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Influence of the Arctic climate on watering of engine oils in operating conditions of road transport

A V Kolunin[1], **I A Bur'yan**[1] **and S A Gel'ver**[2]
[1]Branch of Federal State-Owned “Khrulev Military Educational Institution of Logistics” of the Ministry of Defense of the Russian Federation in Omsk, 14th military town, Omsk, 644098 , Russia
[2]Omsk State Transport University, 35, prospect Marksa, Omsk, 644046 , Russia

Abstract. A characteristic feature of the Arctic climate is negative temperatures. They have a negative impact on the condition of the equipment. The engine is the least adapted unit for the use in such conditions. The lubrication system of the engine undergoes significant state changes. The changes include the reduction of the operational properties of engine oils and the formation of buttery sediments, which block the grids of oil receivers, oil filters and violate the permeability of oil lines. The factor of watering in low-temperature sedimentation is of paramount importance. The water in the crankcase is formed as a result of condensation processes when operating at low temperature.

1. Introduction

Strategically, the Russian North is a powerful reserve for Russia's development in the 21st century.
For the sustainable development of the Russian Arctic economy, the advanced development of the Arctic transport system is necessary. The implementation of advanced scientific achievements will provide reliable transport links, comfortable living conditions in the harsh region, accelerated development of mineral resources, oil and gas exports, the development of the Arctic transit. In the long term, further work on the development of the Arctic region depends on how advanced the technologies of offshore oil and gas production in the Arctic will be and how far people are willing to go to the Arctic for its development. This readiness is largely determined by the effectiveness of the work of scientists and the functioning of the Russian science.
Today, all the projects implemented on the Arctic shelf are significantly different from each other in terms of manufacturing, due to the different natural and climatic conditions of the regions to which they are oriented. Low temperatures is a general distinctive feature of climatic conditions that limits possibilities of the use of equipment in many respects. The problematic issue of the use of operational materials occupies a special place. The adaptability of lubricants to work in conditions of negative temperatures largely determines the friction conditions of the conjugated surfaces in particular and the service life of the equipment as a whole.
Such circumstances require the implementation of new science-based technological and design solutions.
Extreme climatic conditions of the Arctic region create a complex of problems in the field of operation of automotive vehicles. The influence of low temperatures on the state of the vehicles are described in the works of such famous scientists as Reznik L. G., Semenov N. In. Koch p. I., Englin B. A., Nepogodev A.V., Glavati O. L. Low temperatures have a negative impact on the reliability of all mechanisms and systems, reduce the operational lifetime of the equipment. The average life of the vehicles operated in the conditions of negative temperatures of the severe climate is 75% of the

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time provided by the manufacturer. A comparative analysis of such effects is described in [1]. In addition, the least adapted to such conditions unit was identified. The failure distribution per units, systems and mechanisms in percentage terms is presented in Table 1.

Table 1. The failure distribution of vehicles per units, systems and mechanisms

Units, systems, mechanisms	**Engine**	**Running gear**	**Transmission units**	**Cab body, hull, platform**	**Brake system**	**Electrical system**	**Steering**	**Others**
%	30	17	16	13	8	7	5	4

The least adapted unit to operate in such conditions is the engine. The engine, figuratively called the heart of the vehicle, converts the thermal energy into the mechanical one. The engine operates in a wide temperature and loading range with chemically active compounds. Engine failures occupy 30 % of all equipment failures.

2. Theory

The reliability of the engine operation is largely determined by the perfection of the design, compliance with the operating instruction and application conditions. The engine operation is conjugated with a number of factors such as:
- significant differences in speed and load modes;
- wide temperature, pressure and humidity ranges;
- vibration and shock loads.

Seasonality changes in the flow of engine failures, vehicles under control is of interest due to the severity of the operating conditions. To carry out the analysis based on the collected data, the dependences of the failure flow during the calendar year were obtained.

