Influence of nanodispersed modifications of magnetite powders on spray nozzle efficiency of diesel engine injector

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Abstract. The paper presents data on the impact of new environmental requirements relating to the quality of diesel fuel on the anti-wear properties of fuel. Anti-wear additive is proposed as a material for increasing the tribotechnical characteristics of diesel fuel. This additive consists of diesel fuel with micelles contained in it, formed on the basis of molecules of solid plasticity lubrication of iron oxide (Fe_3O_4) – magnetite, and with surrounding molecules of oleic acid ($C_{18}H_{34}O_2$). The additive has low shear resistance and increased lubricity of diesel fuel when this additive is introduced into it.

1. Introduction

The problem of wear and tear of spray nozzles of diesel engines became urgent in connection with the new requirements for environmental protection relating to the quality of diesel fuel. It is believed that when these requirements are met, it is necessary, in order to maintain the lubricity level, to introduce anti-wear additives into the fuel. In this regard, the European standard for the quality of diesel fuel introduced the index of lubricity [1, 2]. This problem has clearly become apparent in Russia, where the production of environmentally friendly fuel grows quite rapidly.

The traditional way to increase the tribotechnical characteristics of lubricants, by introducing various kinds of soluble additives in them, as shown by the studies of different authors, is not very effective for fuels. Therefore, the preservation of the anti-wear properties of fuel is an important task, the solution of which is possible only on the basis of fundamental studies of tribochemical processes and the search for new materials on their basis as additives.

2. Materials and methods

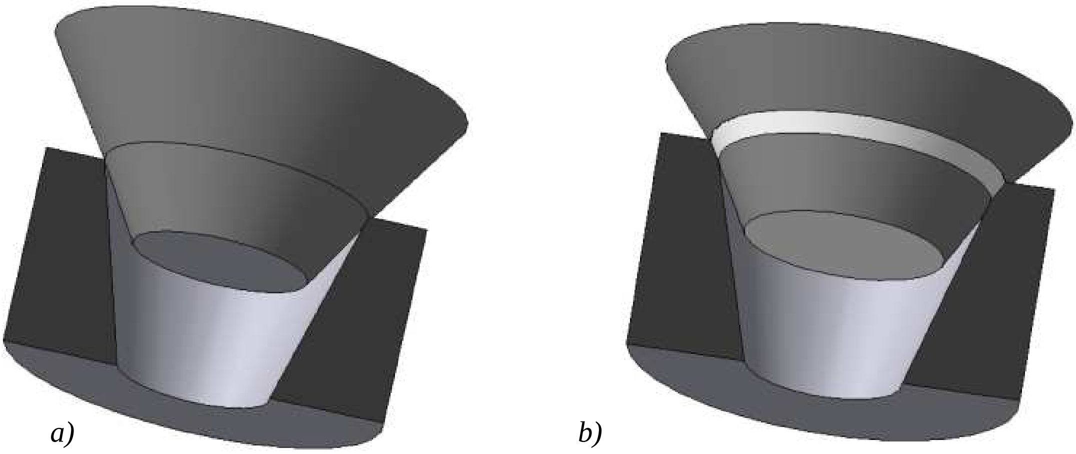
The antiwear agent [3] consisting of diesel fuel with 0.00001% micelles, formed on the basis of the molecules of solid plastic lubricant of iron oxide (Fe_3O_4), and with surrounding molecules of oleic acid ($C_{18}H_{34}O_2$) in the amount of 0.0001%.

The additive has low shear resistance and increased lubricity of diesel fuel when this additive is introduced into it. The antiwear additive was added to the diesel fuel in a ratio of 1/10 at a temperature of 60 ° C and continuous stirring for one hour. The obtained fuel was used for operating in the test stand KI-921M equipped with injectors with an intrinsic magnetic field [4]. To compare the antiwear properties of fuels, depending on the sulfur content, tests were carried out for fuels with a sulfur content of 0.035%, 0.2% and 0.035% with the above antiwear additive introduced. The course of the tests and the procedure for processing experimental data using the tools of modern software products of computer mathematics are given in [5].

3. Modeling the intensity of wear of the cone seal.

The working process of fuel supply to the cylinder of a diesel engine is considered and it is concluded that the active interaction of the locking cones of the needle and the seat of the atomizer causing their wear occurs at the end of injection of a single (cyclic) portion of fuel. To explain the physical nature of wear conical compacting, the works of N B Demkina, E V Ryzhova, G M Kharacha, I I Argatov, where the deformation processes appearing in relatively thin, surface layers of solids during their frictional interaction are reflected.

It was found that as the wear cones wear out, the needle settles in the nozzle body, reduces the diameter of the fixation and forms the "sealing bands" shown in Figure 1.



a) b)

Figure 1. 3D model of the interaction between the needle and the saddle of the nebulizer: *a) initial contact on the line; b) contact over the surface of the «sealing line».*

The cone seal of the nebulizer is under continuous lubrication, a boundary layer is formed on its surfaces, preventing direct metallic contact, increased wear, the possibility of scoring and seizing of the surfaces.

