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EXPERIMENTAL MECHANICS,  
DIAGNOSTICS, AND TESTING

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## Assessment of the Interaction between Crankcase Gases and Engine Oil

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**Abstract**—Topical aspects of assessing the effect of crankcase gases of an internal combustion engine on the operational properties of engine oil taking into account its service life are considered. For a mathematical description of the change in the condition of engine oil, a complex criterion for assessing oil operational properties and a criterion for assessing the saturation with crankcase gases are proposed. At the same time, it has been found that the change in each of the criteria depending on the service life and engine rotational speed can be approximated by an exponent at a confidence level amounting to 0.95. The parameters of the proposed criteria have been assessed. It is shown that these criteria can be used jointly for diagnosing the condition of engine oil. It has been established preliminarily that the detailed service life of the engine affected by the properties of engine oil can be determined by the simulated time of interaction between the oil and the crankcase gases.

**Keywords:** engine oil, crankcase gases, pressure, viscosity, criterion, service life

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### INTRODUCTION

It is known that the reliability of internal combustion engines is determined by three groups of factors like the structural, technological, and operational ones. Moreover, if in the design and production of engines the reliability is provided in accordance with the design and technological documentation, then in the course of the intended use thereof the reliability drawbacks are exhibited in the form of failures, and the proper reliability level should be supported by a wide range of measures according to the instructions and recommendations. The faultless operation of the crank mechanism, lubrication systems, and crankcase ventilation is one of the properties of the parametric reliability in general. The efficient functioning of the structural elements mentioned is inseparably linked with the processes of supplying engine oil to plain bearings and interaction between oil aerosol in the engine cavities (crankcase space, cylinder head, and channels) and the crankcase gases, purifying and removing these gases. The studies on these processes seem to be an urgent scientific and engineering problem that should be solved in order to provide for the operational reliability of engines intended for various purposes.

To date, great attention has been paid to providing the efficient functioning of crankcase ventilation systems and the relationship between the engine condition and changes in the operational properties of engine oils [1–9].

Thus, the authors of [1–3] have improved the design of crankcase ventilation systems: a new design of an oil separator is proposed, an additional bellows-type heat exchanger is introduced, and additional elements are made in the form of walls and communication channels, alongside with other technical solutions. The content of engine oil in crankcase gases has been examined and evaluated therein. In [4], a relationship between the wear level of the cylinder–piston group and the consumption of crankcase gases has been estimated. At the same time, it has been established that, in the course of oil aging, the flow rate of crankcase exhibits an increase. The author of [5] proposed a variant for controlling the viscosity of ship engine oils by intensifying oil replenishment in the oil system, as well as by adding surfactants to the oil.

At the same time, it is established that a decrease in the growing wall and bulk viscosity level inherent in Castrol MLC30 engine oil occurs as a Mitsubishi S6A2 diesel engine operates.

Studies are being performed for establishing the thermal oxidative stability of engine oils; some of them, for example, are presented in the authors' papers [6, 7]. In this case, special units are used wherein only fresh portions of fuel are placed, with no saturation with any other gaseous substances. The authors of [7, 8] consider the effect of engine oil aging on the wear-preventive properties thereof. To do this, it is proposed to sample oils from running engines which makes it possible to evaluate changing their properties according to the light absorption coefficient (direct photometric method), according to the relative viscosity coefficient, as well as according to measuring the wear-protective properties using a three-ball-type friction testing machine. In this case, when the oil has been used taking into account the interaction with crankcase gases, which implies an objective assessment of the quality deterioration according to the viscosity and thermal oxidation parameters, the materials of the friction testing machine balls have not matched the tribotechnical properties of the materials used in making engine parts.

