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Research of the Properties of Engine Oil Sae 10W-40 During Operation in Vehicles

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Abstract

The reliability of a car engine is ensured by the combination of oil properties that are laid in the oil production process. The properties of engine oil change with the mileage of the car compared to the initial state. When the rejection parameters of the oil reach the limit level, then it is necessary to replace the old oil with a new one. The rate of change intensity in the properties of particular oil depends on both the make of the vehicle and the operating its conditions. In difficult conditions of operation of the car, it is necessary to reduce the run period of between oil changes. But if the car is operated in light or gentle conditions, then the normative oil change may not realize its full potential. In this case, extending the oil change intervals beyond the norm leads to an increase in the efficiency of its use, which reduces the overall operating costs. It will be optimal when the service life of the oil will be determined by the actual state of the basic properties. The paper presents the results of experimental studies on changes in the concentration and rate of iron entry into motor oil. In addition, other indicators of oil in samples were determined: the viscosity, the flash point in an open crucible, the dielectric constant, the acidity and alkali numbers. The study involved motor oils of the same group, but from different manufacturers, for various brands of trucks and cars at different stages of the life cycle. The energy loading on the engine can be estimated by fuel consumption, which depends on the operating speed or operating conditions of the vehicle. An analysis of the results experiment was carried out, which established a relationship between the concentration of iron in oil and fuel consumption or car mileage. In conclusion, recommendations are given on the values of indicators at which further operation of oils is not recommended.

Keywords: *Vehicle; Engine oil; Properties; Fuel; Operating conditions; Concentration.*

1. Introduction

Today there are a large number of motor oils from various manufacturers on the market. Classification systems SAE, API, ILSAC, JASO, ACEA, etc. have been introduced to facilitate the selection of oils of the required quality for a particular engine type and operating conditions [1-4].

SAE determines the degree of viscosity of the ambient temperatures range in which the oil ensures normal operation of the engine. This is understood as such a temperature at which normal cranking of the crankshaft by the starter will be ensured, uninterrupted oil supply by the pump through the lubrication system during cold start-up and reliable lubrication in summer during long-term operation at maximum loads and speeds.

According to the ARI system, operational categories are established for the purpose and quality of motor oils. In addition, car manufacturers may impose additional and more stringent requirements on oils that are designed for engines of the latest designs. Only when the use of oils meets all requirements can manufacturers guarantee reliable operation of the engine and units throughout the entire life of the vehicle.

Such action as assessing the properties of oils, the technical condition of aggregates and vehicle components, allows us to consider this as a purposeful process. This approach will allow us to identify potential failures in units and systems, as well as to ensure the timely adoption or issuance of control actions that are aimed at preventing the occurrence of an actual failure.

The task of replacing oils according to the actual state and operational management of the resource of power units makes it possible to determine new patterns in the formation of methods for assessing the main indicators of the quality of oils and predicting the timing of their change, which would take into account energy parameters, individual characteristics and operating conditions of a particular vehicle.

2. Purpose and setting of the task

Increasing requirements for motor oils are associated with the development of modern technology and the emergence of new design solutions in the automotive industry, as well as increased requirements for environmental regulations and standards. Strict requirements of environmental standards lead to an increase in the proportion of oils that have the properties of energy saving and biodegradation.

An increase in engine power leads to an increase in specific loads on vegetable oil. The requirements for increasing the intervals of car maintenance due to the durability of parts and the service life of materials impose additional requirements on the performance properties of motor oils, such as: viscous stability, anti-wear, antioxidant, anti-corrosion, detergent, etc.

Currently, oil refineries are ready to extend the oil change interval for passenger car engines to 50,000 km, and for diesel engines of main road trains to 190,000 km [5–8].

Proper selection of engine oil is critical to the performance and durability of engine components. Oil performs several functions in an engine. Oil should lubricate surfaces well, reducing friction and wear of parts; should protect metal surfaces from corrosion; must seal the combustion chamber and other connections; good at dissipating heat that is caused by friction; should ensure the removal of wear products from the friction zone, should prevent the accumulation and settling of impurities, and also maintain operational properties over time [9-12].

