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Increasing the wear resistance of plunger pairs of high-pressure fuel pumps using extreme pressure additives

D.D. Marchenko*, K.S. Matvyeyeva, V.M. Kurepin

**Mykolayiv National Agrarian University, Mykolayiv, Ukraine*
E-mail: marchenkodd@mnau.edu.ua

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Abstract

The paper presents studies and substantiates extreme pressure additives that are in demand in almost all areas where heavy equipment and machines operate: in heavy industry, metallurgy and metalworking, machine tool manufacturing, aircraft and shipbuilding, automotive production, construction, and power engineering. At the same time, the development and use of this type of additives in energy facilities of the agro-industrial complex is very difficult due to their relative high cost, and the lack of a complete scientific study of the problem does not contribute to the widespread use of extreme pressure additives in agricultural tractor engines. Therefore, there was a need to conduct scientific research to assess the effect of extreme pressure additives on the performance of high-pressure fuel pumps and, based on the information obtained, to develop production recommendations. In the course of the research, a functional model of the plunger pair performance indicator was obtained, taking into account the performance properties of summer diesel fuel with extreme pressure additives. The results of experimental studies are presented, taking into account the performance properties of summer diesel fuel with extreme pressure additives. The results of production tests of plunger pairs of high-pressure fuel pumps using summer diesel fuel with an extreme pressure additive have been obtained. The use of summer diesel fuel with an extreme pressure additive allows increasing the service life of plunger pairs of high-pressure fuel pumps from 1230 to 2214 hours; recommendations for using fuel for 14 kN traction class engines have been developed. The friction coefficient decreases from 0.005 to 0.001 when plunger pairs operate on summer diesel fuel with an extreme pressure additive. The results have been obtained for selecting the component composition of the additive in diesel fuel and recommendations for using the extreme pressure additive in diesel fuel have been developed.

Key words: wear resistance, coefficient of friction, fuel pump, friction steam, diesel fuel, anti-seize additive, resource tests.

Introduction

The main type of motor fuel used in modern internal combustion engines (ICEs) used in agriculture is diesel fuel. In an internal combustion engine, motor fuel is not only a source of thermal energy, it performs a number of other functions that are directly related to ensuring the longevity and economy of the engine. In particular, motor fuel in diesel fuel equipment is used as a working fluid and as a lubricating medium for fuel equipment pairs that rub, etc. Insufficient lubricity of diesel fuel is the reason for the failure of the working elements of diesel fuel equipment of internal combustion engines, namely piston pairs high pressure fuel pumps (HPFP). HPFP plunger pair failures account for 20 to 35% of all engine failures. The failure of the plunger pairs occurs due to wear, galling and seizing of the materials of the parts of the precision pairs.

One of the ways to ensure the serviceable condition and resource of piston pairs of diesel equipment is the use of an anti-seize additive in diesel fuel. Currently, such additives are not used in diesel fuel. However, in the domestic and foreign literature, there is no information about the chemotological composition of the anti-caking additive. In this regard, the thesis proposes the use of an anti-caking additive based on ethylene triglyceride hydrogen hydroxide. Such an additive consists of a lubricating component, an oxidizer and a fuel combustion stabilizer. The use of an anti-seize additive contributes to the adsorption of boundary films on the rubbing surfaces of precision pairs. The anti-seize additive for diesel fuel, consisting of polar molecules of a chain structure, has high compressive strength, elasticity and, in the presence of normal pressure, provides the possibility of sliding as a result of shifting along the planes formed by the end groups of molecules. The strength of the structured film increases with increasing pressure, which helps prevent contact between rubbing surfaces [1].

Additive components have both a high lubricating capacity and the ability to increase the energy capacity of diesel fuel.

The research in the article, aimed at ensuring the working condition of the plunger pairs of the high-pressure fuel pump by using an anti-seize additive in diesel fuel, is relevant.

Literature review

It is known from the practice of operating diesel fuel equipment that failures of plunger pairs account for about 65...80% of all HPFP failures (depending on the HPFP brand).

Failures of plunger pairs are mainly caused by natural mechanical wear of materials on the surfaces of plunger pairs.

