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OPERATIONAL EVALUATION OF MOTOR OILS OF TRUCKS BY THEIR THERMAL OXIDATIVE STABILITY

Об'єктом дослідження є процес визначення термічного окислення робочої моторної оливи вантажних автомобілів підчас їх експлуатації. Одними з найбільш проблемних місць є встановлення відповідних режимів окислення робочої моторної оливи та підбір необхідного лабораторного обладнання, а також формування рекомендацій відносно експлуатаційної оцінки досліджуваних олив.

В ході дослідження використовували способи термічного окислення проб робочої моторної оливи в режимах ламінарного перемішування, а також фотометрування для визначення ступеня забруднень продуктами окиснення.

Виявлено, що моторна олива TEMOL Extra Diesel 15W-40, CF-4/CG в автомобілях КамАЗ 6520 (Росія) забезпечує свої функціональні можливості. Разом з тим змінювати інтервали пробігу для заміни оливи, при усталених експлуатаційних режимах, заборонено. Оскільки на пробігу 12,8 тис. км значення за термоокислювальною стабільністю оливи підчас експлуатації має резерв лише 0,2 %, що характерне як критичне. Це пов'язано з тим, що запропонований метод контролю стану робочої оливи відображає залишковий ресурс оливи зазначеної марки на досліджуваному інтервалі пробігу вантажних автомобілів. Встановлено, що моторна олива Rovas Truck 15W-40, CI-4/SN, яка експлуатується на вантажних автомобілях MAN TGA 6×4 (Німеччина), за характеристикою термоокислювальної стабільності відповідає експлуатаційним умовам. Експлуатаційний запас за термоокислювальною стабільністю даної марки оливи складає 2,5 % на пробігу 43,2 тис. км, що дає підстави для розширення інтервалу її заміни на 1,1 тис. км пробігу. Збільшення ресурсу моторної оливи, встановленої марки, можливо за рахунок визначення термоокислювальної стабільності, що також опосередковано характеризує працездатність присадок і доступність ресурсу оливи на зазначений інтервал напрацювання.

Завдяки визначенню термоокислювальної стабільності оливи забезпечується можливість обґрунтованої експлуатаційної оцінки робочої моторної оливи для відповідної марки вантажного автомобіля підчас їх експлуатації.

Ключові слова: *вантажний автомобіль, моторна олива, фотометрування окиснених олив, коефіцієнт випаровуваності, заміна оливи, температурний фактор.*

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1. Introduction

The effectiveness of machines is characterized by processes that occur in the mates of parts. Corresponding pairing of parts can be characterized by high wear resistance and self-organization of their surface layers, in the first place, it directly affects the performance of consumable lubricant – oil. Analysis and evaluation of the characteristics of the oil during operation makes it possible to gradually solve the problem of increasing the operational reliability of systems and units of transport vehicles.

Currently, increasing the reliability of systems and assemblies of transport vehicles is carried out by selecting structural materials, as well as the formation of oils for them. The solution to the problem of selecting structural materials for mating parts has achieved significant success, but the choice of lubricant for tribological mating of the parts of systems and assemblies of machines is a more complex problem. In the market of lubricants there is fairly large number of oils, the use of which has a low level of validity. The service life of oils is considered to be constant, characterized by the corresponding guarantee operating time. This parameter does not take into account the operating conditions and the current state of the mates of the parts of the corresponding systems and units of transport vehicles, the presence of an oil filtration system, its actual properties during operation, renovations and destructive changes in materials.

The processes of destructive changes in the materials of mating parts during operation are significantly depends on the properties of the oil. The main properties of oils are formed when additives are added to them during their production and further operation. The operational properties of oils change during the course of friction and wear processes in the mates of parts, intensifies their oxidation and the physicochemical transformations of additives and additives. All this creates the prerequisites for the aging of working oils.