Besser in his studies [13] pays great attention to the change in the quality of engine oil when a car is running on bioethanol. They were able to establish that alcohol gasolines have a significant effect on the rapid oxidation and aging of engine oil.

Sikora and Miszczak noted in their work [14] on the study of the change in viscosity and lubricity of engine oil, Fuchs Oil Corporation, which meets the SAE 15W-40 specification used in Caterpillar CAT3516DITA engines, that olive deterioration has a significant impact on lubrication and wear of plain bearings, and consequently on the wear rate.

Dam *et al.* [15],studied how the deterioration and aging of SAE 15W-40 engine oil in a high power diesel engine (12.7 lL) affects its level of emissions in exhaust gases. They found that engine oil aging has a limited effect on gaseous and mass emissions, as well as on the content of metals in exhaust gases. Motor oil accumulates wear products of organic and inorganic origin [1-2]. This fact leads to an accurate display of the technical condition of the engine and the operating conditions of vehicles.

An analysis of the quality indicators of used engine oil makes it possible to predict the limiting wear of rubbing pairs. By registering the fact of an increase in the wear rate, it is possible to prevent the moment of engine failure, but for this it is necessary to monitor the quality of the oil during operation. An appropriate interpretation of the results of the analyzes carried out allows not only to identify the symptoms of failures that occur before they occur, but in many cases can determine the location of the mechanical failure [1,9].

In modern cars, the terms for changing engine oil are regulated by the data that are indicated in the service book. The frequency of oil change is indicated in kilometers or months of operation (whichever comes first). For example, for a Hyundai car, the following engine oil change periods are set: • the 15,000 km (12 months);• the 30,000 km (24 months);• the 45,000 km (36 months);• the 60,000 km (48 months);• etc.

In Hyundai cars, the first replacement must be performed at a vehicle mileage by 15,000 km or after a vehicle operation time by 12 months.

When changing engine oil, in most cases, vehicle owners and locksmith on service technical stations (STS) do not know what the actual state of the oil drained from the engine is and how quickly the oil loses its properties under specific operating conditions.

The aim of the work is to study the change in the quality of SAE 10W-40 engine oil. To do this:

- the rate of entry of wear products (iron) into oils of different manufacturers during the operation of vehicles is investigated;
- the value of the required interval for changing these oils is determined.

It will be necessary to solve the following tasks in order to achieve the set goals:

- it is necessary to obtain the results of changes in the main indicators of the quality of engine oil during the operation of cars and trucks;
- get the results of changes in the rate of iron intake in engine oil during the operation of cars and trucks.

3. Results and discussion

The resource of engines and units is primarily determined by the degree of wear of friction pairs. In order to reduce the number and frequency of failures of engine friction units, it is necessary to timely detect any changes in the main indicators of oil quality during vehicle operation. If the content of wear products in the engine oil increases, then the cause of the failure must be eliminated. The total fuel consumption is an integral energy indicator, with the help of which it is possible to more objectively take into account changes in the actual operating conditions of the vehicle than to control the vehicle mileage in km [5].

When the break-in period ends and the first oil change occurs, you can begin to collect information about the quality of the drained oil. Some indicator indicators characterizing the operation of the engine have been established. The change in these indicator indicators per liter of fuel consumed is calculated. Knowing the initial values of the indicators and the rate of change of these indicators, one can judge the reliability of the engine and predict the operation of its systems in further operation.

During the break-in period, car manufacturers recommend that drivers observe the minimum load on the vehicle and drive at low speeds when the vehicle's operating modes are optimal. By diagnosing engine oil at the first change or after a break-in, you can get objective basic information about the process of changing the main indicators of oil quality, which affect the wear rate of interfaces in the engine and the efficiency of its systems.

