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INVESTIGATION OF THE LUBRICITY OF DIESEL FUEL AND AVIATION FUEL ON A HIGH-PRESSURE FUEL PUMP

This paper presents comparative experimental study's results of diesel fuel and aviation fuel effect on operational properties of a high-pressure fuel pump of a common rail injection system. The two identical fuel injection systems mounted on a test bed of the fuel injection pumps were prepared for the experimental durability tests. The lubricity properties of diesel fuel and aviation fuel (Jet-A1) were studied using the High-Frequency Reciprocating Rig (HFRR) method. The values of wear scar diameter (WSD) obtained with Jet-A1 fuels were compared to the respective values measured with the reference diesel fuel. The microscopic photographs of the wear scar diameters obtained on above mentioned fuels are presented in the paper. The test results showed that long-term (about 300 hours) using aviation fuels produced a negative effect on the durability of the high-pressure fuel pump. Due to the wear of plunger-barrel units the decrease in the fuel delivery rate occurred of about 6.7 % operating with aviation fuel. The average friction coefficients of Jet-A1 fuels were higher than that of the normal diesel fuel.

Keywords: diesel fuel, aviation Jet-A1 fuel, lubricity, plunger-barrel units, wear scar diameter.

INTRODUCTION

Diesel fuel is currently the most popular types among others motor fuels. Consumption of the diesel fuel has been growing steadily over the last two decades. The Jet fuel is a special-purpose blended fuel extracted during the distillation of crude oil. Kerosene distilled from mineral oil or shale oil is the main component in many Jet fuels. The fuel Jet-A1 is actually a kerosene type turbine aviation fuel used for powering of turbine engines in ground-aerial machines [1].

In 1988, the North Atlantic Treaty Organization (NATO) countries decided to simplify the delivery of petroleum products to the combat zone and improve the interoperability of aircraft and land equipment with JP-8 (F-34) military kerosene. In order to put this decision into practice, the NATO Pipeline Committee (NPC) adopted the Single Fuel Policy (SFP) in 2004. The US legislation on the "One Fuel Delivery Policy" stipulates that US military ground vehicles used must be able to work with aviation fuel (JP-8) [11]. JP-8 petroleum-based fuel is very similar in specification to the commercially available Jet A-1 fuel. Jet A1 fuel is a light distillate of complex hydrocarbons such as 50-65% paraffin's, 10-20% aromatics and 20-30% naphthenic [2]. Jet (JP-8) fuel is a military kerosene turbine fuel made from civilian (Jet A-1) fuel and widely used by the United States Air Force and Europe [3]. Aviation turbine fuel is extracted almost exclusively from the kerosene fraction of crude oil, the distillation points of which are between the gasoline fraction and the diesel fraction.

Specific properties of the fuel such as density, viscosity, calorific value, cetane number, freezing point, etc. change when using alternative fuels. The physical properties related features affect the fuel delivery and injection characteristics and thus the quality of the combustible mixture, which in turn affects the performance and the ecological parameters of the diesel engine. The cetane number of a fuel is one of the most important factors affecting the autoignition quality in diesel engines. It was found that the JP-8 and ULSD with similar CN have highly comparable combustion characteristics in a DI compression ignition engine and CN is the paramount characteristic in comparing these fuels. Authors investigated the combustion and ignition characteristics of varying blend ratios of JP-8 and a coal to liquid Fischer-Tropsch Jet fuel. The specific challenges facing the JP-8 fuel is the lack of specified combustion affecting properties including ignition quality, high temperature viscosity, and density. This parameter affecting combustion was explored by evaluating a low ignition grade synthesized jet fuel mixed in volumetric proportions of 25% with JP-8 to effectively cover a cetane number range of 25 to 45 in an engine. Authors used single cylinder diesel engine operating at various light, medium and high load operating conditions. The low ignition quality fuel was a Fischer-Tropsch Synthesized, coal-to-liquid (CTL) paraffinic kerosene (FT-SPK) which exhibited low temperature chemistry behavior at light load operating conditions including unstable combustion at lower engine speeds. The experiments were conducted to explore the impact of the cylinder charge density on the ignition delay of the CTL FT-SPK covering average charge densities of 19, 25 and 30 kg/m^3 and a temperature range of 750 K to 950 K. Such experiments revealed an excessive ignition delay peninsula with an average ignition pressure of less than 55 bar and an average ignition temperature of less than 800 K, which represented unstable operating at lower loads. Blending CTL FT-SPK with JP-8 increased activity at low temperatures and ensured stable combustion at lower, light-load engine speeds. In particular, a mixing ratio of 50-50 reduced any ignition problems of CTL FT-SPK under the test conditions specified in this experiment, and a mixing ratio of 25-75 (JP-8 / CTL FT-SPK) eliminated most of these problem concerns for ignition under full, medium and certain low load operating conditions [11].

