**Results of Quality Indicators Assessment of Hydraulic Oils during the Operation of Heavy-Duty Dump Trucks in Mining Transport**

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**Abstract.** The purpose of this study is to investigate the performance characteristics of Chilon NVI 46, 68; Chilon HVLPD 46, 68 hydraulic oils used in the hydraulic systems of construction and road machinery – specifically motor graders – under hot climatic conditions. During operation in hydraulic systems, the oil heats up and is intensively mixed with air. The main conditions in which oils operate in hydraulic systems are characterized by wide fluctuations in ambient temperature, transmission of high forces and exposure to high specific loads in pumps, as well as dustiness and humidity of the surrounding air. The results of operational tests of hydraulic oils produced by Chilon Lubricants LLC (Republic of Uzbekistan) on mining transport equipment, assemblies, and units of the Automobile Transport Department of the Central Mining Administration of the “Navoi Mining and Metallurgical Combine” Joint-Stock Company are presented. The main physicochemical indicators of properties affecting the operational characteristics of the oil were studied. To achieve the stated objective, samples of Chilon NVI 46, 68; Chilon HVLPD 46, 68 hydraulic oils were taken from the BelAZ-75307 and BelAZ-7513 dump trucks and analyzed according to the main quality indicators. Laboratory physicochemical and spectral analyses of the oils were carried out in accordance with established methodology.

**Keywords:** hydraulic systems, hydraulic oils, physicochemical properties, oxidation, contamination, additives, zinc, alkaline number, durability, air dustiness.

**INTRODUCTION**

The operation of hydraulic systems is based on the transmission of energy through a working fluid contained in a closed volume. When force is applied to actuators, due to the practical incompressibility of the fluid, the force is transmitted evenly and instantly in all directions.

The main function of working fluids in hydraulic systems is the transfer of mechanical energy from its source to the point of application, with a change in the magnitude or direction of the applied force. A hydraulic drive cannot operate without a liquid working medium, which is an essential structural element of any hydraulic system. Energy transfer is the primary function of hydraulic fluid. For efficient transmission of hydraulic energy, a fluid is required that is incompressible and flows easily [1].

During operation, oil in hydraulic systems heats up and mixes intensively with air. The main conditions in which oils operate in hydraulic systems are characterized by wide fluctuations in ambient temperature, the transmission of high forces and exposure to high specific loads in pumps, as well as dust and humidity of the surrounding air [2].

The presence of small clearances in working pairs of modern hydraulic systems (especially those equipped with axial-piston mechanisms) imposes strict requirements on the cleanliness of working fluids. Therefore, the presence of mechanical impurities and water in hydraulic oils is highly undesirable, as they can cause not only wear of hydraulic equipment components but also seizure of parts. Even a small amount (0.05–0.1%) of water entering the hydraulic system with the oil or during operation accelerates the oxidation process of the oil and causes hydrolysis of hydrolytically unstable components (in particular, additives such as metal salts). Thus, water contributes to the formation of sludge of inorganic and organic origin, which clogs filters and component clearances [3].

**MATERIALS AND METHODS**

The purpose of this study is to investigate the operational characteristics of Chilon NVI 46, 68; Chilon HVLPD 46, 68 hydraulic oils used in the hydraulic systems of transport equipment under hot climatic conditions with dusty air.

During the operation of the monitored vehicles, tests were carried out on samples of fresh, in-service, and used oil with mileage recorded. The main physicochemical indicators (viscosity, alkaline number, moisture content, and mechanical impurities) affecting oil performance were studied.

Since 2015, operational tests of the following oils have been conducted in cooperation between Navoi Mining and Metallurgical Combine JSC (NMMC) and Chilon Lubricants LLC: hydraulic oils Chilon HLP 46 and 68, Chilon NVI 46 and 68, Chilon HVLPD 46 and 68. During the tests, work was carried out to assess the quality and determine the possibility of using hydraulic oils produced by Chilon Lubricants LLC as substitutes for imported analogues applied in heavily loaded mining transport equipment in operation at the Muruntau Automobile Transport Department (UAT).

Before the start of each test, a “Program for Conducting Operational Tests of Oils” was developed. It was also taken into account that Chilon Lubricants LLC oils do not have recommendations or approvals from manufacturers of mining transport equipment and major manufacturers of transmission and hydraulic equipment. Therefore, tests were conducted on mining transport vehicles that had already passed the warranty mileage (warranty period). In this regard, NMMC and Chilon Lubricants LLC were tasked with carrying out tests and, based on the results, improving the quality of locally produced lubricants to meet the requirements of leading global manufacturers of mining equipment.