### FORMULATION OF THE PROBLEM

Engine idling is accompanied by poor ventilation of the combustion chamber owing to a closed throttle valve, a low turbulence level of the fuel–air mixture owing to the relatively slow movement of the piston, and, accordingly, a low combustion rate. In this case, the breakthrough of gases into the crankcase is maximum [8], which is connected with a decrease in gas pressure on the inner surface of the compression rings, observed to a greater extent when the service life of the cylinder–piston group is spent by 50% or more. The increase in the viscosity of engine oil can be caused by the processes of oil and additive thermal polymerization, oxidation, low-temperature fraction loss due to evaporation, water ingress, aeration, and antifreeze ingress. If the four previous reasons are excluded, then it is worthwhile to pay attention primarily to the thermal polymerization and oxidation [10].

Thus, the effect of crankcase gases on changes in the performance of engine oil takes place and accompanies the engine working processes in cylinders and crankcase. At the same time, the efficiency of crankcase gas removal from the engine is determined by the design of the crankcase ventilation system, whereas the reduction in aeration and foaming level of engine oil is determined both by the oil properties and by the design of the engine lubrication systems [10].

This paper is aimed at the assessment of the effect of crankcase gases on the changes in the operational properties of engine oils.

### THEORETICAL ASSESSMENT

The engine run time  $T$  before repair, the engine operating mode, and the crankcase gas pressure affect the physicochemical interaction between the liquid phase (engine oil) and the gas phase (crankcase gases) at the interface. Therefore, it is important to consider a change in the operational properties usually determined under oil monitoring in the course of engine operation: the kinematic viscosity, total base number and acid number, and flash point in an open crucible. The relationship between engine parameters and oil characteristics can be represented by the following system of equations:

$$\left. \begin{aligned} \gamma_{100} &= f(T, n, p_e, p_c), \\ N_{al} &= f(T, n, p_e, p_c), \\ N_{ac} &= f(T, n, p_e, p_c), \end{aligned} \right\} \quad (1)$$

where  $\gamma_{100}$  is the kinematic viscosity,  $T$  is the engine running time between overhauls,  $n$  is the crankshaft rotational speed,  $p_e$  is the engine load (average efficient pressure per cycle),  $p_c$  is the crankcase gas pressure,  $N_{al}$  is the total base number, and  $N_{ac}$  is the acid number.

From the system of equations (1), it follows that the parameters acting as arguments, according to the character of working processes occurring within the engine and to the interrelation between them, can be expressed as a dimensionless criterion for assessing the saturation level of engine oil with crankcase gases  $\pi_c^m$  (2):

$$\pi_c^m = Tn \frac{p_e}{p_c}. \quad (2)$$

In relationship (2), instead of the load on the engine (the average efficient pressure per cycle), it is worthwhile to use the value of the intake pressure  $p_0$ , which can be determined experimentally upon diag-

nosing the engine. This approach makes it possible to rely on directly measured parameters, including those obtained under real engine operating conditions [10].

The operational properties can be presented as a dimensionless integrated assessment criterion  $E_m$  (3). Then system of equations (1) should take the following form (3):

$$E_m = \frac{\gamma_{100}^n N_{al}}{\gamma_{100}^c N_{ac}} = f(\pi_c^m), \quad (3)$$

where  $\gamma_{100}^n$  and  $\gamma_{100}^c$  are the nominal and current values of kinematic viscosity,  $\text{mm}^2 \text{s}^{-1}$ .

Thus, the analysis of the interaction between crankcase gases and engine oil components according to the oil operational properties should make it possible to obtain mathematical models for the proposed comprehensive assessment criterion  $E_m$  depending on the engine running time  $T$ . In other words, it seems possible to obtain regularities for the aging of engine oils, too. However, this requires a long time for the very laborious acquisition of a rather large amount of data.

