IMPACT OF ETHANOL ON FUEL INJECTION PUMP OF DIESEL ENGINE

Juri Olt, Villu Mikita, Risto Ilves, Arne Kuut, Marten Madissoo
Estonian University of Life Sciences
jyri.olt@emu.ee

Abstract. In general, it is not purposeful to use ethanol as diesel engine fuel, because it causes problems in the fuel system. When using ethanol in a high-pressure pump, one common problem is the rapid wear or jamming of the plunger work surfaces. These problems arise due to the physical and chemical properties of ethanol. In order to study the wear-and-tear and work parameters of the pump, a test was performed with a used high-pressure pump. The selection of this pump was based on the average operation period of a tractor, in the case of machinery already used in agriculture. This work provides the test data acquired by using bioethanol in a high-pressure pump and the analysis of the results obtained.

Keywords: diesel engine, high-pressure pump, bioethanol, work surface.

Introduction

The research of potential uses for alternative fuels is becoming more popular worldwide. Various biofuels, alcohol fuels, biogas, and plant oils are used as motor fuels in several countries. The problem with using biofuels consists in the impact of their physical-chemical properties on the fuel supply system. One of such biofuels is bioethanol.

Bioethanol is a prospective and widely used alternative fuel, which is used as motor fuel in many countries, such as the USA, Brazil, Germany, and Sweden [1; 2]. Due to its physical-chemical properties, bioethanol is mostly used in spark ignition engines. Namely, the auto-ignition temperature of ethanol is too high to be used in regular compression-ignition engines. In order to ignite ethanol in the compression-ignition engine, it is necessary to increase the pressure ratio, which results in increased pressure and temperature in the engine cylinder. Besides that the use of ethanol in diesel engine fuel-supply systems is complicated, because the lubricating properties and viscosity of ethanol are significantly lower than in diesel fuel. Another problem arises from the water content in the fuel, which causes corrosion [3]. Due to the aforesaid reasons the precise units of the diesel engine fuel-supply system wear more quickly than when operating on regular fuel. The precise units may also overheat due to increased abrasion, resulting in jamming or breaking of the working parts. Therefore, the use of ethanol in diesel engine fuel-supply systems has not been widely studied. When using ethanol in the diesel engine fuel-supply system it is recommended to use a fuel injection pump with external lubrication or to apply a special layer of nanocomposite materials on the work surfaces of the plungers, in order to increase the durability of the operating systems [4]. The aforesaid solutions have not been widely used in regular diesel engine fuel-supply systems. This may be due to the high cost of the complex systems and special procedures. Without special procedures and external lubrication the work surfaces of plunger pairs are processed well enough to allow short-term operation on liquids with poor lubrication qualities. Earlier studies have no reference to the duration of plunger pair in the environment which lacks the conditions required for operation.

The article examines the impact of 94.6 % bioethanol on the precise working components of diesel supply equipment. A closer look is given to the technical condition of plunger pairs and injectors of the in-line fuel-injection pump before and after operating on ethanol. The article also includes the study of the impact of ethanol on the geometry of the plunger work surfaces and on the changes in section capacity of the fuel injection pump. The aforesaid information is analysed and an evaluation of the impact of ethanol on fuel-supply equipment is provided. The results are gained by means of a fuel-injection pump test bench, where fuel-supply equipment was operated for 100 hours and the test liquid was 94.6 % bioethanol.

Materials and methods

When analysing the lubricating properties, ethanol with absolute alcohol content of 94.6 % (surgical spirit) was used as test fuel in fuel-supply equipment. As ethanol is not defined as regular fuel in its plain form, its lubrication properties were not analysed. The main parameters when comparing ethanol with regular fuel are density and viscosity that enable primary evaluation of using ethanol in the diesel engine fuel-supply system. The main output parameter of the diesel engine fuel-supply system is the fuel section capacity, which characterises the technical condition of the system. The section capacity is directly associated with the good condition of the subsystems in the fuel-supply system (pre-supply pump, fuel injection pump, and injectors). Good condition of the fuel-supply system equipment depends on the surface quality of mutually moving details, which is directly affected by corrosion and abrasion. This article focuses mostly on the abrasion, which is caused by the lubricating properties of the fuel and is expressed by the surface the quality of moving parts and their geometry. The basic moving parts in the fuel-supply system include plungers, delivery valve, and injector nozzles, which require special attention, as they affect the quality and quantity of fuel delivery.