The processes of oil oxidation during operation largely occur in the adjacent layers to the working surfaces of the parts, which is due to high temperatures and the catalytic effect of the materials of the surface layers of the part. Therefore, an important and urgent task during the operation of transport vehicles is in determination of the state of working oils by thermal oxidative stability and to determine the dynamics of its change.

2. The object of research and its technological audit

The object of research is the process of determining the thermal oxidation of the working motor oil of trucks during their operation.

One of the most problematic places is the establishment of appropriate oxidation regimes for working engine oil and the selection of the necessary laboratory equipment, as well as the formation of recommendations regarding the operational evaluation of the investigated oils.

3. The aim and objectives of research

The aim of research is determination of the condition of motor oils of trucks by their thermal oxidative stability.

To solve this aim, the following objectives are developed:

1. To obtain analytical expressions and identify patterns of change in the process of oxidation of motor oil of the corresponding brand during operation.

2. To establish the appropriateness of the operation of motor oils of the corresponding brand on the basis of the study of their condition by thermal oxidative stability.

4. Research of existing solutions of the problem

The destructive processes of oxidation of the working oil can be approximately estimated by acid and alkaline numbers, as well as using a specific set of their chemmotological analysis. An analysis of scientific literature makes it possible to establish a significant number of methods and equipment for evaluating the thermal oxidative stability of gear oils [1]. But the authors did not obtain the laws of thermal oxidative stability of working motor oils. The main diagnostic parameters of working motor oils are the characteristics of viscosity, electrical conductivity, and the change in the specific dielectric loss of working oils for gearboxes [2]. At the same time, it is necessary a more detailed operational assessment of the compliance of working motor oils with thermal oxidative stability. The main indicators of working oils at present are the period of sedimentation, the tendency to varnish, optical density, and corrosion properties that can be used to predict the operational reliability of vehicles [3]. However, most of these parameters for diagnosing the condition of working oils were not widely used due to the lack of depleted developed methods and complexes for their implementation during operation. A significant part of indicators for studying the state of working motor oils requires the use of expensive equipment and they are determined mainly only in laboratory conditions [4]. Therefore, it is desirable to develop methodological and analytical tools for using available diagnostic equipment during the operation of working motor oils.

The use of modeling methods for mating parts of the cylinder-piston group allows for more detailed identification of their main stress-strain states, as well as the study of the corresponding loading and temperature conditions during the course of the friction process [5]. In turn, the authors do not address the issue of oxidation of the working oil and its effect on the operation of a car's diesel engine. The introduction of a wide range of automated systems that operate on the effect of adherence of a substance flow to an adjacent working surface allows, on the other hand, to approach the issue of cleaning working fluids [6]. It is desirable to identify the effect of contamination of the substance flows on the main characteristics of the sticking process of their stream during cleaning. The solution to the issue of controlling the friction process in interfacing parts with ultimate lubrication is possible using various tribological tests, such as pendulum tests. Based on these tests, it is possible to evaluate the condition of the lubricant and the effectiveness of the oil under boundary conditions [7]. In turn, it is desirable to assess the influence of the temperature factor in the tribological parts, as well as to identify patterns of oxidation of the studied oil. Particular attention is paid to industrial monitoring of the condition of working oils and the development of heterogeneous methods for diagnosing lubricants [8]. But the authors examine in detail the assessment of the state of the oil using the photometric process. Carrying out periodic monitoring of motor oil makes it possible to increase the efficiency of the formation of the diagnostic base of diesel trucks [9]. However, the authors have not developed a methodological apparatus for the regimes of replacing motor oils, it is important during the operation of trucks.

On the basis of the formed approaches to studying the state of the oil, it is often difficult to draw the correct conclusion about the working capacity of the engine oil even when the diagnostic parameters are within their tolerance fields [10]. In the operational analysis of the working oil, it is necessary to evaluate their functional reserve, as well as give recommendations based on the diagnosis of the actual state for further operation.

