Petroleum and Coal

Article **Open Access**

Determination of Replacement Terms of Mineral Motor Oils Based on to their Actual Condition

A. Grigorov[1], S. Bondarenko[2], V. Khrystych[2], M. Maliarov[2], N. Maksymovska[3]

[1] *National Technical University «Kharkov Polytechnic Institute», 61002, 2 Kirpichova str., Kharkov 61000, Ukraine*
[2] *National University of Civil Defense of Ukraine, 61023, 94 Chernyshevskaya str., Kharkov, Ukraine*
[3] *Sumy State Pedagogical University named after A.S. Makarenko, 40002, 87 Romenska str., Sumy, Ukraine*

Received October 10, 2024, Accepted December 17, 2024

Abstract

The article proposes an approach to replacing motor oils according to their actual condition, and not according to the terms recommended by motor vehicle operating manuals and manufacturers, expressed in km. Experimental studies have shown that the most informative actual state of used motor oil is determined by TBN and TAN, which are among the main physicochemical indicators of the quality of motor oils. Based on the fact that, under the condition of TBN=TAN, the used oil can be considered as the one that has lost its properties, the rational terms of its operation were determined. These terms are 2,500-10,000 km longer than the recommended engine oil change intervals. By implementing the proposed approach in the conditions of large motor transport enterprises, it is possible to achieve significant savings in consumables and significantly reduce the period of maintenance of road transport. And this, in the end, will help to reduce the cost of transportation and minimize the harmful impact of road transport on the environment.

Keywords: *Motor oils; Additives; Operation; Maintenance; Oil change; Total acid number; Total alkaline number; Informative index.*

1. Introduction

In recent years, engine oils have been regarded as an integral element of the internal combustion engine design. This is primarily due to the fact that the quality of motor oil helps to diagnose the technical condition of the engine and significantly affects the durability and reliability of its operation. At the same time, motor oils are among the most expensive petroleum products, and their rational use will significantly reduce the costs associated with vehicle maintenance, which are included in the final cost of any transportation. In addition, used motor oils pose a significant danger to the environment and are subject to mandatory disposal. Understanding the processes that occur during the operation of motor oils and their impact on the operation of engines and the environment is a key aspect for ensuring the efficiency and environmental friendliness of road transport. Taking this into account, determining the rational terms for replacing motor oils is one of the top priority tasks of today, the solution of which is being worked on by leading scientists of the European Union countries.

2. The objective of the research

During the operation of motor oils, under the influence of various factors shown in Fig. 1, they undergo significant changes in their composition and, as a result, gradually lose their original properties. This process is commonly referred to in the technical literature as ‘aging’ of motor oils [1-3].

