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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Performance analysis of motor oil quality in heavily loaded engines of quarry vehicles

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Abstract: Recent studies focus on the impact of extreme climatic conditions on mining transport equipment performance. In hot climates (over +50°C) with high dust levels, motor oils in heavily loaded engines are quickly contaminated with impurities. The Muruntau quarry, a unique mining site with a depth of 620m and road lengths of 65–70 km, presents challenges such as reduced diesel engine power (by 20–25%) and rapid insulation degradation. This study evaluates the quality of SAE15W-40, API CI-4/SL motor oils used in CAT-789D dump trucks under these harsh conditions.

Keywords: Motor oil, oxidation, contamination, deposits, durability, dustiness

1. Introduction

The increasing growth in transportation volumes within quarries and the rising carrying capacity of dump trucks necessitate enhanced methods to improve their productivity under challenging mountain quarry conditions.

Significant attention has been directed toward understanding how climatic factors impact the performance of mining transport equipment. The Muruntau quarry, a unique mountainous site with a depth exceeding 620 meters, a width of over 2.9 kilometers, and a length surpassing 3.2 kilometers, presents extreme operational challenges. Quarry roads span 65–70 kilometers, with dust concentrations reaching 10–50 g/m³. Conditions such as rarefied air, reduced oxygen levels, low atmospheric pressure, air ionization, and intense solar radiation negatively affect the performance of motor oils in mining dump trucks.

Rarefied air reduces diesel engine power and productivity by 20–25%, while engine insulation rapidly deteriorates. Low atmospheric pressure worsens sealing conditions, reducing the efficiency of seals in bearings and other parts with liquid lubricants. Additionally, extreme air temperatures and varying humidity levels affect the durability of insulation and air gaps under specific pressure conditions [1, 6].

Studies on lubricants used in engines of heavily loaded mining equipment under hot climates (summer temperatures exceeding +50°C) and high dust levels reveal intense contamination from mechanical impurities, water, fuel, and organic residues. This contamination accelerates oil aging and compromises its effectiveness. High thermal stress on engine components and exposure to combustion gases further exacerbate these issues, significantly degrading operating conditions.

Analyzing operating lubricants has proven to be one of the most effective modern diagnostic methods for assessing the condition of mining machine components and their wear levels. This study focuses on evaluating the performance of motor oils used in dump trucks operating mining and transport equipment. Specifically, SAE15W-40, API CI-4/SL motor oils sampled from the engines of CAT-789D dump trucks were analyzed.

CAT-789 dump trucks, equipped with a robust 16-cylinder CAT 3500 series engine (3516C EUI), are designed for intense loads, achieving high power at low speeds. They are recognized for their low cost per ton of transported material, making them ideal for mining operations. Given the extreme operating conditions of quarry dump truck engines, their oil requirements are more demanding than those of passenger car engines.

These challenging conditions necessitate strict adherence to oil and filter change intervals as specified by manufacturers. Oils used in such equipment must maintain their performance under severe conditions and possess high dispersing properties to ensure long-term reliability [2, 4].

2. Materials and methods

Laboratory physico-chemical and spectral analyses were conducted following an established methodology to address the research objectives. Experimental studies were performed on SAE15W-40, API CI-4/SL engine oils used in CAT-789 dump trucks (equipped with DVS-CAT 3516 engines) operating in the "Navoiy MMC" quarry for rock transportation.

To ensure test accuracy, the lubrication system of the CAT-789 dump truck's internal combustion engine was flushed with the test oil according to the specified testing procedure prior to filling. Before commencing the tests, the central laboratory conducted an incoming quality control analysis of the motor oil designated for testing. The analysis confirmed that the physical and chemical parameters of the oil matched the values specified in the regulatory documentation.

For the analysis, 150 ml of oil samples were regularly collected from the lubrication system of the CAT-789D's heated engine after it reached an operating temperature of 50°C and following engine shutdown. Oil sampling was performed in accordance with the test program, and the samples were analyzed in the central laboratory. Physico-chemical and spectral analyses of the oils were carried out using standardized methods to ensure reliable results [5].