Test plan

The study was performed with regard to the condition of subsystems of the fuel-supply system and the wear of parts thereof in the laboratory, based on practical tests and by using common test methods. The fuel injection pump УТН-5А with injectors 6T2 was selected as the fuel-supply system equipment to be tested. The selection of the devices to be tested was based on their use in the most common fuel-supply systems. The laboratory tasks were divided as follows: 1) measurement of initial parameters of the parts and adjustment of the devices to be tested according to the factory requirements; 2) performance of durability test; 3) measurement of final parameters of equipment and details. The measurement methods are based on the standards specially developed by research institutions, for the devices and parts considered in this article in view of their particular type of wear [5].

In order to evaluate the condition of the parts of fuel injection pump, the compliance of operational parameters of plungers and delivery valves (hydraulic density) with the factory requirements was measured both before and after the main test. The test stand KI-759 was used for measuring the hydraulic density of plunger pairs. In the course of measurement the hydraulic density of plunger pairs was evaluated, which characterises the compliance of details with the factory standards upon assembly of the pump. The case was installed in the testing device and filled with special stand liquid. When checking, special attention should be paid to the condition of the bottom cylinder and case front surface. Then the plunger was put in place, so that the active guide flute would not coincide with the exhaust outlet. After that the lever was added to the plunger and the stopper was activated to measure the time until rapid fall of the lever. The test was performed three times for each plunger pair. The minimum drop time is 30 s for new plunger pairs and 3 s for used plungers. Two measurements were performed for checking the delivery valves on the stand KI-1086: hydraulic density of unloading collar; aggregate hydraulic density of unloading collar and delivery cone. In order to determine the hydraulic density of unloading collar the valve with valve seat was placed on the stand and then the pressure was elevated up to 0.22 MPa. The measurement of time started when the pressure dropped to 0.20 MPa, and the time was measured until the pressure in the system dropped to 0.1 MPa. According to the preset values – i.e., minimum 10 s – the unloading collar is considered suitable. For determining the aggregate hydraulic density of unloading collar and delivery cone the pressure in the system was brought to 0.82 MPa. The measurement of time started when the pressure dropped to 0.80 MPa, and it was measured until the pressure dropped to 0.70 MPa. If the time measured is longer than 30 s, the valve is in order. The stand BOCH EFEP 60H was used for checking and adjustment of the injectors pursuant to the prescribed standards. The injection pressure of the injectors in question was adjusted to the pressure of 175 bars [6].

The methods described above can be used for estimated evaluation of the work capacity of the fuel-supply equipment and its change, but not the exact wear process. In order to provide more accurate description of the changes that take place in the course of operation, additional measurements of detail geometry and surface roughness were performed before commencing the main test and after completing the test simultaneously with the measurement of hydraulic density of fuel injection pump parts. The plungers diameter was measured with a micrometer at three different heights towards x axis and each measurement was repeated three times, marked in Figure 1 as: a; b; c. The unloading collar diameter was measured at valves, indicated by letter d in Figure 1. The measurements of unloading collar geometric circularity of plungers and valves was performed by using a device MAHR MMQ-100 (Figure 3), also at three different pre-set heights in order to ensure the repeatability of the measurement. Based on a common measurement method the plungers are measured only at the top (Figure 1) [5]. In addition the surface roughness values R_z and R_a were measured with MAHR MarSurf MP-1 device from two sides of the plunger top. The length of the measurement area was 5.6 mm. MAHR MMQ-100 device was used for measuring the circularity of the work surface of the cylindrical part of the nozzle needle and a micrometer was used for measuring the diameter.

