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Influence of Temperature and Concentration of Additives on the Lubricity of Track Machine Oils

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Abstract. The promising types of additives to hydraulic oils of track machines, which contribute to increasing the lubricity of oils, that is necessary for the introduction of resource saving in railway transport, were substantiated. On the basis of the conducted justification, two types of additives were selected for further study: pure stearic acid and a three-component additive based on carbamide A, stearic and oleic acid. These additives were used in the studies, being added to hydraulic oil I-20A in different concentrations. Methods and results of laboratory studies of the indicators of the lubricity of hydraulic oil with additives depending on the concentration of the additive and the operating temperature of the oil are given. The following indicators of oil lubricity were studied: the dynamic viscosity of the oil measured in a rotary viscometer; the thickness of the boundary lubricant film measured using the "ball stack" method; the load-carrying capacity of the boundary lubricant film measured in a special load device by establishing a load in which the electrical resistance in the point of contact between two lubricated steel balls abruptly approaches the values of resistance of the dry metal contact.

1. Introduction

One of the most promising trends for implementing resource-saving technologies for the railway transport is quality assurance for lubricants [1]. This direction is especially relevant for hydraulic oils of track machines, most of which do not contain any anti-wear and anti-friction additives, such as industrial oils. These oils are commonly used in hydraulic drives of track machines, because of their low cost, but they do not contribute to resource savings due to low lubricity.

The solution to the problem of improving the lubricity of industrial oils lies in the search and study of new and at the same time moderately priced additives which form a lubricant film with increased thickness and load-carrying capacity on the friction surfaces of hydraulic units. In addition, these additives should not significantly affect the viscosity and temperature characteristics of oils; otherwise, oil viscosity values cannot be maintained within the permissible range and the oil cannot be used in specific hydraulic systems at all. Therefore, in the article the main indicators of the lubricity of industrial oil are studied when two different types of additives are added, each meeting the requirements stated above.



2. Analysis of recent studies and publications

The paper [1] contains general ideas about the lubricity of oils, lists indicators of lubricity, test methods, and the influence of oil structure and external factors on them. According to this information, there are three main indicators of lubricity, namely: the dynamic viscosity of the oil, the thickness and load-carrying capacity of the oil film. These indicators reflect phenomena with the different mechanisms of action. For example, the dynamic viscosity of oil affects the efficiency of forming a hydrodynamic lubricating film [2], while the thickness and load-carrying capacity of the oil film are more relevant for boundary friction of parts [2, 3].

During the operation of hydraulic units of track machines, especially hydrostatic ones, all three oil indicators must be maintained at a high or set level, since during operation of these units both the hydrodynamic lubrication and the boundary lubrication exist, because of the design features of the units [4] and wide ranges of loads, relative speeds and temperature [5]. In addition, the viscosity characteristic of the oil significantly affects the efficiency of its application on the friction surface [6], which also confirms the importance of ensuring its performance at the necessary level.

Today, one of the main ways to improve the lubricity of hydraulic oils is to add a certain amount of functional additives to them during the manufacture [1, 7, 8]. However, in the actual operating conditions of track machines, the use of oils doped with modern additives is controversial, since such oils are high-priced, while the hydraulic system can require filling with 2 tons of oil at a time or even more. Therefore, it is reasonable to search for such additives that, on the one hand, improve the lubricating ability of the oil at low concentrations, and on the other hand, are manufactured from reasonably-priced raw materials and have good solubility in hydrocarbons. In [7], 2 types of additives are proposed that meet the specified requirements, but their effect on the lubricity of hydraulic oils has been studied only theoretically. However, for further practical application of such additives, an experimental study of their effect on the lubricity at different concentrations and external conditions is required.

3. Statement of the objective and tasks of the study

The purpose of the study is to determine dependence of the main indicators of the lubricity of hydraulic oils of track machines on the concentration of two types of additives and the oil temperature. To achieve this goal, the following tasks were solved:

- determination of dependence of the dynamic viscosity of the oil on the concentration of the selected types of additives and temperature;
- determination of dependence of the maximum thickness of the lubricant film on the concentration of the selected types of additives and temperature;
- determination of dependence of the load-carrying capacity of the boundary lubricant film on the concentration of the selected types of additives and temperature.

