Розвиток технічної експлуатації засобів транспорту полягає в забезпеченні технічного стану на значному рівні функціональної справності для яких використання якісних мастильних матеріалів є ключовим напрямком. Тому визначення технічного стану трансмісійних олив автомобілів методом термоокислювальної стабільності підчас їх експлуатації є актуальною проблемою.

Вирішення проблеми та дослідження технічного стану трансмісійної оливи виконувалось на основі експлуатаційних завдань та результатів їх хіммотологічних досліджень. Вони можуть бути використані підчас розробки системи технічного обслуговування транспортних засобів та обґрунтування доцільності використання відповідних марок олив підчас експлуатації. Розроблено методику для дослідження, визначення стану і відповідність умовам експлуатації робочих олив за термоокислювальною стабільністю підчас експлуатації транспортних засобів. Дослідження стану трансмісійних олив реалізовано в процесі їх експлуатації на коробках переключення передач вантажних автомобілів марок КамАЗ 6520, MAN TGA 6×4. Проведено дослідження робочої трансмісійної оливи за наступними параметрами: пропускання світлового потоку, випаровуваності, в'язкості. В графічних та аналітичних відображеннях коефіцієнту термоокислювальної стабільності використані результати досліджень пропускання світлового потоку через пробу оливи та її випаровуваності після температурних режимів випробування робочих олив. Визначено зміну коефіцієнту термоокислювальної стабільності олив відповідної марки від їх відносної в'язкості, аналіз отриманих функції дасть змогу розробляти рекомендації про відповідність робочих олив до умов їх експлуатації.

Виявлено, що трансмісійна олива Tedex Gear GL-4 80W90, що експлуатується на автомобілях MAN TGA 6×4, за характеристикою її термоокислювальної стабільності відповідає експлуатаційним умовам. В той час дослідження трансмісійної оливи YUKO TO-4 80W-85 на автомобілях КамАЗ 6520, показало, що дана олива не забезпечує свої функціональні можливості на 8–30 і 45 тис. км. пробігу. Це підтверджується аналізом отриманої математичної моделі зміни термоокислювальної стабільності оливи від відносної в'язкості, а саме виходом її деяких числових значень функції за рівень 0,85 од. на досліджуваному інтервалі пробігу автомобілів.

Встановлено, що дані дослідження необхідні для обґрунтування подальшої експлуатації та підбору трансмісійних олив для досліджуваних марок транспортних засобів підчас виконання транспортної роботи на підприємстві

Ключові слова: автомобіль, пробіг, трансмісійна олива, термоокислювальна стабільність, фотометрування, випаровуваність, відносна в'язкість, маса проби, умови експлуатації

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STUDYING TRUCK TRANSMISSION OILS USING THE METHOD OF THERMAL-OXIDATIVE STABILITY DURING VEHICLE OPERATION

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1. Introduction

Reliability of transport vehicles is determined by the processes occurring in tribological systems of “materials of mating parts – oil” type. These systems can be characterized by running-in modes, coefficient of friction, wear resistance and self-organization having a direct effect on operating capacity of oil. Comprehensive evaluation of oil properties during operation forms a prerequisite for priority solution of the issue of improving operational reliability of vehicle systems and units.

At present, reliability of mechanical systems is raised by selecting durable structural materials and oils for them.

Choice and application of wear-resistant materials is studied more intensively and a significant progress has been achieved in machine designing. Choice of lubricants for mating various systems and units of machines operating in certain ranges of temperatures, loads and speeds refers to more complex problems. This is because one type of oil is often used in one unit and mating parts are made of structural materials having a wide range of mechanical properties. Besides, lubricant markets offer a wide variety of oils poorly substantiated for their use in various mechanisms of transport vehicles. Operating life of oils on mineral, synthetic and mixed bases is taken constant. It is regulated by producers based on machine-hours or run mileage for wheeled vehicles. These parameters do not take into consideration modes and conditions of operation, technical state of mating parts, state and availability of an oil filtering system and actual oil properties.

