results in an increase in compression energy consumption of approximately 1% [4]

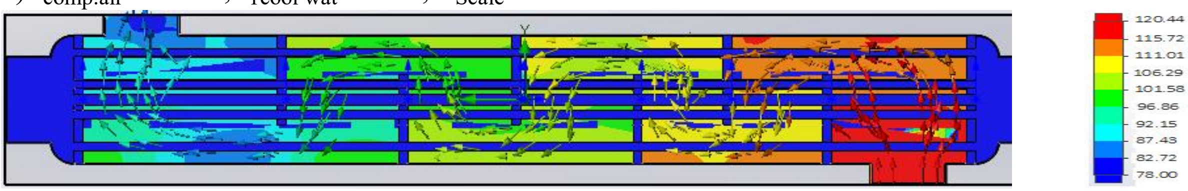
The existing cooling systems for compressor machinery operated in the Kyzylkum region possess significant drawbacks due to their specific operational conditions. The cooling water contains high concentrations of salts and impurities. Typically, the total water hardness in the circulating cooling system exceeds 20 mg-eq/L, which is several times higher than permissible limits. Consequently, rapid fouling of the heat exchanger surfaces occurs. The accumulation of scale deposits reduces the intensity of heat transfer processes, compromising both the safety and economic efficiency of mining compressor operations.

To determine the impact of scale thickness on air-cooling efficiency in the intercooler of a reciprocating compressor, a study was conducted using the advanced SolidWorks Flow Simulation software. The research analyzed compressed air discharge $t_{comp.air}$ temperatures of 100°C, 110°C, 120°C, 130°C, and 140°C. The cooling water inlet temperature was set at 15°C, 20°C, and 25°C, while the scale layer σ_{Scale} thickness was incrementally increased from 1 to 5 mm with a 1 mm step. The simulation was repeated for each air discharge $t_{comp.air}$ temperature across the various cooling water $t_{1cool\ wat}$ temperatures and scale layer thicknesses.

Figure 1 illustrates the test results regarding the influence of scale thickness on cooling efficiency, as obtained through SolidWorks Flow Simulation.

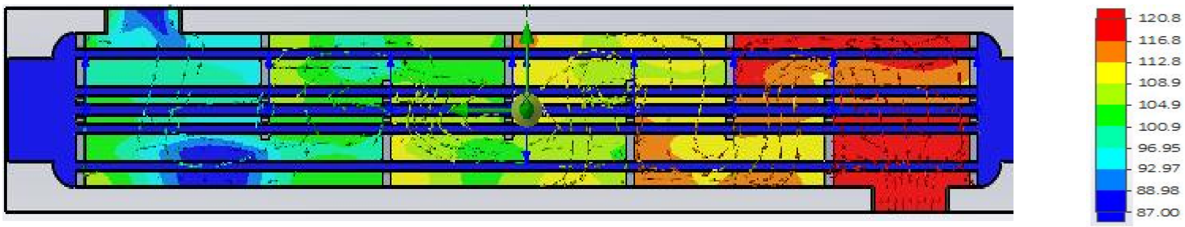


a) $t_{comp.air}$=120°C; $t_{1cool\ wat}$=20°C; σ_{Scale}=0 mm.

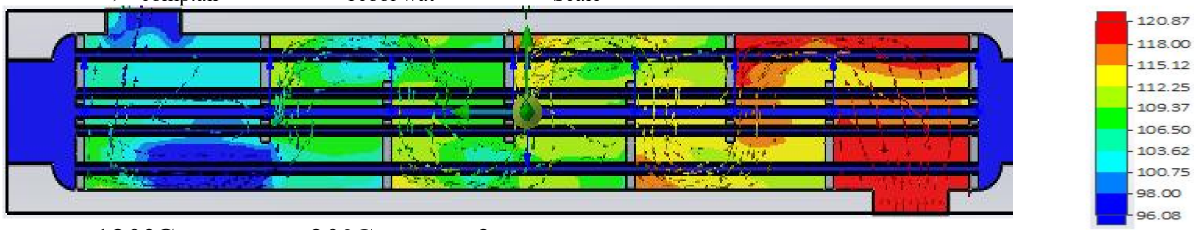


b) $t_{comp.air}$=120°C; $t_{1cool\ wat}$=20°C; σ_{Scale}=1 mm.

