**Results of Quality Indicators Evaluation of Transmission Oils During Operation of Dump Trucks in Hot Climatic Conditions**

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**Abstract.** The replacement intervals of transmission oils are established based on the study of changes in their physicochemical and performance properties during operation, and on this basis, rejection criteria are determined. Dump trucks operating in quarry zones are exposed to increasingly complex mining and technical conditions as excavation depth increases. This study focuses on MAZ 5516A5-373 dump trucks, which operate under high ambient temperatures and heavy air dustiness. The transmission oil used in these vehicles is SAE 85W140, API GL-5.This study presents experimental dependencies of changes in the key quality indicators (density, kinematic viscosity, total base number, and content of insoluble deposits) of SAE 85W140, API GL-5 transmission oil in the gearbox, depending on the mileage of MAZ 5516A5-373 trucks. The test results and calculation of the generalized oil quality coefficient make it possible to objectively monitor the condition of transmission oils during operation and more accurately determine optimal replacement interval.

**Keywords:** vehicles, transmission oil, total base number, kinematic viscosity, gearbox, insoluble deposits, transmission units, experimental dependencies

**INTRODUCTION**

Solving the problems of rational use and increasing the efficiency of lubricating oils is one of the key tasks of tribology. One of the approaches to the economical use of lubricants, including transmission oils, is the extension of oil change intervals. These intervals are determined based on the study of changes in the physicochemical and performance properties of oils during the operation of ground transportation equipment.

Recent international studies have focused on monitoring the degradation of lubricants in heavy-duty transmissions under severe conditions, especially with regard to viscosity, total base number, and wear particles [1, 2, 3, 4].

Dump trucks operating in open-pit mining areas are most exposed to the increasingly complex mining and geological conditions associated with the deepening of the pit. The haul roads at the Muruntau mine are 65–70 km long. The mine currently exceeds 620 meters in depth, with a width of more than 2.9 km and a length of over 3.2 km. Dump trucks operating within the pit are especially affected by the intensifying conditions as the mining depth increases.

The MAZ 5516A5-373 dump trucks were selected as the object of this research. These trucks are operated in harsh environmental conditions characterized by extremely high ambient temperatures (exceeding +50°C in summer) and high airborne dust concentrations, with mine haul roads extending over 65–70 km. The specific effects of high-temperature operation on oil quality in heavy dump trucks have also been studied previously [8].

The MAZ 5516A5-373 dump truck has a payload capacity of 20 tons and is equipped with a rectangular dump body with a rear discharge and a volume of 15.4 m³, making it a preferred choice for heavy-duty cargo transport. In the mining industry, these trucks are commonly used to transport ore, coal, sand, and other mineral resources. The truck is powered by a robust 330 hp YaMZ diesel engine and features a reliable suspension system, which enables operation in the demanding conditions of open-pit mines. The vehicle is equipped with an 8-speed manual   
YaMZ-2381-02 transmission, which ensures reliable and efficient vehicle control. This type of transmission is responsible for receiving, transforming, and transmitting a continuously varying torque. Due to dynamic loads such as sudden clutch engagement, variations in crankshaft speed, and impacts caused by obstacles or uneven terrain, the gearbox may be subjected to torques 2–3 times higher than the engine’s rated torque. As a result, the contact surfaces of cylindrical and bevel gears are exposed to high specific pressures (up to 2500 MPa), sliding speeds (up to 10 m/s), and contact temperatures in the gear tooth friction zone reaching up to 300°C.

During operation, the quality of the lubricating oil changes significantly. Kinematic viscosity may decrease or increase, and the oil can accumulate thermo-oxidative degradation products, mechanical impurities, depleted additives, as well as increased metal content and water contamination. Transmission oil in MAZ vehicle components operates under extremely harsh conditions. According to technical standards, transmission oil must be replaced when its quality indicators reach maximum permissible values or when the vehicle exceeds the specified mileage.