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Table 1

Experimental data on quality indicators of used motor oil SAE15W-40, API CI-4/SL

Dump truck running time, m/h	Oil operating time, m/h	Flash point temperature, °C.	Kinematic viscosity at 100°C, cSt.	Total alkalinity, mg KOH/g	Concentration of Fe, ppm
78296	10	220	15,68	9,27	5,01
78309	15	216	15,87	9,29	7,56
78335	19	217	15,40	9,14	8,38
78360	20	215	14,94	9,11	8,53
78410	25	210	14,84	9,06	9,84
78429	26	214	14,69	9,05	9,25
78452	30	210	14,50	8,97	9,29
78495	35	209	14,24	8,96	9,14
78546	40	210	13,85	8,79	11,79
7595	43	212	13,50	8,27	12,24
78631	49	210	13,24	7,91	12,78
78702	50	208	14,14	7,28	12,90
78773	51	195	14,10	6,89	13,56
78802	71	190	12,93	6,56	15,30
Oil change at operating time of 256 engine hours					
78863	10	220	15,68	9,27	5,01
78910	15	216	15,87	9,29	7,56
78957	19	217	15,40	9,14	8,38
79028	20	215	14,94	9,11	8,53
79058	25	210	14,84	9,06	12,84
Oil change at operating time of 256 engine hours					
79099	26	214	14,69	9,05	9,25
79170	30	210	14,50	8,97	9,29
79242	35	209	14,24	8,96	9,14

79327	40	205	13,85	8,79	15,79
Oil change at operating time of 269 engine hours					
79390	63	208	14,36	8,87	7,29
79486	69	209	14,32	8,83	12,78
79555	63	195	14,09	8,75	12,28
79602	96	190	13,95	8,69	15,06
Oil change at operating time of 275 engine hours					
79669	24	215	14,29	8,97	5,01
79730	48	210	14,16	8,82	7,56
79778	62	209	13,84	8,26	12,38
79802	66	202	13,87	7,95	13,53
79871	69	185	13,14	8,02	19,84
Oil change at operating time of 269 engine hours					
79911	37	214	14,43	8,76	5,01
79948	40	210	14,12	8,48	7,56
79998	47	209	14,12	8,42	8,38
80052	50	205	14,01	8,39	9,53
80099	54	195	13,89	8,02	10,84
80149	62	190	13,26	7,85	13,05
Oil change at operating time of 278 engine hours					
80202	48	214	14,74	8,76	5,01
80250	53	210	14,56	8,48	9,56
80302	55	209	13,87	8,42	10,38
80364	62	205	13,18	8,39	12,53
80431	67	195	13,25	7,85	14,33

Tests were carried out on devices:

-analysis of kinematic viscosity was carried out according to GOST 31391-2009 on a VIS-T-08 liquid thermostat;

-flash point determination was carried out in accordance with GOST 4333-87 using a flash point analyzer in an open crucible,

-determination of the base number according to GOST 11362-96 on an I-160MI ionometer,

- spectral analysis of iron concentration was carried out according to GOST 20759-90 on an MFS-11 spectrometer.

3. Results

Based on the analysis of laboratory studies, deviations in quality indicators (viscosity, base number and flash point) became noticeable when the dump truck ran 200 m/h or more. During operation, the viscosity of the oil decreased to 12.93. This is due to changes in the structural-group composition and the ingress of fuel.

As follows from Table 1, the flash point of 190ºC has approached the rejection value, which indicates the need for replacement and the impossibility of further use of this oil without reducing the operational reliability of the engine. The flash point changes when unburnt fuel gets into it and fuel leaks. For operating oils, the flash point limit is 170–180°C. Oil dilution with fuel causes a sharp deterioration in its anti-wear properties and accelerates the processes of carbon and varnish formation on the pistons.

In order to maintain cleaning properties, motor oils must have a certain alkalinity. The ability to wash away contaminants inside the engine is one of the most important characteristics of modern oil. The higher the alkaline number, the greater the amount of acids formed during oil oxidation and fuel combustion that can be converted into neutral compounds. Having reacted with an acid, the alkali is consumed irrevocably, therefore, at a certain point in time, the reserve of the alkaline number decreases so much that the additives are no longer enough to neutralize all the acids that enter the oil. High sulfur content in fuel causes the oil base number to decrease rapidly. The operating conditions of mining equipment should also be taken into account. It works in highly dusty conditions.