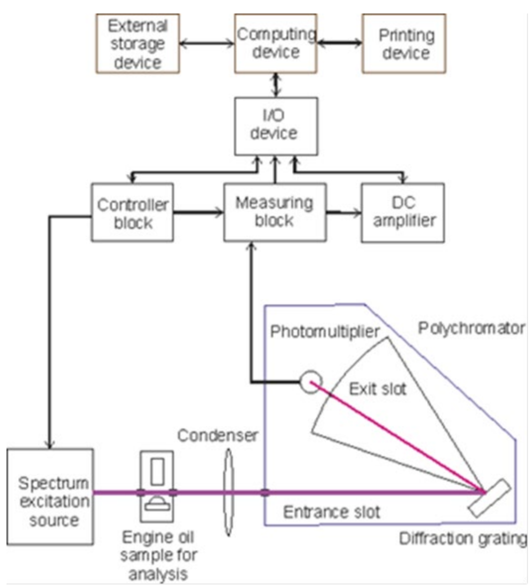

Figure 1. Schematic diagram of the measuring system of the stand MFS-7.

The analysis of selected samples of engine oil, which is drained from vehicles during its replacement, was carried out in accordance with the requirements of DSTU. All experimental work was carried out in the testing and analytical laboratory for the study of fuels and operating materials, which is located in the Kharkov National Automobile and Highway University. The laboratory has an accreditation certificate No. 100-030/2014.

The concentration of wear products (iron) in engine oil was determined on a photovoltaic installation MFS-7. The schematic diagram of the operation of the MFS-7 installation, the method for obtaining and processing information on the concentration of iron in an oil sample is shown in Figure 3.

Stand MFS-7 works as follows. The oil sample is fed into the electrical discharge zone, where the oil and wear products are burned. Under the influence of high temperature, the metals in the wear products emit radiation of different wavelengths. Light passing through the condenser and the entrance slit enters the diffraction grating, where it is reflected at a certain angle and directed to the surface of the polychromator. The angle of refraction will depend on the wavelength, which will be different for each material. When the reflected beam enters the exit slit, this fact will be registered by a photomultiplier. The strength of the photocurrent is proportional to the concentration of the element in the oil sample.

Stand MFS-7 can simultaneously analyze up to 24 elements (various metals). We investigated only the iron content in wear products. Other impurity elements have been investigated by various authors, for example, in article [16] it was zinc and copper. The article [17] has already given studies of impurities in oil samples for 16 elements. The following limit values of quality indicators were used in the studies, according to which the properties of engine oil were evaluated and the degree of suitability of the oil for further operation was determined:

- the kinematics viscosity at 100°C, maximum increase/decrease – 4 mm^2/s from the nominal value of fresh oil;
- the flash point in an open crucible, reduction – 20°C;
- the coking, % – 4;
- the base number, mg of KOH/g of oil – 0.5;
- the mass fraction of water, % – 0.3;
- the dielectric constant, increase – 0.3;
- the concentration of wear products, iron (Fe), g/t – 150.

The rate of entry of wear products into the engine oil during the operation of the vehicle is determined by the expression

$$W = \frac{F \cdot V_O \cdot \rho_O}{L_O} \quad (1)$$

where: F – the concentration of wear products (iron) in oil, g / t; V_O – the engine lubrication system volume, m^3; ρ_O – the oil density, t / m^3; L_O – the engine oil service life, km (hours).

$$W = \frac{F \cdot V_O \cdot \rho_O}{Q} \quad (2)$$

where: Q – the amount of fuel consumed during the period of operation of the oil in the engine, L.

Fuel consumption (Q) can be obtained by experimental and calculated methods. Mathematical models [18-19] make it possible to calculate fuel consumption depending on the design and operating conditions for a vehicle according to the main technical parameters.