At the same time, one could obtain the required result much faster and less laboriously with the use of physical simulation under laboratory conditions. Such a procedure should consist in the simulation of engine oil saturation with crankcase gases. In this case, the parameter for the evaluation of the possible oil operation time should consist in saturation time  $t$ , which represents a parameter of the simulated physical process acceleration occurring in a real engine. Then relationship (3) should take the following form:

$$E_m = f\left(\frac{tnp_0}{P_c}\right). \quad (4)$$

In order to calculate the  $E_m$  criterion according to relationship (4), taking into account the real engine operation, the following are necessary:

to obtain samples of oils that interact with the crankcase gases of a real engine in the appropriate operating modes;

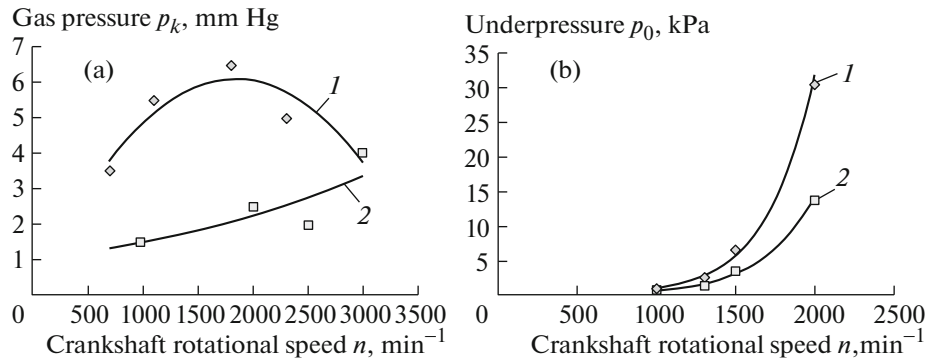
to conduct studies on the parameters of engine oils and to determine the  $E_m$  values;

to determine the coefficients of the functional dependence, which should graphically approximate the statistical data obtained.

The semigraphical models are worthwhile to develop for engine oils that interact with crankcase gases. The dynamics of the interaction between the oils and crankcase gases depends on the duration and the saturation rate inherent in fresh engine oil under the saturation with crankcase gases of real engines, taking into account the wear level of the piston ring–cylinder friction assembly. The models obtained should make it possible, for example, to determine the operating time of the engine, as well as the moment for appropriate controlling of any engine system (for example, the crankcase ventilation system). Then, it becomes possible to provide a predictive assessment of the operational properties of engine oils, taking into account the wear level of the cylinder–piston group and the operation efficiency control of the crankcase ventilation system. However, in this case it is required to use the current running time  $T$  instead of the simulated time  $t$  [10].

The interaction between the components of the liquid and gaseous phases can occur both on the surfaces of fine-dispersed particles taken separately (molecules) and in their clusters (in volume). In our opinion, it is also important which hydrocarbons, in terms of the structure and molecular weight, constitute engine oil: mineral, semisynthetic, or synthetic lubricating compositions with additives determining the purpose of the engine oils and their operating modes.

It seems significant to establish, according to parameter  $E_m$ , the engine oil aging rate depending on the intensity of the corrosion–mechanical wear of friction assemblies based on materials limiting the engine service life. Such assemblies include a shaft journal–liner assembly of the crankshaft and of the camshaft, as well as a ring–cylinder (cylinder liner) assembly of the engine cylinder–piston group. Therefore, it is necessary to pay attention to this issue by simulating the contact interaction between materials with the use of small-sized samples under laboratory-scale conditions. For example, it is proposed to use a disk-pad friction scheme and friction systems based on 40Kh steel (15W-40 and crankcase gases)–AO20-1 alloy, 45 grade steel–(15W-40 and crankcase gases)–AO20-1 alloy, VCh800 cast iron–(10W-40 and crankcase gases)–AO20-1 alloy, KCh50 cast iron (5W-30 and crankcase gases)–AO20-1 alloy, etc.



**Fig. 1.** Experimental results: (a) dependence of the gas pressure on the crankshaft rotational speed: (1) engine warmed up from 40 to 70°C; (2) at a steady-state engine temperature ranging from 85 to 90°C; (b) the values of (1) intake vacuum and (2)  $p_0/p_k$  depending on the crankshaft rotational speed at a steady-state temperature ranging from 85 to 90°C.

