Mathematical modeling of changes in the physical and chemical properties of gas engine oils

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Abstract. The article deals with the mathematical models of physic-chemical changes of oil features of gas engine An engine running on gaseous fuel, in comparison with the same engine running on diesel fuel, sharply decreases the emission of carbon monoxide and hydrocarbons, which have a significant effect on the aging process of engine oil and carbon formation on the pistons. As a result of less contamination and reduced carbon formation and varnish deposits on engine parts that run on gaseous fuels, the service life of their engine oils can be longer than those of engine oils running on liquid fuels. At the same time, the repair time increases by 1.3-1.5 times, the complexity of their maintenance is reduced approximately by 15 %.

1. Introduction
In world practice, the issue of ensuring the reliability of internal combustion engines is an urgent complex task, solved in different spheres. The most important among them are the operating conditions, the type of used fuel, monitoring the condition of engine oils, as well as justification of the service life of the latter.

The widespread use of engines running on gaseous fuels increases the relevance of determining the optimal oil life every year. This is primarily necessary due to the characteristics of gas engines compared to diesel engines, as well as due to the characteristics of the gaseous fuel itself. The fuel, like its combustion products, in most cases does not contain abrasive and sulfur compounds. In gas engines especially, diesel engines, the efficiency of fuel combustion is significantly higher than in diesel fuel. This dramatically reduces the amount of products of incomplete combustion.

An engine running on gaseous fuel, in comparison with the same engine running on diesel fuel, sharply decreases the emission of carbon monoxide and hydrocarbons, which have a significant effect on the aging process of engine oil and carbon formation on the pistons. As a result of less contamination and reduced carbon formation and varnish deposits on engine parts that run on gaseous fuels, the service life of their engine oils can be longer than those of engine oils running on liquid fuels. At the same time, the repair time increases by 1.3-1.5 times, the complexity of their maintenance is reduced approximately by 15% [1,2].

2. Materials and methods
The material for the study was the change in the physicochemical properties of M10G2 motor oil when the engine is running on gaseous fuel. To develop a mathematical model of the aging of a working
engine oil, the results of a study of changes in the physicochemical indicators of engine oil from the operating time of the tractor were used. By calculation, graphs of the dependence of changes in physical and chemical indicators in 100, 200, 300, 400, 500 motor-hours of operation were built.

In the problem under consideration, the model is the operating engine oil and its physicochemical characteristics, and the mathematical model is the mathematical relationships describing the aging process of the engine oil.

3. The study of changes in the physicochemical characteristics of engine oils
The following basic requirements are imposed on oils for internal combustion engines: antifrictional and antiwear action over the entire operating temperature range; heat removal from friction surfaces and some engine parts; sealing above the piston space; minimal tendency to the formation of various kinds of deposits in the engine (varnishes, soot, deposits); anti-corrosion and protective properties; minimum foaming in the engine running; stability of the required performance properties in long-term use and storage.

For this purpose, a number of operational requirements are imposed on the engine oil, the degree of satisfaction of these requirements largely depends on changes in the physico-chemical parameters of the engine oil. The working conditions of engine oil in internal combustion engines are considered to be extremely harsh.

Many researches of native and foreign scientists are devoted to the study of the aging of engine oils during the operation of internal combustion engines. However, besides these works, it should be noted that they do not touch upon the issues of studying the change in the basic performance properties of gas engine oils based on diesel. Many experts emphasize the necessity of justifying the service life of engine oils [2,3].

There is no scientifically based oil change frequency nowadays. The development of a modern methodology for determining reasonable shift date is an important task.

Considering the above, mathematical modeling of engine oil maturing has a certain scientific and practical importance.

In the investigating problem, the model is the physicochemical properties of engine oils for gas engines based on diesel engines.

On developing a mathematical model of the maturing working engine oil, the results of a study of changes in the physicochemical indicators of engine oil from the duration of the engine as D-243, tractor TTZ-80-10 were used.

Dispersive analysis of the oil showed the presence of large (3-4 microns), medium (0.8-1.5 microns) and small (0.4-0.8 microns) particles; moreover, the number of middle particles is 85-90% of the total number of particles [1,3].