Since there is currently insufficient data on the changes in the main physicochemical and performance characteristics of transmission oils during their operation in the transmission systems of heavy-duty dump trucks, as well as on the substantiation of the obtained experimental dependencies, further research in this area is of particular importance. The scientific novelty of this study lies in the establishment of operational degradation trends for SAE 85W140, API GL-5 transmission oil under real mining conditions characterized by extremely high ambient temperatures and heavy dust exposure. Unlike existing studies, this work provides an integrated evaluation of viscosity, total base number, density, and insoluble deposits over time, enabling a more precise determination of oil replacement intervals. The proposed generalized oil quality coefficient can serve as a practical diagnostic tool for assessing oil serviceability in extreme environments.

**METHODS**

To conduct the study of used transmission oils SAE 85W140, API GL-5, and to determine their actual condition, measurements were taken of density, kinematic viscosity, flash point, total base number, content of mechanical impurities, as well as the concentration of wear metal particles using spectroscopic methods.

The aim of the present study is to establish the dependence of changes in key quality indicators — density, kinematic viscosity, total base number, content of insoluble sediments, and mass fraction of active elements — of the transmission oil SAE 85W140, API GL-5 in the transmission units on the mileage of MAZ 5516A5-373 trucks.

Similar sampling and analysis approaches have been described in studies involving agricultural and process machinery [5, 6, 7].

To address the stated objective, an experimental study was conducted on three MAZ 5516A5-373 dump trucks, each with a similar mileage of 50–60 thousand km. These trucks operated in an open-pit mine under the conditions of Navoi Mining & Metallurgical Combinat and underwent analysis of key quality indicators. The transmission oil SAE 85W140, API GL-5, containing anti-scuffing and anti-wear additives, was selected as the research object. This oil is used for lubricating heavily loaded cylindrical, bevel, and spiral bevel gears of heavy-duty MAZ trucks.

Before the start of the tests, the incoming quality control analysis of the transmission oil SAE 85W-140, API GL-5, was carried out in the central laboratory. The analysis results showed that the actual values of the physicochemical parameters corresponded to those declared in the regulatory documentation.

Before conducting the operational studies, the standard transmission oil in the gearboxes, as well as in the front and rear axles of the MAZ 5516A5-373 vehicles, was replaced with the test transmission oil SAE 85W-140, API GL-5. This replacement was preceded by a preliminary flushing of the lubrication systems of the transmission units. After that, the vehicles were operated under observation.

**MATERIALS**

The preparation of the test lubricating oil, its replacement, and sample collection were carried out on the premises of the enterprises. During the period of operational studies, each vehicle covered a mileage of 54,000 km.

During operation, samples of the tested oil were taken from the transmission units every 6,000 km of mileage. Sampling was conducted from the middle volume of the transmission unit’s sump at the end of the work shift (no later than 1 minute after shutdown), when the oil temperature reached its maximum value. At the time of sampling, the transmission oil exhibited its minimum kinematic viscosity. These conditions allow us to assert that the entire oil had a uniform concentration and was in the most thoroughly mixed state.

Samples were taken from the housings of the axles and the transmission through inspection and filler openings. Subsequently, the collected transmission oil SAE 85W140, API GL-5 was tested to determine changes in the main quality indicators (density, kinematic viscosity, alkaline number, and content of insoluble sediments) depending on the mileage of the MAZ 5516A5-373 vehicles. The test results from the three vehicles were averaged to obtain mean values.

In accordance with GOST 23652, the determination of mechanical impurities content in the transmission oil was carried out following GOST 6370. Density was measured according to GOST 3900 at a temperature of 20°C using a hydrometer. The kinematic viscosity of SAE 85W140, API GL-5 oil was determined according to GOST 33 at 100°C using a VPZh-2 viscometer. The acid number was assessed by the method of GOST 5985, using a potassium hydroxide solution in the presence of a colored indicator (nitrozin yellow) on specialized laboratory equipment. For each quality parameter of the oil, the test result was taken as the arithmetic mean of two consecutive measurements.