From the diagram shown in Figure 1, you can see how the flow of engine failures changes during the year. In this case, there are two periods with a predominant failure rate. The peak of the failure flow occurs in February (i.e. winter) [2].

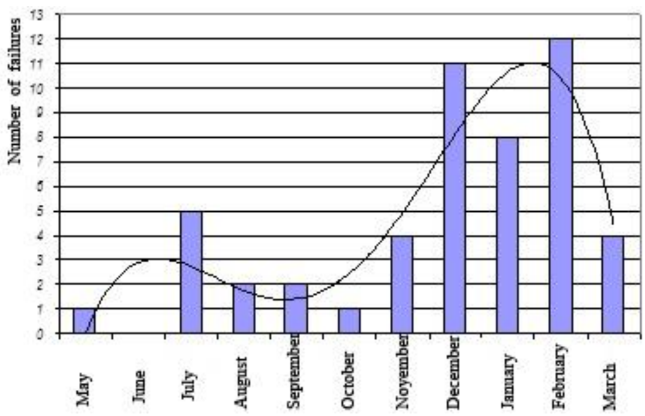

Figure 1. Indicators of the annual distribution of the failure flow of internal combustion engines

A number of factors provide a cause-effect relation between negative temperatures and the engine condition. The engine oil takes a special place in maintaining the stability of the engine condition in this context. The use of vehicles under negative temperatures is accompanied by the active formation of sediments in the engine lubrication system, called "low-temperature" [2].

Because of oxidation of hydrocarbons in the cylinders, there is a complex of combustion products, including water. The bulk of the water, in the form of vapour, is released through the exhaust system, but part of the water enters the crankcase through the parts mating of the cylinder-piston group.

When operating under the optimum temperature, the vapour is released through the ventilation and recirculation system, and under low temperature, it condenses on the surfaces of the engine parts and oil. The oil with the water forms a stable emulsion. It is scientifically proved that the water, forming an unsimilar charge, contributes to the unification of large conglomerates of products with low aggregate stability. The latter include additives that have undergone thermal destruction and partially oxidized fuel fractions, products of thermo-oxidative transformations of hydrocarbon oils, soot, sulfur, nitrogen. In this case, the unrealized washing and dispersing potential of the oil is wasted. Its alkalinity decreases, and the acid number grows [3].

The operational properties of the engine oil are provided by a package of additives introduced in accordance with the processing technology. In the process of operation, its consumption is carried out. Providing the necessary conditions for friction, cooling of mating parts, protection of parts from the effects of active acids, prevention of foaming, dispersion, removal of wear products from the friction zone, is carried out quite effectively in optimal temperature conditions during the resource period. Low-temperature operation of the engine helps to reduce the life of the engine oil. As a rule, no one controls the worked out/residual operating time and the achievement of limit, threshold values in the conditions of ordinary operation. A number of negative consequences, including the formation of greasy sediments of black color, accompany the operation of the engine with the oil of exhausted potential.

Low-temperature sediments block the grids of oil receivers, the elements of oil filters; they lie over in the oil pipelines, reducing their capacity, and have an overall negative impact on the condition of lubrication systems [3]. Figure 2 shows the grids of oil receivers of different states.

a) *b)*

Figure 2. Typical sediments on the grid of the oil receiver: a – the grid of the oil receiver with sediments; b – the grid of the oil receiver without sediments.

3. Problem statement

The most critical periods are accounted for by operation immediately after starting a cold engine. The starting reliability of the engine, fuel economy, the activity of the wear process of parts considerably depend on its temperature condition. Therefore, the effectiveness of the pre-start preparation and the operational materials used is important in the issue under consideration.

Therefore, there are scientific questions: "What factors provide a cause-effect relation between the pasty sediments and the negative temperatures, under which the vehicles are operated? How does the mechanism of low-temperature sedimentation work? What is the dew point temperature of the crankcase gases?»