The process of friction and wear of the mating parts during operation depends to a large extent on the lubricant properties. Oil properties (viscosity, oxidation, friction, dispersity, etc.) are formed with the help of additives in technological operations of oil production. Change of operational properties of oils is caused by oxidation processes, temperature and mechanical degradation, chemical reactions on the materials of mating parts as well as the products formed in oil ageing.

Oxidation of the working oil proceeds more intensively on working surfaces of the mating parts because of high temperatures and catalytic influence of the part materials. Besides, this process reflects connection and effect of elements of the “mating parts materials – oil” tribological system on operational reliability of systems and units of transport vehicles in general. In this regard, it is very important to determine state of working oils by controlling their thermal-oxidative stability. Diagnosis of this property of transmission oil enables improvement and finding possibility of forming a rational diagnostic database of technical state of the vehicle power units. This is a relevant scientific and technical problem.

2. Literature review and problem statement

As a rule, oxidation processes in oils are estimated by acid number and are standardized for some oil grades. Analysis of patents and scientific and technical literature has shown that there is a large variety of engineering methods and devices for assessing thermal-oxidative stability. The following indicators are proposed to be considered as main indicators: magnitude of viscosity change, electrical conductivity, number of deposits on parts, specific dielectric losses in presence and absence of a catalyst, coefficient of light absorption [1]. Auxiliary but not less important indicators of oil include sedimentation period, tendency to lacquer formation, optical density, concentration of insoluble contaminants, mass working and lacquer fractions, evaporability, corrosion properties, etc. [2]. However, most of these indicators are impractical because of lack of standardized industrial means of control. Part of the indicators of the oil state study requires expensive equipment and is only used in laboratory conditions.

Application of rapid methods for studying mating parts of assemblies and units on the basis of tribotechnical tests is described in [3]. Detection of abrasive particles in the medium is an important problem. It is realized with the use of friction machines but the authors did not offer solution to the problem of determining the quantity and size of abrasive particles during operation. The issue of application of non-destructive methods is solved on the basis of analysis of oils for vehicles. Particular attention is paid to controlling dielectric permeability, electromagnetic inspection of oils and other diagnostic parameters of the lubricant state [4]. Urgency of conducting non-destructive oil control is determined by increasing efficiency of forming diagnostic databases for vehicle units. Further improvement of technical service requires control of the load-carrying ability of oils during operation which was not realized by the authors by means of control of technical state of oils by rapid test methods.

Based on available theoretical and applied aspects of the oil state study, it is often impossible to draw a conclusion on operating state of the oil used in hydraulic systems even when diagnostic parameters are within their tolerance field [5]. In the process of operation of mating parts, abrasive particles fall into oil causing destruction of parts and increase in activation of their surface layers that makes impossible to establish exact mechanic effects in hard operating conditions. Therefore, the authors decided to replace certain executive mechanisms with pneumological elements and thus dispense with hydromechanic mechanisms.

It is important for technical maintenance to forecast service life of vehicle units [6]. In order to solve this problem, it is necessary to diagnose units in a timely and qualitative manner and perform necessary operations of technical service. It was proposed to solve this issue with the help of magnetic sensors and online control of stationary power units. Instead of further implementation in mobile machines, these methods have not found their application. It is also impossible to develop recommendations regarding conformity of working oils to operating conditions on their basis.

The main cause of failure of power units is growing degree of wear and degradation of consumables [7]. These processes can be monitored in aggregate on the basis of oil diagnosis by spectral analysis. However, their actual development degree and behavior stages are difficult to assess. To cope with this problem, diagnostic data are analyzed and a model of the space of states of mating parts in the vehicle power units is constructed. Regarding the diagnostic data of oil efficiency in the zone of inter-boundary values of wear product concentration, they may have overshoots in the forecast period because of impossibility of comprehensive consideration of characteristics of working oils by spectroscopy and their reaction to temperature regimes.