RESULTS AND DISCUSSION

Based on the obtained data from testing samples of SAE 85W-140, API GL-5 oil, graphs were constructed showing the dependence of changes in quality parameters of the transmission units on the mileage of MAZ 5516A5-373 vehicles.

The temperature regime of transmission oils is quite severe. The operating temperature of transmission units can reach 150°C and above, while the vehicle start temperature may be low, depending on the ambient temperature. At high temperatures, the oil must maintain sufficient viscosity to support the strength of the heavily loaded oil film. Energy losses in the transmission account for up to 20% of the total power consumed by the vehicle. Reducing the viscosity of transmission oils is one of the main ways to improve vehicle fuel efficiency. Viscous oil hinders smooth movement of a cold vehicle and penetrates more poorly into narrow gaps between friction surfaces. Viscosity is the ability of the oil to adhere to the surfaces of internal engine parts and preserve all the main chemical and physical properties. Therefore, this parameter is also chosen to assess oil quality. Viscosity can vary depending on the ambient temperature. If it becomes too low at high temperatures, the strength of the oil film between rubbing surfaces and the pressure in the lubrication system will be insufficient.

The operational requirements for transmission oils can often be quite contradictory. On one hand, oils must maintain high viscosity at operating temperatures to preserve the lubricating film and properly seal clearances; on the other hand, they should not become too viscous at low ambient temperatures, so that cold oil does not impede the free rotation of gears at the start of the mechanism’s operation. When setting viscosity requirements for transmission oils, it is necessary to balance ensuring high anti-wear properties and preventing leaks on one side, with reducing energy losses due to friction and improving cold-start performance on the other. Generally, the higher the viscosity, the better the anti-wear characteristics and the greater the load the rubbing components can withstand.

FIGURE 1. Dependence of the kinematic viscosity change of transmission oil SAE 85W140, API GL-5 on the mileage of   
MAZ 5516A5-373 vehicles

The kinematic viscosity value of the transmission oil in the gearbox of all three dump trucks decreased from 14.15 to 13.28 mm²/s after 20,000 km of mileage. This is associated with changes in the structural-group composition of the transmission oil (see Fig. 1).

By the final stage of the study, the viscosity values increased to 14.88, 14.95, and 15.02 mm²/s in the respective transmission units. This increase at the final stage was caused by the accumulation of oil oxidation products and wear of the contacting friction surfaces.

Based on the obtained research results, it was established that the density value of the commercial SAE 85W140, API GL-5 oil increased by 2.6 kg/m³, or 0.29%, during the study period in the gearbox (Fig. 2). The increase in the density of the transmission oil is due to the accumulation of insoluble sediments in it (Fig. 4).

FIGURE 2. Dependence of the density change of transmission oil SAE 85W140, API GL-5 on the mileage of the   
MAZ 5516A5-373 vehicle

Alkalinity is a very important quality indicator of oil and its performance. The alkaline number is a conventional measure of the oil’s ability to neutralize acids formed from fuel combustion products and oxidation of the oil base. The alkalinity, provided by the presence of alkaline additives, is consumed at varying rates to neutralize these acids.

The limit of oil serviceability is often considered to be when the total alkaline number equals the total acid number. The acceptable alkaline number value is limited to 1.5–2.0 mg KOH/g, or 50% of the alkaline number of fresh oil. The higher the alkaline number, the greater the amount of acids formed during oil oxidation that can be neutralized. When alkali reacts with acid, it is irreversibly consumed, so at a certain point in time, the reserve of the alkaline number decreases to the extent that the additives are no longer sufficient to neutralize all the acids entering the oil.

The operating conditions of mining equipment should also be taken into account, as it operates in highly dusty environments. It is important to note that the presence of anti-wear and anti-scuffing additives in the transmission oil results in a high alkaline number in the fresh oil. A significant decrease in the alkaline number should be interpreted as a substantial reduction in the concentration of these anti-wear and anti-scuffing additives.