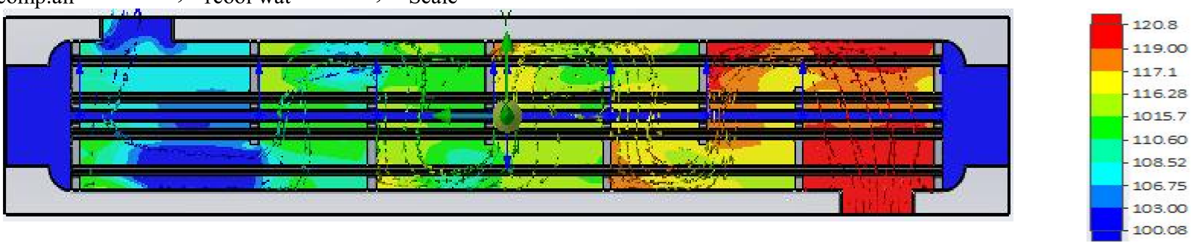
eISSN: 2229-3213 pISSN: 2229-3205
The Journal of Applied Science and Social Science
Volume 16,Issue 05 May, 2026



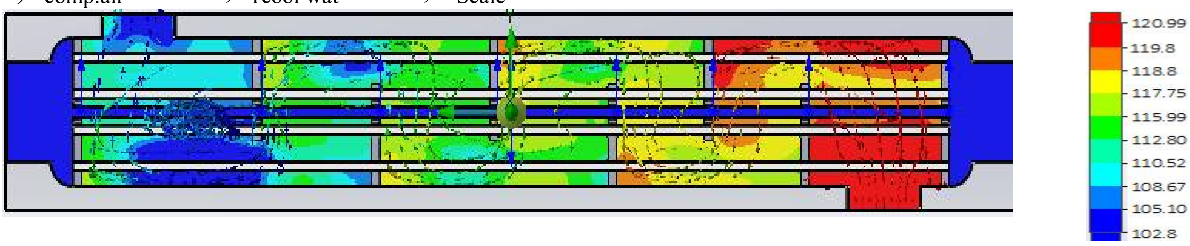
c) $t_{comp.air}$=120°C; $t_{1cool\ wat}$=20°C; σ_{Scale}=2 mm



d) $t_{comp.air}$=120°C; $t_{1cool\ wat}$=20°C; σ_{Scale}=3 mm



e) $t_{comp.air}$=120°C; $t_{1cool\ wat}$=20°C; σ_{Scale}=4 mm.



f) $t_{comp.air}$=120°C; $t_{1cool\ wat}$=20°C; σ_{Scale}=5 mm

Fig. 1. Simulation results illustrating the impact of scale layer thickness on cooling efficiency, obtained using SolidWorks Flow Simulation.

The research results indicate that for every 1 mm increase in scale layer σ_{Scale} thickness on the inner walls of the cooler tubes, the compressed air cooling effectiveness decreases by 9 °C. This trend remains consistent until the scale thickness reaches 4 mm. Once the scale layer thickness reaches 4 mm or more, each subsequent 1 mm increase in scale results in a further reduction in cooling effectiveness by 2–4 °C.

The operation of the lubrication system also significantly impacts the efficiency of reciprocating compressors. Delayed oil changes or the presence of abrasive particles within the lubricant accelerate the wear of moving friction-bearing components. Emergency situations arising from the degradation of these mechanisms result in unscheduled equipment downtime [12, 13, 14].

In particular, the standard oil filter replacement interval for reciprocating compressors is 2,500 operating hours. However, in practice, due to equipment aging, the use of low-quality spare parts (leading to rapid wear), excessive compressor overheating, and the ingress of external contaminants into the lubrication system, the actual service life of filters is often reduced by 50–60% [15, p. 29].

eISSN: 2229-3213 pISSN: 2229-3205
The Journal of Applied Science and Social Science
Volume 16,Issue 05 May, 2026

Reduced oil viscosity and contamination lead to the overheating of the compressor shaft bearings, triggering sudden emergency shutdowns. Furthermore, these factors cause abrasive wear of the bearings and their shells (bushings) and result in bearing misalignment relative to the shaft journal.