Reliability and service life of wheeled vehicles generally depend on technical state of their power units. About 25 % of transport companies claim that they are facing failures of transmission switchboxes associated with oil state [7]. These failures are most of all related to extreme running regimes and elevated operating temperatures which cause growth of stress concentrators on the work surfaces of oil seals, bearings, and gear teeth. Growth of stress concentrators is stimulated by high oxidation of the oil and rapid worsening of its working state. Additives protect seals and improve thermal and oxidation balances and viscous stability [8]. Solution to these problems was achieved through the use of environmentally friendly oils with a certain complex of additives, which attack the mating parts weaker. However, in order to introduce them in vehicle operation, it is necessary to develop a control system that would determine an adequate model of change of technical state of working oils.

The use of oils that do not meet specifications, untimely diagnosis and replacement of oil contribute to its rapid oxidation and development of micro-pitting of parts potentially resulting in the unit failure [9]. These issues were solved on the basis of development of an additive complex for oils but the authors did not provide control during operation. To prevent occurrence of such problem situations, it is necessary to develop a procedure for controlling technical state as for thermal-oxidative stability.

The use of environmentally friendly oils contributing to achievement of energy independence and security through their natural resource recovery is not always effective. Their use is limited by low thermal-oxidative stability and unsatisfactory properties during the cold period of operation of the vehicle systems and units [10]. Improvement of quality of working environmentally friendly oils facilitates search for a combination of additives based on a systematic approach. This reflects the need for creation and use of oils with high thermal-oxidative stability. At the same time, the issue of controlling oil by the indicator of thermal-oxidative stability during operation is not resolved yet which is a very persuasive necessity of introduction of such oils into production and development of instructions as regards their compliance.

Mineral oils operating in severe conditions are strongly subjected to oxidative reactions caused by access of oxygen, water and abrasive metal particles that affect oil performance [11]. The authors have carried out studies of oil oxidation using antioxidants and metal passivators to evaluate and compare thermal-oxidative stability. Thermal-oxidative stability was controlled by observing acid number and content of carbon clusters in oxidized samples of oil in a form of a sediment. All this did not accurately reflect change and action of additives and oil fractions. Implementation of such a scheme in operation requires significant time inputs for even a single study of technical state of the oil.

Environmentally friendly vegetable oils have satisfactory tribological and environmental properties but instead they lack full thermal and hydrolytic stability [12]. The effect of thermal oxidation on lubricating and physical-chemical properties of oil was determined in this study. A method of visible-light spectroscopy was introduced to estimate oil oxidation rate. However, this method did not allow the authors to comprehensively describe the process of variation of temperature stability of the oil under study. It just established initial moments of structural change.

Therefore, it is necessary to develop methods for studying technical state of oils for the transmission units intended for liquid lubrication and for mobile machines on the basis of which one could judge on the oil compliance to operating conditions. These recommendations can be elaborated in more detail with introduction of complex procedures for determining thermal-oxidative stability of working oils.

3. The aim and objectives of the study

The study objective was to identify patterns of change of thermal-oxidative stability of the working oil and develop a method for assessing its working state which would enable improvement of the system of technical maintenance and working out recommendations concerning oil conformity to operating conditions.

To achieve this objective, the following tasks were addressed:

– develop a procedure for studying oil state regarding thermal-oxidative stability and formulate necessary analytical expressions for its realization;

– obtain regularities of variation of characteristics of the transmission oil oxidation process during operation;

– substantiate expediency of use of a transmission oil based on the study of its state regarding thermal-oxidative stability.

4. Materials and methods used in studying the state of a truck transmission oil

The following oil grades were chosen for the study.

– YUKO TO-4 80W-85 (conformity to SAE 80W-85, API GL-4) with the following characteristics:

1) kinematic viscosity at 100 °C, mm^2/s: 12.0;
2) density at 20 °C, kg/m^3: 890;
3) viscosity index: 95;
4) flash temperature in open crucible, °C: 225;
5) congelation point, °C: –25.

