Theoretical analysis of mechanical displacements in the cylinder resulting from increased fluid flow in the hydraulic system and enhanced internal flows due to temperature rise

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Abstract. This study examines how increasing temperature affects hydraulic fluid properties and the dynamic behavior of cylinders. Rising temperature reduces viscosity and density, causing pressure instability, cavitation, internal leakage, and vibration. Mathematical models of thermal expansion, pressure variation, and flow response were developed, and analytical graphs confirmed nonlinear growth of oscillation amplitude at high temperatures. The results highlight the significant role of thermal effects in hydraulic system reliability, efficiency, and control optimization.

INTRODUCTION

When the temperature rises (as the liquid heats up), the viscosity of the liquid decreases. The heated liquid becomes less viscous, and additional pressure develops within it. As a result, internal leakage within the pump increases. The cylinders operate slower or create additional space for oscillation, leading to incomplete closure of the valves. The pressure in the system decreases, and the heated liquid flows more rapidly, but due to its reduced density, the pump cannot generate the required pressure. The risk of cavitation in the system increases. This process causes "noise" and "vibration" to occur. The movement of the cylinders in their working state changes, potentially becoming slower and more erratic [10-12]. The return speed of the cylinder increases, but its force decreases. Connected parts wear out quickly because high temperatures either harden or melt them. The service life of hydraulic units (pumps, hydraulic motors) decreases. Metal surfaces heat up, accelerating wear. During thermal expansion, the liquid volume increases, and the probability of evaporation rises. The hydraulic accumulator pressure changes. "Inexplicable hardening" is observed in mechanical parts. Internal pressure losses increase. Flow resistance in pipelines intensifies. The pump is forced to raise pressure more because it increases. The elasticity of pipe connections decreases. At low temperatures, rubber seals harden and do not close properly, causing leaks to appear [1,2,3,6].

EXPERIMENTAL RESEARCH

In this regard, various effective cooling systems have been implemented that are capable of maintaining a stable operating oil temperature in different climatic conditions. The Navoi region is one of the areas in Uzbekistan that experiences the highest temperatures, with the external temperature potentially rising to +46.7 °C during summer months. Under such conditions, the heat exchange of the hydraulic system decreases sharply, and the efficiency of specialized coolers becomes insufficient [4,7,8].

The figure below shows how a double-sided cylinder works.

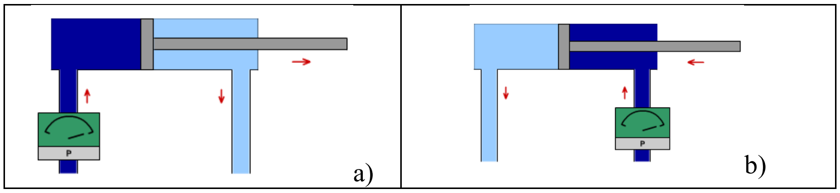

Figure 1. Forward and backward movement of a cylinder in a hydraulic system. a) forward movement b) backward movement.

If the liquid enters through the reception of the liquid on the left (main inlet), it moves to the right (forward impact), which forces the liquid discharged into the cylinder chamber to flow in the secondary direction. If the liquid is supplied to the secondary half (liquid intake on the right), it moves on the surface of the cylinder ring and moves the cylinder and the cylinder piston to the left (reverse motion). In this case, the transferred liquid moves to the primary side. In connection with the construction described above, there is another feature that needs to be taken into account [13-15]. For forward and reverse displacement, the liquid is supplied to the primary side, if the entire piston surface A_P is available for the acting force, then during reverse motion, the liquid enters the secondary side A_S. The following image illustrates this situation.

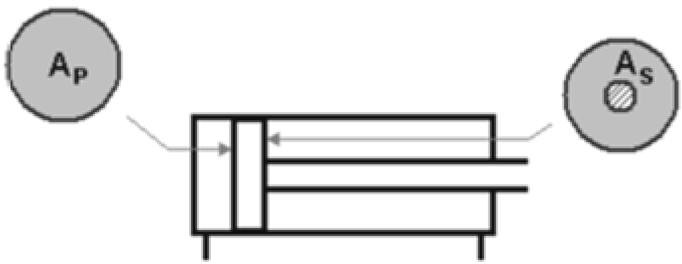

Figure 2. Surfaces of liquid pressure on the cylinder.