A significant number of service companies claim that they are faced with power unit failures due to the condition of the oil. These failures are most associated with extreme operating conditions, increased operating temperatures, which lead to an increase in the temperature regime of tribological conjugation of parts and oils [11]. Therefore, it is desirable to develop an operational complex for monitoring and evaluating working engine oils, taking into account the temperature regime. The change in the physicochemical parameters of motor oils depends on the fuel used in this engine. A low accumulation in working motor oils during their operation, indicators of wear, as well as carbon and varnish deposits on the working surfaces of parts, in gas-fueled engines, was revealed [12]. These neoplasms significantly affect the further aging of the working engine oil during operation, but in addition it is necessary to establish their effect on the thermal oxidative stability of the oil in the operating modes of the engines. For many years, diesel engine operating services have used a chemmotological analysis of used oil to refine its resource interval by periodically monitoring the condition of the oil and the diesel engine as a whole. To control the condition of motor oil, its linear voltammetric regularities were carried out during operation of trucks in the vehicle fleet [13]. But, the current-voltage characteristics of the working engine oil are more dependent on the metal wear particles present in it. This type of monitoring the condition of the working engine oil does not fully reflect the aging process.

The use of oils that do not meet the technical conditions, its untimely diagnosis and replacement contribute to the rapid development of their oxidation process and micropitting of parts, which can lead to breakdown of the power unit [14]. To prevent the occurrence of these situations, it is desirable to introduce a methodology for determining the dynamics of changes in the state of motor oil in the technology of technical service.

Thus, at the moment, for diesel engines of trucks is the need to develop an appropriate methodology for determining the condition of oils to confirm their compliance with operating conditions. As a basis for the development of this technique, it is possible to use the methodological and analytical apparatus for studying the thermal oxidative stability of working motor oils during their operation.

5. Methods of research

The following grades of oil were selected for the research: TEMOL Extra Diesel 15W-40, CF-4/CG and Rovas Truck 15W-40, CI-4/SN. Samples of the studied brands of working oils were formed from KamAZ 6520 truck, Russia (3 pcs.) With a mileage interval (102–116 thousand km) and MAN TGA 6×4, Germany (3 pcs.) with a mileage interval (86–129 thousand km) were in the rolling stock of the auto transport enterprise 2004, Kropyvnytskyi, Ukraine. Drivers of vehicles have been required a driving experience of more than 7 years; serious violations and emergency situations with their participation were not recorded at the enterprise. Sampling was carried out in KamAZ 6520 every 3.2 thousand km of mileage, with maintenance No. 1, and MAN TGA 6×4 every 10.8 thousand km of mileage, that is, 4 studies were carried out on the operating period of the oil. Samples were formed with 250 ml of oil from each diesel engine at a time. Sites for sampling were respectively measured places of oil in a diesel engine of the corresponding brand of a transport vehicle.

When determining the thermal oxidative stability, the TOS-10 equipment (Ukraine) is used; it consists of mechanical and electrical units. The mechanical block contains a glass cup on which a heater with thermal insulation is installed and placed in the housing and made with a handle. The heater is connected to an electrical unit through an electric wire. A container with the studied oil samples is installed on a platform with hinges and the possibility of its removal. In the upper position, the platform is fixed. In this case, a thermocouple and a glass stirrer are immersed in the tank, connected to an electric motor that ensures its rotation. The electric unit includes a temperature regulator TRM-200 (Russia), a heater power source and a micromotor.

Laboratory scales TBE-0.21 (Ukraine) with a permissible measurement mass of 300 g and an error value of 0.01 g is used. These weights are necessary to determine the mass of evaporating motor oil. The mass determination of the motor oil sample was carried out before each start and completion of the oxidation process.