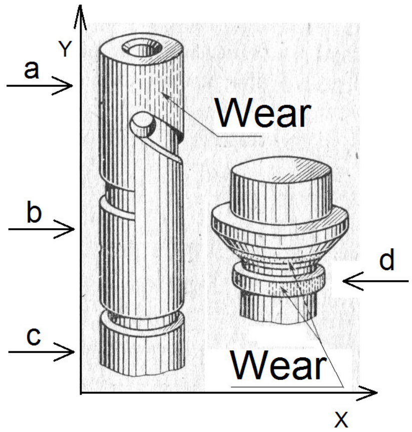


Fig. 1. **Measurement methods for fuel injection pump parts [5]**

In order to test the fuel-supply system equipment the authors decided that the main test should be a short-term operation method, during which the impact of fuel on the subsystems and work parameters of the fuel-supply equipment was evaluated. According to the reference materials the duration of the short-term operation method is 50 hours with interim section capacity measurements carried out every 10 hours [5]. The first section capacity measurement was performed after adjusting the subsystems of the fuel-supply equipment to match the factory requirements. The second measurement was carried out before the main test, i.e., after running the device for one hour, in order to check whether the setup of the fuel-supply system equipment remained within the prescribed standards. The duration of our main test was 100 hours with interim measurements performed in every 10 hours. The interim measurements were required for checking the stability of the work parameters studied when testing the equipment. A test device was built for performing the test, based on a fuel-injection pump test bench SDTA-1 and additional devices. Using additional devices on the aforesaid fuel-injection pump test bench was necessary for several reasons: to prevent the impact of fuel (ethanol) on the test stand; to reduce the quantity of fuel used for the test. When preparing the test stand for the main test, it was equipped with the following: fuel container; fine filter; cooling device; fuel pipes; and thermometer (Figure 2).

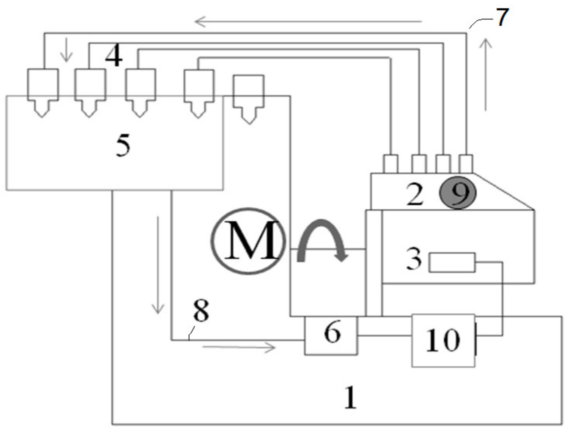


Fig. 2. **Scheme of test principle:** 1– stand; 2 – fuel injection pump; 3 – fuel pre-supply pump; 4 – injector; 5 – fuel container; 6 – cooling system; 7 – fuel injection pipes; 8 – fuel pre-supply pipes; 9 – thermometer; 10 – fine filter

The stability of the operating temperature of the fuel injection pump t_{fp} = 37 °C was ensured by an additional cooling device installed on the stand. The rotational speed of the test stand when performing the tests and measurements was n_{fp}=800 rpm, based on the rotational speed of the test engine equipped with a fuel injection pump and operating at rated power n_e=1600 rpm. The fuel section capacity was checked separately for each section and the duration of one measurement was n_c=800 operating cycles. The fuel quantity was measured in cm^3.

Results and discussion

The technical condition of the fuel-supply equipment can be evaluated by means of the section capacity. If the capacity complies with the values indicated in the technical specifications, the engine receives the required amount of fuel in every operating mode, provided that the regulator of the fuel injection pump and other subsystems are in good order. The results of section capacity measurement carried out in the course of the test are shown in Figure 3.