Analysis of engine oil during the first oil change for new vehicles with a mileage of 2.5 thousand km showed that the rate of iron (Fe) entering the oil was for:

- the Hyundai Accent – 0.48 mg/L of fuel consumed;
- the Hyundai Getz – 0.32 mg/L of fuel consumed;
- the Hyundai i30 – 0.47 mg/L of fuel consumed;
- the Toyta Land Cruser 80 – 0.75 mg/L of fuel consumed;
- the Mitsubishi Lancer with vehicle mileage of 5915 km – 0.34 mg/L of fuel consumed;
- the BMW 520 with vehicle mileage of 15000 km – 0,21 mg/L of fuel consumed.

Monitoring of engine oil drained from engines during maintenance (TO-2) for KamAZ vehicles showed that for a significant number of vehicles, at the time of oil change, the rate of wear products (iron) entering the engine oil is in the range of 0.05 ... 0.28 mg per liter spent fuel.

The information obtained about the rate of entry of wear products into the oil and the change in the main missing indicators of oil quality in the initial period of operation (running mode) must be entered into the vehicle's diagnostic card or a computer storage file. In the future, it will be possible to use this information to conduct a comparative analysis when the vehicle will operate on oils from other manufacturers or in other operating conditions.

The change in the rate of iron entry into the oil and the quality indicators of engine oil during the operation of a RENAULT Magnum car on SAE 10W-40 engine oil are presented in Table 1.

Table 1. The results of physical and chemical analysis of used engine oil of XADO Atomic Oil SAE 10W-40 API SL/CI-4 with vehicle engine RENAULT Magnum.

The name of indicators	Pure oil	Used oil
Vehicle mileage, thousand km	-	850
Motor oil work life, km	-	70000
Kinematical viscosity at 100 ºC, mm²/s	14.0	12.15
Flash point in an open crucible, ºC	211	212
Coking, %	1.1	2,0
Base number, mg KOH/g oil	10.3	4.48
Acid number, mg KOH/g oil	1.14	1.78
Mass fraction of water, %	0.03	0,13
Dielectric constant	2.4801	2.6412
Concentration of the iron wear products (Fe), g/t	-	66
Iron entry rate (Fe) into oil, mg/km (mg/L fuel)	-	0.029 (0.08)

By the time the oil is changed (Table 1), we see the following:

- the kinematics viscosity decreased by 13.2 %;
- the base number decreased by 56.5 %;
- the flash point increased by 0.47 %;
- the coking increased by 81.8 %;
- the acid number increased by 56.1 %;
- the dielectric constant increased by 6.5 %;
- the mass fraction of water increased by 333 %.

The limit value of the mass fraction of water did not exceed the value of 0.3 for diesel vehicles. This oil can be operated further, but attention must be paid to the cooling system (poking or condensate enters the oil) or operation during the cold period with stops for a significant period. The rate of entry of wear products (iron) into the engine oil was 0.08 mg per liter of fuel used, which is within normal operational wear.

Table 2 shows the change in the quality of engine oil and the rate of iron entry into SAE 10W-40 oil when this oil was in operation for Komatsu HD 1200 and BelAZ-75121 dump trucks.

Table 2. The results of the analysis of physical and chemical indicators of the quality of Krol Alpha SAE 10W-40 API CF-4 / SH oil during the operation of dump trucks.

The name of indicators		Pure oil	Komatsu HD 1200	BelAZ -75121
Oil work life, year		0	508	503
Kinematical viscosity at 100 °C, mm²/s		14.2	13.3	13.6
Flash point in an open crucible, ºC		218	207	205
Base number, mg KOH/g oil		9.76	8.15	8.7
Acid number, mg KOH/g oil		1.85	2.71	2.54
Sulphate ash content, %		1.36	1.46	1.45
Iron concentration (Fe), g / t		-	15	22
Dielectric constant		2.3525	2.3989	2.4586
Rate of iron entry (Fe) of into the oil	mg/h	-	3.49	9.99
	mg/km	-	0.32	0.91
	mg/L fuel	-	0.047	0.15

When the oil is running in the engine of the Komatsu HD 1200 dump truck (Table 2), the following can be noted:the kinematics viscosity decreased by 6.3 %; the flash point decreased by 5.1 %; the base number decreased by 16.5 %; the acid number increased by 46.5 %; the sulfate ash content increased by 7.4 %; the dielectric constant increased by 1.9 7 %. It can be concluded that the oil can work further.