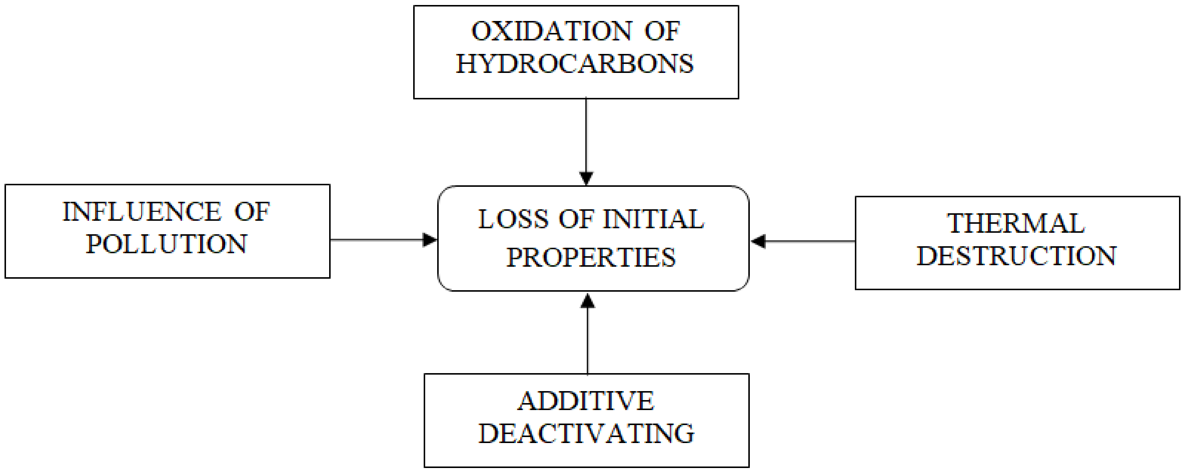

Figure 1. Factors affecting the aging of motor oil in operation.

Oxidation of motor oil hydrocarbons is a chain reaction with the participation of radicals, which leads to the formation of various soluble and insoluble substances in oil, which are capable of forming varnishes, sludges and carbon deposits, and in addition, intensify corrosion processes in the engine.

Activation of additives. During the operation of motor oils in the engine, the concentration of additives in the oil decreases unevenly over time. So, in the first hours of engine operation, this process is particularly intense, and then gradually fades away. This is explained by the fact that during the initial period of engine operation, the additive actively interacts with the surface of its parts that are lubricated with oil. The activation of some additives in the initial period of oil operation is explained by their adsorption on engine parts and solid products of incomplete fuel combustion [4] and their physicochemical interaction with the products of oil aging and fuel combustion [5].

Thermal destruction. Under the influence of high temperatures (over 300°C), motor oil hydrocarbons can decompose with the formation of products of lower molecular weight. As a result, the evaporation rate of the oil increases and its viscosity decreases. It is known that oil viscosity plays a key role in engine operation. In a normal condition, the oil passes through the channels of the engine lubrication system, covers the rubbing parts with a film, reducing the wear of the engine's working units. But thermal destruction of oil changes its structure and lubricating properties [6]. At the same time, the products of thermal destruction of oil hydrocarbons are able to form solid coke-like products that complicate the movement of oil through the channels of the engine lubrication system, which, ultimately, will lead to a lack of oil in the friction zone of the metal surfaces of the engine and cause it to jam. Along with hydrocarbons, oils are prone to thermal destruction and additives that can decompose with the formation of products that can cause engine corrosion [7].

Oil contamination is the main factor leading to the loss of its original properties (aging) [8]. It should be noted that contamination of motor oils begins at the stage of their production and continues during transportation, storage, the process of pouring into the engine and further operation. The main types of motor oil contamination in operation are shown in Fig. 2.

All the contaminants shown in Fig. 2 can be divided into two large groups: those that occur during normal operation and those that occur during emergency operation of the engine. Thus, oil oxidation products, products of incomplete combustion of fuel, wear products of engine parts, dust particles and water are present in any used oil in small quantities. Whereas degradation and decomposition products of additives, a significant amount of water and dust particles, and antifreeze are found in engine oils drained from engines during emergency shutdowns.