This means that even if the same amount of fluid is supplied, the forces that begin to move during the forward and reverse impacts are equal [16-17].

When the temperature rises, the following happens:

The density of the oil decreases, and as the mass decreases, the pressure inside the chamber also decreases.

The volume of the liquid expands, the free space in the chamber increases.

The viscosity of the oil decreases, and the flow rate increases, but the pressure holding capacity decreases.

Due to changes in piston movement, micro-cavities and bubbles (initial cavitation) appear in the chamber.

As a result:

The pressure in the left chamber is unstable, a cavity can form behind the piston, and the cylinder moves "with vibration."

We can see such gaps in the figure below.

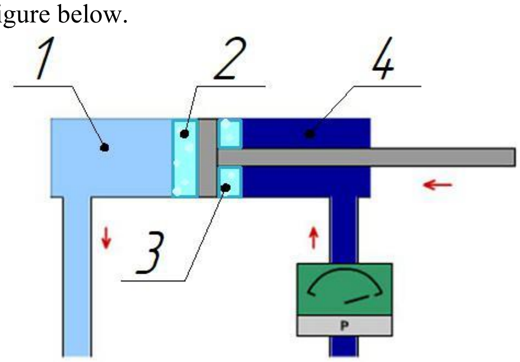

Figure 3. Changes in pressure zones inside the cylinder with increasing temperature

Based on Figure 3 above, the quantity of the 1st reversible fluid. 2, 3 - cavities formed on the piston sides of the cylinder. 4-amount of propellant fluid. Increasing the temperature causes cavities, vapor bubbles, internal leaks, and deformations in all pressure zones of the hydraulic cylinder. As a result, the transmission capacity of the cylinder decreases, and the rod stroke becomes unstable. [7,8].

RESEARCH RESULTS

If the system is partially or completely closed and the fluid temperature rises, the volume of the fluid changes due to thermal expansion:

$$\frac{\Delta V_{th}}{V} = \beta \Delta T \quad (1)$$

it creates pressure if the system volume remains constant. The pressure generated in a closed state can be expressed as follows.

$$\Delta P_{th} = -K \frac{\Delta V_{th}}{V} = -K\beta\Delta T \quad (2)$$

From this formula, it can be seen that if the temperature increases and the volume is not eliminated accordingly, the pressure can reach large values, but in practical systems with an increase in a large amount of space or temperature, the viscosity of the liquid μ(T) decreases, which reduces hydraulic resistance, and under the same pump parameters, the flow Q increases.

$$R(T) = C\mu(T) \quad (3)$$

Let's compose the following formula depending on the fluid yield and temperature.

$$Q = \frac{\Delta P_{th}}{C\mu(T)} \quad (4)$$

Here; ΔV_{th} - volume change (m^3), V-volume in the hydraulic system (m^3), β-coefficient of thermal expansion of the liquid, ΔT-external temperature affecting the liquid (°C), ΔP_{th}-pressure change in the hydraulic system (bar), K-temperature change coefficient, μ-liquid viscosity coefficient. Q-liquid flow rate (ml/s), R-liquid resistance force (Newtons),

Based on the above formulas, we obtain the following graph by calculating the fluid flow rate at T_1=10°C, T_2=20°C, T_3=30°C, T_4=40°C, T_5=46.7°C, and 0-120 ml/s at various temperature values between 10-46.7°C.