4. Materials, equipment and research program

Hydraulic oil I-20A (GOST 20799-88), which is commonly used in most hydraulic systems of track machines in Ukraine, was selected for the study. Pure stearic acid (GOST 6484-96) and a three-component additive consisting of carbamid A (GOST 2081-92), stearic acid (GOST 6484-96) and oleic acid (GOST 7580-91) were used as additives. Such additives are well soluble in the tested oil within the studied concentration range and were selected according to the physical representations of the works [8, 9]. Stearic acid is a surfactant that, at a certain concentration, is inclined to aggregation of molecules in solution to form "reverse" micelles. The studied concentration range was selected from 0 to 0.6 % by volume, which exceeds the values of the critical micelle concentration. The three-component additive is dissolved in the oil to the level of ordered molecular "adducts", which retain their high surface activity throughout the studied concentration range. In the studies, this range was limited only by the solubility limit of the additive, so it varied from 0 to 0.2 % by volume.

The dynamic viscosity of the oil was measured using a rotary viscometer Rheomat RM100i with a relative measurement error of $\pm 1\%$. The liquid temperature was maintained in the LNG-500 heater.

The dynamic viscosity study program included measuring the oil viscosity at a stearic acid concentration in the range of 0 to 0.6 % with an increment of 0.15 %; measuring the oil viscosity at a three-component additive concentration in the range of 0 to 0.2 % with an increment of 0.05 %. In both series of studies, oil temperature was maintained in the range of 40 to 100 °C with an increment of 20 °C.

The thickness of the boundary lubricant film was measured in a special laboratory device that uses the "ball stack" method [8] (figure 1).

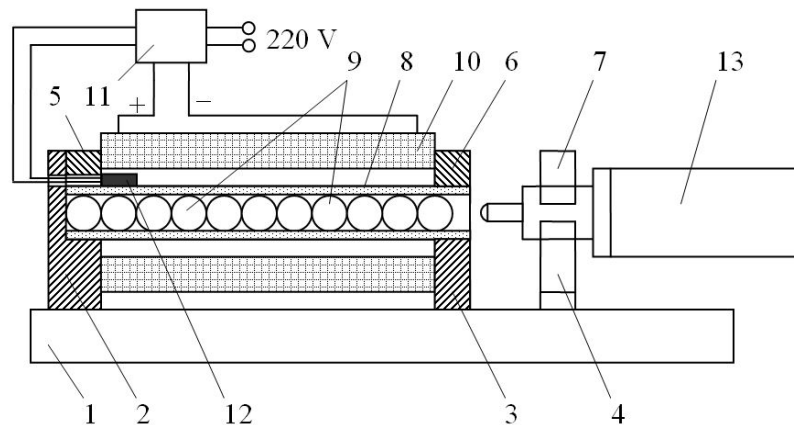


Figure 1. Schematic diagram of the boundary lubricant film thickness measurement system: 1 - plate; 2, 3, 4 - guide supports; 5, 6, 7 - covers; 8 - glass tube; 9 - steel balls; 10 – heater; 11 – temperature controller; 12 – temperature sensor; 13 – dial-type micrometer.

According to the proposed method, the total thickness of the lubricant films on the balls is

$$\Sigma h = 2 \cdot (n+1) \cdot h_i, \quad (1)$$

where n is the number of balls in the stack; h_i is the thickness of the film on one surface.

The minimum number of balls in the stack is determined based on the micrometric accuracy of the device and the predicted value of the change in film thickness after an additive is added.

$$n = \frac{e}{2 \cdot \Delta h} - 1, \quad (2)$$

where e is the accuracy of the measuring device; Δh is the predicted change in the thickness of the limiting film.

The program for study of the thickness of the boundary lubricant film included: measuring the thickness at a concentration of stearic acid in the range of 0 to 0.4 % with an increment of 0.05 %; measuring the thickness at a concentration of the three-component additive in the range of 0 to 0.2 % with an increment of 0.02%. In both series of tests, the oil temperature was maintained in the range of 40 to 80 °C with an increment of 20 °C.