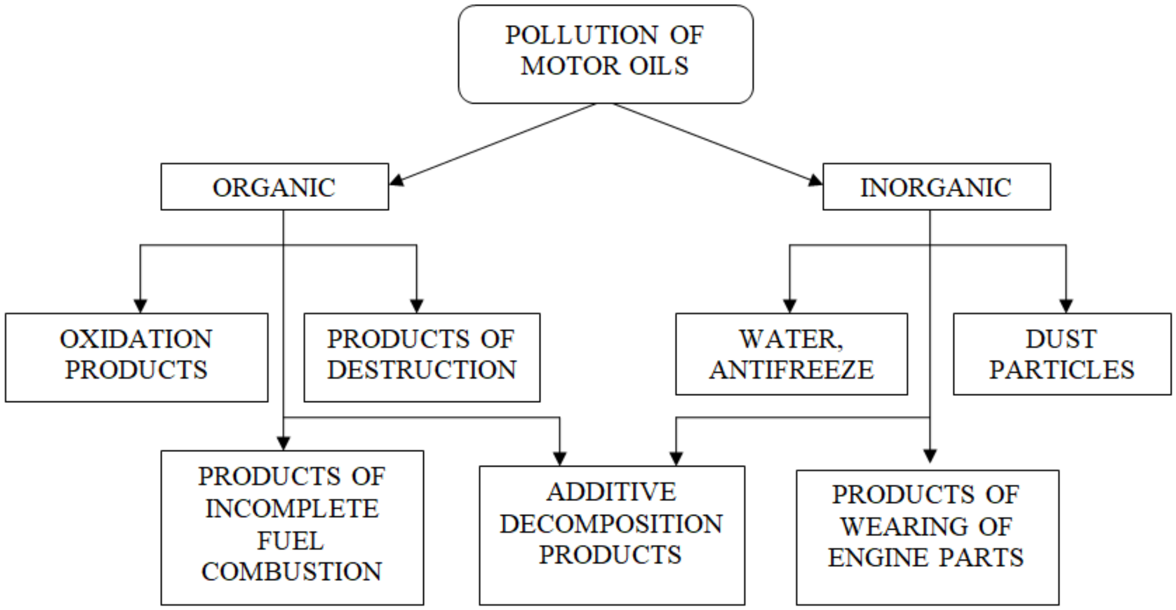

Figure 2. Types of motor oil contamination in operation.

It should also be noted that acids are the most dangerous products of oil oxidation and incomplete combustion of fuel for the engine. During the oxidation and decomposition of hydrocarbons that make up the oil, organic low-molecular weight and high-molecular weight acids can be formed. Low molecular weight acids cause corrosion of metals by the following chemical mechanism [9]. High-molecular acids in the composition of oils cause corrosion of non-ferrous metals (lead, cadmium and others), leading to the formation of oil-soluble salts. In addition, contaminants such as water and antifreeze cause additives to be leached from the oil [10], products of incomplete combustion of fuel dilute the oil, products of wear of engine parts have a catalytic effect in the oxidation of hydrocarbons in engine oil [8-9].

So, based on the above information, it is clear that the actual condition of the engine oil is crucial when deciding whether to replace it with fresh oil [11] during maintenance.

At the same time, in the manuals for the operation of cars and the regulations in force at many motor vehicle enterprises, the replacement of motor oils is carried out according to its service life, expressed in kilometers of mileage. Today, this term is 8-10 thousand km, sometimes 12 thousand km [12-14]. Within this term, motor oil manufacturers guarantee that the motor oil will preserve its properties, but at the same time, such factors as the culture of driving the vehicle, the quality of consumables and maintenance, the technical condition of the car, the load-speed mode of operation, which are capable of affect the premature loss of engine oil properties, and vice versa, contribute to the preservation of its properties during a long period of operation.

Thus, the purpose of this work is to determine the timing of replacement of mineral motor oils according to their actual condition, based on the results of determining the main physical and chemical indicators of their quality.

3. Materials and methods of the research

Materials. Five fresh and used (with different mileage) mineral motor oils of the following brands were chosen as materials for the study: Shell Rimula R4 x 15W-40; Fuchs Titan Truck Plus 15W-40; GT Super Diesel 15W-40; Titan UHPD 15W-40; API SG/CD 15W-40.

Methods. By the methods used to determine their actual state, such indicators as the viscosity index (VI, unit), kinematic viscosity at 100°C (v^{100}, mm^2/s), total alkalinity (TBN, mg

KOH/g), total acid number (TAN, mg KOH/g), flash point (t, °C), mass fraction of water (Xw, %) have been chosen. The selected indicators were determined according to standardized methods that are used today for laboratory research of the quality of lubricating oils, in particular motor oils: ASTM D445-21e1 «Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)»; ASTM D2270-10(2016) «Standard Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 °C and 100 °C»; ASTM D664-18e2 «Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration»; ASTM D2896-21 «Standard Test Method for Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration»; ASTM D95-13(2018) «Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation»; ASTM D92-18 «Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester».