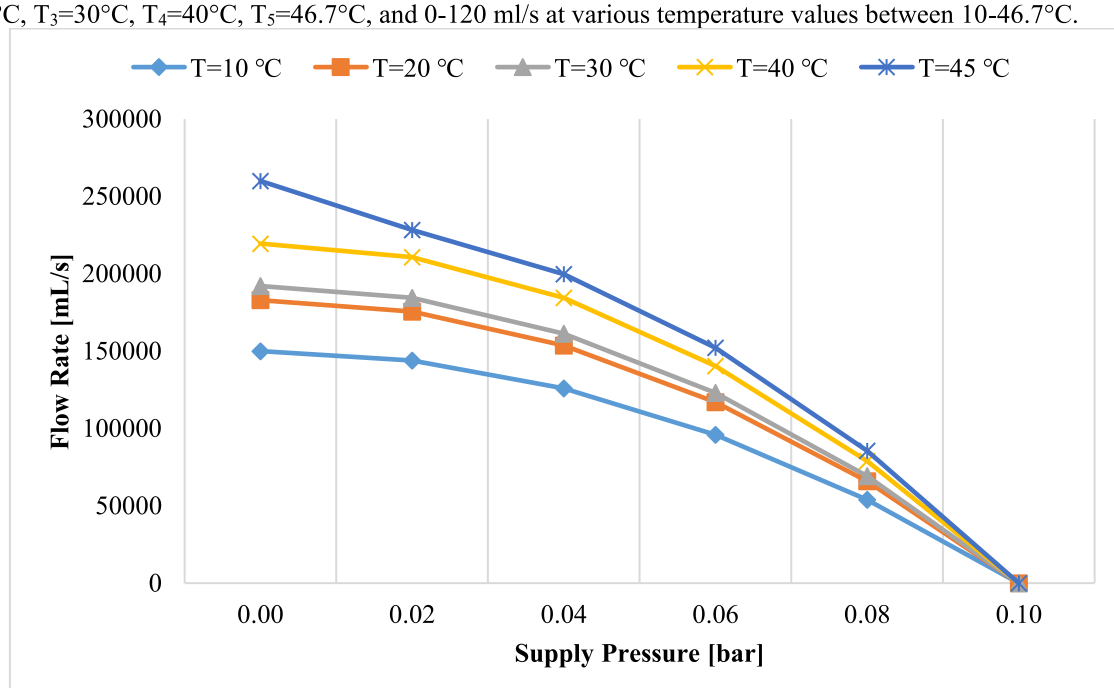

Figure 4. Analytical graph of pressure and liquid flow rate

As can be seen from the graph, the slope of the lines increases with increasing temperature - this is the result of a decrease and an increase in the actual volumetric capacity of the pump. At the same time, at high temperatures, the risk of cavitation arises due to an increase in the liquid vapor pressure (according to the Clausius-Clapeyron equation), which negatively affects the pump's operation.

One of the main physical properties of hydraulic fluids is density (ρ), which decreases with increasing temperature. This process occurs as a result of the expansion of the distance between liquid molecules.
With increasing temperature, the kinetic energy of liquid molecules increases.
As a result:
Molecules move away from each other
The volume occupied by the liquid increases.
The mass corresponding to this volume remains constant.
We express the decrease in density using the following formula.

$$\rho(T) = \rho_0(1 + \beta T) \quad (5)$$

If;

$$\frac{\rho}{\rho_0} = (1 + \beta T) \rightarrow \frac{V}{V_0} = (1 + \alpha T) \rightarrow K_V = 1 - \frac{V}{V_0} = 1 - \frac{X}{X_E} \quad (6)$$

Here; ρ - density of the liquid affected by temperature (kg/m^3), ρ_0 - initial density of the liquid (kg/m^3), K_V - coefficient of volume change, X_e - displacement of the cylinder rod due to temperature change (mm), X - initial displacement of the cylinder rod (mm)

Analysis of 5 different values, T_0=0°C, T_1=10°C, T_2=20°C, T_3=30°C, T_4=40°C, T_5=46.7°C in the range of values from 10 to 46.7°C through the coefficient of temperature and volume change is shown by the graph in Figure 5.