– Tedex Gear GL-4 80W90 (conformity to SAE 80W-90, API GL-5) with the following characteristics:

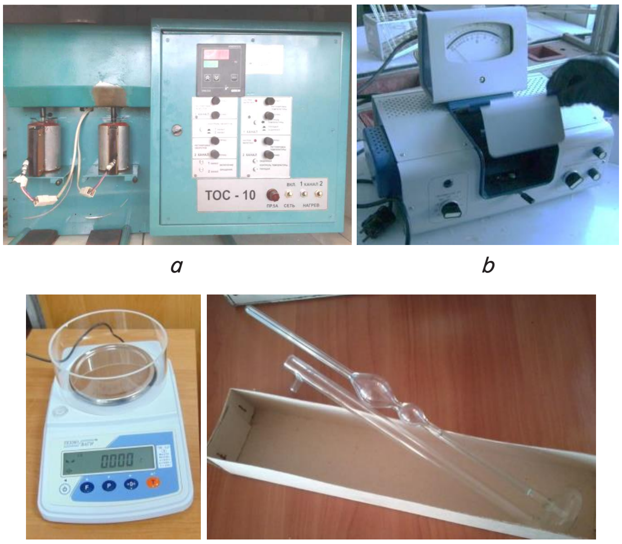
1) kinematic viscosity at 100 °C, mm^2/s: 14.6;
2) density at 20 °C, kg/m^3: 920;
3) viscosity index: 105;
4) flash temperature in open crucible, °C: 228;
5) congelation point, °C: –33.

The above oil grades were sampled from KamAZ 6520 trucks (3 trucks) and MAN TGA 6×4 trucks (3 trucks) involved in transportation works at ATP 2004 enterprise, Kropyvnytsky, Ukraine. Samples were taken during each technical maintenance service No. 2 in a quantity of 250 ml of oil (by 40 ml for three repeat examinations) from each gearbox according to DSTU 4488:2005. The samples were taken in the oil level measuring and filling points of gearboxes of corresponding vehicle models.

To determine thermal-oxidative stability, TOS-10 (Electronprylad NTK) device was used (Fig. 1) which consisted of a mechanical and an electric unit. The mechanical unit containing a glass beaker with a heater insulated from external environment by thermal insulation and enclosed in a case with a handle. Output of the heater is connected to the electric unit through a plug. A glass container with a sample is put on a platform with hinges with a possibility of its removal. The platform is locked in the top position. A thermocouple and a glass stirrer connected to the electric motor ensuring the stirrer rotation are immersed in the vessel. The electric unit consists of TRM-200 thermoregulator and power sources for the heater and the micromotor.

TVE-0.21 laboratory balance (Fig. 1, *c*) for a maximum weighing mass of 300 g and error value of 0.01 g is intended for measuring mass of the evaporated oil. Measurement was performed before the start and at the end of the oxidation process.

Photometric equipment is intended for estimation of pollution of industrial hydraulic, motor and transmission oils. Coefficient of light absorption is the indicator of oil evaluation in this case. Photoelectric device КФК-2 (Fig. 1, *b*) consists of optical and measuring units. The optical unit is intended for direct photometry of oils with various transparencies. Photometric cuvette is intended to form a photometric layer of oil of a given thickness. Cuvettes of 3 mm in length were used in experimental determination of the coefficient of light absorption. Stabilized monochromatic light passes through a layer of the oil under study to the photodetector.



a *b* *c* *d*

Fig. 1. Instruments used in the study of thermal-oxidative stability of oils: TOS-10 laboratory device for thermal oxidation of oils (Ukraine) (*a*); KFK-2 photoelectric colorimeter for measuring concentration (Russia) (*b*); TVE-0.21 laboratory balance (Ukraine) (*c*); VPZhT-2 viscosimeter (Ukraine) (*d*)