The cause of mechanical wear of the materials of the plunger pair is metal contact, which occurs as a result of the contact pressure between the parts and is a consequence of the displacement of the lubricating liquid (namely, diesel fuel) from the gap. Moreover, the magnitude of the contact voltage is subject to Hertz's law and increases depending on the movement of the plunger in accordance with the law of motion of the camshaft cam (the law of motion of the plunger).

Numerous studies have established that fuel equipment, being one of the main elements of a diesel engine, in a number of cases does not ensure its required reliability in operating conditions and causes 25...30% of all engine failures [2].

Conducted studies on determining the average working life in real operating conditions show a significant reduction in the resource of pumps. With a confidence probability of 0.9, the average operating time of the pumps before their replacement was from 2.94 to 4.24 thousand. motorcycle watch

As research by V.E. Gorbanevsky showed, in the vast majority of cases, deterioration of fuel injection parameters is associated with problems of friction and wear of friction pairs of fuel equipment. Parts of friction pairs are made of steel, have high hardness (about 60 HRC) and low roughness (Ra up to 0.04 μm for precision and up to 0.32 μm for precise surfaces). The diametric gaps are 1...2 μm in precision and 10...40 μm in precise sliding pairs.

In works on ensuring the durability of friction steel pairs of fuel equipment, the most profound generalizing works are taken as a basis, such as, for example, the domestic structural and energy theory of friction by B.I. Kostecki.

From [3] studies of natural of fuel equipment friction pairs, data on plunger pairs are of particular interest. Gorbanevskyi V.E. and Kyslov V.G. it was found that the wear of the precision surface of the plunger is more often observed on the head on the side opposite to the working cutting spiral, i.e. in the zone where the influence of the maximum pressing forces (created by the pressure of 50...80 MPa) of an impact nature (the period of pressure build-up) is observed, it is superimposed on the effect of the maximum (2...4 m/s) movement speed of the plunger in each working cycle.

Our studies of the jamming of the plunger pairs of 36 in-line pumps of the MW type of combine diesel engines (the pump's service life 746...2740 engine hours) showed that, as a rule, in in-line pumps, jamming of one, rarely - two pairs of plungers occurs. At the same time, a similar jamming pattern was observed. It should be noted that the other pump plunger pairs had good surface condition, without visible damage or stains. An element-by-element analysis of the injection line of the failed sections revealed that when the nozzles of the nozzles of the nozzles coked in the high-pressure line, the effect of water hammer was observed. Since HPFPs of the MW type have a high injection pressure and the plunger is unbalanced (there is no symmetrical groove in relation to the cut-off groove), as a result, jamming of the plunger pair occurs [4].

Antipov V.V., Bakhtiyarov N.I., Zagorodskikh B.P. and others note that the working surfaces of the plungers and bushings are worn by abrasive particles contained in the fuel.

Research conducted by TsNITA showed that the wear of the plunger pair is local, in the area of the inlet and outlet windows. The total value of the worn friction surface does not exceed 5%, and the nature of the micro-uniformities on it indicates wear from abrasive particles that, together with the fuel, enter the super-plunger space during suction of the plunger. During the injection stroke, part of the fuel flows back into the filler, and the fuel flow is throttled along the plunger stroke, which is accompanied by an increase in pressure in the space above the plunger and a sharp increase in flow rates [5].

The resource of precision pairs increases with a decrease to certain limits of their initial clearances and an increase in hydraulic density [6]. The rational limit of reducing the gap in pairs is determined by the amount of installation and working deformations of the bushings, as well as the fineness of fuel filtration. As the pairs wear, their gap increases, and larger particles begin to have a sharp effect on wear. A change in the gap within 0.6...2.5 μm does not significantly affect the rate of wear, so it is impractical to further reduce the gap. In ND distribution pumps, this gap varies within 0.6...1.6 μm.