### EXPERIMENTAL ASSESSMENT

In order to estimate preliminarily the changes in the operational properties of engine oil under forced saturation with crankcase gases, the following full-scale testing has been performed.

The testing technique consisted in the following procedures. The outlet pipe of the engine ventilation system (the engine being warmed up to the operating temperature) was placed in a glass vessel filled with the Wolf 10W-40 semisynthetic oil. The engine service life consumption amounted to more than 85%, with the car mileage being 130 000 km. The volume of the engine oil sample amounted to 200 mL. At that, the values of saturation time  $t_1$  amounted to 1 min and 3 min at a rotational speed  $n_1 = 975 \text{ min}^{-1}$  and at a rotational speed  $n_2 = 1000\text{--}3500 \text{ min}^{-1}$  in the mode of change for time  $t_2 = 35 \text{ s}$ , respectively.

In the course of the saturation of the oil portions measured, the pressure of the pulsed crankcase gas outflow through the ventilation pipe was registered. To do this, a hole with the corresponding diameter was made in the pipe. The pressure was measured using a MediTech manometer. The measured values of pressure  $p_c$  for a warmed-up engine at the rotational speed  $n = 1000 \text{ min}^{-1}$  amounted to 0.2–0.3 kPa, whereas at  $n = 3000 \text{ min}^{-1}$  we had  $p_c = 0.53\text{--}0.59 \text{ kPa}$ .

It should be noted that the lower the frequency of the crankshaft rotation, the higher the pressure fluctuation amplitude of the crankcase gases. In this case, the change in gas pressure with increasing idle rotational speed as the engine is warmed up exhibits an ambiguous character (see Fig. 1a). At a temperature of 25–35°C and  $n = 2200 \text{ min}^{-1}$ , pressure  $p_c = 1.07 \text{ kPa}$  has been registered. When the engine is warmed up from 40 to 70°C, the approximation of the obtained data is expressed by a polynomial with the confidence level of  $R^2 = 0.82$  having maximum gas pressures in the range of  $n = 1500\text{--}2000 \text{ min}^{-1}$ . At a steady-state normal engine temperature amounting to 85–90°C, the approximation of the obtained data is expressed by an exponential dependence with a confidence level of  $R^2 = 0.72$ . In addition, the diffuser underpressure has been measured in the throttle space of the carburetor for the warmed-up engine and at different throttle opening angles (Fig. 1b). The approximation of the obtained data can be expressed by an exponent at a confidence level of  $R^2 = 0.99$ . The  $p_0/p_c$  ratio can also be approximated by an exponent with a confidence level of  $R^2 = 0.99$ .

For the comparative assessment of the engine oil characteristics, we used samples with a Remol-2 additive taken from the crankcase at the beginning of the oil operation period and at the end thereof.

All the samples of engine oil have been tested in a specialized laboratory. The following characteristics have been determined: kinematic viscosity  $\gamma$  at 100°C and 40°C, in  $\text{mm}^2 \text{ s}^{-1}$ ; total base number (TBN)  $N_{ab}$ , in mg KOH/g; acid number  $N_{ac}$ , in mg KOH/g; and the concentrations of the chemical elements Zn, P, S, Ba, and Ca.

The analysis of the data obtained indicates the following features. As a whole, the direction of interaction between the crankcase gases and the engine oil coincides with the character of the decrease in the kinematic viscosity. This primarily indicates the dilution of engine oil by unburned fuel products contained in the crankcase gases. In this case, it is unlikely that thermal destruction processes occur.