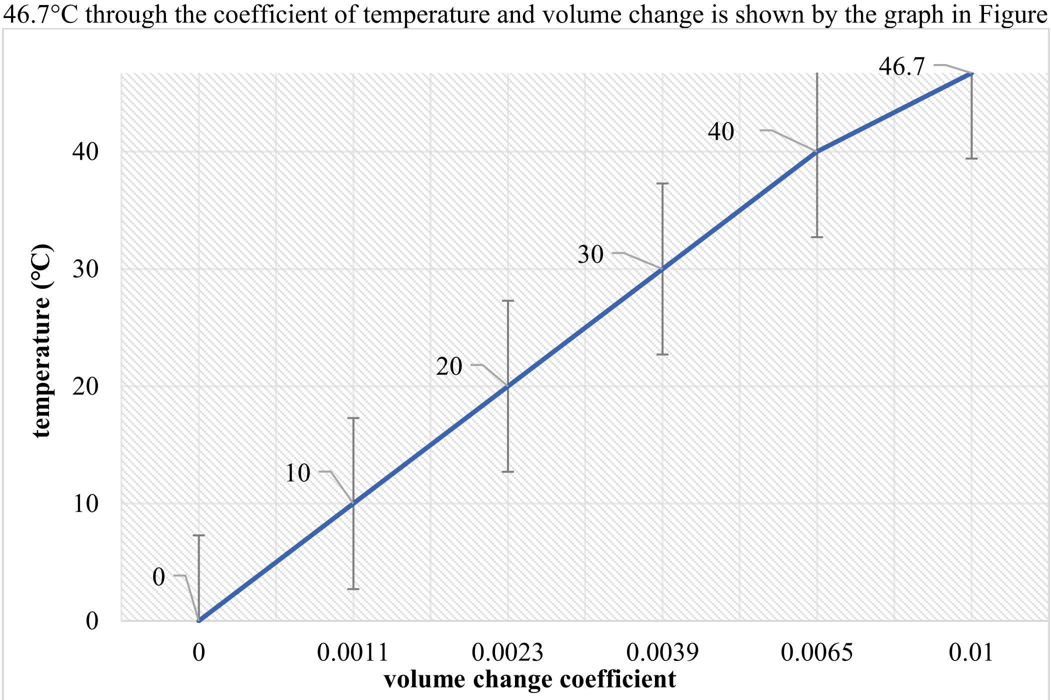

Figure 5. Analytical graph of the volume change coefficient and temperature at different values.

In this analysis, the change in volume of the same type of liquid in the temperature range from 10°C to 46.7°C was considered. In the study, a different value of the volumetric expansion coefficient of the liquid (from 0 to 0.001) was chosen as the basis. Each value represents, to a certain extent, the temperature sensitivity of the liquid; As the volume change coefficient increases, the volume response of the liquid to temperature change increases.

1. At small values of the volume change coefficient, the sensitivity of the liquid to thermal effects in this range is very low, and in the range from 10°C to 20°C, the volume increases almost linearly and uniformly. Since the volume difference formed with increasing temperature is very small, the difference between the lines will also be minimal. This shows that the thermal density of the liquid is unstable, which leads to a change in pressure.

2. At values in the middle range. In this case, the volume response of the liquid to temperature increases significantly. In the range of 20-40 °C, the change in volume relatively accelerates, but the overall trend remains linear. This reflects the expansion of internal distances with an increase in thermal energy in the structural connections of the liquid.

3. Maximum value (0.01). This coefficient represents the highest thermal sensitivity. In the study, it was noted that above 40°C, the line became slightly curved. This can be based on two reasons:

Disruption of the molecular order of a liquid (i.e., rapid expansion of the intermolecular space under the influence of heat),

The transition of volumetric expansion to a nonlinear regime is a typical physical phenomenon observed in many liquids at high temperatures.

At the same time, for all other K_V values above 40°C, such a significant difference is not observed. This indicates that the deviation of the volumetric expansion from the linear model occurs only in the case of high sensitivity.

The dependence of liquid volume on temperature is proportional, and with an increase in K_V, the intensity of volume increase also increases.

For coefficients in the range from 0 to 0.00075, the change in volume is mainly linear. At temperature T_1=10°C, K_v=0.0011, at T_2=20°C, K_v=0.00232, at T_3=30°C, K_v=0.0039, at T_4=40°C, K_v=0.0065, and at T_5=46.7°C, K_v=0.01.

This situation in practical hydraulic systems means that in high-temperature regimes, a sharp change in pressure occurs precisely in liquids with high temperatures, which leads to a redistribution of loads inside the cylinder.

If;

$$T=\text{const.}\ \Delta P_{th} = f_1(K_V)\ ; \quad \Delta P_{th} = \frac{\beta \Delta T}{K + \frac{1}{K_V}} \tag{7}$$

We present an analysis of the pressure dependence graph at the values of the volume change coefficient in Figure 6 below.