When using fuel with a low sulfur content, alkaline additives in the oil are spent to a lesser extent on neutralizing fuel combustion products and, to a greater extent, on neutralizing oil oxidation products and protecting it from oxidation in general [3].

The service life of motor oil in our experiment was assessed by the balance of acid and base numbers in samples of used oil. These indicators were determined using a titrator in mg KOH/g. It is generally accepted that when the acid and alkaline numbers reach equivalent values, the oil reaches a limiting state and its further use is unacceptable. Oil samples were taken from engines with an average frequency of 2000 km. Based on the data obtained, the average daily operating time of vehicles ranged from 50 to 140 km/day.

The table also shows that the alkaline number during operation decreased from 9.27 to 6.56. Operating the engine on oil with an alkaline number below the limit leads to accelerated wear of engine parts, which also shows an increase in iron concentration. The main lubricated components and parts of a piston engine are main and connecting rod bearings, camshaft bearings and gears, piston rings, valve rods and lifters, piston-cylinder interfaces, piston-piston rings.

In a diesel engine, engine oil components are exposed to the following factors: high surface temperatures of parts and the gas mixture, the catalytic effect of wear products of parts during oil oxidation, the presence of atmospheric oxygen, nitrogen and carbon oxides, sulfur oxides, products of incomplete combustion of the fuel mixture, which leads to the formation high-temperature deposits - carbon deposits, varnish and sludge.

When engines operate, significantly more large metal wear particles accumulate in the engine oil, indicating increased wear of rubbing parts. The wear of engine parts can be monitored by the concentration of wear products in the oil.

To monitor the engine wear process, the method of determining iron in oil is widely used. For this purpose, a spectral analysis was carried out on the iron (Fe) content of SAE 15W-40, API CI-4/SL motor oil, depending on the duration of operation of dump trucks (Table 1).

Analysis of the research results shows that during the research the average value of iron content increases. The iron content characterizes the anti-wear properties of the oil and their changes during operation, the wear resistance of engine parts and the effectiveness of cleaning agents included in the lubrication system.

The most dangerous component from the point of view of engine durability is the component of mechanical impurities, which includes wear products (Fe) and other solid particles. Increased iron content indicates intensified wear processes of iron-containing engine parts. With an increase in the iron content in the oil, the frictional, anti-wear, antioxidant and detergent properties of the oil change. This influence leads to the following negative phenomena:

– coking of piston rings, which leads to increased friction losses, increased emissions of harmful substances, increased fuel and oil consumption, scuffing of the rubbing surfaces of cylinder-piston parts;

– significant “bulging” of the piston rings, especially the upper ones, due to the formation of deposits of solid carbon particles on the inner walls of the grooves and, as a result, increased wear, scoring of rings and cylinders;

– carbon formation on the side surface of the pistons, which causes cylinder polishing, increased oil consumption, deterioration of environmental characteristics, and surface scuffing;

– corrosion - mechanical wear of parts of the cylinder - piston group, crank - connecting rod mechanism, especially those made of non-ferrous metal alloys;

– abrasive wear of parts caused by solid particles of contaminants.

These reasons reduce the reliability of diesel engines, increase the cost of their maintenance, and in some cases cause emergency situations and premature failure..

In this regard, we offer a new alkylsalicylic additive, which has high-temperature detergent, dispersant, anti-oxidative and neutralizing properties. The additive Detersol is a colloidal dispersion of calcium carbonate in a diluent oil, stabilized with calcium alkyl salicylate based on ethylene oligomers.

This additive, compared to other additives, is quite effective and stable at relatively high temperatures. The additive is completely soluble in oil and is applicable as not only an anti-wear, but also an antioxidant additive in motor oils operating in hot climates and high dust levels [4].

4. Conclusion

For advanced diesel engines, lubricant developers provide a wide range of motor oils with multifunctional additives designed to significantly reduce contamination by mechanical impurities within the lubrication system, thereby enhancing equipment reliability.

Additives such as Detersol (D-50, D-140, D-180, D-300) impart valuable detergent, neutralizing, and antioxidant properties to motor oils. For heavily loaded quarry transport engines, we propose the use of the D-180 additive. This detergent additive ensures that engine pistons remain clean, preventing piston ring burning even under demanding conditions. Additionally, these additives improve other vital oil properties, including anti-corrosion and anti-wear characteristics, thereby extending the service life and reliability of the engine oil [7].

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