The dynamics of the total base number decrease ranges from 0.2% to 3.9%. However, an increase in the total acid number is not observed. Nevertheless, the situation with one of the oil samples is quite dif-

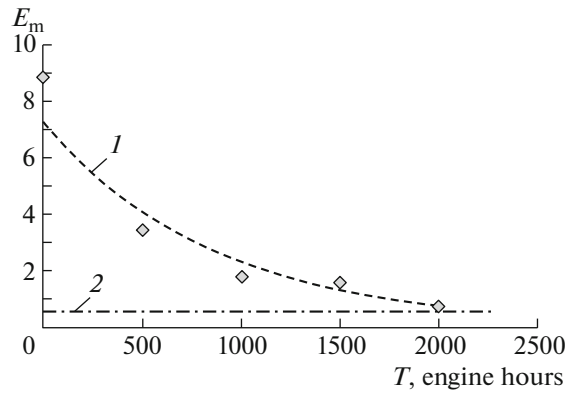


Fig. 2. Criterion  $E_m$  depending on the running time of gas piston engines: (1) current values and (2) a critical value.

ferent. In this case, there is a loss of the operational properties of engine oil according to the characteristics under consideration: a 41% decrease in viscosity, a 17% decrease in the total base number, and a 2% decrease in the acid number have been observed. It should be noted that the addition of the Remol-2 additive causes a 12% decrease in viscosity, which exceeds the critical level. In this case, the total base number exhibits a 6% decrease, whereas the acid number has a 24% decrease. Thus, against the background of a significant saturation level of fresh engine oil with crankcase gases, the effect of the Remol-2 additive exerted on the operation of the main additive package was ambiguous. This could be attributed to the limited amount of available experimental data. As far as the changes in the concentration of chemical elements is concerned, it is approximately proportional to the change in the total base number.

If one evaluates the  $E_m$  criterion in accordance with relationship (3), then the  $E_m$  values for the engine oil samples are as follows: 2.33 for no. 1; 2.45 for no. 2; 3.11 for no. 3; 3.27 for no. 4; 3.17 for no. 5. Preliminarily, evaluating only oil samples nos. 1–3, it should be considered that the smaller the value of the criterion  $E_m$ , the higher the functionality level with respect to the operational properties.

However, by evaluating the  $E_m$  criterion for the GProfi PSN 40 engine oil (used in high-power gas piston engines of power plants) under processing the experimental results [9], other results have been obtained (see Fig. 2). Figure 2 shows that the criterion  $E_m$  decreases exponentially with increasing engine running time  $T$  (at a confidence level of the data approximation  $R^2 = 0.95$ ), according to the following relationship:

$$E_m = ae^{bT}, \quad (5)$$

where  $T$  is the engine running time, engine hours, and  $a = 7.23$  and  $b = -0.001$  are the coefficients in the exponential dependence for the GProfi PSN 40 engine oil.

The results of the studies presented in Fig. 2 show that

the  $E_m$  criterion reflects the dynamics of changes in oil characteristics depending on the engine running time;

more extensive statistics is required in order to determine the law of changing in  $E_m$  at a more precise level;

for the specific class of engine oil under consideration, coefficients  $a$  and  $b$  from relationship (5) should have their specific values.

Thus, the prerequisites for obtaining an array of data according to the criterion proposed are formed. At the same time, it becomes possible to predict the operational properties of engine oils based on the engine running time in the course of engine operation in the corresponding modes [10].

From relationship (5) it follows that the detailed engine operational service life  $T$ , affected by the properties of the engine oil in accordance with relationship (4) can be determined by the simulated time  $t$  for the interaction between the fresh volume of engine oil and the crankcase gases. It seems logical that this time value can be considered as a convolute simulated service life taking into account the scale factor (the acceleration coefficient for engine oil saturation with crankcase gases).

## CONCLUSIONS

Taking into account the criteria proposed in this paper makes it possible to evaluate the impact of crankcase gases on the operational condition of the engine oil as the engine spends the operating service life. To determine the quantitative characteristics of the specific varieties of oil more precisely, it is necessary to conduct a more extensive statistical investigation. The approaches proposed, taking into account the results of experimental studies, are also applicable to other types of oils, as well as to other types and models of internal combustion engines.

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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