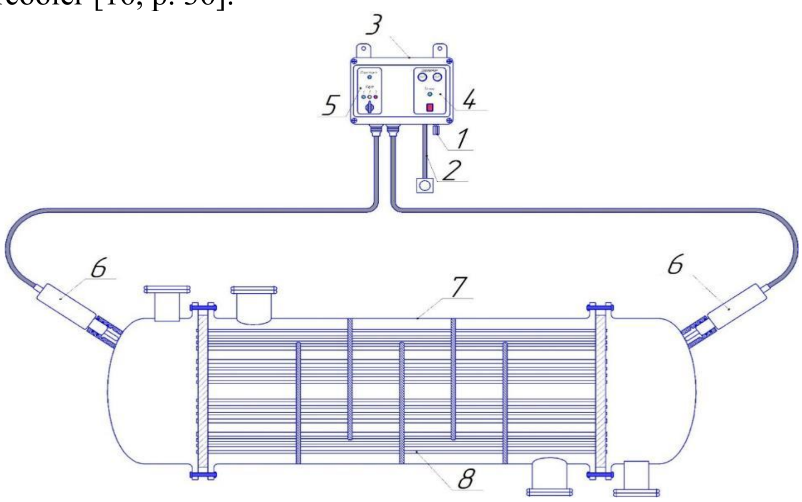
Oil contamination causes wear on the shaft body and the sections connected to the crank webs, leading to shaft deflection and premature failure. The operational reliability of the crosshead, piston rod, and sliding block—which facilitate the transmission of motion from the shaft to the piston—likewise depends on the purity and viscosity of the oil. The formation of abrasive particles within the lubricant leads to the wear of the crosshead, its slider surfaces, and the crosshead pin, resulting in a reduction of their dimensional tolerances and a shorter overall service life.

Reducing Deposit Formation on the Heat Exchange Surfaces of Reciprocating Compressor Air Coolers

Enhancing the operational efficiency of mining compressor unit cooling systems can be achieved by improving the heat transfer processes between the compressed air and the cooling water. This is primarily realized by preventing the accumulation of sludge and scale within the coolers. In modern industrial environments, chemical water softening is an effective method; however, this approach requires recurring capital expenditures, poses environmental risks, and can be hazardous to the health of maintenance personnel. Consequently, there is a clear need for alternative solutions to prevent scale formation on heat exchange surfaces.

To eliminate carbon deposits and scale on the heat exchange surfaces of air coolers during compressor operation—without requiring disassembly or additional labor—the application of an ultrasonic acoustic device is proposed.

The ultrasonic descaling device is applicable to various types of heat exchangers and operates as follows: special waveguide sensors (transducers) are mounted onto the acoustic wave generator, with the quantity determined by the total heat exchange surface area. The impulses generated by the ultrasonic device are transmitted through these sensors to the processed tube or heat exchanger. High-speed amplitude oscillations, with an average frequency of 12–25 kHz, are transferred to the walls of the heat exchanger, leading to the disintegration of the scale layer forming on the surfaces. Figure 2 illustrates the connection diagram of this device to an intercooler [16, p. 36].



1 – grounding; 2 – power supply unit; 3 – housing; 4 – fuses and indicator;
5 – control panel; 6 – pulse transmission sensors; 7 – intercooler shell; 8 – pipelines.

Fig. 2. Connection schematic of the ultrasonic acoustic descaling device to the intercooler.

When applying an ultrasonic acoustic descaling device to a tubular heat exchanger, a specific challenge arises: while the ultrasonic oscillations fully reach and effectively treat exposed surfaces, they do not fully penetrate the internal surfaces of the tubes. Due to this insufficient oscillation intensity, the descaling of the inner tube walls is rendered less effective.