As photometric equipment designed to assess the contamination of hydraulic, industrial, motor and gear oils, the KFK-2 device (Russia) is used. Using this device, the absorption coefficient of the luminous flux of engine oil is determined. During the study of the absorption coefficient of the light flux, 3 mm cuvettes are used. The device passes stabilized monochrome light waves through a layer of the studied oil to a photodetector. Depending on the concentration of harmful impurities and oil oxidation products, the photodetector takes a different light dose, which is inversely proportional to the amount and size of impurities. The optical density of the oil was measured using a KFK-2 device, which makes it possible to determine the optical density in the range of 0–2 units, the light wavelength of 440 nm. After 15–20 minutes in the on state of KFK-2 in mode 2, the sensitivity coefficient of the device is determined. Cuvette before and after each measurement are wiped with alcohol-ethereal liquid. 40 ml of the test oil was poured into a measuring cup and diluted with 4 ml of benzene. The resulting mixtures are intensively mixed and poured into cuvettes, 3 portions of 10 ml each are prepared. The oil samples formed are necessary for calibrating the device for a specific type of oil. When the arrows are shifted from the zero position, it is brought to zero using the adjustment knobs. After setting the instrument to zero for oil, the photometer was ready to measure working oils. By installing a sample of working oil in a cuvette holder KMF-2 (Russia) on a solution in the ratio of 10:1 working oil and benzene, the optical density of the studied oil is determined on a scale of the device. Repeated measurements are performed 3 times in a row, determining the average optical density of the oil.

It is known that the oxidation stability of working oils determines their antioxidant properties. High oxidation intensity occurs on the surfaces of parts heated to high temperatures (from 90 °C). Tests for thermal oxidative stability are carried out using a TOS-10 device that simulates the oxidation processes in the working mates of parts during operation of the studied engine oils in diesel engines of trucks. The process of research on thermal oxidative stability is carried out as follows: an oil sample of 250±0.1 ml is poured into a device for determining thermal oxidative stability, in which it is maintained at a temperature of 180 °C with stirring with a stirrer at 350±3 rpm. The rotation mode of the mixer is selected experimentally, the turbulent mode is not allowed, and the oxidation rate reaches a maximum. The test time is 3 hours. After each hour, samples were weighed to determine the mass of oil evaporation and samples are taken for photometry. The remainder of the volume of the studied oil is continued to be investigated previously by the modes.

Photometry of oxidized oils is carried out at an oil layer thickness of 2 mm. The limiting values of the absorption coefficients of the light flux and volatility of the studied brands of oils are characterized by the values of 0.82 and 0.13, respectively. The limits of variation of these coefficients are determined on the basis of tribological studies of oils according to ASTMD 2783. The evaporation coefficient is characterized as the fraction between the oxidation are represented by the coefficient of relative viscosity, characterized as the corresponding mass after the *i*-th oxidation (g) and the mass before the *i*-th oxidation (g). The kinematic viscosity of motor oil is determined according to DSTU 33-2003 using a ВПЖТ-2 viscometer (Russia). The dependences of measuring viscosity during oil proportion between the kinematic viscosity at the beginning of the *i*-th oxidation (m^2/s) and the kinematic viscosity after the i-th oxidation (m^2/s).

The reliability of instrument readings and experimental data when determining the absorption coefficients of the light flux and volatility is duplicated three times for the corresponding brands of working motor oils. The results are processed in the Excel 2010 product program, in which the determination of the coefficient of determination and the limits of error with relative errors are performed. Diagnosing the condition of the oil using the above methods is important for the technology of technical operation of transport enterprises. Therefore, they are selected to ensure a minimum amount of time for implementation.

6. Research results

In the operation of the trucks that were under observation, samples of working oil were periodically taken from their diesel engines for research and determination of their thermal oxidative stability. All data on the technical condition of motor oils were entered in Tables 1, 2. The mileages of transport vehicles were deducted from the last maintenance No. 2 of the corresponding year in order to cover the full operational period of the corresponding oil grade.