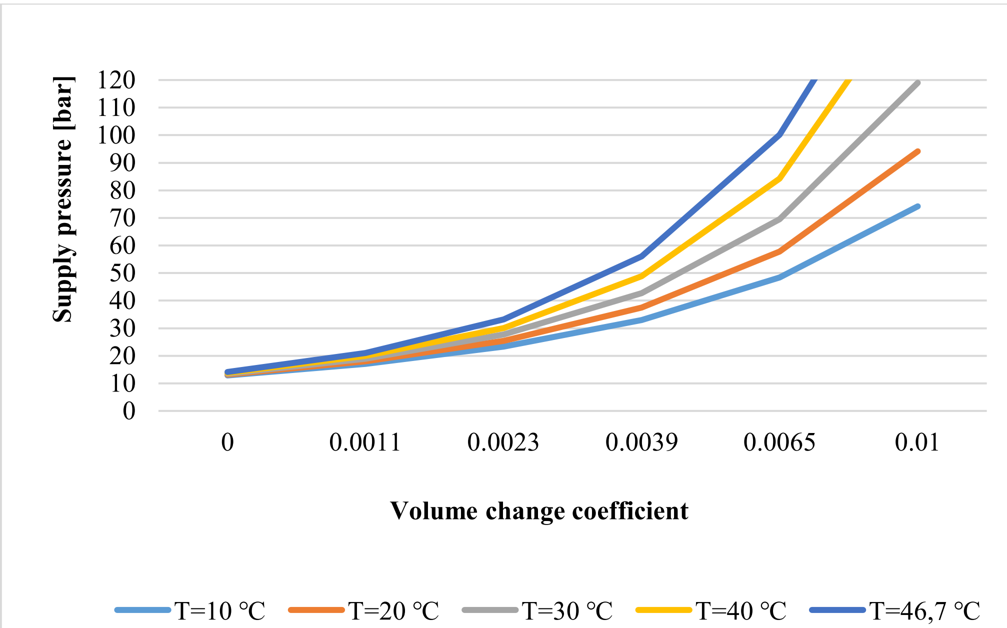

Figure 6. Analytical graph of the volume change coefficient and pressure at different values.

An analysis was conducted on the parabolic change in pressure increase within a hydraulic system, resulting from the increase in volume change coefficient of identical liquids at different temperatures: T_1=10°C, T_2=20°C, T_3=30°C, T_4=40°C, T_5=46.7°C. It was found that an increase in temperature due to external influence raises the pressure of the liquid in the closed system, causing additional cavities to form in the cylinder rod. This, in turn, creates a gap that allows for piston vibration. This relationship can be expressed through the following function.

$$F = ma = m\frac{dv}{dt} = \frac{\Delta P_{th}}{A_S} => \frac{\Delta P_{th}}{A_S \cdot m} = \frac{dv}{dt} => \int dv = \frac{\Delta P_{th}}{A_S \cdot m} \int dt => v = \frac{\Delta P_{th}}{A_S \cdot m} \cdot t =>$$

$$=> \int dX = \frac{\Delta P_{th}}{A_S \cdot m}\, t \int dt => \ X = \frac{\Delta P_{th}}{A_S \cdot m} \cdot \frac{t^2}{2} \tag{8}$$

If the function $\Delta P_{th} = f_1(K_V)$ in formula 7 depends on the pressure and volume change coefficients, we will construct the following function.

$$X_E = f_2(\Delta P_{th}) \tag{9}$$

Here; A_s - surface area of the rod in contact with the liquid (m^2), F - force exerted by the liquid (Newton), m - mass of the liquid in the cylinder (kg), a - acceleration of the cylinder piston (m/s^2), v - velocity of the cylinder piston (m/s), t - time (s), We will analyze the change in the amplitude of oscillations of the cylinder and the pressure in the hydraulic system due to various reasons with a liquid at 5 different constant temperatures using Figure 7 below.