Prior to testing, incoming quality control analyses of the oils were carried out at the Central Laboratory of Fuels and Lubricants (CLFL) of UAT and in the laboratory of Chilon Lubricants LLC, both equipped with modern instruments and devices. Testing was initiated only after the actual values of physicochemical parameters conformed to the standards specified in the regulatory documentation.

Studies of the contamination of hydraulic oils used in the hydraulic systems operating under hot climate conditions showed that the oils became intensively contaminated with mechanical impurities, water, and organic products, leading to premature aging of the oil [4].

The studies revealed that downtime of of dump trucks due to hydraulic system failures accounted for 49% of the total downtime balance, directly increasing operating costs and reducing productivity. Power units have no redundancy, and as a result, the failure of one or more components leads to the failure of the entire hydraulic system.

The use of oil at elevated ambient temperatures (+40 °C, +45 °C, +50 °C) revealed specific failures caused by the deterioration of physical and mechanical properties.

From laboratory studies, it can be said that during operation, the viscosity of the oil changes both in the direction of increase so it goes downwards, due to changes in structural-group composition and mechanical impurities. Furthermore, during operation, engine components and parts become contaminated with various deposits [5]. Throughout the testing period, the technical condition of the systems was closely monitored by specialists from UAT and Chilon Lubricants LLC.

The main criteria for determining the quality of oils and their suitability for use in mining transport equipment were: failure-free operation of mining equipment on the tested oil throughout the testing period (in accordance with the recommendations of the manufacturers of units and hydraulic systems); absence of negative effects of the oil on the performance and condition of components and units during the tests (determined by spectral analysis of the oil and visual inspection of units during maintenance and repair); compliance of the actual service life of the oil with the established replacement intervals in compartments (determined by laboratory tests of the main physicochemical indicators of the oil and monitoring of changes within permissible limits at the CLFL of UAT and the Chilon Lubricants LLC laboratory).

**RESULTS AND DISCUSSION**

When testing Chilon HLP-46,68 and Chilon NVI -46, 68 hydraulic oils for 1000 operating hours, intensive depletion of anti-wear and anti-corrosion additives was observed. At this point, the operational tests were stopped. It should be noted that through the continuous joint efforts of specialists from Chilon Lubricants LLC and NMMC JSC to improve the quality of hydraulic oils, the cleanliness class of ChilonHLP-46 and ChilonHLP-68 oils was improved to -/18/14 (according to ISO 4406 standard).

The operating conditions of hydraulic oils are severe: large temperature variations (-50 ºC to 120 ºC), sliding speeds of parts up to 20 m/s, and pressures up to 15 MPa. Therefore, in order to ensure reliable performance of hydraulic systems, specific requirements are imposed on the fluids:

– since the working temperatures and pressures are quite high, the fluids must have high chemical stability (resistance to oxidation);

– they should not stratify, form sediments, or foam;

– they should not damage metallic or rubber components.

To increase productivity and reduce leakage, clearances in hydraulic system components are being reduced, making them increasingly precise (manufactured with high accuracy and tight tolerances). Hydraulic system components are becoming more compact, while their energy intensity is increasing. Their operating temperature range extends from –50 ºC during cold starts to 120 ºC in steady-state operation. The accuracy of positioning working tools is improving, and the influence of the human factor is reduced through the use of servomechanisms (i.e., drives with automatic feedback). The use of servo valves in control and monitoring systems is expanding, and these are equipped with highly sensitive electric actuators[5].

During pump operation in the hydraulic system, the oil heats up and mixes intensively with air. Studies of hydraulic oil contamination under hot climate conditions and high air dustiness show that oils become intensively contaminated with atmospheric dust and mechanical impurities. Dust is the main cause of component wear, and therefore its concentration in the air significantly affects reliability. Operating conditions are complicated by the considerable dustiness of the environment, which leads to oil oxidation, increased viscosity, and accumulation of oxidation products that form deposits and varnish films. All of this results in increased energy consumption for driving the hydraulic system[6].

The results of spectral analysis of fresh Fastroil Hydraulic Winter oil 68 hydraulic oils are shown in Table 1.