Table 1

Averaged data on the study of the state of TEMOL Extra Diesel 15W-40, CF-4/CG engine oil (KamAZ 6520 – 3 pcs.) according to thermally oxidized stability during car operation for 2018

Mileage, thousand km	Light flux permeability coefficient	Evaporation coefficient	Thermal oxidative stability coefficient	Relative viscosity coefficient
0	0.38	0.025	0.405	1.0
3.2	0.49	0.05	0.54	1.11
6.4	0.62	0.1	0.72	1.21
9.6	0.75	0.125	0.875	1.36
12.8	0.81	0.138	0.948	1.48

Table 2

Averaged research data on the state of Rovas Truck 15W-40, CI-4/SN engine oil (MAN TGA 6×4 – 3 pcs.) on thermal oxidative stability during car operation for 2018

Mileage, thousand km	Light flux permeability coefficient	Evaporation coefficient	Thermal oxidative stability coefficient	Relative viscosity coefficient
0	0.44	0.0325	0.4725	1
10.8	0.52	0.0625	0.5825	1.04
21.6	0.66	0.095	0.755	1.1
32.4	0.72	0.11	0.83	1.16
43.2	0.78	0.115	0.895	1.27

Formed experimental data in Table 1 are shown graphically (Fig. 1, 2) and their mathematical models are obtained with a determination coefficient that was not less than 0.95.

Formed experimental data in Table 2 are subjected to regression analysis and graphically shown (Fig. 3, 4). The mathematical models with the specified limits and estimates are obtained. The coefficient of determination is greater than or equal to 0.95.

The change in the thermally oxidized stability of motor oils also reflects a change in the relative viscosity of the oil, which additionally takes into account the conditions for the operation of the additive complex, their additional elements. The more additives and functional additives are worked out, the more the process of formation of clusters of waste inclusions in the working oil begins. Control of these inclusions and further oil performance is determined by the stability of the oil relative to the temperature factor.

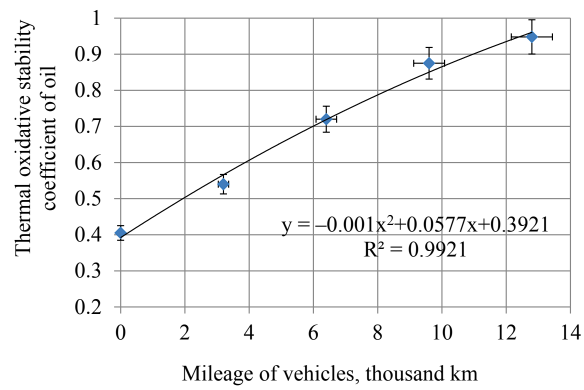

Fig. 1. Change in the coefficient of thermal oxidative stability of TEMOL Extra Diesel 15W-40, CF-4/CG engine oil depending on the mileage of vehicles

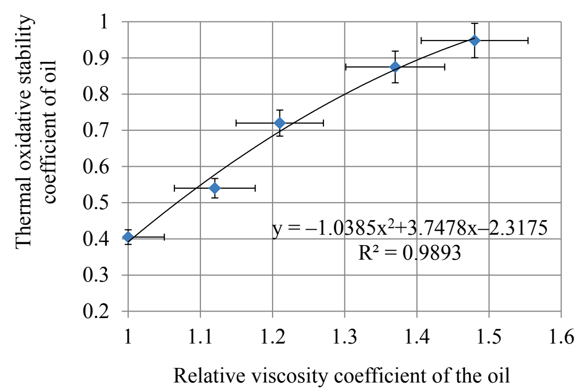

Fig. 2. Change in the coefficient of thermal oxidative stability of TEMOL Extra Diesel 15W-40, CF-4/CG engine oil depending on the relative viscosity coefficient of the oil