As you know, the oil is a kind of storage of various products, namely: wear products of mating surfaces of parts subjected to thermal destruction and partially oxidized fuel fractions, products of thermo-oxidative transformations of oil hydrocarbons, nitrogen oxides of atmospheric air, soot and active acids. These products are in a dissolved state and circulate in the oil volume. However, they have low colloidal stability, and are "ready" to change their state under the influence of certain factors. The most influential factor ensuring the change of states of substances is the presence of water in the oil. The effect of water on the condition of engine oils is described in [4]. The mechanism of low-temperature sedimentation is shown schematically in Figure 3.

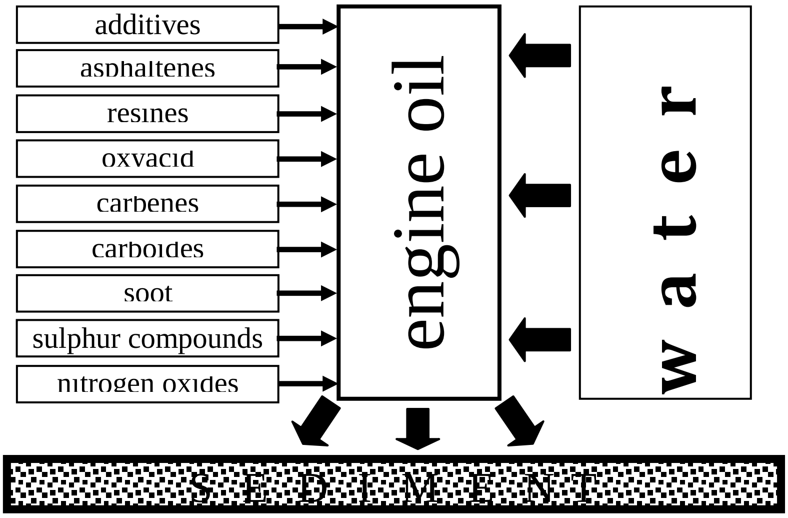

Figure 3. Diagram of low-temperature sedimentation mechanism in lubrication systems of the engines.

How does water get into the engine oil in work and what is the connection between the harsh climate of the Arctic and watering?

In the conditions of ordinary operation of the equipment, negative temperatures of the Arctic zone have a lowering effect on the temperature state of the engine. Low temperature operation can be during the warm-up period after long-term parking, as well as when working under low loads (idle).

Fuels used for internal combustion engines have a hydrocarbon composition. The carbon (C) and the hydrogen (H) contained in the fuel are oxidized by oxygen atoms of atmospheric air. As you know, carbonic oxide or so-called carbon dioxide is formed during the oxidation of carbon. The reaction is described by the dependence:

$$C + O_2 \rightarrow CO_2 \tag{1}$$

When hydrogen is oxidized, water vapor is formed. The reaction is described by the dependence:

$$H_2 + 0{,}5O_2 \rightarrow H_2O \tag{2}$$

In the combustion chamber under the temperature of 2000 °C, gases have a high saturation pressure, and the water is in a gaseous state. A part of the fuel combustion products inevitably penetrates into the cold environment of the crankcase space through the parts conjugations of the cylinder-piston

IOP Conf. Series: Journal of Physics: Conf. Series **1260** (2019) 062012 doi:10.1088/1742-6596/1260/6/062012

group. If the temperature in the volume of the crankcase space is lower than the dew point temperature of the gases, the water changes the phase state and is mixed with the engine oil in work [5].

Different scientists have studied the mechanism of low-temperature sedimentation again and again. The conclusions of the researchers are unambiguous. For the formation of sediments, it is necessary for the engine to operate in a low temperature mode. In this case, there is condensation of water vapors of crankcase gases and accumulation of subjected to thermal degradation and partially oxidized fuel fractions in the oil.

The question arises about the degree of absolute watering of the oil when the engine is warmed-up under negative temperatures, and the value of the temperature corresponding to the dew point temperature is the temperature under which the condensation processes are completed and the processes of evaporation of water from the oil surface begin. To solve this problem, an experiment was conducted using five KAMAZ-5350 vehicles under control with the same operating time.

