Influence of fractional composition of fuel on engine performance

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Abstract. The fractional composition of the fuel is associated with the operational characteristics of engines, in particular, the temperature regime and start-up, the tendency to form steam locks in the fuel system, and fuel costs. In the case of using fuel with an octane number lower than that required for this engine, knocking occurs. Therefore, the fuel must be knock-resistant, i.e. the ability to burn in the engine at rated speed without explosions. The chemical stability of the fuel is also important - the ability to resist the formation of tar and oxidation during a certain (induction) period at a temperature of 100°C. The physical stability of the fuel is characterized by the absence of light fractions that evaporate during storage and transportation of gasoline. Fuel contamination is caused by the ingress of various mechanical impurities or water into its composition during storage and transportation. The presence of these impurities affects the performance of the fuel system, clogs it, as a result of which it fails, and in winter can lead to its freezing. Thus, the fractional composition of the fuel should be such that a good start of the engine and rapid acceleration of the power plant, low specific fuel consumption, uniform qualitative and quantitative distribution of the combustible mixture over the engine cylinders, minimal wear of pistons and cylinders are ensured, which confirms the relevance of studies aimed at study of the influence of the fractional composition of fuel on the performance of the engine.

1. Introduction
The problem of supplying fuel to the constantly increasing automotive fleet of the country in the context of a decrease in production growth and an increase in oil prices on the world market is currently being solved in two ways - the development of alternative fuels and more efficient use of hydrocarbon fuels in internal combustion engines [1-11].

Diesel fuel resources are limited by the content of straight-run diesel fractions in oil, the amount of which does not exceed 25%. To increase the yield of fuels suitable for use in diesel engines up to 50 ... 60% allow fuels with expanded fractional composition (EFC), obtained by adding gasoline, naphtha, kerosene and gas oil fractions to diesel, boiling within the temperature range of 80 ... 400°C.

The use of fuels with a density difference of 0.01 g / cm³ in diesel engines changes the hourly fuel consumption by 1.8 ... 1.9%, and an increase in the fuel temperature in the pump head by 10°C causes a decrease in its hourly consumption by about 2%. The extreme values of the density of diesel fuels of grades L, Z and A (according to GOST 305-82) are 0.805 ... 0.860 g / cm³, and the temperature of the fuel in the high pressure pump heads under operating conditions can reach values of 70 ... 100°C.
Consequently, the change in the hourly fuel consumption in diesel engines can reach 10% due to a change in the density of the fuels used by 16 ... 18% due to an increase in their temperature. The change in the hourly fuel consumption in this case reaches 20 ... 25%, which significantly worsens the operational properties of diesel engines (with a decrease in the hourly consumption) and reduces their reliability (with an increase in the hourly consumption).

2. Research results
To study the effect of the properties of injected motor fuels on the performance of a diesel engine, a number of fuels with a wide range of physical and chemical properties were selected (table 1).

**Table 1. Physical and mechanical properties of motor fuels.**

| Fuel                                      | Properties |                  |                  |
|-------------------------------------------|------------|------------------|------------------|
|                                           | density, $p_{20}$, kg/m$^3$ | static viscosity, $v_{20}$, mm/s | surface tension coefficient, $\sigma$, N/m$^2$ |
| Gasoline A-92                             | 747        | 0.700            | 2.2              |
| L-0.05-40 GOST 305-82                     | 835        | 4.690            | 2.5              |
| Fuel EFC according to TU 38.401500-84    | 823        | 4.090            | 2.4              |
| A mixture of 50% A-92 gasoline + 50% EFC fuel | 796        | 1.720            | 2.3              |
| Motor fuel GOST 1667-68                  | 908        | 20$^*$           | 3.0              |
|                                           |            | 12$^{**}$        |                  |

$^*$ – viscosity at 50°C; $^{**}$ – viscosity at 60°C.

The results of dynamometric tests of the influence of the properties of fuels on the indicator indicators of a single-cylinder engine are shown in figure 1.