**TABLE 1.** Results of spectral analysis of fresh hydraulic oil Fastroil Hydraulic Winter Oil 68, concentration, ppm (g/t)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Oil grade | Fe | Si | Cu | Pb | Sn | Ni | Cr | Al | Mo | Na  (intens.V) | Mg  (intens.  V) | Zn  (intens.  V) | Ca  (intens.  V) |
| Fastroil Hydraulic Winteroil 68 | 0,00 | 0,05 | 0,47 | 0,72 | 0,19 | 0,00 | 0,00 | 0,02 | 0,00 | 0.08 | 2,19 | 1,00 | 0,31 |

From the results of the analysis of fresh Fastroil Hydraulic Winter oil 68 hydraulic oil, it can be seen that there is zinc in the composition.

The disadvantages of zinc-containing additives include:

– insufficient hydrolytic stability (they decompose under the influence of water, the likelihood of which entering the hydraulic system units operating outdoors is quite high);

– low thermal stability (they decompose under the influence of high operating temperatures, which are continuously increasing in modern hydraulic systems);

– environmental aggressiveness, since they are non-biodegradable (when entering water they quickly make it toxic, and in the event of an oil spill they can contaminate groundwater);

– increased aggressiveness of zinc-containing oils towards non-ferrous metals, especially copper-based alloys such as bronze and brass (for example, the cylinder block of an axial-piston pump is most often made of brass).

Conventional anti-wear additives containing zinc have weak hydrolytic stability and decompose under the influence of water, producing contaminants. Hydraulic oils with an ashless additive package possess excellent hydrolytic stability, meaning they do not decompose under the influence of water. This property ensures oil cleanliness and, consequently, long service life of the hydraulic system.

The above-mentioned problems are automatically eliminated when using zinc-free hydraulic oils. In zinc-free hydraulic oils, an ashless additive package LZ-5782S is used. Modern hydraulic systems of machinery and mechanisms contain components made of non-ferrous metals such as aluminum and bronze, which may be subject to corrosive chemical effects. The use of ashless additives makes zinc-free oils optimally suitable to meet the requirements of chemical neutrality in relation to various metallic surfaces[7].

Chilon Lubricants LLC has started production of a new brand of HVLPD all-season hydraulic oil, which is ash-free (does not contain zinc).

The technologists of Chilon Lubricants LLC have developed the structure of the new Chilon NVI 46 and 68 hydraulic oil to ensure a reliable reserve of operational properties. Table 2 shows the results of spectral analyses of studies of Chilon HVLPD hydraulic oils 46.68

**TABLE 2.** Results of spectral analysis of hydraulic oils Chilon HVLPD 46, 68, concentration, ppm (g/t)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Oil grade | Fe | Si | Cu | Pb | Sn | Ni | Cr | Al | Mo | Mg | Zn | Ca |
| Chilon HVLPD 46 | 0,00 | 0,00 | 0,86 | 0,00 | 0,00 | 0,76 | 0,00 | 0,00 | 0,00 | 1,11 | 0,18 | 0,22 |
| Chilon HVLPD 68 | 0,00 | 0,32 | 0,00 | 0,00 | 0,00 | 0,58 | 0,00 | 0,00 | 0,00 | 1,90 | 0,18 | 0,32 |

Based on the obtained results, technologists of Chilon Lubricants LLC developed the formulation of a new hydraulic oil “ChilonNVI 46 and 68” to ensure a reliable reserve of operational properties. During the production of new samples of hydraulic oils oriented to DIN 51524-3 standards, the requirements of equipment manufacturers at UAT (Muruntau) and the specific operating conditions (climatic features of the region) were taken into account. In this regard, joint tests of the new oil grades were carried out on heavy-duty mining equipment with the participation of specialists from Chilon Lubricants LLC and UAT (Muruntau). These changes were intended to extend the service life of the oil under real operating conditions.

The main difference between Chilon HVLPD 46.68 zinc-free hydraulic oils and the previous generation Fastroil Hydraulic Winter oil 68 oils lies in the use of ashless additives based primarily on amine salts and esters of dithiophosphoric acids. The antioxidant and chemical stability of zinc-free oils is quite high. Since they do not contain metallic compounds, oxidation of such oils proceeds more slowly. There is also evidence that they clean the walls of hydraulic systems from carbon and varnish deposits, while causing significantly less harm to the environment.

Since the measured oil parameters complied with regulatory documentation, the oils were approved for operational testing on the vehicles of the UAT Central Mining Administration. For the tests, the following dump trucks were selected: BelAZ-75307 and BelAZ-7513.