Consequently, to achieve efficient scale removal from the intercooler of a reciprocating compressor, it is necessary to determine the optimal oscillation frequency and pulse duration for the proposed acoustic device.

The acoustic device developed in this study features adjustable pulse duration and oscillation frequency. Its technical specifications are summarized in the table below.

Table. 1.

Power consumption, W	Acoustic power, W	Oscillation frequency, kHz	Pulse duration, ms	Impact area, m^2	Number of sensors, pcs.
300	120	5-30	0,5-3	150	2-4

To ensure the effective descaling of the intercooler, experimental trials were conducted to determine the optimal oscillation frequency and pulse duration for the acoustic device. During the initial stage of the experiments, the scale delamination time from the test surface was measured across various pulse durations and amplitude-frequency characteristics.

Acoustic treatment was applied to metal specimens with a uniform scale layer thickness. Within the ultrasonic device, the oscillation frequency was incrementally increased from 5 kHz to 30 kHz in 5 kHz steps, while the pulse duration was varied at levels of 1, 1.5, and 2 ms. For each configuration, the time required for total scale removal from the specimen surface was recorded. The results obtained are presented as a graph in Figure 3.

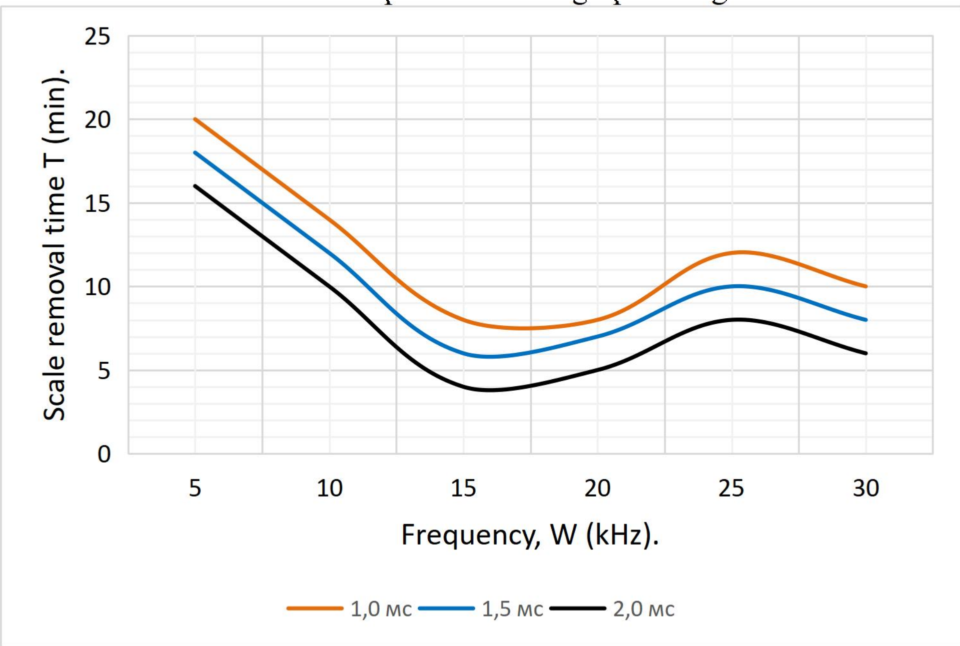
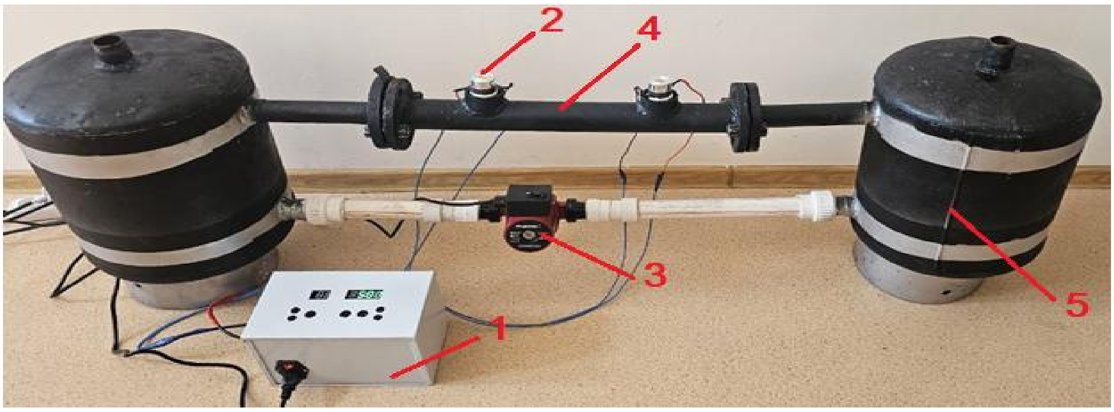