When the same oil is used in the engine of a BelAZ-75121 dump truck under the same conditions (Table 2), we can say the following: the kinematics viscosity decreased by 4.2 %; the flash point decreased by 5.96 %; the base number decreased by 10.9 %; the acid number increased by 37.3 %; the sulfate ash content increased by 6.61 %; the permittivity increased by 4.51 %.

The rate of iron entry into engine oil for the engine of the BelAZ-75121 dump truck will be as compared to the Komatsu HD 1200 dump truck: in mg per hour of work more than 2.86 times; in mg per km run 2.84 times more; in mg per liter of fuel consumed, it is 3.2 times more. The engine life during operation of 75121 km on this engine oil will be less than that of the Komatsu HD 1200 dump truck engine.

The change in the quality indicators of engine oil and the rate of iron entry into SAE 10W-40 oil during the operation of a VAZ-2107 passenger car, on which an engine running on gasoline and gas fuel, is presented in Table 3.

Figure 2 shows a graphical view of the influence of the resource of VAZ-21104 vehicles on changes in the characteristics of SAE 10W-40 engine oil during operation.

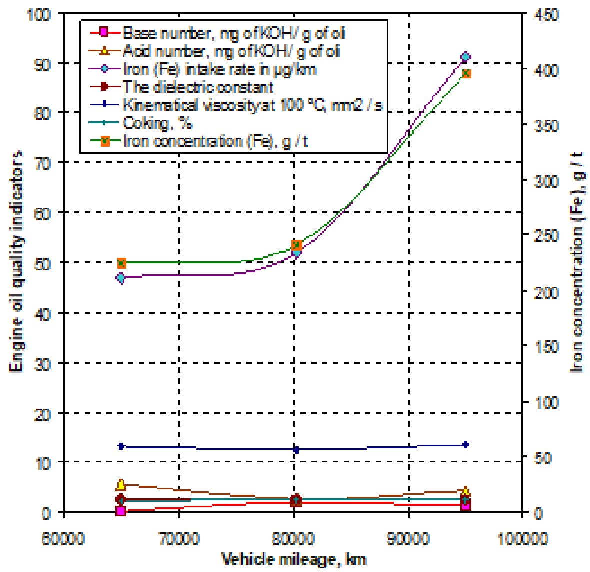

Figure 2. Graphs of changes in oil quality indicators for the VAZ-2107 car.

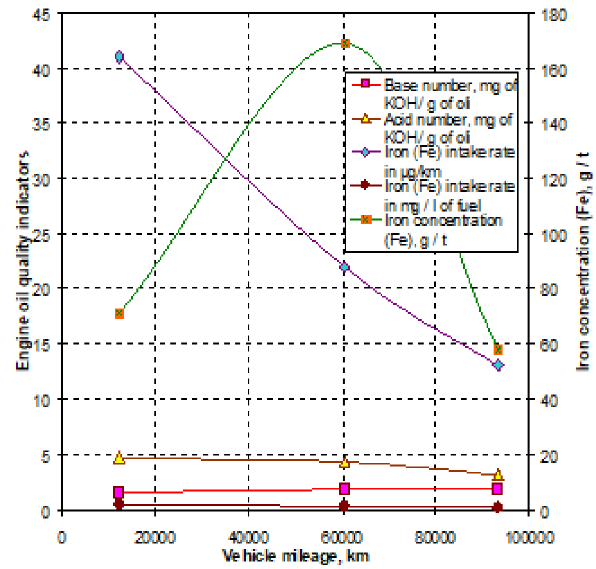

Figure 3. Graphs of changes in oil quality indicators from the mileage of a car of GAS - 31105 models.