Throughout the tests, the technical condition of the hydraulic systems was under special supervision by engineers from the Diagnostics and Analytics Department of UAT. Sampling of oils and laboratory physicochemical analyses were carried out in accordance with the established methodology.

The tests were carried out using the following instruments: kinematic viscosity analysis was performed according to GOST 31391-2009 on a VIS-T-08 liquid thermostat, serial No. 307068; flash point determination was conducted in accordance with GOST 4333-87 using a Cleveland open-cup flash point analyzer HFP-386, serial No. 0938600272; spectral analysis was carried out in accordance with GOST 20759-90 on an MFS-11 spectrometer, serial No. 140014; analysis of cleanliness class according to ISO 4406 was performed on a Pamas S40 contamination analyzer, serial No. 400-3099.

From December 2024 to March 2025, operational tests of hydraulic oils HVLPD 46 and HVLPD 68 produced by Chilon Lubricants LLC were carried out at UAT (Muruntau). The results of the tests of HVLPD 46 and HVLPD 68 hydraulic oils were positive.

To achieve the stated goal, samples of hydraulic oils were taken and analyzed for key quality indicators (Tables 3, 4, 5).

**TABLE 3.** Results of laboratory studies of hydraulic oils Chilon NVI 46, 68

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| № | Oil grade | Density at 20 °C (kg/m³) | | Water content, % | | Kinematic viscosity at 100 °C, cSt | | Flash point in open cup, °C | |
| Acc.to ND | Actual | Acc.to ND | Actual | Acc.to ND | Actual | Acc.to ND | Actual |
| 1 | Chilon NVI 46 | ≤890 | 880 | - | - | ≥ 6.1 | 8,669 | ≥ 195 | 198 |
| 2 | Chilon NVI 68 | ≤895 | 886 | - | - | ≥ 10 | 10,88 | ≥ 200 | 207 |

**TABLE 4.** Results of laboratory studies of hydraulic oils Chilon HVLPD 46, 68

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| № | Oil grade | Density at 20 °C, kg/m³ | | Water content, % | | Kinematic viscosity at 100 °C, cSt | | Kinematic viscosity at 40 °C, cSt | |
| Acc.to ND | Actual | Acc.to ND | Actual | Acc.to ND | Actual | Acc.to ND | Actual |
| 1 | Chilon HVLPD 46 | ≤885 | 840 | - | - | ≥7,8 | 8,65 | 41,4-50,6 | 47,63 |
| 2 | Chilon HVLPD 68 | ≤890 | 840 | - | - | ≥10,2 | 10,6 | 61,2-74,8 | 66,41 |

**TABLE 5.** Results of laboratory studies of hydraulic oils Chilon HVLPD 46, 68

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| № | Oil grade | Viscosityindex | | Flash point in open cup, °C | | Cleanlinessclass (ISO 4406) | |
| Acc.to ND | Actual | Acc.to ND | Actual | Acc.to ND | Actual |
| 1 | Chilon HVLPD 46 | ≥140 | 162 | ≥ 220 | 220 | Notregulated | -/18/14 |
| 2 | Chilon HVLPD 68 | ≥140 | 162 | ≥230 | 230 | Notregulated | -/18/14 |

Studies of oils operating in hydraulic systems under hot climate conditions (with summer air temperatures exceeding +50 °C) show that hydraulic oils become heavily contaminated with mechanical impurities, water, and organic products, leading to premature aging of the oil. According to research, 70% of hydraulic system failures are related to the condition of the oil. Of these, 40% are directly associated with the operational properties of the oil, while 60% are linked to oil cleanliness.

Corrosion products and decomposition products of zinc-containing additives form both contaminants in the oil (sometimes referred to as “loose sediment”), which clog filters, and varnish deposits formed under high-temperature conditions. The presence of contaminants in the oil and varnish deposits in the clearances of the spool mechanism increase resistance to spool movement, or may even cause it to seize (resulting in either shutdown or burnout of the electric actuator). If the servo valve is equipped with a filtering element, it will inevitably become clogged with contaminants present in the oil and will also fail [8-10].

Since the measured oil parameters complied with regulatory documentation, the oils Chilon HVLPD 68were approved for operational testing on the vehicles of the UAT Central Mining Administration. For the tests, the following dump trucks were selected: BelAZ-75307 and BelAZ-7513.