The load-carrying capacity of the lubricant film was studied in a special laboratory device, in which the direct physical measurement of the electrical resistance in the contact point of two steel balls was used (figure 2). The load-carrying capacity is understood as the minimum load at which the electrical resistance of the lubricated contact rapidly fell to the value of the electrical resistance of the dry metal contact. I.e., it was considered that at this moment the lubricant film is destroyed, and as a result, metal-to-metal contact occurs.

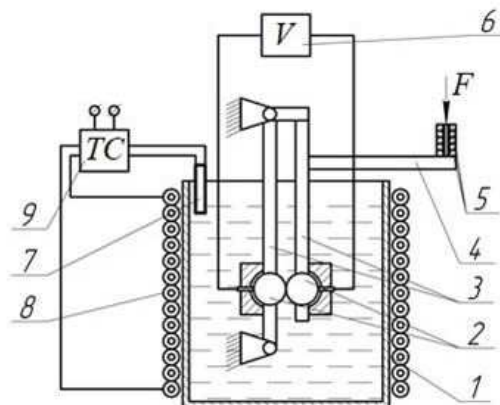


Figure 2. Schematic diagram of the device for measuring the maximum load-carrying capacity of the lubricant film: 1 - bowl; 2 - steel balls; 3 - lever system; 4 - load lever; 5 - calibrated loads; 6 - universal voltmeter; 7 - temperature sensor; 8 - heating element; 9 – temperature controller.

The program of studies of the load-carrying capacity of the lubricant film included: the measurement of the critical load when the concentration of stearic acid was in the range 0 to 0.6 % with an increment of 0.3 %; measurement of critical loads at a concentration of three-component additive in the range 0 to 0.2 % with an increment of 0.1 %. In both series of tests, the oil temperature was maintained in the range of 20 to 140 °C with an increment of 20 °C.

5. Results of the study and discussion

The results of dynamic viscosity studies are shown in figure 3.

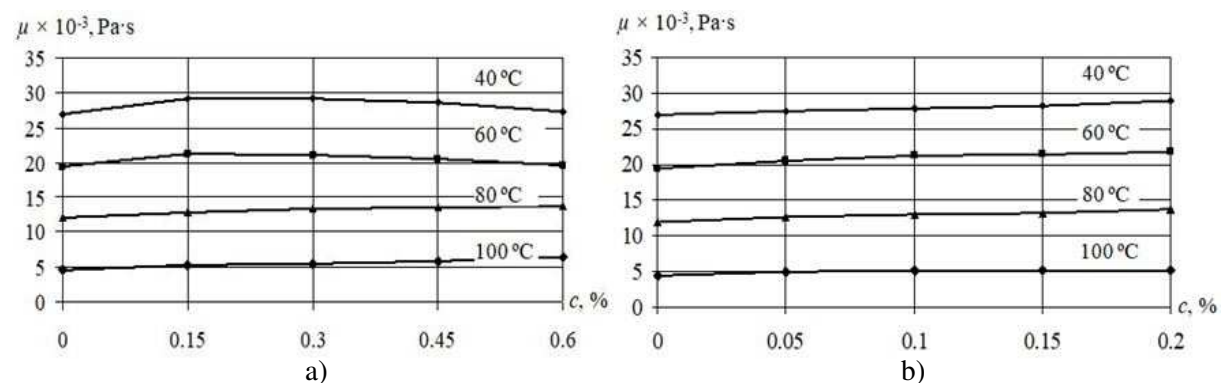


Figure 3. Results of studies of the dynamic viscosity of the oil: a) stearic acid as an additive; b) three-component additive.