With small gaps in pairs, the issue of reducing the probability of the plunger sticking in the bushing becomes particularly important, which is achieved, in particular, by reducing the mounting deformations of the bushing by reducing the tightening force of the pump fitting, increasing the stiffness of the bushing and improving its design. Research in the State found that when the pressure fitting of the TN type fuel pump is tightened with a torque of 120 Nm, the bushing in the section below the windows is deformed by up to 3 microns. These data were confirmed by studies of the deformation of the parts of the plunger pair during the assembly of the UTN-5 pumps, which were carried out at the IMESH [7, 8].

Gorbanevsky V.E. and Vashchenko O.M. found that with high-quality fuel filtration (cardboard or paper fuel), the filters retain up to 99.5% or more of mechanical particles 2 μm in size and larger, abrasive wear cannot be decisive. The working medium for precision friction pairs is diesel fuel, for precise ones (inside the HPFP) it is a mixture of oil from the diesel oil system with fuel that seeped into the pump crankcase through the gaps of the precision plunger friction pairs.

The use of fuels containing rapeseed oil, FAME - fatty acid methyl ethers, etc., leads to the appearance of deposits, resin formation on parts and assemblies of HPFP, loosening and destruction of non-metallic seals. In HPFP with electronic control, such deposits can cause a change in the characteristics of the control of the fuel supply process and the appearance of numerous diesel malfunctions in general.

The failure of fuel pumps is due to the wear of parts and, as a result, the main adjustment characteristics change. The processing of data obtained by TsNITA during operational tests of UTN-5 pumps showed that 29% of all failures are due to wear of camshaft bearings, 12.5% to violations of the tightness of seals, 29.2% to increased unevenness of fuel distribution and reduced cyclic supply (wear of plunger pairs and injection valves) and 8.5% - to reduce the rotation frequency of the start of the regulator [9].

In fuel-lubricated VE and VP pumps, when low-quality fuel is used or the drive belt is improperly tensioned (in diesels with a belt drive), the drive shaft and its bushings wear out, a gap appears between the drive shaft, the cross and the cam washer, which reaches 0.35 mm. The permissible radial gap between the sleeve and the shaft is 0.25 mm.

Due to the decrease in stiffness of the springs of the mechanical regulators of the HPFP during operation, the rotation frequency of the start of its operation will significantly decrease. Of the parts of the regulator, the following are mainly worn out: legs and axles of loads, bearing brackets, control lever, adjusting bolts, etc. work is 0.127 mm.

In the process of routine work, 32 MW-type pumps were checked for RSV-type all-mode regulators (the regulator unit could not be disassembled). The analysis of the control parameters of 18 HPFPs of the MW type of Cummins 6CTA diesels of Case 2366 combines and 4 VE pumps with all-mode regulators of 4T390 diesels of Case 8825HP self-propelled mowers showed the stability of the regulator parameters set at the factory. In particular, for MW pumps, the value of the rail position differed from the one specified by the manufacturer at the nominal frequency of rotation of the camshaft by 2%, at the regulator start-up mode - by 3%.

At the same time, the volumetric supply of 8 pumps did not satisfy the regulation value due to the low hydraulic density of the plunger pairs. A feature of the operating conditions of distribution pump regulators (types VE, VP) is that fuel is fed into the superplunger space through the regulator cavity. If the fuel is not cleaned satisfactorily, deposits accumulate on the internal walls and parts of the regulator, which later peel off and enter the injection line, disrupting the operation of the plunger pair and the nozzle. In addition, the reduction of the passage section of the jet in the drain fitting due to its clogging negatively affects both the size and the uniformity of cyclic feeds [10].

Along with model mixtures of individual hydrocarbons, naphthenic and aromatic hydrocarbons isolated from kerosene fractions of oil were studied [11].

The tests were carried out in the following mode: sliding speed 1.18 m/s; axial load 100 N; test duration 30 min. The material of the parts of the friction unit is ShKh15 steel.

During sliding friction, the maximum wear is observed in the environment of H-paraffin hydrocarbons. Allowable wear in naphthenic and isoparaffinic hydrocarbons. In aromatic hydrocarbons, the wear regime corresponds to the standard one. The mixture of naphthenic hydrocarbons isolated from kerosene fractions is optimal in terms of lubricating properties. The addition of 10% of aromatic hydrocarbons to the mixture of naphthenic hydrocarbons significantly improves their lubricating properties, while bicyclic aromatic hydrocarbons are more effective [12].

