# Analysis of the dependence of the hydraulic system training coefficient in quarry excavators on the concentration of contaminated particles in the working fluid

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**Abstract.** During the operation of hydraulic excavators, a constant process of contamination of working fluids with atmospheric and other contaminants occurs. Pollutants affecting the system include two main components: mechanical impurities and water. As noted above, for various reasons of an objective and subjective nature, in the work of many researchers during the operation of excavators, changes in the general pollution indicators of working fluids occur, and the uncontrolled state of their contamination leads to a more intensive accumulation of pollution in their tanks in the hydraulic system, failure of their filters. As a result, there is a decrease in the reliability of hydraulic ridges of hydraulic excavators.

## 1 Introduction

The main function of the working fluid in the hydraulic system will be composed of the transportation of pressure energy, the storage of details from the carriage, the feature of lubricating between the details, the reduction of temperature exceeding, which is released by friction [1,2].

In the resource of many scientists around the world, an analysis was made of the results of a negative impact on the useful coefficient of work, efficient operation and the overall system itself, as a result of which the failures of the hydraulic system instilled the porosity of working fluids to the quality and viscosity of purity [3,4].

The ingress of water into the working fluid in the hydraulic system destroys the lubricating layer of the parts, resulting in corrosion, solid particles are rubbed between the paired parts and cause them to wear out in the cracks. The mixed air rises to a temperature of 300-350 degrees, burns the additives in the working fluid, and creates small alloy particles [5-7].

The most dangerous for hydraulic system components and hydraulic systems are dust particles, the hardness of these particles is high, causing 50-80% of failures. They reduce the

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life of hydraulic components, especially hydraulic pumps, hydraulic distributors or hydraulic systems, from 3 to 50 times.

In this work [8], i.e., when studying fluid contamination in hydraulic systems, it was found that the content of impurities in the working fluid in the amount of 0.005% by mass of particles corresponds to the 9th class of industrial cleanliness according to the technological standard. However, in many analyses, this amount was observed to increase by a factor of up to 10. According to the professor's research data, the working fluid in the warehouse contains 0.011% by mass, in the summer - 0.016%, in the winter - 0.030%, in the summer - 0.05-0.08%, in general - even 0.2%. In hydraulic excavators, the contamination of the working fluid during loading increases by 2-4 times, and during pouring - by 5-8 times. The contaminated working fluids contained 30-40% metal, 4-29% varnishes, and 18-50% rubber products. The composition of the working fluid contaminated with the atmosphere in the hydraulic system was 70% quartz sand, 3-5% iron oxide, 15-17% aluminium, and 2-4% calcium components.

## 2 Methods and materials

High dust and pollution levels in open pit mines reduce the reliability of the hydraulic system of quarry excavators. Therefore, one of the urgent tasks of the mining industry is to develop technical solutions that ensure the reliability of quarry excavators with minimal costs and technical operation [9].

The technical performance of a hydraulic system depends on the cleanliness of the hydraulic working fluids used in it. Contamination of the hydraulic working fluid leads to abrasive wear of the elements in the hydraulic system, as well as to the expansion of the gaps due to abrasive wear of the friction pairs in the hydraulic grooves. This, in turn, worsens the technical performance of the equipment due to a drop in pressure in the hydraulic system and increases operating costs [10, 11].

Most hydraulic system failures are caused by contamination of the working fluid. Working fluids become contaminated during transportation, improper storage, filling into equipment, and during operation.

Another indicator that ensures the reliable operation of quarry excavators is the hydraulic system efficiency. Studies have shown that this indicator is significantly affected by the level of contamination of the working fluid. Therefore, establishing the dependence of the efficiency on the change in the level of contaminated particles can also help predict the reliability of hydraulic systems [12].

To establish this relationship, we express the relationship through the following function:

$$K_p = f(\eta_{yu}, \frac{1}{C}), \tag{1}$$

where, $\eta_{yu}$- coefficient of useful work of the hydraulic system; $C$ - mass concentration of mechanical impurities.

The formula for the full useful work coefficient of a hydraulic system is as follows:

$$\eta_{yu} = \eta_G * \eta_M * \eta_H, \tag{2}$$

where, $\eta_G$ - is the hydraulic work coefficient; $\eta_M$ - is the mechanical work coefficient; $\eta_H$ - is the volumetric work coefficient.