The ignition delay period (IDP) was determined by processing indicator diagrams as the time between the start of fuel injection (along the curve of the nozzle needle stroke) and the beginning of separation of the combustion line from the compression line (along the pressure curve in the cylinder). Analysis of the IDP curves depending on the fuel injection advance angle $\Theta_{\text{adv}}$ shows that mixtures of 50% A-92 gasoline + 50% EFC fuel have significantly higher IDP values over the entire variation range $\Theta_{\text{adv}}$. This is due to the fact that the addition of a significant proportion of gasoline fractions leads to a noticeable decrease in the cetane number of the fuel.

Unlike mixed fuel, the use of EFC fuel and motor fuel in accordance with GOST 1667-68 does not lead to a significant increase in IDP. This is due to the fact that the cetane numbers of these fuels are in the range of 42 ... 45, which is not very different from the cetane number for a standard fuel. And the change in evaporation for a given operating mode of a diesel engine, apparently, does not have a noticeable effect on the IDP. Evaporation affects to a greater extent the rate of pressure rise during combustion ($dp/d\Theta$) in the first (“fast”) phase of kinetic combustion, which is illustrated by the dependence $dp/d\Theta = f(\Theta)$. The maximum values $dp/d\Theta = 0.87$ MPa / deg at the optimal $\Theta_{\text{adv}}$ are obtained when operating on a mixed fuel.
Figure 1. Dependence of specific fuel consumption (a), indicator pressure (b), maximum combustion pressure (c) and rate of pressure rise during combustion (d) on the injection advance angle of fuels with different physicochemical properties. 1 - fuel L-0.05-40 GOST 305-82; 2 - EFC fuel according to TU 38.401500-84; 3 - fuel GOST 1667-68; 4 - a mixture of 50% A-92 + 50% EFC.

The dependence $dp/d\theta = f(\theta)$ for the rest of the fuels practically does not differ from the analogous dependence when operating on standard fuel.

A similar course of the curves obtained when operating on various fuels is observed for the dependences of the maximum combustion pressure $p_z = f(\theta)$.

A feature of the curves of the dependence of the average indicator pressure ($p_i$) and the specific indicator fuel consumption ($g_i$) is the presence of their respective “maximum” and “minimum” for different fuel injection advance angles for each of the fuels used. This is primarily due to differences in IDPs, volatility of fuels, and the amount of heat released in the first and second phases of combustion.

It is characteristic that in the tested range for heavier and more viscous fuel GOST 1667-68, a clearly expressed extremum along the curves $g_i$ and $p_i$ was not achieved. This is apparently due to the peculiarities of the burnup of heavy fuel, which is characterized by a more prolonged process of the diffusion stage of combustion, which can be seen from the heat release characteristics shown in figure 2.

Analysis of the characteristics of heat release when using fuels with different physicochemical properties shows that the maximum rate of active heat release in the first phase $d\chi_1/d\theta$ for a composite fuel significantly exceeds the rate of heat release for other fuels. This is primarily due to the large amount of fuel introduced and evaporated during the ignition delay time. EFC fuel and heavy fuel in this phase have lower rates of active heat release than mixed fuel, but close to the rate of heat release when operating on standard fuel.
Figure 2. Influence of the physical and chemical properties of fuels on the characteristics of heat release (a) and the average temperature of gases in the cylinder (b). 1 - a mixture of 50% A-92 + 50% EFC; 2 - fuel GOST 1667-68; 3 - EFC fuel according to TU 38.401500-84; 4 - fuel L-0.05-40 GOST 305-82.

Attention is drawn to the clearly pronounced prolonged nature of active heat generation (\( \chi_i \)) for heavy fuel (GOST 1667-68), which, apparently, is associated with a significantly higher level of exhaust gas smoke (table 2).