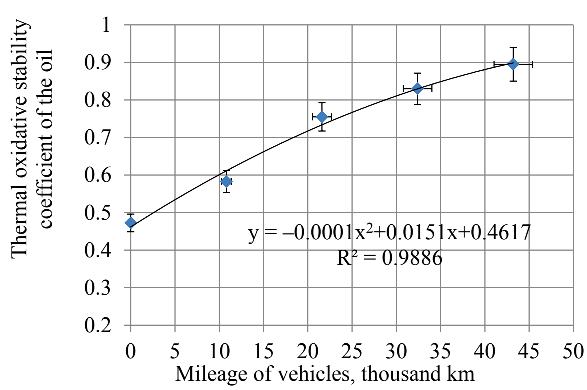

Fig. 3. Change in the coefficient of thermal oxidative stability of Rovas Truck 15W-40, CI-4/SN engine oil depending on the vehicle mileage

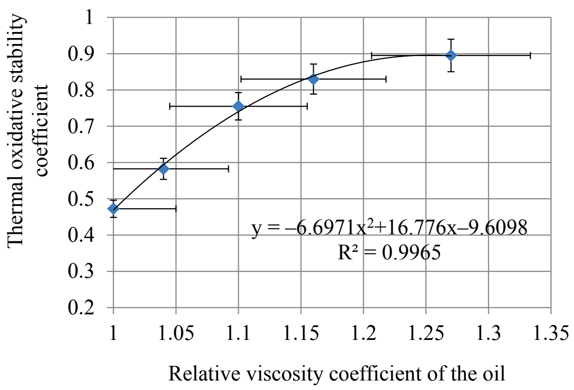

Fig. 4. Change in the coefficient of thermal oxidative stability of Rovas Truck 15W-40, CI-4/SN engine oil, depending on the relative coefficient viscosity of the oil

The process of engine oil oxidation causes a change in its optical characteristics, volatility, and viscosity. Therefore, it is possible to assume that the viscosity changes as a result of additional ingress of fuel vapors, aqueous mixtures, coolants, as well as intense wear of the additive package and functional additives. This leads to the intensity of the formation of wear clusters of working oils and surfaces of materials. A decrease in the viscosity index of engine oil provides the conditions for maximum lubrication of diesel parts, can't ensure a normal friction during operation. Under such conditions, there is a lubrication problem, because the portion of oil is not enough to form the necessary oil wedge, it contributes to overheating of the diesel parts and thereby increases the intensity of the oil oxidation process. In this case, it is advisable to analyze the performance of the working engine oil by changing the value of its thermal oxidative stability coefficient. This indicator characterizes the amount of thermal energy that is absorbed in cash, or formed by clusters of products of wear, oxidation, and also the evaporation of various inclusions in the investigated oils.

Analyzing the results of thermal oxidative stability of TEMOL Extra Diesel 15W-40, CF-4/CG motor oil on KamAZ 6520 vehicles in the amount of 3 pcs., an oil change every 12.8 thousand km ensures operating conditions. This is evidenced by Fig. 1, according to which the mathematical model of changes in thermal oxidative stability on the mileage of 0–12.8 thousand km of vehicles does not go beyond the permissible limits of 0.95 of its value. This nature of the development of the process reflects the conformity of the investigated brand oil to the operating modes of KamAZ 6520 transport vehicles in full. But it is forbidden to change the mileage intervals to replace the oil of the investigated brand on this vehicle under the prevailing operating conditions. Since on the mileage 12.8 thousand km, this value during operation has a reserve of only 0.2 %, which is typical as critical. Analyzing the dependence of changes in the coefficient of thermal oxidative stability of oil on the increase in its viscosity Fig. 2, it is possible to conclude that the investigated brand of oil in the load conditions of the diesel engine.