4 Experiment

The experimental procedure provided for the oil sampling under negative temperatures during the warm-up of the engines.

The samples were tested for moisture content in laboratory conditions. Water concentration in oil was determined by weight in international units of ppm (partspermillion — parts per million, $1 \cdot 10^{-6}$).

The arithmetic mean values determined by five individual values allowed determining the graphical dependence of the water concentration on the temperature in the volume of the crankcase space, as well as the dew point temperature of the crankcase gases. The degree of reliability was provided by a sufficient number of samples; modern research methods; sufficient reasonableness of fabricated assumptions.

The activity of condensation processes is significantly affected by the temperature condition of the engine. When gases enter the crankcase space, they are rapidly cooled due to active heat-and-mass transfer. Pulsed movements of the gas layers, back-and fourth motions of the pistons, as well as the rotation of the crankshaft and complex plane-parallel motions of the connecting rods facilitate active heat-and-mass transfer. The shape of the crankcase is quite complex, the movement of gases and oil in the crankcase is difficult to describe by any laws. Therefore, in the preparation of the experiment, the following assumption was made: the temperature of the gas-oil medium is uniform throughout the volume of the crankcase space and corresponds to the values recorded by the multi-channel temperature meter MIT-12 on the signals of thermocouples installed in the oil pans of the crankcases. The installation of thermocouples was provided by a special design of drain plugs as shown in Figure 4.

Figure 4. A drain plug with a thermocouple.

Figure 5. Oil sampling.

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The oil filter housings were fitted with samplers in the form of drain valves as shown in Figure 5.

With the aim of greater clearness, the experiment was conducted without the use of a preheater. The experimental conditions are presented in Table 2.

Table 2. The conditions of the experiment

Climatic parameters, dimension	Value
Air temperature, °C	minus 32
Atmospheric pressure, mm Hg.	774
Air humidity, %	98
Wind speed, m / s	1

The user manual for KAMAZ recommends starting the engine of KAMAZ-740 in the conditions of negative temperatures using electric torch providing air heating in the intake manifold directly at the startup. The recommended crankshaft speed during the warm-up should be in the range of 1200-1600 min^{-1}.

The parameters of the experiment were divided into fixed and varied ones. The fixed parameters were the crankshaft speed (min^{-1}) and the load (N/m). The varied parameters were the temperature of the gas-oil medium in the volume of the crankcase space (°C) and the concentration of water in the oil (ppm).

After starting up, the engine was warmed up to the oil temperature of plus 75 °C at the crankshaft speed of 1400 min^{-1}. The sampling during the engine warm-up was carried out without stopping in a certain temperature interval.

The first oil sample was taken immediately after the start of the vehicle engines, and the following ones – according to the previously developed schedule. The sampling was made into the containers. Samples were taken for 25 ml. They were marked. The sample numbers were recorded in the work sheets with the data according to the vehicle number, the date and the time of sampling, the engine oil temperature.

The required volume of each sample, equal to 25 ml, was sufficient for the analysis. Thus, 12 samples were taken for the entire warm-up period. The samples were analyzed using a coulometric titrator according to the method of Karl Fischer MKC-501N. The method of measuring ASTMD 1744 was used to assess the moisture content of oil samples in the laboratory conditions. As a laboratory equipment, coulometric titrator of the brand Schott Titro Line alpha plus was used.

Based on the test report on the arithmetic mean values in the Cartesian coordinate system, a graphical dependence of the change in the moisture content of the oil on the temperature in the volume of the crankcase space was drawn. It is shown in Figure 6.

