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BENCH TESTS OF THE MODERNIZED TRACTOR DIESEL

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The car and tractor diesel engines are used in various natural and climatic zones of the country, where the ambient temperature varies in a wide range. The effective performance of a diesel engine largely depends on the performance properties of fuel and lubricants exposed to ambient temperatures. The purpose of this work is to study and substantiate the temperature of the fuel in the filling cavity of the high-pressure fuel pump, which ensures the optimal technical and economic performance of the diesel engine. The purpose of the work was achieved by analyzing scientific publications in domestic and foreign peer-reviewed journals, by conducting bench tests of the fuel pump and brake tests of a diesel engine under conditions of a forced change in fuel temperature. Using the method of planning a multifactorial experiment, the optimal temperature range of diesel fuel was determined, which provides the effective performance of a tractor diesel engine. The studies made it possible to determine the optimal technical and economic indicators of a tractor diesel engine.

Keywords: diesel, diesel fuel, torque, effective power, temperature, pressure.

Introduction

Higher efficiency of car and tractor machinery equipped with diesel engines largely depends on the operational properties of fuel and lubricants. The operation of tractor diesel engines is carried out in various natural and climatic zones of the country, where the ambient temperature varies in a wide range from -35 °C to +30 °C and above [1-5].

The fuel in the units of the fuel system (FS) is most exposed to ambient temperature. In summer, at an ambient temperature of +23 °C, when the MTZ-80 tractor was operating on summer diesel fuel, equipped with a standard fuel system, and with an engine load close to the nominal, the fuel temperature in the filling cavity of the fuel pump was +78 °C. In winter, at an air temperature of -26 °C, when the MTZ-80 tractor was filled with winter diesel fuel, the fuel temperature was +2 °C [1-5].

The temperature of the fuel in the fuel system units is influenced by both design factors (location of the fuel tank, fine filter, length of the low pressure line) and the operating modes of the diesel engine in operation (load, speed, temperature modes).

The change in the fuel physical properties, that depend on its temperature, affects the change in the output parameters of the high-pressure fuel pump (HPFP) (average cycle and hourly fuel supply, uneven fuel supply along the pressure lines) and the effective indicators of a diesel engine (effective power, specific effective fuel consumption, effective torque on the engine crankshaft).

To automatically maintain the optimal fuel temperature in the high-pressure fuel pump on

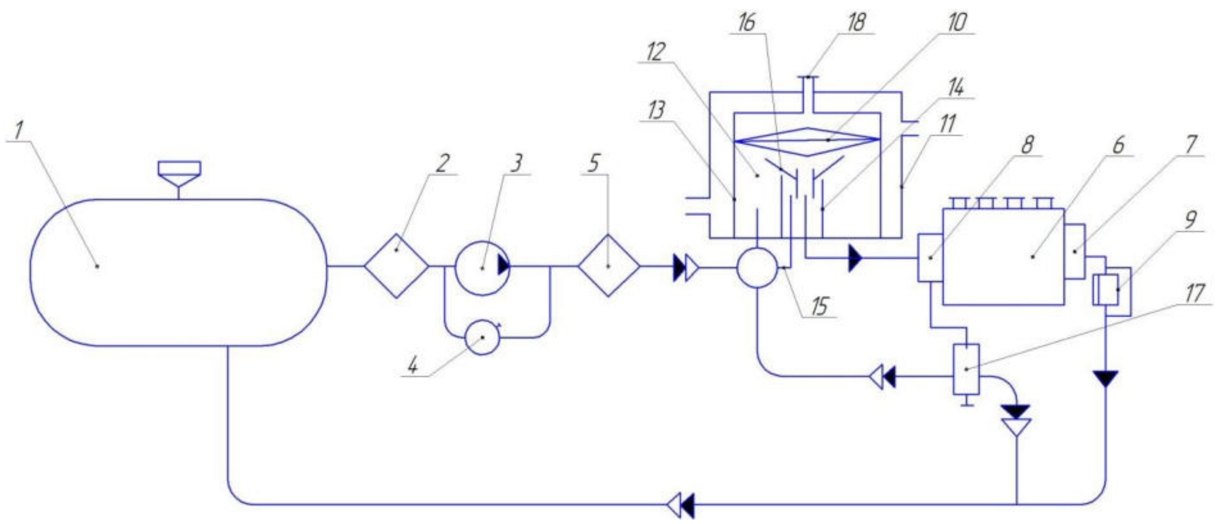

Figure 1. Diagram of the diesel fuel supply system with a thermostatic device:
1 – fuel tank; 2 and 5 – coarse and fine filters; 3 – booster pump; 4 – pressure reducing valve;
6 – high pressure fuel pump; 7 and 8 – inlet and outlet cavities of the high-pressure fuel pump;
9 – pressure reducing valve; 10 – electric heater, 11 – votator; 12 and 17 – air separators; 13 and 14 – external and internal pipes of the mixer; 15 – delivery line; 16 – dividing cone; 18 – valve

a working diesel engine of a tractor in a temperate climate, an upgraded diesel fuel system with a heat exchanger-mixer is proposed [6], the diagram of which is shown in Figure 1.