Authors conducted test with kerosene on High Frequency Reciprocating Rig. They found that it causes unacceptable wear due to the poor lubricity of aviation fuel. Authors carried out investigation with ten mono–carboxylic acid esters to improve the lubricity of kerosene. Tribological results showed that all esters tested, were suitable for increasing the kerosene lubricity to a satisfactory level. Among the esters of the same molecular type, those having the ester group around the middle of the molecule appear to have better lubrication performance [3].

Special experiments were conducted on 3.8 kW Petter AV1-LAB diesel engine with neat JP-5 fuel and its various mixtures with animal fat derived biodiesel and diesel fuel [4]. Using of JP-5 fuel led to the large wear scar diameter, however adding of biodiesel to JP-5 fuel, lubricity properties of which are excellent, improved situation. The compatibility tests showed that biodiesel with short chain esters would be better alternative for mixing it with Jet A-1 fuel rather than long chain polyunsaturates [5]. It should be noted that biodiesel provides excellent lubricity to the fuel injection system that can reduce excessive wear of precision nozzle-needle-valve parts, which may cause a long-term use of a lighter aviation turbine fuel. In addition, a new important factor comes into action since mixing of RME with jet fuel provides fuel–oxygen, which helps to complete combustion of the fuel-rich mixture.

The experimental test results have demonstrated the potential operation of the diesel engine with aviation turbine-type Jet A-1 fuel without significant changes in engine performance and efficiency [6; 7]. However, the long-term impact on the fuel injection system components of Jet A-1 fuel having lower density, viscosity and poorer lubricity properties compared to conventional diesel fuel still remains unexplored to a greater extent and thus requires specific experimental tests.

MATERIALS AND METHODS OF THE RESEARCH

Diesel fuel (DF) and aviation fuel (Jet-A1) have been used for the experimental tests. The main properties of the tested fuels are listed in Table 1

Table 1. Properties of the tested aviation fuel (Jet-A1) and diesel fuel (DF)

Property parameters	JP-A1	DF
Density at 15°C, kg/m3	797.2	830.5
Kinematic viscosity at 40 °C, mm^2/s	4.0	2.07
Cetane number	42,3	51.5
Oxygen content, max wt. %	–	0.4
Carbon-to-hydrogen ratio (C/H)	6.13	6.9
Net heating value, MJ/kg	43.30	42.95
Stoichiometric air/fuel ratio, kg/kg	14.84	14.45

The common rail injection system has been used for the experimental tests. The principal arrangement of the test stand, equipment and apparatus are shown in in another research paper [10].

The two Bosch-type high-pressure fuel pumps were connected by the same belt driven in the same mode at speed of 1000 rpm. The electric delivery pump (2) mounted in the fuel tank (1) supplied the fuel through the fine-porous fuel filter (3) to the high-pressure fuel pump (4). The two Bosch-type CR/CP1S3/R65/10 high-pressure fuel pumps were connected by the same belt driven in the same mode. Moreover, both fuel pumps maintained the changeable pre-set pressure values of 20, 40, 70, 90, and the 110 MPa depending on the on-going time of every 30 minutes. Powered by an electrical motor, the high-pressure fuel pumps operated continuously to build up the needed injection pressure, which was retained in the volume of the fuel accumulator (7). The pressure was adjusted via a pressure regulator (5) connected to the control unit (8). The sensor installed in the pressure accumulator transferred the resulting signals to the control unit to evaluate the present fuel pressure.