Mineral liquid (DP) [7] (DSTU 2511) is used as a fuel in ground machinery. Under the operating conditions, the DP is in the system and repeatedly passes through friction pairs, being exposed to high temperatures and pressures. During operation, accumulation of oxidation products can occur in the DP during operation, as well as due to long periods of time, the formation of insoluble solid wear products of the system's frictional elements.

For some non-hydrocarbon liquids (synthetic), the wear of ShX15 steel is significantly dependent on the sliding speed (compared to hydrocarbon liquids), which indicates that more complex processes than in hydrocarbons occur in the friction zone.

Purpose

The purpose of the research is to ensure the operational condition and increase the wear resistance of the plunger pairs of the high-pressure fuel pump using an anti-seize additive based on ethylene triglyceride hydrogen hydroxide diesel fuel.

Research methodology

The research stages included:

- selection and justification of the components of the anti-seize additive for summer diesel fuel;
- conducting laboratory comparative resource tests on commercial diesel fuel and diesel fuel with an anti-seize additive;
- estimation of hydraulic density of plunger pairs;
- conducting operational production tests of plunger pairs with an anti-seize additive in diesel fuel.

The experimental research program included the development and improvement of the following methods:

- methods of selection of anti-seize additive components and the process of obtaining finished motor fuel;
- methods of assessing the stability of additive components in diesel fuel;
- methods of evaluating the operational properties of diesel fuel with an anti-seize additive;
- methods of comparative resource tests of plunger pairs of a high-pressure fuel pump;
- methods of estimating the hydraulic density of plunger pairs of a high-pressure fuel pump;
- methods of operational and motor tests of plunger pairs in the high-pressure fuel pump of the D-240 engine.

The method of selecting anti-seize additive components in summer commercial diesel fuel was based on a cluster analysis of existing components of numerical modeling. Numerical modeling involved modeling the density of multicomponent hydrocarbon liquids and the calorific value of fuel with an anti-seize additive.

For numerical modeling, optimization methods were used taking into account vector algebra.

The stability of the additive in diesel fuel was evaluated in static and dynamic mode. Static mode provided evaluation of the delamination of the components of the anti-seize additive in diesel fuel without mechanical influence under the conditions of natural settling of diesel fuel.

In the dynamic mode, the diesel fuel was affected by forced mechanical oscillations with a frequency and amplitude equal to the operating frequency and amplitude of the tractor.

The evaluation of operational properties was carried out according to the methodology outlined in [8] and involved determining the viscosity and density of diesel fuel with an anti-seize additive.

Bench comparative resource tests of plunger pairs were carried out on HPFP type UTN-5 on commercial summer diesel fuel L-40 (DSTU 2511) and commercial summer diesel fuel L-40 (DSTU 2511) with an anti-seize additive.

Research was conducted on serial and specially manufactured equipment.

Diesel fuel of operational group E5/E100 according to DIN classification was used as a prototype of diesel fuel. This motor fuel is a mixture of hydrocarbon petroleum fuel and organic raw material (ethanol), used as an oxidizer and density regulator.

As research [13] shows, ethanol in the hydrocarbon fuel solution is a solvent that reduces the lubricating ability of motor fuel.

The second criterion for the use of ethanol in fuel is a relatively lower calorific value, which reduces the calorific value of the main fuel. The use of pure ethanol in motor fuel, as a rule, involves the modification of diesel fuel equipment and some engine systems.

It is known from [14] that the use of triglyceride helps to change the contact conditions and increase (by 2 or more times) the carrying capacity of hydrocarbon fuels. However, in modern scientific literature, data on the use of this component (including as a component of an anti-caking additive) are not confirmed [15].

Hydrogen hydroxide is used to form a stable colloidal compound, a combustion stabilizer, and a fuel density regulator. The influence of which resource of precision pairs is currently also not investigated.

To obtain a stable solution of hydrocarbon motor fuel based on commercial diesel summer fuel with an anti-seize additive, the method of mixing fuel components with the help of ultrasonic influence was used.