Then, for the elastic contact of lubricated and sufficiently smooth metal surfaces (8th class and higher), the calculation formula for estimating wear has the form [6]:

$$I_h = C \cdot \left(\frac{p_a \cdot \theta}{k_v^{'}} \right)^{1+\beta t} \cdot \Delta^{\frac{t}{2}(1-\beta)} \cdot \left(\frac{K_f^y}{\sigma_o \theta} \right)^t \cdot \eta_{c,a}^{-\beta t}, \qquad (1)$$

$$\Delta = \frac{R_{\max}}{rb^{\frac{1}{\nu}}};\ C = \frac{\nu^{\frac{1}{2}} \Gamma(\nu) \Gamma\left(1+\frac{t}{2}\right)}{4(\nu+1)\Gamma\left(\nu+\frac{t}{2}\right)};\ \beta = \frac{1}{2 \cdot \nu + 1};\ k_v^{'} = \frac{k_v}{2\sqrt{\pi}};\ K_f^y = \frac{4kf}{3\pi}.$$

In the process of running-in on surfaces, an equilibrium roughness is formed, equal to:

$$\Delta = \frac{k_1^{\frac{2\nu-1}{2\nu}}}{\left(0.38 k_\nu^y\right)^{\frac{2\nu+1}{2\nu}}} \left(\frac{\tau_o}{\alpha_h} \right)^{\frac{2\nu+1}{2\nu}} \frac{\theta^{\frac{2\nu-1}{2\nu}}}{p_c^{\frac{1}{\nu}}}, \qquad (2)$$

According to the operating values of the roughness parameters for the surfaces of the diesel injector, there is:

$$\Delta = \frac{k_1^{0.7}}{\left(0.38k_\nu^y\right)^{1.2}}\left(\frac{\tau_o}{\alpha_h}\right)^{1.2}\frac{\theta^{0.7}}{p_c^{0.5}}, \qquad (3)$$

Substituting expression (3) into expression (1) and taking into account that the nominal pressure on the contacting surfaces of the valve and the seat can be taken as a contour pressure; formula (1) takes the form:

$$I_h = C_1\alpha_h p_c \tau_o^{\frac{t}{2}}\Theta^{1-\frac{t}{2}}\left(\frac{kf}{\sigma_o}\right)^t;\ C_1 = 0.12\frac{16^{\frac{2t}{5}}}{2.6^{t-\frac{5}{4}}}. \qquad (4)$$

a_h-coefficient of hysteresis losses in friction; τ_o-shear resistance; Θ,σ_o- Kirchgoff elastic constant and friction fatigue parameter of the abradable body; p_c – contour pressure; k – coefficient of proportionality between the equivalent contact voltage and the specific friction force; f – coefficient of friction.

When using an effective lubricant, in expression (3) with the invariance of all the parameters entering into it, the coefficient of friction varies. Then it follows from (4) that:

$$I_h \sim f^{\,t} \qquad (5)$$

For example, by changing the value of the friction coefficient by n times in formula (5), we obtain a change in the wear rate by a factor of n^t.

In connection with the absence of the possibility of a mathematical description of the influence of all factors on the process of wear conical densification, the method of the theory of dimensional analysis has been used, and as a result criterial relations have been obtained that allow us to judge the qualitative relationship of the parameters of the operating factors.

Based on the similarity pi-theorem, the functional dependence of wear can be expressed as follows:

$$I_h = f\left(\gamma;\frac{qn^2}{Z};\frac{P\sqrt{R}}{Z};\frac{mn^2}{Z};\frac{\sigma_{-1}R}{Z^2};Tn;\frac{\theta'}{\sqrt{\theta}};\frac{\rho n^4R^3}{Z^2};\frac{HR}{Z^2};\frac{D}{\sqrt{R}};\frac{\lambda\theta}{Z^2n^2R};\frac{\lambda_T\sqrt{R}}{Zn\sqrt{R}};\frac{ER}{Z^2}\right), \qquad (6)$$

Z – injector spring stiffness; θ_T, θ –fuel temperature, needles and spray gun housings; n – number of injections per time unit; R–height of microroughness; γ – angle of cone opening; q – cyclic fuel supply; P – spring tightening pressure; m – mass of moving parts of injector; σ_{-1} – limit endurance of needle and nebulizer materials; T – wear time; ρ – density of needle and nebulizer materials; E, H – elastic modulus and the hardness of the surface of materials needles and nebulizer; D – wear spot diameter; λ , λ_T – coefficients of thermal conductivity of fuel, needle materials and nebulizer.