4. Experimental research

The results of determining the main physical and chemical parameters of the quality of selected used mineral motor oils are shown in Fig. 3-10.

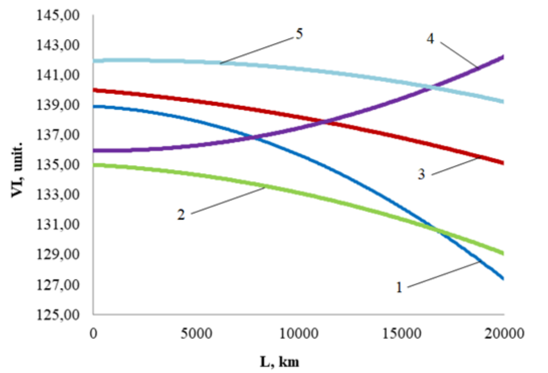

Figure 3. Dependence of VI on L for mineral oils: 1 – Shell Rimula r4 x 15W-40; 2 – Fuchs Titan Truck Plus 15W-40; 3 – GT Super Disel 15W-40; 4 – Titan UHPD 15W-40; 5 – API SG/CD 15W-40

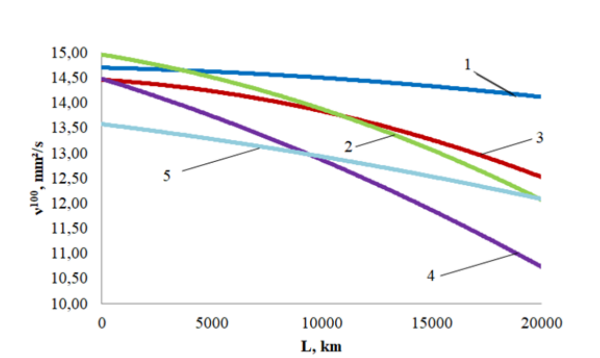

Figure 4. Dependence of v^{100} on L for mineral oils: 1 – Shell Rimula r4 x 15W-40; 2 – Fuchs Titan Truck Plus 15W-40; 3 – GT Super Disel 15W-40; 4 – Titan UHPD 15W-40; 5 – API SG/CD 15W-40

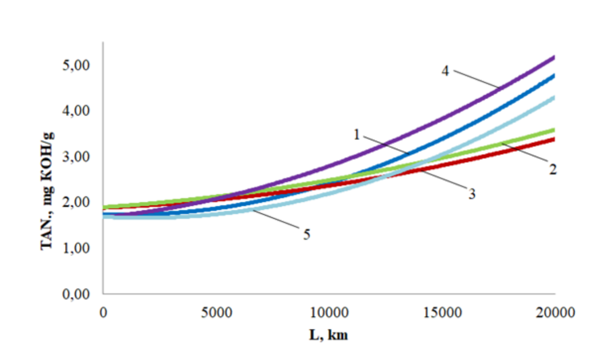

Figure 5. Dependence of TAN on L for mineral oils: 1 – Shell Rimula r4 x 15W-40; 2 – Fuchs Titan Truck Plus 15W-40;3 – GT Super Disel 15W-40; 4 – Titan UHPD 15W-40;5 – API SG/CD 15W-40.

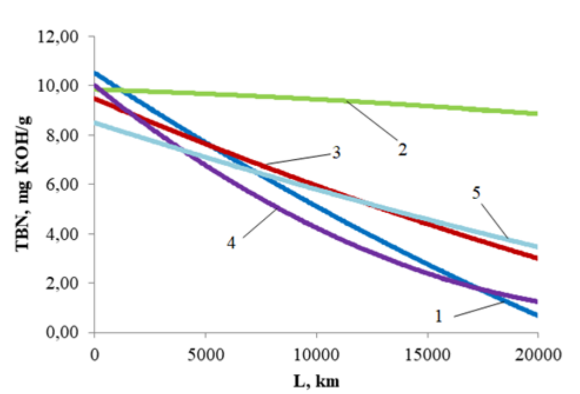

Figure 6. Dependence of TBN on L for mineral oils: 1 – Shell Rimula r4 x 15W-40; 2 – Fuchs Titan Truck Plus 15W-40; 3 – GT Super Disel 15W-40; 4 – Titan UHPD 15W-40; 5 – API SG/CD 15W-40.