To ensure test accuracy, before filling with oil, the hydraulic systems of the dump trucks were cleaned and flushed with the tested oil Chilon HVLPD 68. Throughout the tests, the technical condition of the hydraulic systems was under special supervision by engineers from the Diagnostics and Analytics Department of UAT. Sampling of oils and laboratory physicochemical analyses were carried out in accordance with the established methodology.

**TABLE 6.** Results of analysis of hydraulic oil HVLPD-68 from BelAZ-75307 dump truck

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Engine operating hours (h) | Oil service time, h | Kinematic viscosity at 100°C (cSt) | Water content | Clean liness class  (ISO 4406) |
| 25033 | start | 10,6 | absent | 19/17/13 |
| 25163 | 150 | 10,30 | absent | 21/17/15 |
| 25295 | 250 | 10,09 | absent | 21/18/15 |
| 25378 | 350 | 9,90 | absent | 20/17/14 |
| 25763 | 500 | 9,72 | absent | 21/17/14 |
| 26005 | 750 | 9,59 | absent | 21/18/14 |
| 26292 | 900 | 9,42 | absent | 21/18/15 |
| 26625 | 1000 | 9,37 | absent | 20/18/14 |
| 26895 | 1500 | 9,30 | absent | 20/17/15 |
| 27225 | 2000 | 9,25 | absent | 20/18/14 |

**TABLE 7.** Results of analysis of hydraulic oil HVLPD-68 from BelAZ-7513 dump truck

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Engine operating hours (h) | Oil service time, h | Kinematic viscosity at 100°C (cSt) | Water content | Clean liness class  (ISO 4406) |
| 23206 | start | 10,6 | absent | 20/18/14 |
| 23282 | 150 | 10,36 | absent | 21/18/14 |
| 23520 | 250 | 10,19 | absent | 22/18/15 |
| 23833 | 350 | 10,00 | absent | 20/18/14 |
| 24169 | 500 | 9,62 | absent | 21/17/14 |
| 24283 | 750 | 9,50 | absent | 20/18/14 |
| 24333 | 900 | 9,32 | absent | 21/18/15 |
| 24563 | 1000 | 9,35 | absent | 21/17/14 |
| 24695 | 1500 | 9,14 | absent | 20/17/14 |
| 24978 | 2000 | 9,15 | absent | 20/17/14 |

The tests were carried out using the following instruments: kinematic viscosity analysis was performed according to GOST 31391-2009 on a VIS-T-08 liquid thermostat, serial No. 307068; flash point determination was conducted in accordance with GOST 4333-87 using a Cleveland open-cup flash point analyzer HFP-386, serial No. 0938600272; spectral analysis was carried out in accordance with GOST 20759-90 on an MFS-11 spectrometer, serial No. 140014; analysis of cleanliness class according to ISO 4406 was performed on a Pamas S40 contamination analyzer, serial No. 400-3099.

Based on the results of the analyses performed and the samples taken (according to the test program), the tested hydraulic oil HVLPD-68 shows satisfactory results. According to the test results, the hydraulic oil HVLPD-46,68 produced by Chilon Lubricants LLC, which is ash-free (does not contain zinc), complies with the submitted regulatory documentation (technical specifications).

**CONCLUSION**

According to the test results of Chilon HVLPD 46.68 hydraulic oil produced by JV Chilon Lubricants LLC, which is ash-free and does not contain zinc, it complies with the submitted regulatory documentation (technical specifications) and can be used on Belaz dump trucks that have passed the warranty period of operation.

At present, hydraulic oils produced by Chilon Lubricants LLC are used in mining transport equipment that has passed the warranty period. Operational tests conducted during 2000 m/h showed satisfactory results, there were no drastic changes in the operation of the hydraulic system.

Warranty obligations imposed by the world’s leading manufacturers of mining transport equipment require NMMC JSC to use only the oils recommended by them during the warranty period in order to avoid significant costs associated with the failure of expensive warranty units and spare parts.

Taking into account all the above factors, it is possible to select hydraulic oils that provide maximum protection, reduce the number of failures, and significantly extend the service life of the vehicle.

In this regard, joint work is currently being carried out by representatives of NMMC JSC and Chilon Lubricants LLC to obtain approvals from the world’s leading manufacturers of mining transport equipment for the permanent use of hydraulic oils produced by Chilon Lubricants LLC, which meet all established requirements.

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