Depending on concentration of mechanical impurities and oil oxidation products, the photodetector receives light flows inversely proportional to concentration of impurities. Optical density of oil was measured on the KFK-2 device which enables measurement of optical density in a range from 0 to 2 units. Photometric examination of oil was carried out at an optical wavelength of 440 nm. The sensitivity coefficient in mode 2 was determined in 15 to 20 minutes after the device switch-on. The cuvette compartment was open during warming up. Working surfaces of the cuvette were cleaned with an alcohol-ether mixture before each measurement. A fresh portion (40 ml) of oil was poured into the measuring flask and diluted with 4 ml of solvent (benzene). The mixture was stirred and then three samples of 10 ml each were poured into cuvettes. The samples of pure oil needed setting of the photocolorimeter pointer to the zero mark. When the pointer moved from zero position, it was set back using the rotary knob "set 10 coarse" and "precise". Following the zero setting for a fresh oil sample, the photometer was ready to measure working oils. After replacement of the control oil solution in the KFK-2 cuvette holder with 40 ml of working oil diluted with 4 ml solvent (benzene), optical density of the oil under study was read from the device scale. Repeated measurements were performed three times in a row with calculation of the mean value of optical density of the oil.

It is known that resistance of working oils to oxidation determines their antioxidant properties. High intensity of oxidation occurs on surfaces of the parts subjected to high temperatures (above 90 °C). Tests for thermal-oxidative stability were carried out by means of a device simulating oxidation processes in the working mating parts during operation of transmission oils in the truck gearbox. The process of study on thermal-oxidative stability was carried out as follows. A 250±0.1 ml oil sample was poured into device determining thermal-oxidative stability in which it was maintained at 180 °C with stirring at 350±3 rpm. To eliminate influence of metals on the oxidation processes, the glass and the stirrer were made of glass and the stirrer speed was optimized to achieve maximum oxidation rate while avoiding turbulence. The test time was 3 hours. The samples were weighed each hour to determine mass of the oil evaporated and samples were taken for photometry. The residual volume of the oil under test was re-oxidized.

Photometry of oxidized oils was carried out at a 2 mm thickness of oil layer. Limit values of the coefficient of light absorption and evaporability of the transmission oil were equal to 0.7 un. and 0.15 un., respectively. The determined limits were derived on the basis of tribological studies of oils according to ASTMD 2783. Based on the measurement results, graphic dependences of the coefficient of light absorption and evaporability on the oxidation time were plotted. The coefficient of thermal-oxidative stability, K_{TO}, was determined from the following formula:

$$K_{TOS} = K_{lf} + K_e, \tag{1}$$

where K_{lf} is the coefficient of light absorption; K_e is the coefficient of oil evaporability:

$$K_e = m_{0i} / m_i, \tag{2}$$

where m_{0i} is the mass at the beginning of the i-th oxidation, g; m_i is the mass after the i-th oxidation, g.

Kinematic viscosity of the oil under study was determined according to DSTU GOST 33-2003 by means of viscosimeter of VPZhT-2 type (ISO 3105-76). Graphic dependences of viscosity measurement during oil oxidation are presented by the coefficient of relative viscosity:

$$K_\nu = \nu_{0i} / \nu_i, \tag{3}$$

where ν_{0i} is the kinematic viscosity at the beginning of the i-th oxidation, m^2/s; ν_i is the kinematic viscosity after the i-th oxidation, m^2/s.

Reliability of the device readings and experimental data on determination of the coefficient of light absorption and evaporability was checked in three experiments with corresponding grades of oils in each diagnosis. In this case, absolute and relative deviations were determined. To process the study results, licensed Excel 2007 program was used which computed the mean square deviation, correlation coefficient, regression coefficient and mean approximation error.