Table 3. The results of the analysis of oil quality indicators during the vehicle operation for models VAZ-2107

The name of indicators	Penacol SAE 10W-40 API SL/CF	AVIA SAE 10W – 40 API SJ/CF	AVIA SAE 10W – 40 API SL/CF	AVIA SAE 10W – 40 API SL/CF
Vehicle mileage, km	35000	65000	80300	94994
Oil work life, km	15000	16000	15300	14694
Kinematical viscosity at 100 ºC, mm^2/s	14.8	13.2	12.6	13.6
Base number, mg KOH/g oil	0.82	0.29	1.98	1.28
Acid number, mg KOH/g oil	6.71	5.77	2.73	4.39
Coking, %	2.27	2.31	2.46	2.53
Iron concentration (Fe), g/t	211	225	241	395
Dielectric constant	2.6177	2.6184	2.6177	2.6234
Rate of iron entry (Fe) of into the oil, mg/km	0.047	0.047	0.052	0.091

For these operating conditions of the VAZ-2107 car (Table 3), the terms for changing engine oil are too high and they need to be reduced, since the acid number exceeded the limit value in 2.8 mg of KOH/g of oil [1,20].

An analysis of the rate of iron entry into the AVIA SAE 10W-40 API SL / CF engine oil for the VAZ-2107 car engine showed that with an increase in the vehicle mileage from the start of operation (94994 km), the concentration of wear products (iron) in the oil increases by 1.87 times. The rate of iron intake in mg per km of run is 1.94 times higher when compared with a car mileage of 35 thousand km. Table 4 shows the results of the experiment, which was aimed at obtaining quality indicators of engine oil and the rate of iron (Fe) entry into SAE 10W-40 oil for a GAZ-31105 passenger car at different periods of operation.

Table 4. The results of the analysis of oil quality indicators during the vehicle operation for models GAS -31105

The name of indicators		OPTIMAL Classic SAE 10W-40 API SG/CF-4	AVIA SAE 10W-40 API SL/CI-4	AVIA SAE 10W-40 API SL/CI-4	AVIA SAE 10W-40 API SL/CI-4	SPECIAL PLUS SAE 10W-40 API SG/CD
Vehicle mileage, km		96000	111300	121000	126500	141500
Oil work life, km		10000	15300	9700	15200	15000
Kinematical viscosity at 100 ºC, mm^2/s		14.6	15.1	15	15.8	17.42
Base number, mg KOH/g oil		0.06	2.1	0	0	0
Acid number, mg KOH/g oil		3.44	2.6	8.66	12.54	4.7
Iron concentration (Fe), g/t		300	441	346	528	423
The dielectric constant		2.6214	2.5779	2.7503	2.6707	2.6877
Rate of iron entry (Fe) of into the oil	mg/km	0.16	0.15	0.19	0.19	0.15
	mg/L fuel	1.65	1.59	1.61	1.56	1.69

Figure 3 shows a graphical view of the influence of the resource of GAS-31105 vehicles on changes in the characteristics of SAE 10W-40 API SL / CI-4 engine oil during operation.

During the operation of the GAZ-31105 car on various motor oils (Table 4), there is a rapid decrease in the base number (0 mg KOH/g oil) and at the same time an increase in the acid number (8.66 mg KOH/g oil) already at a run of 9,700 km. This indicates the low effectiveness of alkaline additives in the filled oil, which quickly lost its ability to neutralize acidity.

It is undesirable to use engine oil when the base number drops below 0.5 mg of KOH / g of oil. In this case, it was necessary to replace the engine oil OPTIMAL Classic SAE 10W-40 API SG / CF-4, AVIA SAE 10W-40 API SL / CI-4 and SPECIAL PLUS SAE 10W-40 API SG / CD earlier, when the vehicle was operation under these conditions.