Analyzing the obtained dependencies, it becomes obvious that the decrease in the quality index VI and v^{100} occurs mainly due to the contamination of the motor oil with high-boiling fuel fractions, and, to a lesser extent, due to the destruction of the viscosity additive. A decrease in the value of the TBN indicator occurs due to the activation of the detergent-dispersant additive, which is used to neutralize acidic components formed during the operation of the oil in the engine. The increase in the value of the TAN indicator occurs due to the formation of acidic components

- products of oxidation of hydrocarbons of the base oil, which are formed during the operation of the oil in the engine. The nature of the change in quality indicators remains unchanged for all samples of the studied oils, regardless of the technical condition of the engines in which the oils were used. This, in turn, indicates the objectivity of the diagnostic information obtained.

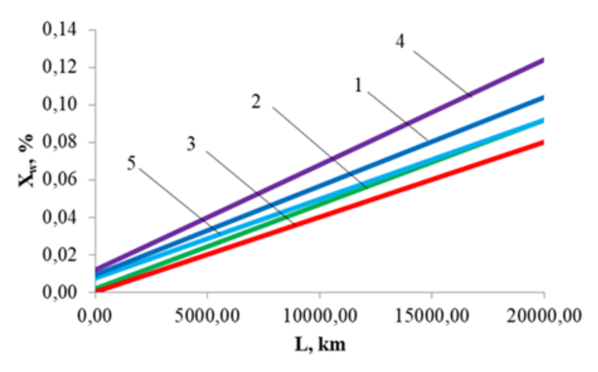

Figure 7. Dependence of X_w on L for mineral oils: 1 – Shell Rimula r4 x 15W-40; 2 – Fuchs Titan Truck Plus 15W-40;3 – GT Super Disel 15W-40; 4 – Titan UHPD 15W-40;5 – API SG/CD 15W-40.

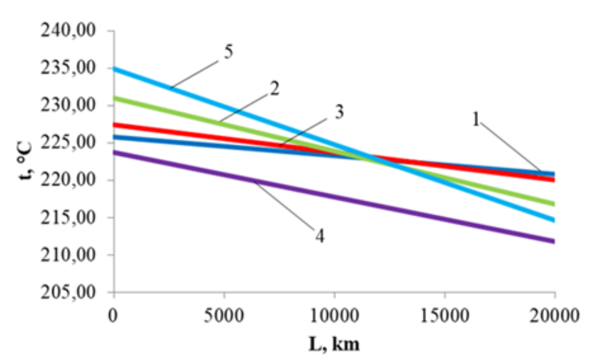

Figure 8. Dependence of t on L for mineral oils: 1 – Shell Rimula r4 x 15W-40; 2 – Fuchs Titan Truck Plus 15W-40;3 – GT Super Disel 15W-40; 4 – Titan UHPD 15W-40;5 – API SG/CD 15W-40.

It is possible to analyses the informativeness of the determined quality indicators (see Fig. 9), which vary depending on the service life (L, km) for the studied oil samples, using the informativeness coefficient (K_{inf}), which is calculated using the following formula [15]:

$$K_{\text{inf}} = 1 - \frac{X_{\text{min}}}{X_{\text{max}}} \qquad (1)$$

where X_{min}, X_{max} – minimum and maximum values of quality indicators of motor oil samples determined experimentally.