Compared to diesel engines, the operation of gas engines is characterized by a significant increase in midrepair dates. In the combustion products of gaseous fuel, there are practically no particles of solid carbon, which cause additional wear of the mating engine parts. The absence of dilution of the lubricant and a decrease in the amount of carbon deposits entering the crankcase from the combustion chamber will increase the life of the engine oil.

In gas engines based on diesel engines, the efficiency of fuel combustion is significantly higher than in diesel fuel.

In considering the process of contamination of the engine oil of an engine running on gaseous fuel, the model is the operating engine oil, the mathematical model is the change in the physicochemical parameters of the engine oil. In developing a mathematical model, depending on the duration of the oil, the results of changes in the physicochemical parameters of engine oil were used [1,2,5].

During the oil operation by the time $\tau$, the amount of contamination in the engine lubrication system will be $x$. In the lubricating oil, after time $d\tau$, more contaminants $a$ are entered [1].

The general differential formula that determines the change in the content of contaminants in the oil of an engine running on gaseous fuel during the time $d\tau$ will have the form:

$$[Q_0 - (Q_x - Q_d) \tau] d\tau = (a + xQ_d - xQ_0) d\tau$$  \hspace{1cm} (1)
The equation formula that determines the content of impurities in the oil is:

\[ G \delta x = (a - Q \gamma x) d \tau \]  

Integrating and carrying out the necessary transformations, assuming that at \( \tau = 0, x = 0 \), we obtain an expression for the content of impurities in the oil by the time:

\[ x = \frac{a}{\gamma} (1 - e^{-\frac{Q \gamma \tau}{a}}) d\tau \]  

If the content of impurities is expressed by \( \% \), then formula (2) will look like:

\[ x = \frac{100a}{\gamma} (1 - e^{-\frac{Q \gamma \tau}{a}}) \]  

It is important to take into consideration that some of the contaminants are retained by the cleaning units, therefore the real rate of contamination entering the engine oil will be lower than the value \( a \). Thus, the filtering factor \( f \), expressed in\( \% \), will look like:

\[ f = \frac{100}{a \tau - x\text{,}Q \gamma \tau}, \]  

and the real rate of contamination entering directly into the oil will be, and \( (1-f) \). Then formula (4) will take the form:

\[ x = \frac{100}{Q \gamma} \left(1 - f\right) \left(1 - e^{-\frac{Q \gamma \tau}{a}}\right) \]  

Formulas (4) and (6) are the main ones for calculating the content of pollution \( x \) in oil.

The relationship between the parameters can be represented in the form of a graph \( x = f(T) \). Based on the calculated results, it is possible to create a graph of the dependence of the change in the concentration of contaminants on the duration of oil operation. The calculation results are presented in Table 1.

![Figure 1](image_url)

**Figure 1.** Graphical dependence of the change in the concentration of contaminants on the duration of oil operation

During diesel operation, the alkalinity of the oil is spent on neutralizing and dispersing impurities, and the pH changes. For example, oil M-12 G₂, which has a pH of 9.5, after 100 h of operation had a pH of 7.5–8.0 [4].
Alkaline additives decrease as the oils interact with fuel combustion products containing significant amounts of sulfur and nitrogen.

The study of the kinetics of changes in the alkalinity of oil is considered the easiest way to investigate the kinetics of the actuation of additives. The consumption rate of the alkaline additive depends on the content of acidic substances in the fuel combustion products [2,3].

According to the research works of A.G. Morozov, O. M. Ortsiomov, the rate of change in alkalinity K is determined from the formula:

$$K = 0.35y FS \text{ (mg KOH/g)}$$  \hspace{1cm} (7)

where F is fuel consumption, kg/h; S - sulfur content in fuel, %; y = 0.07. ... ... 0.013 is a measure that determines what part of the sulfur oxides formed during fuel combustion enters the piston ring zone and reacts with an alkaline additive.

To indicate that the expression K = 0.35y FS was obtained under the assumption of complete neutralization of sulfur oxides entering the oil.

The expression for the response rate of the additive can be written in the form:

$$\frac{dC}{dt} = -KC,$$  \hspace{1cm} (8)

where C - alkalinity, K – working rate constant.

By integrating this expression, one can obtain the simplest (without taking into account the waste and adding oil) dependence of the alkalinity of the oil on time:

$$C = C_0 e^{-Kt}$$  \hspace{1cm} (9)

Where $C_0$ - the initial alkalinity of the oil.