According to the results shown in Figure 3, there are two dependences of oil viscosity on the concentration of additives. First, when stearic acid is added at a solution temperature of 40 °C and 60 °C, the maximum increase in viscosity occurs at the concentration of 0.3 % and 0.15 %, respectively. The increase in viscosity for these concentrations is about 7 %. With further increase in the concentration, the oil viscosity slightly decreases (figure 3 a)). The indicated values of concentrations are consistent with the data of colloid chemistry regarding the critical micelle concentrations (CMC) of stearic acid dissolved in hydrocarbons [9]. I.e., at concentrations lower than CMC, stearic acid molecules are predominantly in the monomeric state, which means that they increase the free energy of the solution. At concentrations above CMC, the additive molecules are in the micellar state. Such micelles are known to be "reverse": the surface-active parts of the molecules are in the middle, while the activity of micelles drops to almost zero [10]. As a result, the free energy

of the solution falls almost to the level of the initial value. Therefore, at solution temperatures of 80 °C and 100 °C, the viscosity increases steadily over the entire concentration range, since micelle formation does not occur at such temperatures (figure 3 a)).

When a three-component additive is added to oils, the viscosity steadily increases by 5 to 10 % in all concentration and temperature ranges (figure 3 b)), which indicates that there is no micelle formation of the three-component additive in these ranges.

The results of studies of the thickness of the boundary lubricant film are shown in figure 4.

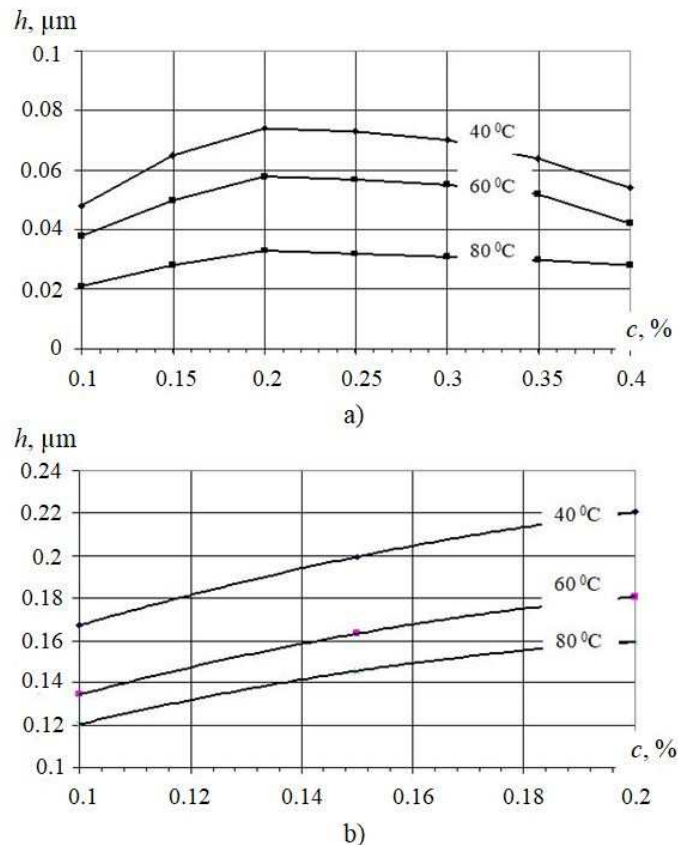


Figure 4. Results of studies of the thickness of the boundary lubricant film: a) stearic acid as an additive; b) three-component additive.

When stearic acid is added to oils, the dependence of the film thickness on the additive concentration also has a maximum (figure 4 a)). It was found that the maximum thickness increase is observed at a concentration of 0.2 % for all temperatures. A further increase in the concentration leads, as in the case of dynamic viscosity, to a decrease in the film thickness, which also indicates the influence of micelle formation. In general, when stearic acid is used, the maximum increase in the thickness of the lubricating film is achieved by 55 to 65 %.

When a three-component additive is added to the oil, the film thickness is significantly higher than when stearic acid is added, namely 2.5 to 6 times at additive concentrations of 0.1% (figure 4 a) and figure 4 b)). The reason is the high surface activity and size of the molecular "adducts" of the three-component additive. When the concentration of the three-component additive increases from 0.1 % to 0.2 %, the film thickness steadily increases by 32 to 33 %, which also indicates that there is no micelle formation.

The results of studies of the load-carrying capacity of the boundary lubricant film are shown in figure 5.