Fig. 3. Dependence of descaling time on oscillation frequency and pulse duration generated by the acoustic device.

The experimental results established that when using the proposed ultrasonic acoustic descaling device, the most efficient and rapid removal of scale from metallic surfaces is achieved at an oscillation frequency of 15–20 kHz and a pulse duration of 2 ms.

However, the application of acoustic descaling devices for cleaning the internal surfaces of tubes exceeding 1000 mm in length presents certain technical challenges. The primary reason is the difficulty of ensuring that ultrasonic oscillations fully propagate into the tube interior, as well as the degradation of the oscillation pulse duration as the tube length increases. Therefore, to ensure the effective use of an acoustic device for descaling the internal surfaces of long tubes, it is necessary to identify the optimal values for oscillation amplitude, frequency, and pulse duration that provide a consistent impact throughout the entire length of the tube. To determine these optimal parameters for the acoustic cleaning of internal tube surfaces, a series of experimental trials were conducted. A general view of the experimental setup is shown in **Figure 4**.



1 – ultrasonic device; 2 – ultrasonic transmitting sensors (transducers);
3 – pump; 4 – pipe; 5 – water tank.

Fig. 4. Experimental setup for investigating ultrasonic acoustic descaling of internal pipe surfaces.

During the experimental procedure, the ultrasonic acoustic device was mounted on a metal pipe with a diameter of 32 mm and a length of 1000 mm. Subsequently, the application of ultrasonic oscillations—characterized by varying amplitudes, frequencies, and pulse durations—facilitated the determination of descaling efficiency. Specifically, the study quantified the effective propagation distance along the pipe over which the generated frequencies induced scale destruction. The results of these experimental trials are illustrated graphically in **Figure 5**.