Research results

The conducted resource tests of the plunger pairs of the high-pressure fuel pump showed that the use of commercial summer diesel fuel with an anti-seize additive reduces the intensity of the cyclic supply reduction. That increases the coefficient of stability by 35%, and this indicates an increase in the hydraulic density of the plunger pairs.

The error of approximation of experimental data curves does not exceed 5%, estimated by the method of least squares. The fuel supply at the starting revolutions allows you to determine the technical condition and predict the remaining life of the plunger pairs of the fuel pump. According to the recommendations, fuel supply by plunger pairs of HPFP brand UTN-5 at 100 min^{-1} should be at least 14.5 cm^3 [16].

The obtained experimental data show that when using commercial diesel summer fuel with an anti-seize additive, the resource of the plunger pairs of the fuel equipment increases from 1230 to 2214 motor hours.

Deviations in the resulting data do not exceed 5%, this indicates an accurate theoretical description of the operation of plungers. pairs of HPFP.

At the same time, the comparative resource during resource tests of plunger pairs was 2214 engine hours. when using commercial summer diesel fuel with an anti-seize additive and 1230 engine hours. when running on commercial summer diesel fuel. The data are presented in Fig. 1.

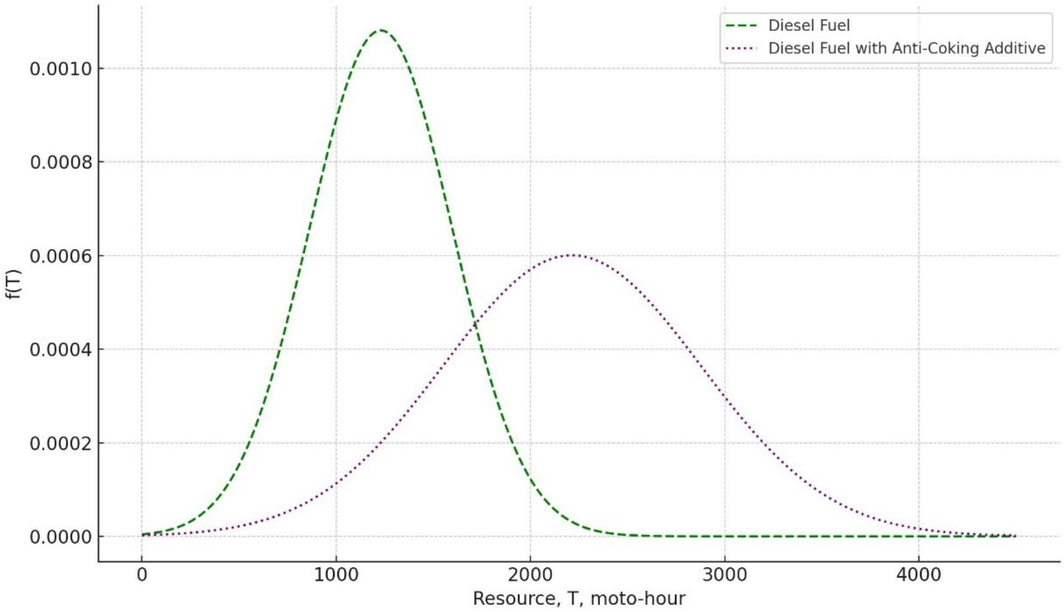

Fig. 1. The density function of the resource distribution of plunger pairs during resource tests

To determine the relationship between the factors, the correlation coefficient was determined. This coefficient was 0.8889 between the coefficient of kinematic viscosity and the density of fuels, -0.8796 between the kinematic viscosity and hydraulic density of piston pairs, -0.8851 between the density and hydraulic density of piston pairs, -0.99647 between the coefficient of friction and hydraulic density of plunger pairs. This indicates a close interrelation of factors.

In Fig. 2, 3 show graphs of changes in the hydraulic density of plunger pairs as a function of kinematic viscosity and friction coefficient.