Diesel fuel (DD) and aviation fuel (JET A1) have been used for the experimental research. During the reliability tests of the fuel pumps the fuel-flow was cooled in order its temperature do not exceed the 35 ºC. The changes in the fuel delivery rates determined for the various pressure values built up by both fuel pumps at the very beginning (0 hours) of the experiments are illustrated by the columns in Fig. 1a.

Analysis of lubricating properties of the fuel was performed on the basis of the wear data obtained by using High Frequency Reciprocating Rig (HFFR) apparatus. Lubricity of the fuel was determined on the basis of the wear traces formed on the swinging ball due to the contact with the stationary plate immersed into the tested fuel. The testing procedures were performed according to the international standard ISO 12156 requirements [8;9]. During the lubricity tests the fuel temperature was maintained to be of a constant value of about 30º C. The intensity of the balls’ surface wear images was evaluated by using Nikon Elipse MA100 optical microscope.

RESULTS AND DISCUSSION

The changes in the fuel delivery rates determined for the various pressure values built up by both fuel pumps at the beginning (0 hours) of the experiments are illustrated by the columns in Fig. 1.

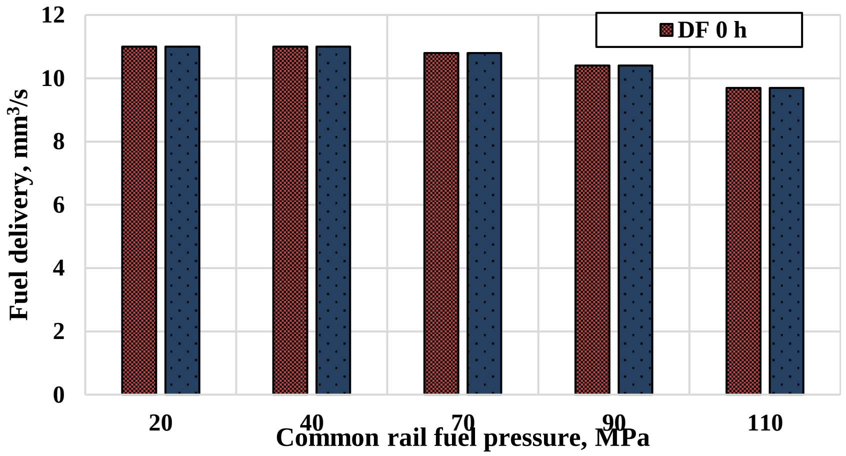

Fig. 1. Dependency of the fuel delivery rate on the fuel injection pressure built up by the fuel pump at the beginning of the reliability tests

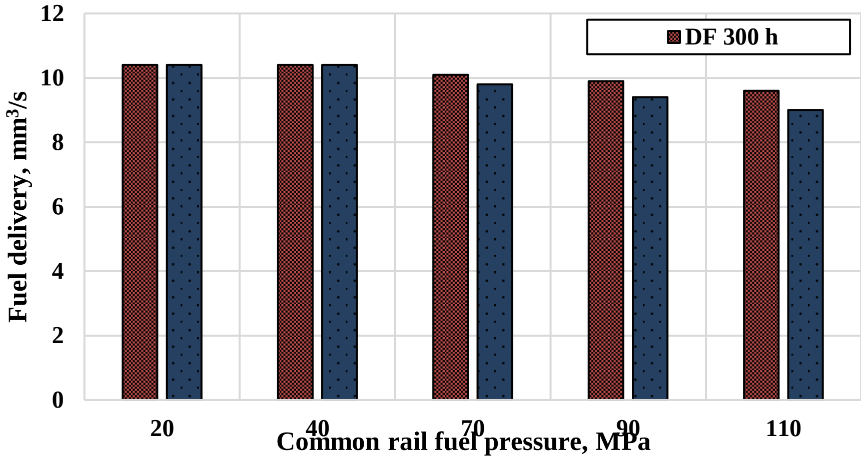

Fig. 2. Dependency of the fuel delivery rate on the fuel injection pressure built up by the fuel pump at the end of the reliability tests