Methods and materials

During the research, analytical methods were used for calculating the parameters of a diesel engine's working process using computer application program, as well as the method for planning a multifactor experiment during bench tests of a fuel pump and brake tests of a diesel engine under conditions of a forced change in fuel temperature.

Results

One of the ways to change the effective torque of a tractor diesel engine is to ensure the feed consistency of the average cycle fuel supply of the high-pressure fuel pump along the discharge lines.

The calculation of the indicators of the working process of the diesel engine, including the torque, is carried out for one kg of diesel fuel.

It is known that the effective torque of the engine is [7]:

$$M_e = M_i - M_{\text{мп}} = \frac{10^3 V_h \cdot z}{\pi \cdot \tau}(p_i - p_{\text{мп}}),$$

where M_i – indicated torque, Н м;

$M_{\text{мп}}$ – mechanical loss moment, Н м;

V_h – working volume of the cylinder, l;

z – number of engine cylinders;

τ – engine stroke;

p_i – average indicator pressure, MPa;

$p_{\text{мп}}$ − average pressure of mechanical losses, MPa.

The average indicated pressure can be determined through the fuel cycle using the formula [7]:

$$p_i = \frac{g_{\text{ц}} \cdot \eta_i \cdot H_u}{V_h},$$

where $g_{\text{ц}}$ – mass cycle fuel supply, g/cycle;

η_i – engine indicator efficiency;

H_u – fuel lower heating value, MJ/kg.

The average pressure of mechanical losses is [7]:

$$p_{\text{мп}} = 0.09 + 0.012\text{С}_{\text{п}} = 0.09 + 0.0008 r_{\text{кр}} \cdot n,$$

where $C_{\text{п}} = S \cdot n/30 = 2 \cdot r_{\text{кр}} \cdot n/30$ − average piston speed (m/s);

S – piston stroke, m;

$r_{\text{кр}}$ – radius of the crankshaft crank, m;

n – crankshaft rotation speed, min $^{-1}$.

Diesel effective power (kW) is determined by the formula

$$N_e = \frac{p_e \cdot V_h \cdot n}{30 \cdot \tau},$$

where p_e – average effective pressure, MPa, $p_e = p_i - p_{\text{мп}}$.

Thus, it follows from the above that it is possible to change the value of the effective power and effective torque by changing the cyclic feed ($g_{\text{ц}}$) and heating value (H_u) of the fuel.

The fuel lower heating value of summer diesel fuel is determined by the formula [8]:

$$H_u = 34.013 \cdot C + 125 \cdot H - 10.9(O - S) - 2.52(9 \cdot H + W),$$

where S and W – sulfur and water content ($S = 0, W = 0$) and H_u = 42.4 MJ/kg.

The cyclic fuel supply is determined from the expression

$$g_ц = V_ц \cdot \rho_т,$$

where $V_ц$ – average cycle feed, mm^3/cycle;

$\rho_т$ – fuel density, g/mm ^{3} [1]:

$$\rho_т = \rho_0 - 10^{-4}(18-13\rho_0)(t_т - t_0),$$

where ρ_0 – fuel density under normal conditions (t_0 = 20 °C);

$t_т$ – fuel temperature, °C.

When the initial temperature state is constant, characterized by the initial temperature of the fuel before entering the compression cavities of the high pressure fuel pump higher than the standard, the fuel density in the cavities remains practically unchanged due to the fact that with temperature increase the density decreases according to the dependence [1]

$$\rho_т(T) = \rho_0 - 10^{-4}(18–13)\ \rho_0(T–T_0),$$

and when the pressure increases, the density increases according to the law [9]

$$\rho_т(p) = \rho_0 + \frac{400 \cdot p}{10^6 \cdot \rho_0^5},$$

where ρ_0 – fuel density at standard conditions (T_0 = 293 K, p_0 = 101325 Pa).

Within the range of pressure (from 2 to 100 MPa) and temperature (from 293 to 373 K) of the fuel in the high pressure fuel pump, a positive increase in density [$\Delta\rho_т(p)$] with increasing pressure, is practically compensated by a negative linear increase (decrease) of density [$\Delta\rho_т(T)$] from temperature rise. In this case, the fuel density as a function of two variables $\rho_т(p,T) = \text{const} \cong \rho_т$.

However, the initial fuel temperature on a running diesel engine is a random function of many variables and depends at any time on the ambient temperature, load, speed and temperature modes of engine operation [10-21].