We also determined the changes in the alkaline number of the SAE 85W140, API GL-5 transmission oil over the operating duration in MAZ 5516A5-373 dump trucks, and constructed the corresponding graphs (Fig. 3).

FIGURE 3. Dependence of the change in alkaline number of transmission oil SAE 85W140, API GL-5 on the mileage of   
MAZ 5516A5-373 vehicles

The average alkaline number of SAE 85W140, API GL-5 oil in the gearbox decreased to 0.93 mg KOH after 50,000 km of mileage. Operating with oil having an alkaline number below the critical limit leads to accelerated wear of transmission parts, which is also indicated by an increased concentration of iron.

The observed decrease in total base number (TBN) aligns with results from previous studies on heavy-duty gear oils operated in high-temperature environments [1, 2]. According to Yan et al. (2022), such decline is largely attributed to oxidative degradation of additives under thermal and mechanical stress. Compared to those findings, our test conditions show a slightly faster TBN degradation rate, most likely due to the extreme ambient temperatures above 50°C and high airborne dust concentrations encountered in the Muruntau quarry. This accelerated depletion may reduce the effective lifespan of the lubricant, suggesting that standard oil change intervals (based on temperate climate data) may not be sufficient for such environments. A limitation of this study is the sample size, which includes only three vehicles. While the trends are clear, a larger sample group would be needed for statistical generalization. In future work, it is advisable to analyze wear particle content and consider spectroscopic oil condition monitoring to complement physicochemical measurements.

Based on the experimental research results, mechanical impurities have the greatest impact on the wear rate of engine parts. Analysis of the study data shows that during the research period, the average content of insoluble impurities increased (see Fig. 4).

FIGURE 4. Dependence of the change in insoluble mechanical impurities (IMI) in the transmission oil SAE 85W140, API GL-5 on the vehicle mileage

Analysis of the dependence of the change in insoluble deposits content in SAE 85W140, API GL-5 oil shows that up to 20,000 km of mileage, the values of this parameter sharply increase in all dump trucks, followed by a stabilization phase. The significant rise in insoluble deposits content during the initial period of operation is caused by intense oxidation of thermally unstable hydrocarbons and contamination of fresh oil with used oil. This negatively affects the reliability, efficiency, and durability of the transmission system.

Dump trucks operating in quarry zones are particularly exposed to increasingly severe mining conditions with depth. As a result, lubricants become heavily contaminated with mechanical impurities. For instance, when these impurities reach a concentration of 0.016% in the oil, the average wear rate increases by four times compared to operation with clean oil. The operating conditions of transmission oils in mining transport equipment, where air dust levels are high, are especially critical. In mechanical transmission lubrication systems, a residual amount of oil remains during oil changes. Additionally, sediments and sludge accumulate on parts and inside the transmission housing, which further increases the amount of mechanical impurities in the oil during operation.

The use of lubricants based on secondary raw materials could be a promising direction for extending oil service life under severe operating conditions [9].

**DISCUSSION**

As a result of the conducted research, experimental dependencies of the main quality indicators (kinematic viscosity, total base number, density, and content of insoluble sediments) of the transmission oil SAE 85W140, API GL-5 on the mileage of MAZ 5516A5-373 trucks were obtained. The study results show that during the operation of SAE 85W-140, API GL-5 transmission oil in the transmission units of MAZ 5516A5-373 trucks, its quality indicators deteriorate. As evident from the graphs, deviations in the quality indicators (viscosity, total base number, and density) became noticeable at truck mileage of 20,000 km and above.

Thus, based on the obtained test results and subsequent calculation of the overall oil quality coefficient, it becomes possible to objectively monitor the actual condition of transmission oils during vehicle operation and more reliably determine the appropriate oil replacement intervals.

Environmental considerations should be taken into account when optimizing lubricant replacement strategies in mining operations [10, 11].

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