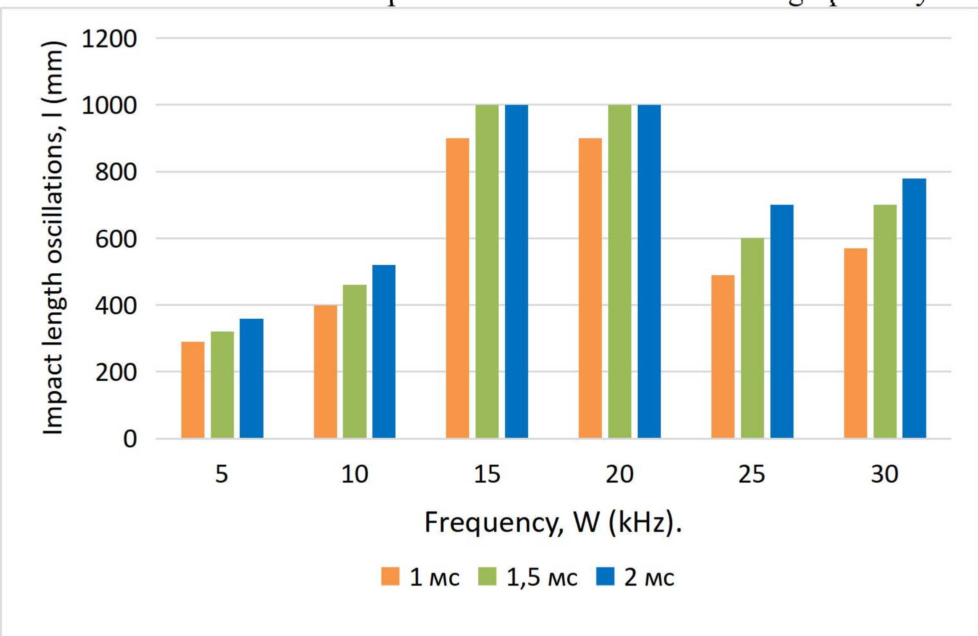


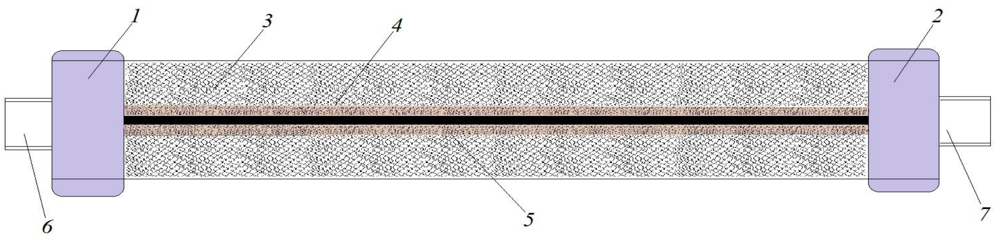
Fig. 5. Dependence of oscillation amplitude, oscillation frequency, and pulse duration on pipe length.

An analysis of the experimental results regarding the effective application of the acoustic descaling device for internal tube surfaces leads to the conclusion that for tubes with a length of 1000 mm or more, an oscillation frequency within 15–20 kHz and a pulse duration of 1.5–2 ms must be maintained to achieve high efficiency. The practical implementation of this device has resulted in improved cooling efficiency of the compressed air within the intercoolers of the reciprocating compressor [16, p. 38].

Improvement of the Lubrication System for Reciprocating Compressors

Analysis of oil samples after more than **1,000 operating hours** in the lubrication systems of the **4VM10-100/9** and **2VM10-63/9** compressor models operated at the compressor station revealed the presence of metallic particles. These particles are primarily formed due to the wear of the metallic surfaces of shaft bearings, crossheads, connecting rod bushings and pins, as well as the oil pump and gears.

To enhance oil filtration efficiency, a new oil filter design has been developed based on a **porous filter media**. This design allows for the high-quality purification of the circulating oil by capturing abrasive metallic particles as small as **0.5 mcm**, while also allowing for the **regeneration** of the filter media. The distinctive feature of this design compared to other similar porous filters is its cylindrical configuration with a **magnetic rod** installed at the center. The filter media itself is dual-layered: the pore size of the layer adjacent to the magnetic rod is **0.5–1.0 mcm**, while the pore size of the second (outer) layer is **3–5 mcm**. The structural schematic of the developed filter is shown in **Figure 6** [12, p. 16].



1, 2 – removable covers; 3 – filter media with a pore size of 3–5 μm;
4 – filter media with a pore size of 0.5–1.0 μm; 5 – permanent magnet;
6, 7 – connecting parts.

Fig. 6. Design of the magnetic oil filter.

Two-stage experimental trials were conducted to evaluate the efficiency of the developed magnetic oil filter. In the first stage, 5 liters of KS-19 compressor oil, which had been in operation for 2,500 operating hours, were filtered. The oil contained metallic particles ranging from 880 to 900 mg/kg with particle sizes between 0.5 and 25 mm. Filtration was performed using a standard porous filter with porosities of 40%, 50%, 60%, and 70% under a pressure of 4 bar. In the second stage, the proposed magnetic oil filter was tested. These experiments involved varying the thickness of the filter media surrounding the magnet (5, 10, and 15 mm) across the same porosity levels (40%, 50%, 60%, and 70%).

The experimental results indicated that the integration of a magnetic rod into the porous filter media reduces the oil flow velocity. For instance, the oil flow velocity through a standard filter with 70% porosity is 75 mm/s, whereas the velocity through the magnetic filter with the same porosity and a 5 mm media thickness is 50 mm/s. The flow velocity is further influenced by the thickness and porosity of the magnetic surface filter. However, the reduction in oil flow velocity within the magnetic filter is compensated by its significantly enhanced cleaning capacity (filtration efficiency).