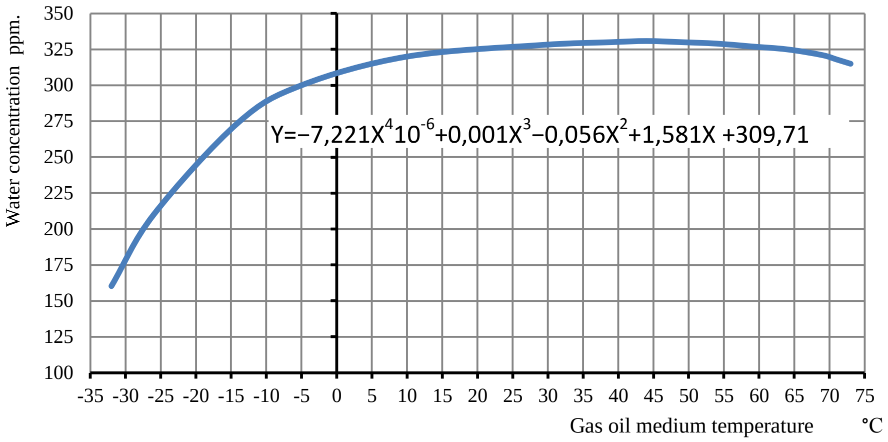

Figure 6. The diagram of dependence of the concentration of water in the oil on the temperature of the volume of the crankcase space when starting up the engine.

The dependence curve is approximated using the program "Origin". A fourth-degree polynomial is the sum of constants multiplied by a variable with different exponents. The resulting regression equation is shown on the coordinate plane of Figure 6. The initial water content in the oil was 160 ppm. During the warm-up of the engine to the oil temperature of 44 ° C, the water concentration increased to 330 ppm. A further increase in temperature contributed to a decrease in moisture content because of evaporation of water from the oil surface and the release of vapor through the crankcase ventilation system.

The extremum of the dependence curve indicates the temperature of the dew point of the crankcase gases - plus 44 ° C. It is the temperature, under which the condensation processes are completed and the processes of evaporation of water accompany further temperature increase from the oil surface, which is consistent with the theoretical concepts presented in [6].

5. Experimental results

Thus, based on the described experiment, the presence of condensation processes in the crankcase space of the engine operating under low temperatures, which is typical for the conditions of the Arctic zone, is proved.

The dependence of the influence of the temperature of the gas-oil medium on the accumulation of water in the oil of piston engines during warming-up at negative temperatures is determined. It was found that the water concentration increased by 2 times in relation to the initial value. The increase in moisture content was 170 ppm and corresponded to 0.0170% by weight. The dew point temperature for the experimental conditions was 44 °C. In the experimental conditions, the moisture content during engine warming-up increased by 101% relative to the initial value.

Based on the analysis of the works of such researchers as Semenov N.V., Boltanin M.A., Losavko, G.S., Papok, K.K., Vipper A.B. on the influence of negative temperatures on the sedimentation in the lubricating system of piston engines, it is possible to conclude that water initiates strengthening of intermolecular interactions of products with low aggregate stability. These products are contained in the engine oil, which leads to the change of their aggregate states, including additives, and the reduction of their concentrations in the volume of oil. Solid (or amorphous) compounds are deposited on the surfaces of engine parts in the form of pasty sediments.

6. Conclusions

Negative temperatures of the Arctic zone initiate processes that provide a cause- effect relation between the first and pasty sediments that block the grids of oil receivers and oil filters. They reduce the throughput of the oil lines changing the status of the lubricating system in this way. One of these processes is the condensation process in the volume of the crankcase space. It should be noted that one-time watering of 0,033% is not able to have a significant impact on the performance of the engine oil. However, with respect to multiple, periodic watering, the total negative effect can significantly reduce its service life.

The newly created designs of modern engines, focused on the use in conditions of negative temperatures of the severe climate, should be different in adaptability to such conditions. Operation of vehicles in the Arctic should be carried out taking into account the negative impact of specific features of the climate. A scientifically based approach to the production of modern engine oils, provided with high colloidal stability and intended for use in conditions of negative temperatures of the cold climate, will largely ensure the adaptability of equipment for operation in such conditions; will increase its reliability, service life and life cycle.

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