The primary purpose of the fuel-injection system is to supply the fuel to the cylinder of a diesel engine. The fuel-injection pump builds up the fuel pressure needed for injection and then at the required rate delivers the fuel to the engine. The plunger-barrel unit is one of the most overloaded components of the fuel system. It can be assumed that this element is one of the most friction-sensitive units operating in the heaviest friction conditions in the diesel engine and therefore it can be chosen to evaluate the effects done by the relatively worse lubricating properties of Jet A-1 fuel.

The columns in Fig. 2 illustrate the changing trends in fuel delivery rate determined for various pressure values built up by the both fuel pumps at the end (after 300 h) of the experimental tests. Analysis of the obtained results shows that the resulting decrease in the fuel delivery rate was about 3.1 % higher with Jet A-1 fuel at the injection pressure of 70 MPa, while the relative decrease was equal to 6.7 % at a higher pressure of 110 MPa. From the observation of the test results, it can be assumed that the wear intensity of the plunger-barrel units was significantly greater when using Jet A-1 fuel that is especially a case at the injection pressure of 110 MPa.

The columns in Fig.3 show how the average wear scar diameter (WSD) of the test ball changed when using the normal diesel fuel and aviation Jet A-1 fuel.

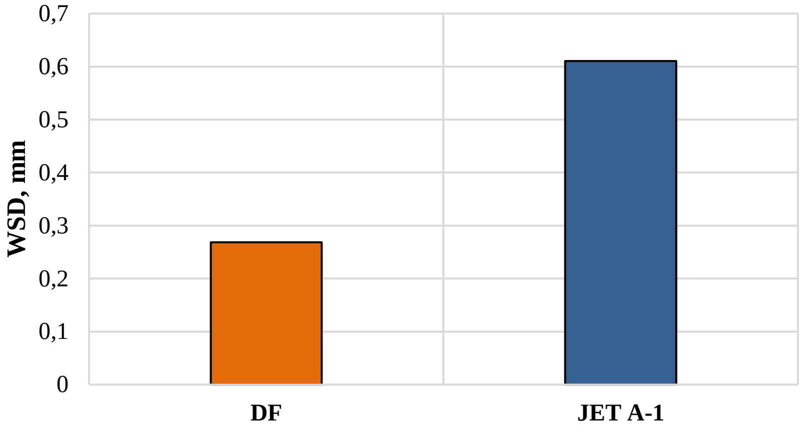

Fig. 3. The dependency of the average wear scar caused by the diesel fuel, neat (100%) aviation Jet A-1 fuel

The test results demonstrate that according to maximum decrease in the diameter of 0.6 mm the biggest scar wear was obtained when using neat (100 %) aviation Jet A-1 fuel. The minimum wear scar diameter of 0.28 mm was recorded with the normal diesel fuel.