The mean square deviation to estimate the magnitude of the random error in the diagnostic results was calculated from formula:

$$S_{D_j} = \sqrt{\frac{\sum(\overline{D_j} - D_{ji})}{n-1}}, \tag{4}$$

where n is the number of repetitions; $\overline{D_j} = \frac{1}{n}\sum_{i=1}^{n} D_{ji}$ is the diagnostic parameter; D_{ji} is the diagnostic parameter at the i-th diagnosis repetition. To characterize magnitude of the random error, a confidence interval and a confidence probability value were determined which allowed us to estimate degree of reliability of the diagnosis result. The confidence probability in measurements was limited by γ=0.95. Therefore, for each indicator measured at different test temperatures, the confidence interval was determined from formula:

$$\Delta\tau_{\overline{D_j}} = 2 \cdot \frac{t_\gamma \cdot S_{D_j}}{\sqrt{n}}, \tag{5}$$

where t_γ is Student's criterion for $\alpha = 1 - \gamma$.

The mathematical model of development of the investigated processes was constructed and evaluated according to the method of least squares and the coefficient of determination:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(D_{ji} - D_{j.theor.})}{\sum_{i=1}^{n}(D_{ji} - \bar{D})^2}, \qquad (6)$$

where D_{ji}, $D_{j.theor.}$, $\bar{D}$ are actual, theoretical and mean values of the function of the process described by the j-th diagnostic parameter.

Diagnosis of the transmission oil according to the above techniques is important for technical service at the enterprises operating transport equipment. Therefore, they were selected to ensure minimum time for implementation.

5. Results of obtaining regularities of change of the process of oxidation of transmission oils and their evaluation according to the operating conditions

Samples of working oil were taken from gearboxes of operated vehicles for studying and determining thermal oxidation stability of oils. The studied oils contained thickening additives resistant to degradation. All data of the technical state of transmission oils are shown in Tables 1, 2. Values of the vehicle runs were deducted from the initial value for the current year. In order to obtain more accurate results, the vehicles were grouped by their runs that did not exceed 3,000 km.

Table 1

Averaged data of the state of the YUKO TO-4 80W-85 transmission oil (KamAZ 6520, 3 trucks.) regarding thermal-oxidative stability during operation of the vehicles in 2018

Run, 1000 km	Coefficient of light transmission	Coefficient of evaporability	Coefficient of thermal-oxidative stability	Coefficient of relative viscosity
0	0.45	0.141	0.591	1.6
12	0.68	0.145	0.825	1.9
24	0.72	0.147	0.867	2.1
36	0.79	0.151	0.941	2.4
48	0.81	0.158	0.968	2.52

The experimental data in Table 1 are graphically represented in Fig. 2, 3 and their mathematical models were obtained for a coefficient of determination not less than 0.95.

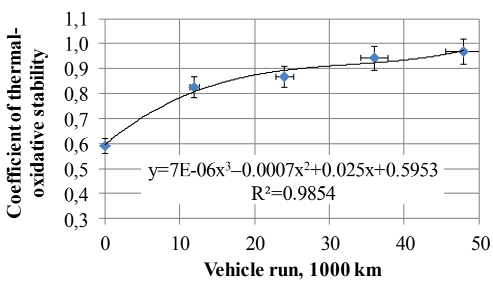


Fig. 2. Variation of the coefficient of thermal-oxidative stability of the YUKO TO-4 80W85 transmission oil depending on the vehicle run

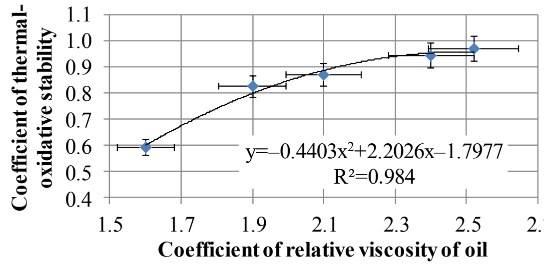


Fig. 3. Variation of the coefficient of thermal-oxidative stability of the YUKO TO-4 80W85 transmission oil depending on the coefficient of relative viscosity of the oil