Experimental data, which was obtained from the results of non-motorized tests to assess the effect of fuel temperature on the hydrodynamic and control parameters of the fuel system and the parameters of the 4UTNM pump, show that as a result of the forced change in the fuel temperature from +20 °C to +60 C, at the nominal rotational speed of the cam pump shaft, the average volumetric cyclic fuel supply is reduced by 6.1%, hourly supply – by 9.1%. Approximating equations that establish the dependences of the average volumetric cyclic feed ($V_ц$) and hourly feed ($G_ч$) in the range of fuel temperature ($t_т$) from +15 °C to +65 °C:

$$V_ц = 73.338787 + 0.5973218t_т – 0.036896t_т^2 + 0.0007481t_т^3 – 0.00000516t_т^4;$$

$$G_ч = 19.17098 – 0.1392795t_т + 0.0023881t_т^2 – 0.0000175\ t_т^3.$$

With this, stabilization of the volumetric cyclic supply, which has a direct effect on the effective performance of the diesel engine, occurs at a temperature range of +35...+50 °C, which corresponds to the value of the volumetric cyclic feed ($V_ц$), equal to 73.5...72.3 mm3/cycle.

Based on the results obtained, brake studies of the 4CH 11/12.5 diesel engine were carried out using the method of a multifactor experiment planning.

The following factors were taken as operating factors: fuel temperature ($t_т$) in the filling cavity of the high pressure fuel pump, engine oil temperature ($t_м$) in the oil pan, coolant temperature ($t_в$) at the radiator inlet. As a result of the brake tests of the diesel engine and the processing of the obtained experimental data, dependences were obtained that establish the relationship between the effective engine power (N_e) and the specific fuel consumption (g_e) and the temperatures of the fuel in the filling cavity of the high pressure fuel pump, of the engine oil in the crankcase and of the coolant in the system:

$$N_e = –17.2 + 0.01855t_т + 1.2581t_м + 0.3347t_в – 0.0023t_т^2 – 0.0077t_м^2 – 0.0033t_в^2 + 0.0015t_тt_в + 0.00278t_мt_в;$$

$$g_e = 753.469 – 0.2767t_т – 7.4253t_м – 3.0722t_в + 0.0077t_т^{2ь} + 0.04386t_м^2 + 0.02675t_в^2 – 0.007t_тt_в – 0.0125t_мt_в.$$

The obtained mathematical models make it possible to find the optimal ranges of fuel temperature, taking into account the influence of operating materials on the technical and economic indicators of a diesel engine.

Analysis of the experimental data obtained from two-dimensional sections of the response surfaces (Figure 2) in the range of factor variation made it possible to find the optimal ranges of fuel temperature, taking into account the influence of operating materials on the technical and economic indicators of a diesel engine. From the analysis of two-dimensional sections, it follows that with an increase of the fuel temperature from +32 °C to +58 °C (movement along the x-axis), the diesel power decreases from 57.247 to 54.283 kW, and with an increase of the engine oil temperature (movement along the y-axis), the power increases up to 57.247 kW when the temperature reaches 93 °C.

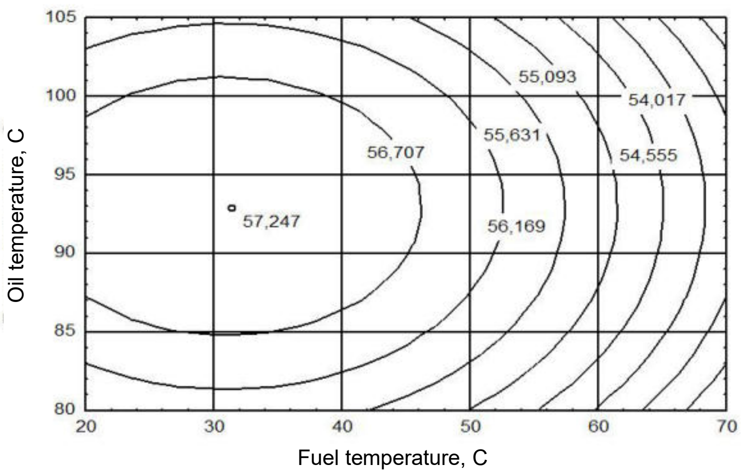

Figure 2. Two-dimensional cross-section of the response surface, characterizing the effective power of the D-240 diesel depending on the temperature values of the fuel and engine oil at a coolant temperature of 85 °C

Conclusion

Calculated and substantiated optimal temperature range of fuel in the filling cavity of the 4UTNM pump, that equals to $t_т$ = +38...+41 °C at engine oil temperature $t_м$ = +94...+97 °C, coolant temperature $t_в$ = +87...+93 °C, provides an increase in operating power and effective torque on the engine crankshaft by 3...5%, and a decrease in fuel consumption by 2...4%.

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