The test results reveal that when using the stand liquid and ethanol in the fuel injection pump there was no significant change in the section capacity, irrespective of the differences in the density and viscosity of diesel fuel and ethanol. This leads to a conclusion that the fuel injection pump does not need a separate section capacity adjustment when using ethanol. In order to compensate the difference in the calorific value of the fuel compared to using diesel fuel in the engine, it is possible to increase the section capacity. After the first ten-hour test cycle the capacity of the first and fourth section was reduced by 6 cm^3. The reduction of the section capacity was caused by the shifting that occurred between the case and control rack when running in the fuel injection pump. No significant reduction of the section capacity was observed in the course of further test cycles, as seen in Figure 3. By the end of the second test cycle (after 10 hours of operation) the capacity of the second section increased by 2 cm^3. During the fourth operating cycle (after 30 hours of operation) the capacities of the third and the first section were also increased. Based on the final measurements of injection pressures we may conclude that the increase in capacity is caused by the reduction of the injection pressure: I section – 28 bar; II section – 30 bar; III section – 40 bar; IV section – 20 bar.

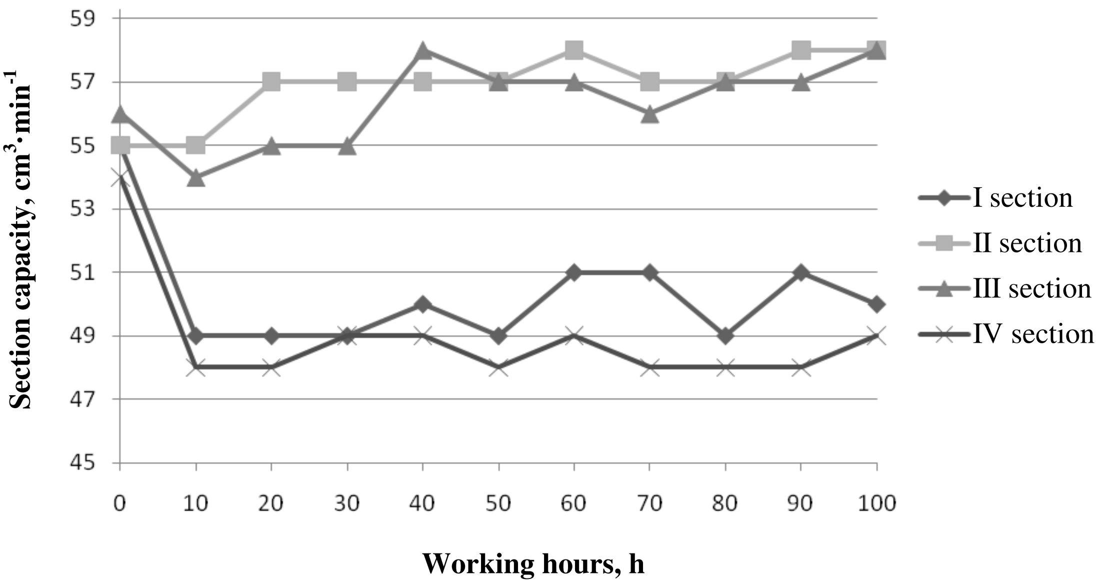
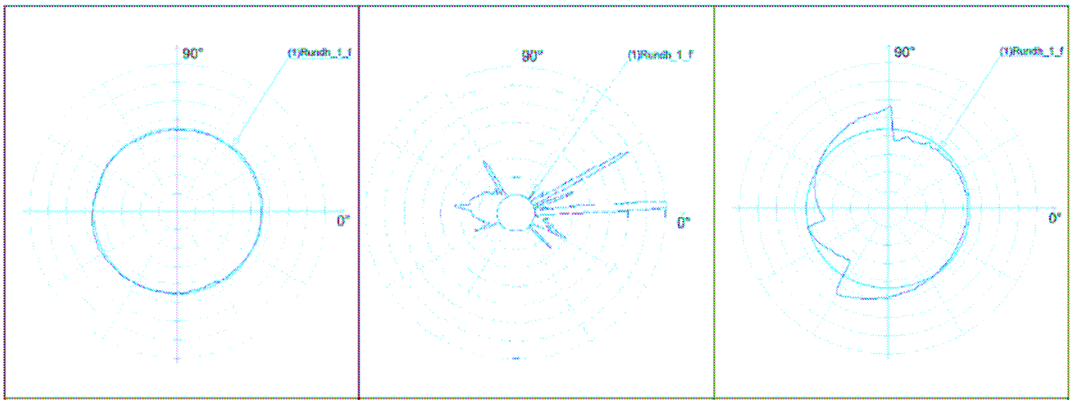