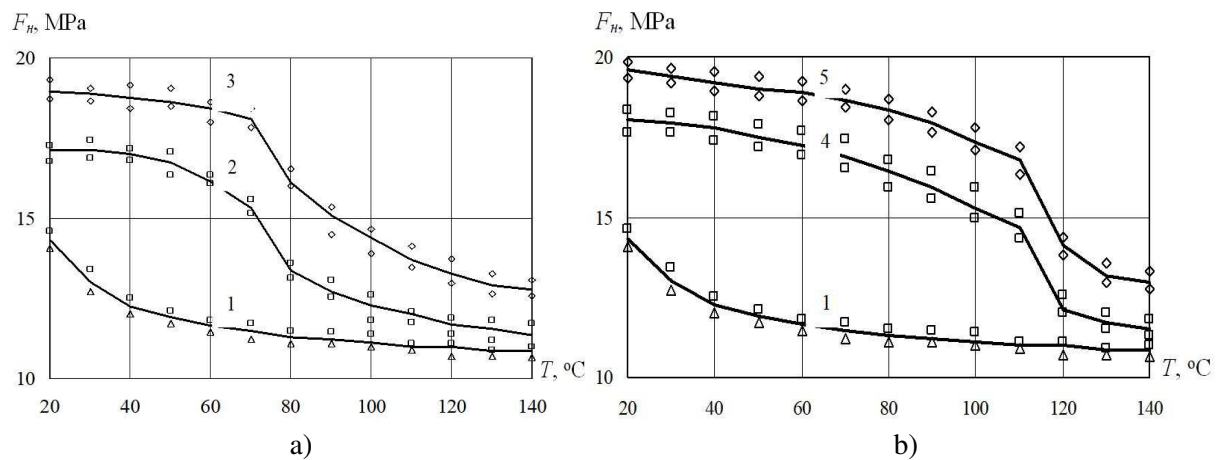


Figure 5. Results of the studies of the load-carrying capacity of the boundary lubricating film: a) stearic acid as an additive; b) three-component additive.

The results of the study shown in figure 5 are presented in the form of temperature curves, since the load-carrying capacity of the film is the main indicator of lubricity of the oil, which should ensure effective lubrication of the surfaces of the parts within a wide temperature range.

The load-carrying capacity of the oil film without additives decreases steadily with temperature and is 14 MPa for 20 °C and 11 MPa for 140 °C (curve 1). For the oil with both additives, the temperature dependence of the load-carrying capacity is different. In each case (curves 2-5), there is a gradual decrease in the load-carrying capacity to a certain critical temperature, after which the load-carrying capacity decreases abruptly, and all curves become similar to curve 1. For stearic acid, the load-carrying capacity changes abruptly at 70 °C, and for a three-component additive - at 110 °C. Interestingly, these values are close to the melting temperatures of both substances. I.e., as soon as these temperatures are reached, a phase change occurs in the boundary films of additives – from a more ordered phase to a less ordered one, as a result, the load-carrying capacity decreases abruptly. In general, when stearic acid is used, an increase in the load-carrying capacity of the oil by 16 to 30 % can be achieved. For a three-component additive, this increase varies from 17 to 37 %.

6. Conclusions

1. Adding two types of additives to industrial oil in the selected concentrations leads to a maximum increase in dynamic viscosity by 5 to 10 %, which does not change the scope of application of oil in hydraulic drives of track machines.

2. The use of the studied additives results in a significant improvement in the lubricity of the oil according to the criteria of thickness and load-carrying capacity of the lubricant film. When a particular type of additive is used, its tendency to micelle formation should be taken into account. For example, stearic acid maximizes the lubricity at concentrations of 0.15 to 0.2 % and a temperature not higher than 70°C. The maximum efficiency of the three-component additive is achieved at a concentration of 0.2 % and a temperature not exceeding 110°C.

3. In general, the use of the studied additives, especially the three-component additive, will lead to the implementation of resource saving in hydraulic drives of track machines, since increasing the thickness and load-carrying capacity of the oil film are direct factors in reducing the wear rate of friction parts of hydraulic units.

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