To determine the coefficient of hydraulic efficiency, we write the following expression:

$$\eta_G = \frac{P_{hd}}{P_{pp}}, \tag{3}$$

where, $P_{hd}$ - is the pressure in the hydraulic motor; $P_{pp}$ - is the pressure generated by the pump.

The expression for determining the volumetric efficiency is as follows:

$$\eta_H = \frac{Q}{Q_{pf}}, \tag{4}$$

where, $Q$ - fluid flow entering the hydraulic motor; $Q_{pf}$ - pump supply.

The expression for determining the coefficient of mechanical useful work is as follows:

$$\eta_M = \eta_{mn} \cdot \frac{F}{F_{pp}}, \tag{5}$$

where, $\eta_{mn}$ - is the mechanical efficiency of the pump; $F$ - is the payload applied to the hydraulic motor rod; $F_{pp}$ - is the force received by the hydraulic motor piston;

Now we will construct an expression for the relationship between the mass concentration of mechanical impurities and the useful work coefficient of the hydraulic system, the density of the working fluid, the density of the particles, and their sizes.

Previously, we expressed that the value of the hydraulic efficiency coefficient is related to the flow efficiency:

$$\acute{\eta} = \frac{Q_o - \triangle Q_o}{Q_o} = 1 - \frac{\triangle Q_o}{Q_o}, \tag{6}$$

Here, $Q_o$ - is the flow rate of the hydraulic pumps, l/m; $\triangle Q_o$ - is the leakage in the hydraulic actuator, l/m. In turn, the leakage is determined by the well-known expression:

$$\Delta Q_o = K \cdot d^{2.73} \cdot C, \tag{7}$$

where, $K$ - 1.6•10-6- is the scaling factor; $d$ - particle size, m; $C$ - particle concentration, tons/l; then the expression for efficiency looks like this:

$$\Delta Q_o = 1 - \ ((K \cdot d^{2.73} \cdot C)/Q_o), \tag{8}$$

We can reduce the $\Delta Q_o$ exponent of this expression to the following condition by establishing the dependence $C$:

$$C = \frac{Q_0(1-\eta_{yu})}{k \cdot d^{2{,}73}}, \tag{9}$$

If we expand $\eta_{yu}$ here, the expression will look like this:

$$C = \frac{Q_0(1-\eta_G * \eta_M * \eta_H)}{k \cdot d^{2{,}73}}, \tag{10}$$

## 3 Results and discussion

We derive the following expression for the relationship between the mass concentration of mechanical impurities, the density of the working fluid, and the density of the particles.

$$C = 3\pi 10^{-6} (^{\rho_z}/_{\rho_{i.s.}}) \cdot d^3_{o`r} \cdot n_z, \tag{11}$$

Here; $\rho_z$-particle density; $\rho_{i.s.}$-working fluid density; $d_{o`r}$-average particle size; $n_z$ - number of particles;

Now, when we equate expressions (10) and (11), we can write in the following case:

$$\frac{Q_0(1-\eta_G * \eta_M * \eta_H)}{k \cdot d^{2{,}73}} = 3\pi 10^{-6} (^{\rho_z}/_{\rho_{i.s.}}) \cdot d^3_{o`r} \cdot n_z, \tag{12}$$

To relate expression (12) to the preparation coefficient, we find the dependence of productivity on the working fluid and operating time:

$$Q_0 = \frac{V}{t_{ish}}, \tag{13}$$

The expression for the preparation coefficient; $K_p = \frac{T_{ish}}{T_{ish}+T_{re}}$ when combined with expression (13) becomes:

$$Q_0 = \frac{V(1-K_p)}{T_{re} \cdot K_p}, \tag{14}$$

When we substitute expression (14) into the expansion (12) for $Q_0$:

$$\frac{V\,(1-K_p)(1-\eta_G * \eta_M * \eta_H)}{T_{re} \cdot K_p \cdot k \cdot d^{2{,}73}} = 3\pi 10^{-6} (^{\rho_z}/_{\rho_{i.s.}}) \cdot d^3_{o`r} \cdot n_z, \tag{15}$$

It appears.