The optimal parameters for the proposed magnetic filter were determined to be a 70% porosity and a 10 mm thickness. These parameters ensure maximum oil purity and the highest achievable flow velocity while maintaining the ability to capture sub-micron particles (less than 1 mm) contained within the oil.

The cleaning performance of the proposed magnetic filter was field-tested on a 4VM10-

100/9 type compressor over 2,500 operating hours. Simultaneously, a baseline oil filter was monitored over the same period, with oil samples collected every 500 operating hours. The results of these comparative experimental trials are presented graphically in Figure 7.

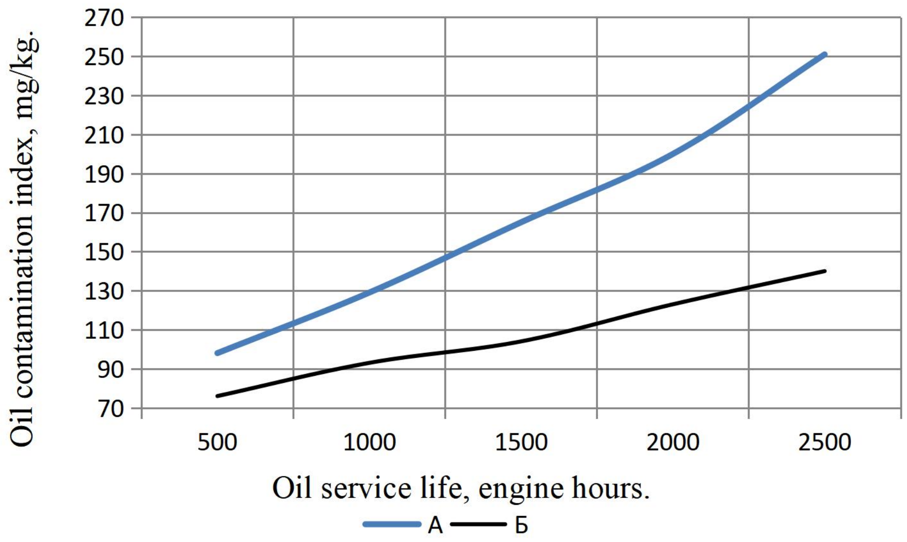


Fig. 7. Dependence of oil contamination increase on operating time using the baseline (A) and proposed (B) filters.

A comparison between the baseline and magnetic filters established that the proposed magnetic filtration system is approximately **40–50%** more effective at purifying the oil.

Conclusion.

Based on the research conducted, the following conclusions of theoretical and practical significance have been drawn:

Each 1 mm increase in scale thickness on the heat exchange surfaces of the intercoolers in multi-stage reciprocating compressors leads to an average 5% increase in the temperature of the air delivered to the next stage cylinder.

An ultrasonic acoustic device has been developed, enabling the effective descaling of the intercooler heat exchange surfaces in multi-stage reciprocating compressors. The practical application of this device has resulted in a **95% reduction** in scale formation within the air coolers and a **2% reduction** in energy consumption for air compression.

The optimal values for oscillation amplitude, frequency, and pulse duration generated by the ultrasonic acoustic device have been determined, ensuring effective descaling of the internal surfaces of metallic tubes.

The optimal parameters for the improved design of the compressor lubrication system filter have been established. A porosity of **70%** and a filter media thickness of **10 mm** over the magnet ensure maximum oil purity and the highest flow velocity, while achieving the capability to capture sub-micron particles (less than **1 mcm**) contained in the oil.

The implementation of the improved filter design in the compressor lubrication system allows for an increase in the service life of the crosshead by **20%**, the oil pump by **30%**, the connecting rod by **20%**, and both the oil filter and the lubricant itself by **60%**.

Reference list.

1. Khatamova D.N. Development of a device for softening the circulating water of the cooling system of stationary mine compressor units // The American Journal of Engineering and Technology. – Vol. 03. – Issue 08-03. – 2021. – P.18-26.