The rate of iron entry into engine oil is in the range of 1.56-1.69 mg/L of fuel, which is much higher than during normal operation 0.21...0.75 mg/L. Changes in the quality characteristics of engine oil and the rate of iron entry into SAE 10W-40 oil during the operation of VAZ passenger cars are presented in Table 5. Figure 6 shows a graphical view of the influence of the resource of VAZ-21104 vehicles on changes in the characteristics of SAE 10W-40 engine oil during operation.

Table 5. The results of the analysis of oil quality indicators during the vehicle operation for models VAZ's

The name of indicators		VAZ-21104 Galaxis Extra 2 SAE 10W– 40 API SJ/CF	VAZ-21104 Shell Helix Plus SAE 10W – 40 API SJ/CF	VAZ-21104 Shell Helix Plus SAE 10W – 40 API SJ/CF	VAZ-2109 Mobil Delvac MX SAE 10W– 40 API CF/SJ
Vehicle mileage, km		12170	60570	93240	96000
Oil work life, km		9868	11640	14560	17000
Base number, mg KOH/g oil		1.5	1.83	1.86	1.88
Acid number, mg KOH / g oil		4.74	4.36	3.14	2.75
Iron concentration (Fe), g/t		71	169	58	243
The rate of iron entry (Fe) of into the oil	mg/km	0.041	0.022	0.013	0.057
	mg/L fuel	0.56	0.31	0.17	0.64

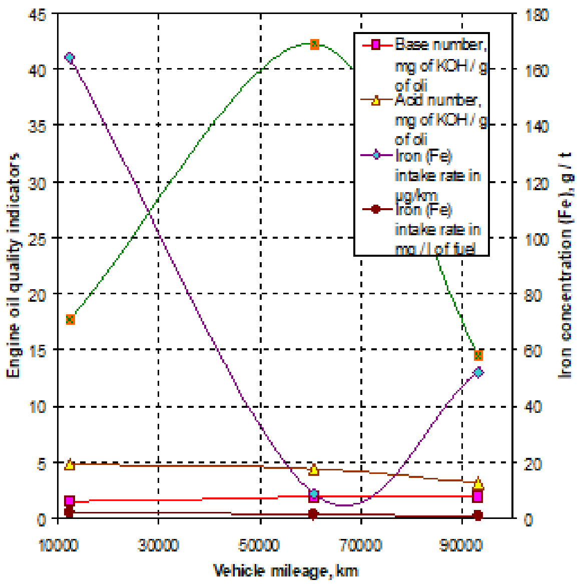

Figure 4. Graphs of changes in oil quality indicators from the mileage of a car of VAZ-21104 models.

An analysis of the oil quality indicators during the operation of a VAZ-21104 car using Shell Helix Plus SAE 10W-40 API SJ/CF engine oil (Table 5) confirmed that it is possible to change oils at a mileage of 15 thousand km. The rate of iron entry into the engine oil was 0.17 mg/L of fuel consumed. For the VAZ-2109 car, when operating on Mobil Delvac MX SAE 10W-40 API CF/SJ engine oil and replacing it at 17,000 km, it was found that the rate of iron entering the engine oil was 0.64 mg/L of fuel consumed.

4. Conclusions

Studies have established a stable relationship between fuel consumption, operating conditions, engine oil life and the total mileage of the vehicle. An analysis of the results of changes in engine oil quality indicators during the operation of cars and trucks confirmed that it is necessary to replace oils according to rejection indicators, taking into account the actual state of the engine oil.

Having the value of the rate of entry of wear products into the engine oil, which were obtained during the break-in period for each specific vehicle and comparing these with the values obtained later during the next oil change, it is possible to timely establish the onset of intensive wear in the joints and elements of engine, as well as indicate the malfunctioning of its systems, taking into account the design features of this vehicle.

If there is information about the rate of entry of wear products and the quality of the engine oil used, when the vehicle operates under the same conditions and on oils from different manufacturers, then it can be argued with a greater probability that the engine is operable on these oils and these terms for their replacement.

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