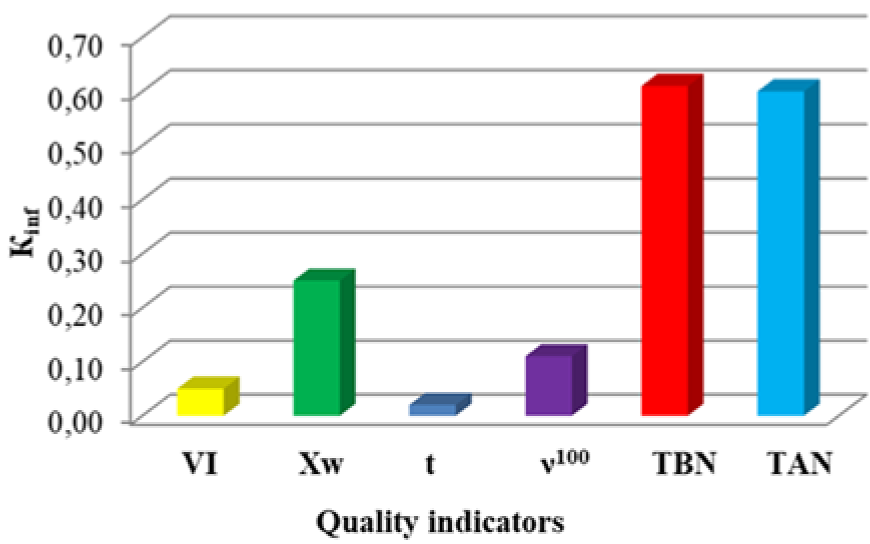

Figure 9. Informativeness of quality indicators for the used motor oils under study.

Based on the research, it becomes obvious that the most informative quality indicators for used all-season motor oils of mineral nature are the alkaline and acid numbers. Exactly these indicators are the most appropriate for determining the service life of oils before they are replaced [16-17].

According to research presented by Lubrizol Corporation [18] if the alkaline and acid values are equal, the engine oil loses its quality (wear of friction surfaces increases rapidly) and must be replaced with fresh oil. Then, based on this information, determine the safe service life of the oils under study based on the results of experimental studies (see Figures 10-14).

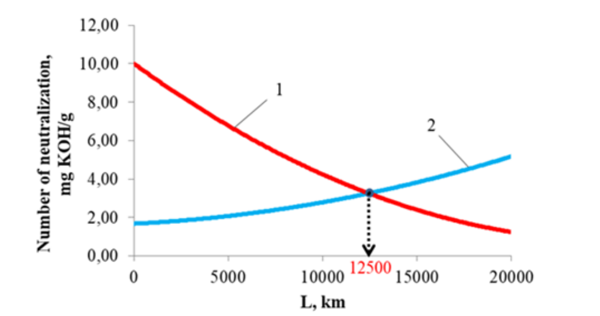

Figure 10. Dependence of the neutralization number on L for oil Titan UHPD 15W-40: 1 – TBN; 2 – TAN.

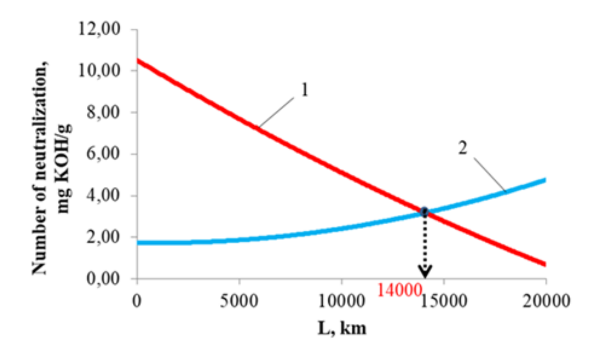

Figure 11. Dependence of the neutralization number on L for oil Shell Rimula r4 x 15W-40: 1 – TBN; 2 – TAN.