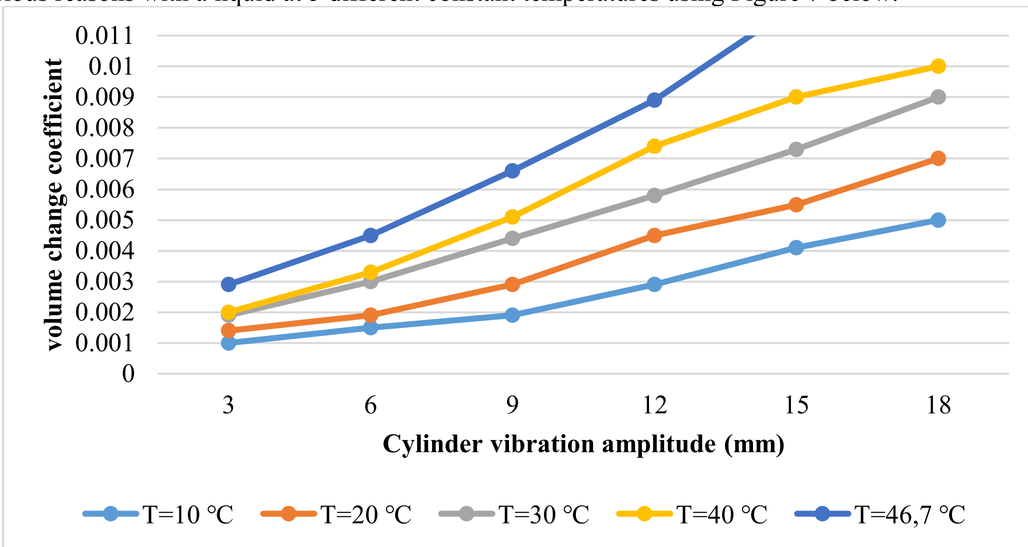

Figure 7. Analytical graph of the volume change coefficient and the oscillation amplitude of the cylinder at different temperature values.

The same liquids at different temperatures at T_1=10°C, T_2=20°C, T_3=30°C, T_4=40°C, T_5=46.7°C, as a result of increasing the volume change coefficient, influence the change in cylinder movement in the hydraulic system through small oscillations. The higher the temperature of the liquid, the greater the amplitude of oscillations of the piston in the cylinder, causing a parabolic increase. Mechanical reactions of dynamic and cyclic displacement were systematically analyzed.

CONCLUSIONS

Research results indicate that changes in the thermodynamic parameters of the fluid significantly affect its influence on the mechanical parts of the hydraulic system. In a closed hydraulic system, if heat is continuously transferred to the fluid, the internal energy received by the system generates mechanical energy. This mechanical energy can cause harmful movements in the system, primarily leading to vibration and disconnection of connecting parts. Based on external temperature values, temperatures ranging from 10°C to 46.7°C are considered an important external factor in various hydraulic machines within hydraulic systems, and the principles of fluid mechanics are applied in these conditions. The type, temperature, volume, and viscosity coefficients of the fluid are the main parameters for controlling the movement and force of mechanisms in a hydraulic system. This study theoretically examined the influence of increasing fluid temperature on the dynamic properties that arise during cylinder movement. These results provide a foundation for graphical analysis of theoretical studies through mathematical equations in the design of hydraulic control systems, maintaining and operating temperature in a steady state to achieve optimal temperature, load, operation, reliability, and efficiency. Future research, especially in higher educational institutions in the field of engineering, will contribute to the study of hydraulic system designs, control methods, and further optimization of system performance.

REFERENCES

1. Xiuliang Liu, Jianye Yang, Qifan Zou, Yongyan Hu, Pengkun Li, Li Tan, Nenad Miljkovic, and Ronggui Yang ACS Nano 2025 19 (10), 9513-9589 DOI: 10.1021/acsnano.4c15277R. Schürhuber, B. R. Oswald, L. Fickert, J. Fortmann. Verhalten von Windkraftanlagen mit doppelt speisenden Asynchrongeneratoren (DFIG) bei Kurzschlüssen und anderen Netzfehlern. Elektrotechnik & Informationstechnik (2020) 137/8: 415–424. https://doi.org/10.1007/s00502-020-00829-2