2. Хазин М.Л., Волегов С.А., Сокерина О.В. Надежность поршневого компрессора // Горное оборудование и электромеханика. 2025. № 6 (182). С. 58-65. DOI: 10.26730/1816-4528-2025-6-58-65, EDN: ORSZBD.

3. Khatamova D.N., Djuraev R.U. Energy saving during operation of mining compressor units based on modernization of their cooling systems // International Journal of Future Generation Communication and Networking. 2021. Vol. 14. №2. P. 41-52.

4. Меркулов М. В., Джураев Р. У., Хатамова Д. Н. Повышение эффективности рудничных компрессорных установок на основе ресурсосберегающих технических решений // Горный журнал, 2024. – № 12. – С.75-81. DOI: 10.17580/gzh.2024.12.10

5. Сеидахмедов Н. С. Исследования основных эксплуатационных характеристик работы клапанов поршневых компрессоров // Sciences of Europe. 2021. № 79-1 (79). С. 52-55. DOI: 10.24412/3162-2364-2021-79-1-52-55.

6. Zhang J., Yin W., Shi Y., Gao Z., Pan L., Li Y. Effects of the Damping Parameters on the Opening and Closing Characteristics of Vent Valves // Applied Sciences. 2022. Vol. 12. № 10. Pp. 5169. DOI: 10.3390/app12105169.

7. Sotoodeh K., Gudmestad O. T. Safety and reliability improvement of valves and actuators in the of shore oil and gas industry // Life Cycle Reliability and Safety Engineering. 2022. Vol. 11. Pp. 293-302.

8. Файрушин Ш. З., Байков И. Р., Китаев С. В. Определение показателей надёжности поршневых компрессоров // Нефтегазовое дело. 2016. Т. 15. № 2. С. 120-124.

9. Guo F-Y., Zhang Y-C., Wang Y., Ren P-J., Wang P. Fault Diagnosis of Reciprocating Compressor Valve Based on Transfer Learning Convolutional Neural Network // Mathematical Problems in Engineering. 2021. Vol. 2021. Article ID 8891424. 13 p. DOI: 10.1155/2021/8891424.

10. Han L., Jiang K., Wang Q., Wang X., Zhou Y. Quantitative Evaluation on Valve Leakage of Reciprocat-ing Compressor Using System Characteristic Diagnosis Method // Applied sciences. 2020 Vol. 10. Pp. 1946-1966. DOI: 10.3390/app10061946.

11. Хазин М. Л., Волегов С. А., Сокерина О. В. Анализ причин неисправности клапанов поршневых компрессоров и пути улучшения их конструкции // Горный информационно-аналитический бюллетень. 2024. № 1-1. С. 21-33. DOI: 10.25018/0236_1493_2024_011_0_21.

12. Fritz, B., & Scheichl, B. (2023). Comprehensive multi-scale cylinder lubrication model for reciprocating piston compressors: From rigid-body dynamics to lubricant-flow simulation. Tribology International, 178, 108028. https://doi.org/10.1016/j.triboint.2022.108028.

13. Pöllinger, A., Thalhammer, J., Heupl, S., et al. (2024). Characterization of PPS piston and packing ring materials for reciprocating piston compressors under non-lubricated and lubricated conditions. Polymers, 16(3), 412. https://doi.org/10.3390/polym16030412.

14. Sun, S., et al. (2023). Lubrication Analysis of Small-End Bearings in Reciprocating Mechanisms. Applied Sciences, 13(6), 3756. https://doi.org/10.3390/app13063756

15. Юлдошов Х.Э. Разработка технических решений, повышающих эффективности эксплуатации рудничных компрессорных установок // Автореферат дисс. … на соискание ученой степени доктора философии (PhD) по техническим наукам. – Навоий, 2023. – 44 с.

16. Пардаева Ш.С. Совершенствование системы охлаждения рудничных компрессорных установок // Автореферат дисс. … на соискание ученой степени доктора философии (PhD) по техническим наукам. – Навоий, 2025. – 45 с.

17. Rahimdel M. J., Ghodrati B. Reliability analysis of the compressed air supplying system in undergroundmines. Scientific Reports. 2023, vol. 13, article 6836. DOI: 10.1038/s41598-023-33736-5.