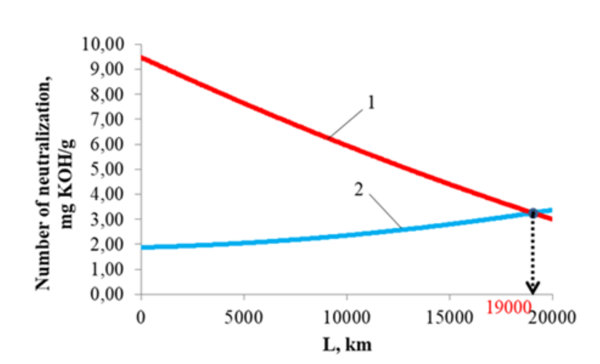

Figure 12. Dependence of the neutralization number on L for oil GT Super Disel SAE 15W-40: 1 – TBN; 2 – TAN.

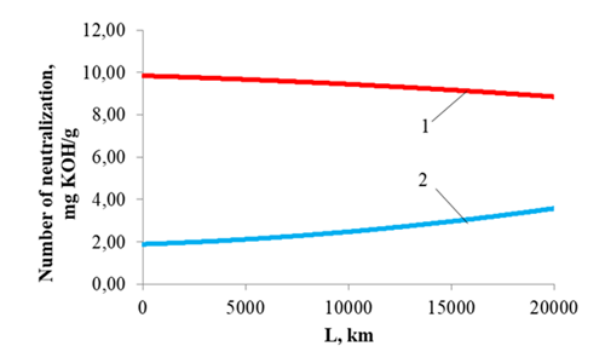

Figure 13. Dependence of the neutralization number on L fo roil Fuchs Titan Truck Plus 15W-40: 1 – TBN; 2 – TAN.

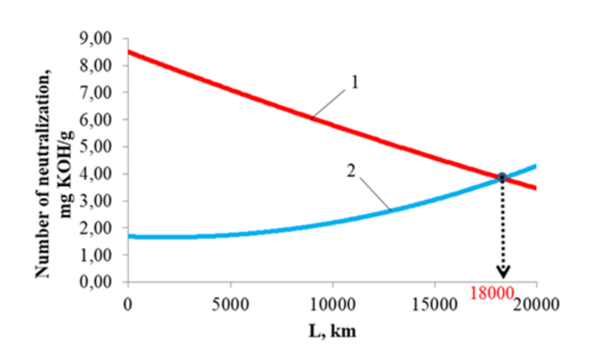

Figure 14. Dependence of the neutralization number on L foroil API SG/CD 15W-40: 1 – TBN; 2 – TAN.

Thus, the results of the study on determining the service life of motor oils are presented in Table 1.

Table 1. Determining the period of use of motor oil before its replacement by the value of the neutralization number.

Brand of used motor oil	Shell Rimula R4 x 15W-40	Fuchs Titan Truck Plus 15W-40	GT Super Diesel 15W-40	Titan UHPD 15W-40	API SG/CD 15W-40
Recommended service life of the oil, km	8000-10000				
The actually determined service life of the oil, km	14000	>20000	19000	12500	18000

Analyzing the data in Table 1, it is obvious that the actual service life of motor oils is significantly longer (from 2,500 km to 10,000 km) than the periods recommended in the operating manual. This is primarily due to the fact that the recommended service life does not take into account the effect of many subjective operational factors that have a significant impact on the ability of motor oils to perform their functions.

5. Conclusions

Experimental studies have shown that the service life of motor oils in car engines can be extended by an interval of 2,500 km to 10,000 km, compared to the periods recommended in operating manuals and by motor oil manufacturers.

The obtained results fully confirm the opinion of many leading scientists about the need to switch from replacing motor oil based on the service life expressed in km to replacing motor oil based on its actual condition. It is the actual state of used motor oil that should be taken into account in numerous models that are currently proposed to be used to determine the rational timing of engine oil replacement. This approach is more rational because it allows to reduce the consumption of expensive consumables, to reduce the period of maintenance of road transport.