2. Abduazizov, Nabijon, et al. "Analysis of the dependence of the hydraulic system training coefficient in quarry excavators on the concentration of contaminated particles in the working fluid." E3S Web of Conferences. Vol. 627. EDP Sciences, 2025. https://doi.org/10.1051/e3sconf/202562705022
3. Wang, Cuihua, et al. "Effects of temperature-dependent viscosity on fluid flow and heat transfer in a helical rectangular duct with a finite pitch." Brazilian Journal of Chemical Engineering 31 (2014): 787-797. https://doi.org/10.1590/0104-6632.20140313s00002676.
4. Kholbaev, G. ., Shermukhammadov, U. ., Toshboev, Z. ., Eshmirzaev, D. ., Arziqulov, M. ., & Achilov, J. . (2025). DISTRIBUTION OF EFFECTIVE TEMPERATURE SUMS ABOVE 15.0°C. Journal of Geography and Natural Resources, 5(03), 16–29. https://doi.org/10.37547/supsci-jgnr-05-03-04
5. Kholmatjanov, B.M.; Petrov, Y.V.; Khujanazarov, T.; Sulaymonova, N.N.; Abdikulov, F.I.; Tanaka, K. Analysis of Temperature Change in Uzbekistan and the Regional Atmospheric Circulation of Middle Asia during 1961–2016. Climate 2020, 8, 101. https://doi.org/10.3390/cli8090101
6. A. S. Zhuraev, S. A. Turdiyev, S. T. Jurayev, and S.S. Q. Salimova, "Characteristics of packing gland seals in hydraulic systems of quarry excavators and results of comparative analysis of experimental tests," Vibroengineering Procedia, Vol. 54, pp. 252–257, Apr. 2024, https://doi.org/10.21595/vp.2024.24051.
7. Ismatov Adxamjon Alibek o'g'li, Raxmatov Ramazonjon Ravshan o'g'li. Gidravlik tizimlardagi ichki nosozliklardan suyuqlik oqib chiqishini ishqalanish kuchlari asosida matematik modelini ishlab chiqish. Diversity Research: Journal of Analysis and Trends. Vol. 2, pp. 46-49, https://academiaone.org/index.php/2/article/view/854
8. Nabijon Abduazizov, Kamol Xakimov, Sardor Turdiyev, Akbar Zhuraev, Adham Ismatov. The impact of the amount of pollution of the fluid in the hydraulic system on the working resource of the quarry excavator. E3S Web of Conferences, 2025. https://doi.org/10.1051/e3sconf/202562705001
9. Rabatuly M., Myrzathan S.A., Toshov J.B., Nasimov J., Khamzaev A. Views on drilling effectiveness and sampling estimation for solid ore minerals. 2026. https://doi.org/10.31643/2026/6445.01
10. Toshov J.B., Rabatuly M., Khaydarov Sh., Kenetayeva A.A., Khamzayev A., Usmonov M., Zheldikbayeva A.T. Methods for Analysis and Improvement of Dynamic Loads on the Steel Wire Rope Holding the Boom of Steel Wire Rope Excavators. Complex Use of Mineral Resources 2026; 339(4):87-96 https://doi.org/10.31643/2026/6445.43
11. Zokhidov O.U., Khoshimov O.O., Khalilov Sh.Sh. Experimental analysis of microges installation for existing water flows in industrial plants. III International Conference on Improving Energy Efficiency, Environmental Safety and Sustainable Development in Agriculture (EESTE2023), E3S Web of Conferences. 2023. https://doi.org/10.1051/e3sconf/202346302023
12. Zokhidov O.U., Khoshimov O.O., Sunnatov S.Z. Selection of the type and design of special water turbines based on the nominal parameters of Navoi mine metallurgical combine engineering structures. AIP Conf. Proc. 3331, 050022 (2025). https://doi.org/10.1063/5.0306554
13. Khamzaev A.A., Mambetsheripova A., Arislanbek N. Thyristor-based control for high-power and high-voltage synchronous electric drives in ball mill operations/ E3S Web Conf. Volume 498, 2024/ III International Conference on Actual Problems of the Energy Complex: Mining, Production, Transmission, Processing and Environmental Protection (ICAPE2024) DOI: https://doi.org/10.1051/e3sconf/202449801011
14. Toshov B.R., Khamzaev A.A. Development of Technical Solutions for the Improvement of the Smooth Starting Method of High Voltage and Powerful Asynchronous Motors/AIP Conference Proceedings 2552, 040018 (2023); https://doi.org/10.1063/5.0116131 Volume 2552, Issue 1; 5 January 2023
15. Toshov B.R., Khamzaev A.A., Sadovnikov M.E., Rakhmatov B., Abdurakhmanov U./ Automation measures for mine fan installations/ SPIE 12986, Third International Scientific and Practical Symposium on Materials Science and Technology (MST-III 2023), 129860R (19 January 2024); doi: 10.1117/12.3017728. Third International Scientific and Practical Symposium on Materials Science and Technology (MST-III 2023), 2023, Dushanbe, Tadjikistan.
16. Toshov B.R., Khamzaev A.A., Namozova Sh.R.Development of a circuit for automatic control of an electric ball mill drive. AIP Conference Proceedings 2552, 040017 (2023) Volume 2552, Issue 1; 5 January 2023.
17. Toirov, O., Pirmatov, N., Khalbutaeva, A., Jumaeva, D., Khamzaev, A. Method of calculation of the magnetic induction of the stator winding of a spiritual synchronous motor. E3S Web of Conferences, 2023, 401, 04033