Table 2

Averaged data of the study of the Tedex Gear GL-4 80W90 (MAN TGA 6×4-3) transmission oil by thermal-oxidative stability during operation of vehicles in 2018

Run, 1000 km	Coefficient of light transmission	Coefficient of evaporability	Coefficient of thermal-oxidative stability	Coefficient of relative viscosity
0	0.55	0.121	0.671	1.7
12	0.57	0.127	0.697	1.85
24	0.66	0.129	0.789	2.04
36	0.69	0.131	0.821	2.1
48	0.71	0.135	0.845	2.15

The experimental data in Table 2 are graphically represented in Fig. 4, 5 and mathematical models with indicated boundaries and estimates were obtained. The coefficient of determination was greater than or equal to 0.95.

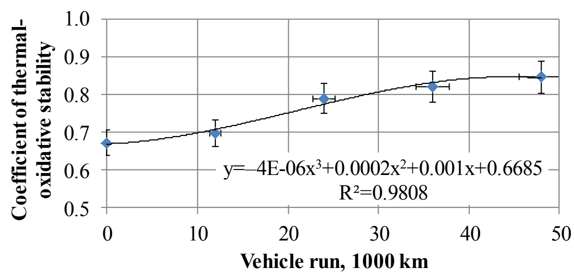


Fig. 4. Variation of the coefficient of thermal-oxidative stability of the Tedex Gear GL-4 80W90 transmission oil depending on the vehicle run.

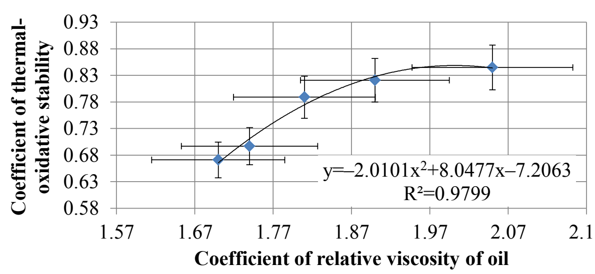


Fig. 5. Variation of the coefficient of thermal-oxidative stability of the Tedex Gear GL-4 80W90 transmission oil depending on the coefficient of relative viscosity of oil

Variation of thermal-oxidative stability of the transmission oil also reflects variation of relative viscosity of oil which additionally takes into consideration conditions of action of additives, their additional elements and formation of clusters of waste inclusions in the oil. Control of these inclusions and subsequent oil efficiency were determined by the oil stability relative to the temperature factor.

6. Discussion of results of determining and diagnosing the state of transmission oil during operation

The process of the transmission oil oxidation stimulates changes in optical properties, volatility and viscosity. Under these conditions, it should be assumed that viscosity changes as a result of action of the set of additives and formation of clusters of oxidation products, therefore, oil efficiency should be evaluated by the coefficient of thermal-oxidative stability which is determined from expression (1). This coefficient characterizes amount of excess thermal energy absorbed by the products of oxidation and evaporation of acid inclusions in the oils under study.

Analyzing the results of the study of thermal oxidation stability of the YUKO TO-4 80W-85 transmission oil in KamAZ 6520 (3 pcs.), replacement of oil every 48 thousand km does not provide conformity to operating conditions. This is evidenced by Fig. 1 according to which mathematical model of variation of thermal-oxidative stability at a run of 14 thousand km is beyond the permissible limits. In addition, in the range of 14–48 thousand km, the level of this diagnostic parameter of the oil exceeds the value of 0.85 units. This character of the process development reflects nonconformity of the oil of the studied grade to operation modes of KamAZ 6520 trucks.