The analysis of criterial equations and their grouping in accordance with the physical essence of the phenomena described allowed us to find generalized similarity criteria:

$F_D = \dfrac{\rho\cdot n^6\cdot\sqrt{R}\cdot m}{\gamma\cdot E\cdot P}$ – complex, characterizing the dynamics of the stressed state of the contact;

$F_U = \dfrac{\sigma_{-1}\cdot T\cdot n}{H}$ – complex, used to characterize the fatigue strength of friction surfaces;

$F_S = \dfrac{\theta_T\cdot D\cdot q_c\cdot n\cdot\lambda}{Z^2\cdot R\cdot\lambda_T}$ – complex, which determines the relative thickness of the lubricating layer in contact.

In the case of mechanical destruction of surfaces, the wear rate I_h is expediently found in the form of dependencies describing the process by the following physically informative generalized factors:

$$I_h = k \cdot F_D^x \cdot F_U^y \cdot F_S^z , \qquad (7)$$

k – matching factor.

To compare the degree of wear of the cone seal, depending on the composition of the fuel used, a test cycle has been developed. According to the experimental data, the dependence of the wear rate on the time of operating on different types of fuel is plotted in Figure 2.

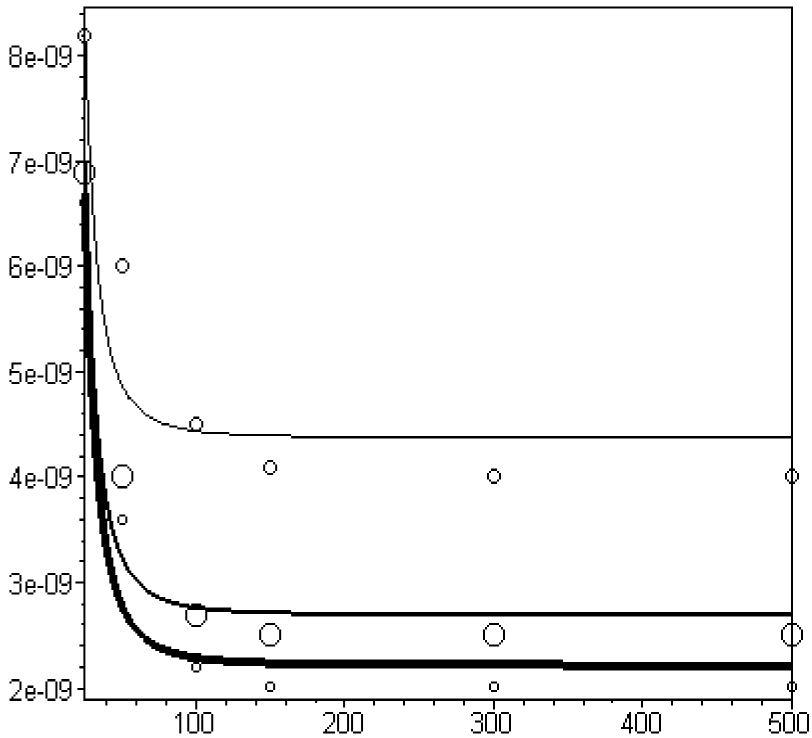


Figure 2. Intensity of wear of a cone seal:
——— S 0.035% + anti-wear additive;
——— S 0.2%;
——— S 0.035%;
○ ○ ○ experimental result S 0.035% + anti-wear additive;
○ ○ ○ experimental result S 0.2%;
○ ○ ○ experimental result S 0.035%.

The physical and mathematical analysis of the obtained experimental data, using software products of computer mathematics, made it possible to obtain coefficients of criterial dependence:

$I_h = 1,618 \cdot F_D^{2.1} \cdot F_U^{1.4} \cdot F_S^{0.9}$, – fuel with a sulfur content of 0.035%;

$I_h = 1.247 \cdot F_D^{1.1} \cdot F_U^{0.6} \cdot F_S^{0.2}$, – fuel with a sulfur content of 0.2%;

$I_h = 1.365 \cdot F_D^{1.8} \cdot F_U^{1.6} \cdot F_S^{1.2}$, – fuel with a sulfur content of 0.035% with anti-wear additive of a new type introduced into it.

4. Conclusion

It is established that changes in modern diesel fuel quality requirements caused by environmental requirements lead to a decrease in the lubricity of the fuel and, as a consequence, an increase in the wear of the cone seal of the nozzle atomizer, which results in a malfunction of the engine as a whole.

Based on a review of existing technical solutions to the problem under investigation and the search for the most rational way to overcome it, an anti-wear additive of a new generation of domestic production was proposed. An experimental study of the wear of the cone seal of the atomizer yielded the actual material, the processing of which allowed us to establish a definite form of dependence between the variable quantities that conditioned this process.

5. Acknowledgments

It is reported that the research was carried out in the framework of the research topic "Theoretical and experimental studies of some phenomena that arise when contacting bodies" (state registration № 01.20.0501723)."

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