References

[1] Idzior M. Aging of engine oils and their influence on the wear of an internal combustion engine. Combustion Engines, 2021;185(2): 15-20.

[2] Khamidullaevna AZ, Faxriddin S. The aging process of motor oils during operation. European International Journal of Multidisciplinary Research and Management Studies, 2022; 02(06):166-169.

[3] Gokul V, Swapna MNS, Korte D, SI Sankararaman. Reflecting the Quality Degradation of Engine Oil by the Thermal Diffusivity: Radiative and Nonradiative Analyses. Materials (Basel), 2023; 16(2): 773.

[4] Al Sheikh Omar A, Salehi FM, Farooq U, Morina A, Neville A. Chemical and physical assessment of engine oils degradation and additive depletion by soot. Tribology International, 2021; 160: 107054.

[5] Karimova SA, Mavlanov BA, Fozilov SF, Khayrullayev ChK. Increasing the Effectiveness of Detergent-Dispersant Additives in Motor Oils. Excellencia: International multi-disciplinary journal of education, 2024; 02(05): 2994-9521.

[6] Tripathi AK, Vinu R. Characterization of Thermal Stability of Synthetic and Semi-Synthetic Engine Oils. Lubricants, 2015; 3(1): 54-79.

[7] Ferguson S, Johnson J, Gonzales D, Hobbs C, Allen C, Williams S. Analysis of ZDDP Content and Thermal Decomposition in Motor Oils Using NAA and NMR. Physics Procedia, 2015; 66: 439-444.

[8] Rațiu SA, Mihon L, Laza I, Armioni MD. Review On The Contamination Of Used Engine Oil. Ingineria automobilului, 2020; 57: 20-25.

[9] Harvath P, Reidy S, Byer J. Identification of Organic Acids in Used Engine Oil Residues by Pyrolysis-Comprehensive 2D Gas Chromatography-Time of Flight Mass Spectrometry, SAE Technical Paper. 2016: 2274.

[10] Grigorov AB, Turkoman IA, Zelenskii OI, Spirina EYu. Selecting features of motor oils for the facilities operation in abnormal conditions. Petroleum & Coal, 2018; 60(3): 453-457.

[11] Nahliuk I, Nahliuk M, Krivoshapov S, Grigorov A. Research of the Properties of Engine Oil Sae 10W-40 During Operation in Vehicles. Petroleum & Coal, 2024; 66(2): 468-476.
[12] Gołębiowski W, Wolak A, Zając G. Definition of oil change intervals based on the analysis of selected physicochemical properties of used engine oils. Combustion Engines, 2018;172(1): 44-50.
[13] How Often Should You Change Engine Oil. AAA Auto Repair Article. By AAA Automotive. URL: https://www.aaa.com/autorepair/articles/how-often-should-you-change-engine-oil
[14] Guide to Periodic Maintenance Service. URL: https://www.mitsubishi-motors.com.ph/service/service-guide
[15] Shahbaz MQ, Ahsanullah M, Shahbaz SH, Al-Zahrani BM. Ordered Random Variables: Theory and Application, Atlantis Press Paris. 2016: 294.
[16] Felkel Y, Dörr N, Glatz F, Varmuza K. Determination of the total acid number (TAN) of used gas engine oils by IR and chemometrics applying a combined strategy for variable selection. Chemometrics and Intelligent Laboratory Systems, 2010; 101(1) :14-22.
[17] Sejkorova M. Determination of Total Alkalinity of Motor Oil by FTIR Spectroscopy. Chemicke Listy, 2013; 107(8):643-647.
[18] Grigorov AB, Nagluk IS. Racional'noe ispol'zovanie motornih masel: monografia. Harkov: NTU HPI, 2012: 183.

To whom correspondence should be addressed: prof. A. Grigorov, National Technical University «Kharkov Polytechnic Institute», 61002, 2 Kirpichova str., Kharkov 61000, Ukraine, E-mail: grigorovandrey@ukr.net