Table 2. Changes in the content of toxic components depending on the fuel injection advance angle for various fuels.

| Injection advancing angle \( \theta \), deg. | Smoke of exhaust gas, units Bosh | Concentration \( CO \) in exhaust gases, ppm | Concentration \( NO \) in exhaust gases, ppm |
|-------------------------------------------|----------------------------------|----------------------------------|----------------------------------|
| L-0.05-40 GOST 305-82 | L-0.05-40 GOST 305-82 | EFC according to TU 38.401500-84 | EFC according to TU 38.401500-84 | 50% A-92+50% EFC | EFC according to TU 38.401500-84 | Motor GOST 1667-68 | Motor GOST 1667-68 |
| 20 | 3.6 | 7.3 | 7.2 | 8.1 | 4200 | 6500 | 5000 | 6800 | 620 | 665 | 450 | 580 |
| 24 | 3.3 | 6.8 | 6.6 | 7.7 | 3600 | 5550 | 4750 | 6200 | 700 | 855 | 1200 | 620 |
| 28 | 3.0 | 5.6 | 5.5 | 6.8 | 3200 | 4800 | 4550 | 5750 | 880 | 990 | 1750 | 1100 |
| 32 | 2.8 | 4.7 | 4.6 | 6.0 | 3100 | 4000 | 4200 | 5500 | 1300 | 1800 | 2500 | 1500 |
| 36 | 2.5 | 4.0 | 4.3 | 5.7 | 3200 | 3200 | 4000 | 4700 | 2000 | 2500 | - | 1800 |

An increased level of smoke is also observed when operating on EFC and mixed fuel (50% A-92 gasoline + 50% EFC fuel), but in the area of optimal fuel injection advance angles, their level does not exceed значений 5 units on the Bosh scale.

Table 2 shows data on the change in the content \( CO \) and \( NO \) in the exhaust gases, depending on \( \theta_{opt} \) for fuels with different physical and chemical properties. It can be seen that when operating on heavy fuel, the content of carbon monoxide \( (CO) \) in almost the entire range of change \( \theta_{opt} \) exceeds the values of concentrations \( CO \) when operating on mixed fuel, standard fuel, and EFC fuel. This can be associated with a delay in the combustion of heavy fuel, which correlates with a more sluggish course of the afterburning section of the heat release curve \( \chi_i = f(\theta) \) (figure 2). Approaching \( \theta_{opt} \) the optimum values for each fuel leads to a decrease in the content \( CO \) in the exhaust gases.
The effect $\theta_{\text{epr}}$ on the content of nitrogen oxides ($NO_x$) is normal, i.e. with a decrease $\theta_{\text{epr}}$ the concentration $NO_x$ decreases. However, the level of concentrations $NO_x$ in the exhaust gases significantly depends on the physicochemical properties of the tested fuels. The maximum concentrations $NO_x$ were observed when using a mixed fuel (50% A-92 gasoline + 50% EFC fuel) practically in the entire range of variation $\theta_{\text{epr}}$. This is due to the higher value of the maximum combustion temperature of the composite fuel, as illustrated by the curves $T(\theta)$ in figure 2, as well as the higher values of the current pressure in the cylinder.

3. Conclusion
The use of more viscous and heavier fuels leads to an increase in the maximum injection pressure and significantly reduces the injection time. The introduction of light gasoline fractions into the fuel increases the IDP, process severity and maximum combustion pressure.

The use of EFC fuel does not have a noticeable effect on the specified characteristics, while some deterioration in the indicator indicators of the diesel engine is observed. The introduction of light gasoline fractions into the fuel leads to an increase in the rate of active heat release in the first phase of combustion and a decrease in it in the second.

The heavier fuel leads to a delay in the combustion process. In this case, there is an increased smoke level of the exhaust gases and an increase $CO$ in the content in them.

An increase in the concentration $NO$ in the exhaust gases in comparison with other tested fuels was noted when operating on a mixture of fuels, the combustion of which is characterized by higher temperatures and maximum cycle pressure.

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