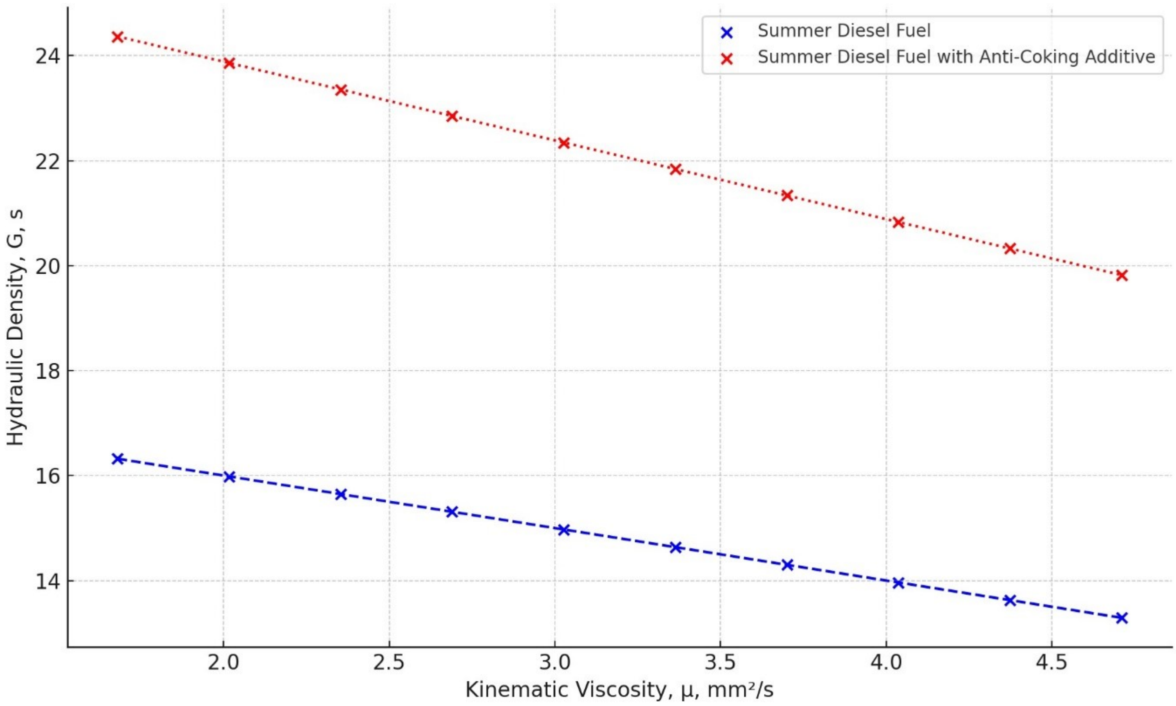

Fig. 2. Graph of changes in hydraulic density of plunger pairs from kinematic viscosity