Analyzing the results of a study of the thermal oxidative stability of Rovas Truck 15W-40, CI-4/SN engine oil on MAN TGA 6×4 vehicles in an amount of 3 pcs., its security to operating conditions is revealed. The indicated can be observed on the basis of the absence of a significant increase in the mathematical model in Fig. 3, as well as the failure to achieve the level of thermal oxidative stability of the oil of 0.95 units during research time 0–43.2 thousand km. Since the operational margin for thermal oxidative stability of this brand of oil is 2.5 %, it can be argued about the possibility of extending the oil change interval by 1.1 thousand kilometers. An analysis of the dependence of the change in the coefficient of thermal oxidative stability of the oil on the increase in its viscosity indicates that there is compliance with the loading conditions of the diesel engine. The nature of the development of the mathematical model is shown in Fig. 4, reflects the gradual actuation of the constituent oil components during operation. The results of operational studies confirm that the operating modes for these brands of trucks are rational and that Rovas Truck 15W-40, CI-4/SN oils correspond to them.

7. SWOT analysis of research results

Strengths. Determination of the condition of the working engine oil by the parameter of thermal oxidative stability allows to determine the correctly selected brand of oil for a truck of a particular brand during their operation. Also, this study of the condition of the oil makes it possible to estimate the resource intervals of working engine oils for a truck of a particular brand. It is revealed that the studied brands of motor oils, the samples of which are taken from vehicles at the auto transport enterprise 2004 (Kropyvnytskyi, Ukraine) are selected correctly, in accordance with the operating conditions.

Weaknesses. When determining the state of oil by thermal oxidative stability, it is difficult to automate this process to autonomous mode. In its definition, a reasonable and fixed periodicity of sampling of working oil from a diesel engine of a truck is required. As well as the methodology for determining thermal oxidative stability, it takes appropriate time to prepare equipment and prototypes of working oil before each study.

Opportunities. Further study of this diagnostic parameter will solve the problem of selecting a complex of additives and functional additives to oils, as well as the possibility of their addition during operation. Determining the state of motor oil by thermal oxidative stability involves establishing reasonable vehicle mileages on which additives or functional additives must be added to the working oil for a guaranteed lifetime.

Threats. When introducing an operational evaluation of working oil by thermal oxidative stability at an enterprise, additional costs are required to equip a laboratory to determine the technical condition of oils, as well as training a laboratory assistant. The most developed analogue of determining the state of the working oil is its full laboratory chemmotological analysis. This analysis makes it possible to further describe the nature of the reduction in the resource of diesel engines of trucks in general.

8. Conclusions

1. It is revealed that TEMOL Extra Diesel 15W-40, CF-4/CG engine oil on KamAZ 6520 trucks provides its functionality for 0–12.8 thousand km of mileage. It is forbidden to change the mileage intervals to replace the oil of the investigated brand on these vehicles under the prevailing operating conditions. Since on the mileage of

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12.8 thousand km, the value of the coefficient of thermal oxidative stability during operation has a reserve of about 0.2 %, which can be characterized as a critical value.

2. It is shown that Rovas Truck 15W-40, CI-4/SN engine oil, which is used on MAN TGA 6×4 trucks, corresponds to operating conditions in terms of its thermal oxidative stability. The development of changes in thermal oxidative stability from relative viscosity reflects the gradual activation of additives and functional additives in the working oil. The operational margin for thermal oxidative stability of this brand of oil is 2.5 %, which can be argued about the extension of the interval for its replacement by 1.1 thousand kilometers of mileage.