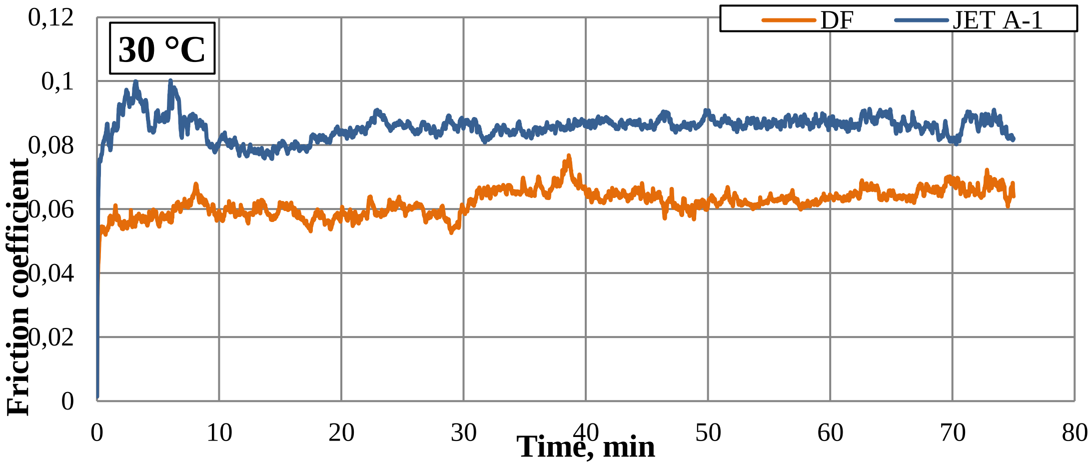

Fig. 4. Variation of friction coefficient for aviation fuel Jet A-1 and the diesel fuel as a function of time

The changing trends in variation of the friction coefficients are illustrated by the diagrams presented in Fig. 4. As can be seen in the diagrams, the friction coefficient was relatively lower and its variation was more stable when using normal diesel fuel.

Fig. 5 shows the images of the worn steel ball surface. The obvious difference in the worn surface area can be seen by comparing the friction pairs lubricated with the different fuels.

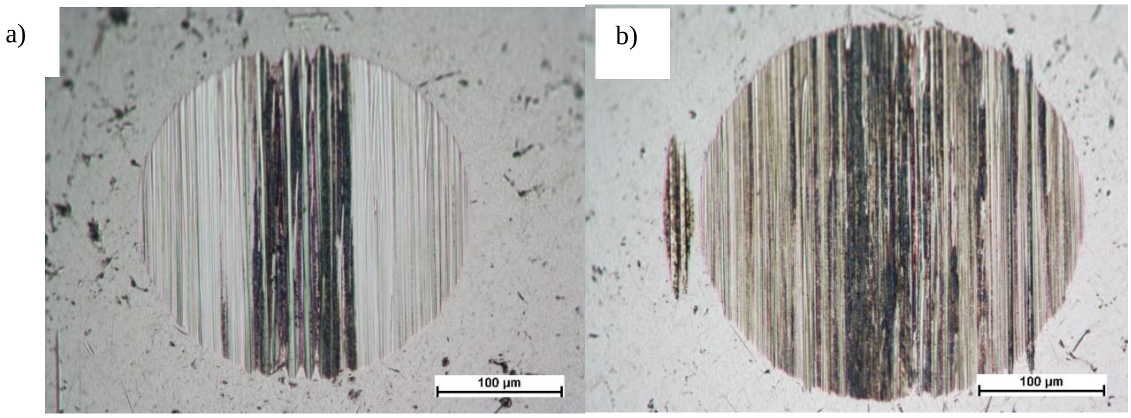

Fig. 5. The images of the worn out surfaces: a) for diesel fuel; b) for aviation Jet A-1 fuel

The images show that using of the diesel fuel resulted in a relatively lower the worn surface area if compared to that caused by aviation fuel.

CONCLUSIONS

1. The capacity (fuel delivery rate) of a high-pressure fuel injection pump decreased by 6.7 % after the 300 hours of operation with aviation fuel Jet A-1under close to real operating conditions.
2. Maximum mean diameter of the wear scar was equal to 0.6 mm when using aviation Jet A-1 fuel and the minimum value of the wear scar was measured when running with the normal diesel fuel.
3. Maximum averaged frictional coefficient was measured when using aviation fuel.
4. Analysis of the experimental data shows that the resulting area of a ball surface wear scar was relatively lower when using diesel fuel due to its better lubricating properties.

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