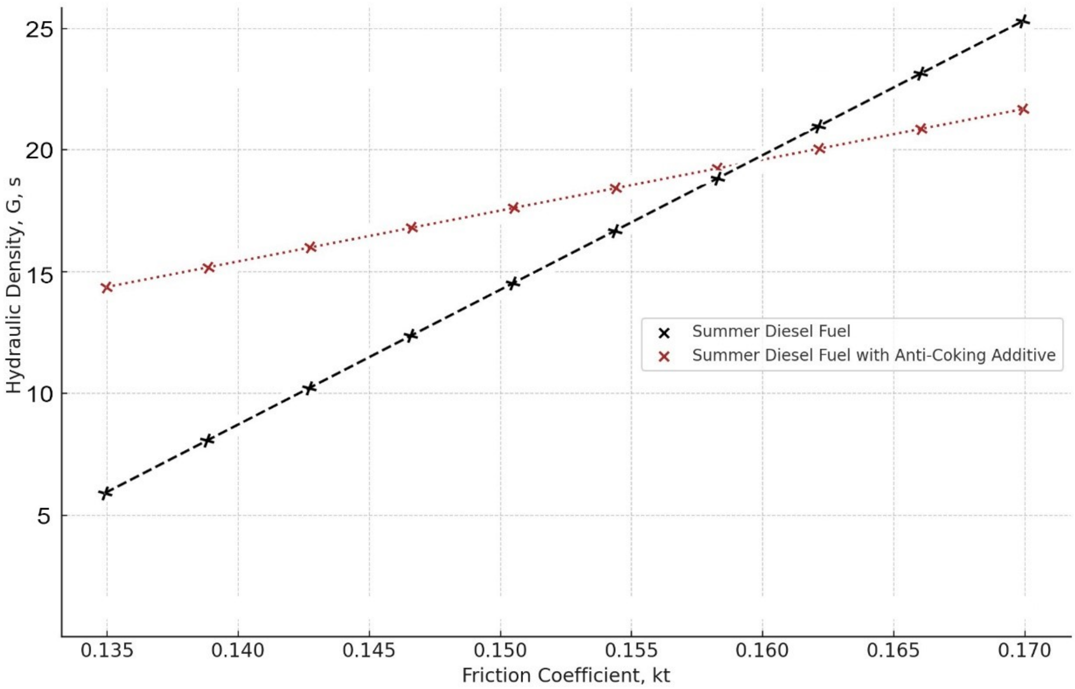

Fig. 3. Graph of changes in the hydraulic density of plunger pairs as a function of the friction coefficient

Fuel with an additive must have certain operational properties. In order to determine the possibility of operation of the plunger pairs of the high-pressure fuel pump on commercial summer diesel fuel with an anti-seize additive, the external speed characteristics of the D-240L diesel engine were determined when it was operating on commercial summer diesel fuel with an anti-seize additive and commercial summer diesel fuel. The obtained results show that when working on commercial summer diesel fuel with an anti-seize additive, the effective power of the engine decreases by 5.7% and the specific effective fuel consumption increases by 10.7%.

Based on the conducted theoretical and experimental studies, when transferring agricultural machinery from one type of fuel to another, no adjustments were made, then it is possible to operate on commercial summer diesel fuel with an anti-seize additive.

The work was carried out on MTZ-82 tractors. Commercial summer diesel fuel and commercial summer diesel fuel with an anti-seize additive were used. Summer diesel fuel (100% DP) was used on the control tractor. The tractors used in the study there are of the same year of production, with the same technical condition.

For the study of piston pairs of HPFP of internal combustion engines, corresponding to the technical requirements of the manufacturing plant were used. Before the test, the hydraulic density of the plunger pairs was determined.

At the HPFP of tractors on the stand, adjustments were made in accordance with the recommendations of the D-240 manufacturer (4Ch 11/12.5). At a frequency of 1100 revolutions per minute, the volumetric cyclic fuel supply in the nominal mode was 74 ± 3% cm^3 for 1000 cycles. After measuring the speed characteristics of HPFP on diesel fuel. In the tractor engine, when working on commercial summer diesel fuel with an anti-seize additive, the angle of the moment of fuel supply has been changed from 26 degrees. p.k.v. up to 28 degrees p.k.v. in accordance with the regulatory documentation of the D-240 diesel engine when operating on diesel fuel. Control of the working hours of the tractors was carried out using the used fuel collection card and the motor-hour counter. Motor fuel was supplied to the farm in the required amount based on the calculation of the variable working hours of the tractor [17]. The tractors used in the study performed the same field and transport work.

Determination of the characteristics of HPFP was carried out with a periodicity of 100 engine hours of operation in the conditions of a repair workshop according to the parameter of hydraulic density of plunger pairs. Cyclic feed measurements with the number of cycles of 1000 were performed at starting and nominal crankshaft revolutions. Experimental data show that during the operation of piston pairs on commercial diesel summer fuel with an anti-seize additive, the cyclic supply decreased on average from Vts=74±3% mm^3/cycle to Vts=55mm^3/cycle after observations, and on control piston pairs HPFP, working at the DP changed on average from Vts=59±3% mm^3/cycle to Vts=37mm^3/cycle. Changes in the hydraulic density of the state from 24 to 17 from the operation of plunger pairs on commercial summer diesel fuel with an anti-seize additive and from 24 s to 6 s when operating on commercial summer diesel fuel.