From this expression we can find the training coefficient:

$$K_p = \frac{V(1-(\frac{P_{hd}}{P_{pp}}) \cdot (\frac{Q}{Q_{pf}}) \cdot (\eta_{mn} \cdot \frac{F}{F_{pp}})}{3 \cdot \pi \cdot 10^{-6} \cdot \frac{\rho_p}{\rho_o} \cdot k \cdot d_a^5 \cdot n_p \cdot T_{re} + V(1-(\frac{P_{hd}}{P_{pp}}) \cdot (\frac{Q}{Q_{pf}}) \cdot (\eta_{mn} \cdot \frac{F}{F_{pp}})}, \tag{16}$$

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Here; $V$ - working fluid flowing through the hydraulic system; $P_{hd}$ -pressure in the hydraulic motor; $P_{pp}$ -pressure generated by the pump; $Q$ -fluid flow entering the hydraulic motor; $Q_{pf}$ -pump supply; $\eta_{mn}$ -mechanical efficiency of the pump; $F$ - payload given to the hydraulic motor rod; $F_{pp}$ -force received by the hydraulic motor piston; $\rho_p$ -density of contaminated particles; $\rho_o$ -density of the working fluid; $k$ -scale coefficient, 1.6∗10-6; $d_a$ - average particle size; $n_p$ -number of particles; $T_{re}$ -modulus recovery after failure.

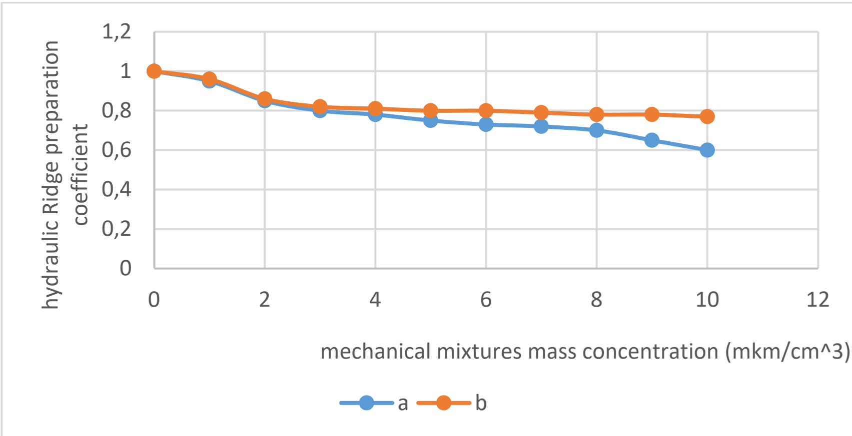


**Fig. 1.** Graph of the relationship between the preparation coefficient of the hydraulic system and the mass concentration of mechanical impurities: a - connection in the case when the working fluid Intermediate is not cleaned; b - connection in the working fluid Intermediate is cleaned.

Based on the above expression (16), Delphi programming software was created that allows determining the preparation coefficient of hydraulic systems of hydraulic excavators, the level of mass concentration of impurities in the hydraulic working fluid, and the APK operating system.

Periodic, rapid monitoring of working fluids for mechanical impurities and water contamination, included in the machine maintenance system, allows you to determine the condition of the hydraulic system and indirectly monitor the condition of installed filters to prevent the accumulation of contamination in the tanks. Figure 1 shows a graphical representation of the effect of the amount of contamination at startup on the operating condition of the hydraulic system.

According to research by many scientists, increasing the purity of the working fluids of hydraulic systems allows you to increase the resource of hydraulic systems by 3-8 times, reduce the number of failures in them by 50-70 percent, and reduce the cost of spare parts for repairing hydraulic system units by 2-7 times.

## 4 Conclusion

Monitoring of the cleanliness of working fluids in hydraulic systems, as well as their reliability by increasing the cleanliness of the working fluid with an additional cleaning device during maintenance of hydraulic systems, can be carried out by assessing and forecasting the coefficient of their preparation based on the program.

One of the promising directions of increasing the intermediate filtration process of the working fluid at the workplace, taking into account the specific characteristics of the operating conditions of quarry hydraulic excavators, is through this monitoring, which ensures reliable operation of machines in technical maintenance work using mobile means.

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