Increase in viscosity of transmission oil provides initial conditions for lubrication of gearbox teeth but cannot provide proper friction mode in operation. In such conditions, incoming of the required portion of oil is impeded which contributes to overheating of the gearbox parts and thus intensifies the process of oil oxidation. Fig. 3 shows variation of relative viscosity of the YUKO TO-4 80W-85 transmission oil. Change of this parameter by more than 1.96 characterizes degradation of additives and formation of wear product clusters. Transformations in such short runs occurred because of non-conformity of the used oil grade to the modes of operation of the KamAZ 6520 trucks. Therefore, its use should be reconsidered for the trucks operated by ATP 2004 enterprise, Kropyvnytsky, Ukraine, taking into consideration the results of study of respective vehicle models.

When analyzing the results of study of thermal-oxidative stability of the Tedex Gear GL-4 80W90 transmission oil for MAN TGA 6×4 trucks (3 trucks), its conformity to operation conditions was found ensured. This conclusion was made on the basis of absence of a significant increase in the mathematical model in Fig. 4 and also the level of thermal-oxidative stability of oil lower than 0.85 un. during trial period of operation. When analyzing behavior of dependence of variation of the coefficient of thermal-oxidative stability of the oil depending on growth of its viscosity, it was found consistent with the loading regimes. Also, this behavior of development of the mathematical model in Fig. 5 shows gradual degradation of the oil components during operation. These regimes are rational and show the oil conformity to the technical maintenance of transport vehicles.

The results of experimental studies of the coefficient of thermal-oxidative stability indicate that the results of studies of coefficients of light transmission, evaporability and relative viscosity must be taken into consideration when determining operating capacity of the transmission oil. The above-mentioned has formed the basis for development of a procedure for determining expiry term of oil operating capacity based on the study results.

Limitations of the study of the coefficient of light transmission were established only for percentage of benzene in the test sample of the working oil which should not exceed 10 %. It was because a significant scatter of recurrent output experimental results took place. It is desirable to conduct study of thermal-oxidative stability in a temperature range no more than 180–182 °C with laminar stirring of the working oil. In turn, this ensures gradual oxidation of oil throughout its volume in a measuring flask without local overheating which additionally prevents formation of significant carbon clusters in it.

Study of thermal-oxidative stability of transmission oils makes it possible to determine whether the oil grade was correctly selected. Further studies of this diagnostic parameter will make it possible to solve the problem of selecting the complex of additives for oils and establish possibility of their addition during operation. Further study of the technical state of transmission oils by their thermal-oxidative stability will enable establishment of the vehicle runs at which working oil additives should be used for a guaranteed period of oil operation.

7. Conclusions

1. Experimental studies have established variation of thermal-oxidative stability depending of the vehicle run using results of studies of the coefficients of light transmission, evaporability, and relative viscosity. The corresponding regression equations of variation of the coefficient of thermal-oxidative stability depending on the vehicle run and the ratio of relative viscosity of YUKO TO-4 80W-85 and Tedex Gear GL-4 80W90 transmission oils during operation of KamAZ 6520 and MAN TGA 6×4 trucks were obtained.

2. It was found that YUKO TO-4 80W-85 transmission oil does not provide its functional capacity for a 14-48 thousand km run for KamAZ 6520 trucks. This was evidenced by acquiring of values of the function of the mathematical model which describes change of thermal-oxidative stability of the oil depending on relative viscosity. It was 0.968 un. for the studied vehicle runs which is greater than the permissible level of 0.85 un. Behavior of variation of the coefficient of thermal-oxidative stability depending on relative viscosity in certain zones outside the permissible limits characterizes destruction of additives and formation of clusters of wear products which also characterizes noncompliance of the given oil to operating conditions.

3. Tedex Gear GL-4 80W90 transmission oil used in MAN TGA 6×4 trucks, met the operating conditions by its thermal-oxidative stability. This is evidenced by acquisition of a maximum value by function of the mathematical model describing variation of thermal-oxidative stability of oil depending on relative viscosity for the studied vehicle runs. Relative viscosity was 0.8450 un. which is less than the permissible level. Behavior of variation of thermal-oxidative stability depending on relative viscosity reflects gradual degradation of additives in the working oil.

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