Conclusions

1. Established:

- the main failure of HPFP of tractor engines is the failure of plunger pairs (about 65 - 80% of all high pressure fuel pumps failures);

- the resource of HPFP plunger pairs under normal operation is generally absorbed in 50-60% of the resource declared by the manufacturer.

Failures of plunger pairs are caused by the seizing of their materials, which is a consequence of contact loads and the absence of an anti-seize additive in summer commercial diesel fuel. To ensure the working condition of the plunger pairs, it is necessary to develop the component composition of the anti-seize additive for commercial summer diesel fuel.

The component composition of the anti-seize additive commercial summer diesel fuel, which includes: ethanol, triglyceride, hydrogen hydroxide, is proposed. In this additive, ethanol is a regulator of the anti-seize density of the additive, triglyceride is a component that regulates the process of adhesion of the materials of the plunger pair parts, hydrogen hydroxide is a component that stabilizes the oxidation of triglyceride and the combustion of diesel fuel. The concentration of the additive components is substantiated: ethanol – 25%, triglyceride – 15%, hydrogen hydroxide – 5%, from the total volume of commercial summer diesel fuel. The concentration of components is determined based on the operational properties and calorific value of diesel fuel.

2. The indicator of the working condition of the plunger pair is theoretically substantiated. The functional dependence of the indicator of working condition (watertightness) was developed, taking into account the gap in the "sleeve-plunger" combination and the operational properties of commercial summer diesel fuel with an anti-seize additive.

3. Operational tests established that:

- the water tightness of plunger pairs when working on summer diesel fuel with an anti-seize additive is 17 - 24 s (with the normative value of the water tightness of new plunger pairs 18 - 24 s);

- the hydraulic density of plunger pairs when working on commercial summer diesel fuel was - 6 - 12 s;

- the friction coefficient is reduced from 0.005 to 0.001 during operation of piston pairs on summer diesel fuel with an anti-seize additive.

4. It was established during comparative bench resource tests that the resource of plunger pairs increases from 1230 to 2214 engine hours when working on summer diesel fuel with an anti-seize additive.

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Марченко Д.Д., Матвєєва К.С., Курепін В.М. Підвищення зносостійкості плунжерних пар паливних насосів високого тиску за допомогою протизадирних присадок

У роботі наведено дослідження та обґрунтовано протизадирні присадки, які затребувані практично у всіх галузях, де працює важке обладнання та машини: у важкій промисловості, металургії та металообробці, верстатобудуванні, авіа- та суднобудуванні, автомобільному виробництві, будівництві, енергетиці. Разом з тим, розробка та застосування даного виду присадок в енергозасобах агропромислового комплексу дуже скрутна через їхню відносну дорожнечу, а недостатність повного наукового дослідження проблеми не сприяє широкому використанню протизадирних присадок у двигунах сільськогосподарських тракторів. Тому виникла необхідність для проведення наукових досліджень щодо оцінки впливу протизадирної присадки на працездатність паливних насосів високого тиску та на базі отриманої інформації розробки виробничих рекомендацій. У ході досліджень отримано функціональну модель показника працездатного стану плунжерної пари з урахуванням експлуатаційних властивостей літнього дизельного палива з протизадирною присадкою. Наведено результати експериментальних досліджень з урахуванням експлуатаційних властивостей літнього дизельного палива з протизадирною присадкою. Отримано результати виробничих випробувань плунжерних пар паливних насосів високого тиску при використанні літнього дизельного палива з протизадирною присадкою. Використання літнього дизельного палива із протизадирною присадкою дозволяє збільшити ресурс плунжерних пар паливних насосів високого тиску з 1230 до 2214 годин; розроблені рекомендації щодо використання палива для двигунів тягового класу 14 кН. Коефіцієнт тертя знижується з 0,005 до 0,001 під час роботи плунжерних пар на літньому дизельному паливі з протизадирною присадкою. Отримано результати щодо підбору компонентного складу присадки у дизельне паливо та розроблено рекомендації щодо застосування протизадирної присадки у дизельне паливо.

Ключові слова: зносостійкість, коефіцієнт тертя, паливний насос, пара тертя, дизельне паливо, протизадирна присадка, ресурсні випробування