Based on the results represented in Table 1, let us create a graph characterizing the dependence of the alkalinity reduction on the duration of the oil operation in the form C = f (T).

![Graphical dependence of alkalinity reduction on the duration of oil operation.](image)

The density of the oil is considered one of the main physical and chemical indicators of the oil. The density value of the oil changes depends on the duration of engine operation.

A decrease in density is usually observed when fuel oil enters the oil. To determine the density of engine oil, a certain amount of liquid fuel is added to the oil, equal to the amount of oil in a ratio of 1:1 or 1:2, and the density value is determined using measuring instruments. Based on the obtained results, the density value of the oil can be calculated. Graph characterizing the dependence of the density change on the duration of the oil operation in the form $\rho = f (T)$.

$$\rho^{19} = 2 \rho_1 - \rho_2, \text{ g/sm}^3$$  \hspace{1cm} (10)

where; $\rho^{19}$ - the density of the oil; $\rho_1$ - the density of the mixture of liquid fuel and oil; $\rho_2$ - the density of liquid fuel;
Figure 3. Graphical dependence of the density change on the duration of oil operation.

Viscosity is one of the most important performance indicators of oil quality, on which the reliability of oil flow into the gaps between the friction surfaces of engine parts, the creation of a sufficiently strong lubricating film during friction, the ease of starting a diesel engine at low temperatures, mechanical losses and specific fuel consumption, intensity wear, etc.

The kinematic viscosity can be determined from the ratio:

\[ \nu = \frac{\mu}{\rho} \cdot \text{sSt} \]  \tag{11}

where: \( \rho \) - the density of the oil;

graph characterizing the dependence of the change in kinematic viscosity on the duration of oil operation in the form \( \nu = f(T) \).

Figure 4. Graphical dependence of the change in kinematic viscosity on the duration of oil operation.

The flash temperature characterizes the flammability of the oil and indicates the presence of volatile fractions in it, but does not give an idea of their quantity. There are two types of devices for determining the flash point - with an open and a closed crucible. In the Brencken device with an open crucible, the flash temperature of oils is 20-25 °S higher than in the Marten-Penskiy device with a closed crucible.

Figure 5. Graphical dependence of the change of kinematic viscosity on the duration of oil operation.

The flash point of engine oils used in tractor diesel engines is determined in accordance with GS 4333-2000 in a device with an open crucible.
Table 1. Calculation results of changes in the main physical and chemical parameters of gas engine oils

| Name of indicators                  | Duration of work, T moto/hour |
|-------------------------------------|------------------------------|
|                                     | 0   | 100  | 200  | 300  | 400  | 500  |
| Percentage of concentration pollution (%) | 0.015 | 0.020 | 0.0231 | 0.0241 | 0.0245 | 0.026 |
| Alkalinity mg KOH / mg              | 6   | 4.3  | 3.2  | 2.2  | 1.94 | 1.9  |
| Kinematic viscosity at 1000 °C cSt  | 11±0.5 | 10.4 | 10.1 | 9.8  | 9.7  | 9.6  |
| Density at 20 °C, kg / cm³          | 0.905 | 0.894 | 0.888 | 0.884 | 0.879 | 0.876 |
| Flash point                         | 210  | 208  | 206  | 204  | 201  | 199  |

4. Conclusion
In conclusion, it can be said, in engines operating on gaseous fuel, the content of contaminants significantly decreases, the oil date of service will increase by an average of 25%, one of the main oil indicators, alkalinity and kinematic viscosity are within the acceptable range for usage, the theoretical data obtained indicate that at the operation of the engine on gaseous fuel is expected to increase the shift period by an average of 1.5 times.

When the engine is running without oil change for 240 hours, the alkalinity reserve of some additives is used up almost completely. The rapid response of the active part of the additive leads to rapid drop in neutralizing and detergent properties, which in turn leads to a reduction in the oil change period in the engine.

Based on the foregoing, the following conclusions can be drawn:
- the rate of oil pollution depends on the operating time of the oil, the from changes in its operational properties and the type of fuel used;
- the longer the operating time of the oil, the greater the rate of accumulation of wear products more;
- as a result of the actuation of additives, the alkalinity of the oil decreases:

5. Acknowledgments
This study was carried out as part of the development of recommendations for analyzing the operation of oil in gas engines based on diesel engines on a machine-tractor fleet

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