References

1. Aulin, V., Hrynkiv, A., Lysenko, S., Rohovskii, I., Chernovol, M., Lyashuk, O., Zamota, T. (2019). Studying truck transmission oils using the method of thermal-oxidative stability during vehicle operation. *Eastern-European Journal of Enterprise Technologies, 1 (6 (97)),* 6–12. doi: http://doi.org/10.15587/1729-4061.2019.156150
2. Aulin, V., Hrinkiv, A., Dykha, A., Chernovol, M., Lyashuk, O., Lysenko, S. (2018). Substantiation of diagnostic parameters for determining the technical condition of transmission assemblies in trucks. *Eastern-European Journal of Enterprise Technologies, 2 (1 (92)),* 4–13. doi: http://doi.org/10.15587/1729-4061.2018.125349
3. Hrynkiv, A. V. (2016). Vykorystannia metodiv prohnozuvannia v keruvanni tekhnichnym stanom ahrehativ ta system transportnykh zasobiv. *Tekhnika v silskohospodarskomu vyrobnytstvi, haluzeve mashynobuduvannia, avtomatyzatsiia, 29,* 25–32.
4. Lutsak, D., Prysyazhnyuk, P., Burda, M., Aulin, V. (2016). Development of a method and an apparatus for tribotechnical tests of materials under loose abrasive friction. *Eastern-European Journal of Enterprise Technologies, 5 (7 (83)),* 19–26. doi: http://doi.org/10.15587/1729-4061.2016.79913
5. Aulin, V. V. (2010). Teoretychne obgruntuvannia zminy rezhymiv tertia v tsylindro-porshnevii hrupi DVZ. *Problems of tribology, 3,* 46–54.
6. Aulin, V., Chernovol, M., Pankov, A., Zamota, T., Panayotov, K. (2017). Sowing machines and systems based on the elements of fluidics. *INMATEH – Agricultural Engineering, 53 (3),* 21–28.
7. Dykha, A., Aulin, V., Makovkin, O., Posonskiy, S. (2017). Determining the characteristics of viscous friction in the sliding supports using the method of pendulum. *Eastern-European Journal of Enterprise Technologies, 3 (7 (87)),* 4–10. doi: http://doi.org/10.15587/1729-4061.2017.99823
8. Van Rensselar, J. (2013). Trends in industrial gear oils. *Tribology and Lubrication Technology, 69 (2),* 26–33.
9. Aulin, A. V., Hrynkiv, V. V. (2016). Metodyka vyboru diahnostychnykh parametriv tekhnichnoho stanu transportnykh zasobiv na osnovi teorii sensytyviv *Tekhnichnyi servis ahropromyslovoho, lisovoho ta transportnoho kompleksiv, 5,* 109–116.
10. Aulin, V. (2014). Vliianie kombinirovannogo fiziko-khimicheskogo modificirovaniia motornogo masla na izmeneniia momenta treniia i potrebliaemoi moschnosti v sopriazheniiakh obrazcov i detalei. *Trenie i smazka v mashinakh i mekhanizmakh, 2,* 21–28.
11. Panchenko, S. V., Hrytsuk, Yu. V., Volkov, Yu. V. (2017). Osoblyvosti modeliuvannia protsesiv otsiniuvannia potochnoho i prohnozovanoho tekhnichnoho stanu avtomobilia pid chas ekspluatatsii v umovakh ITS. *Informatsiino-keruiuchi systemy na zaliznychnomu transporti, 2,* 3–8.
12. Boikov, D. V., Bugai, T. B., Mal'kov, Y. P. (2007). Features of aging of engine oil in a gas engine. *Chemistry and Technology of Fuels and Oils, 43 (4),* 299–304. doi: http://doi.org/10.1007/s10553-007-0053-3
13. Fentress, A., Sander, J., Ameye, J., Toms, A., Dean, S. W. (2011). The Use of Linear Sweep Voltammetry in Condition Monitoring of Diesel Engine Oil. *Journal of ASTM International, 8 (7),* 103442. doi: http://doi.org/10.1520/jai103442
14. Volkov, V. P., Volkova, T. V., Hrytsuk, I. V., Appazov, E. S., Pohorletskyi, D. S., Volodarets, M. V. et. al. (2018). Osoblyvosti vymiriuvalnoho kompleksu dlia doslidzhennia roboty hazomotornoho transportnoho zasobu z systemoiu teplovoi pidhotovky v umovakh ekspluatatsii. *Tekhnichnyi servis ahropromyslovoho, lisovoho ta transportnoho kompleksiv, 13,* 121–131.

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