Fig. 3. **Section capacity of injection pump depending on test time**

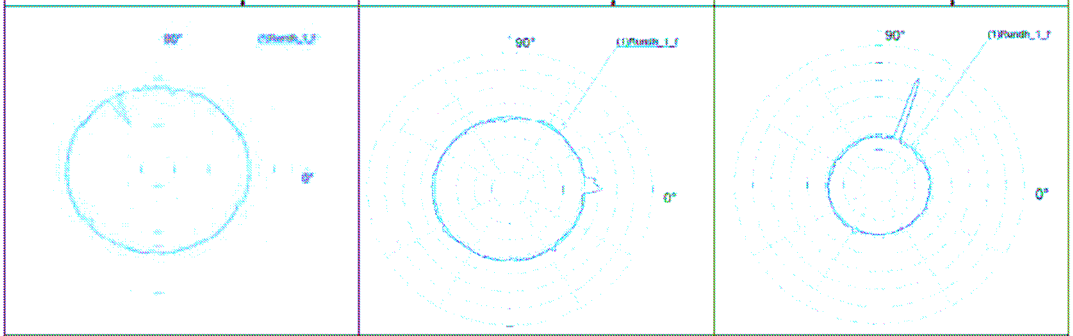
The injection pressure in the fourth section was reduced the least, which is also characterised by the stability of the capacity throughout the test. The section pressures in other sections were reduced more than in the section four, but they remained within the standard limit and did not involve significant increase in capacity.

Reduction of injection pressures was caused by the wear generated when running in the work surfaces of the nozzle needles. The measurement of needle geometric circularity revealed the highest deflection in case of the nozzle needle in the third section (see Figure 4). It follows that the reduction of the injection pressure in the third section was due to the increased deflection of shape, in comparison with other sections. According to a general tendency the shape deflections were reduced in the course of the test. But in case of the injector in the third section the deflection increased instead.

Irrespective of that we may conclude that using ethanol does not cause ultrafast wear of the precise units of injectors.



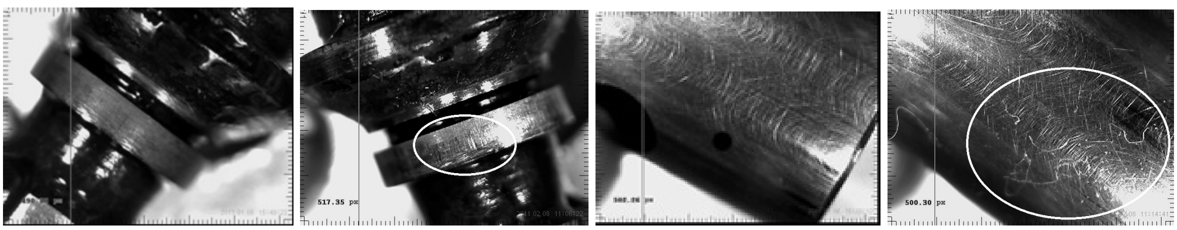
Nozzle needle 3, before testing Deflection 0.338 µm	**Unloading collar 3, before testing Deflection 11.667 µm**	**Pump plunger 4, before testing Deflection 2.203 µm**



Nozzle needle 3, after 100 work-hour. Deflection 2.093µm	**Unloading collar 3, after 100 work-hour. Deflection 1.272 µm**	**Pump plunger 4, after 100 work-hour. Deflection 3.870 µm**

Fig. 4. **Measurement results of geometric circularity of subsystem parts**

The results of measuring the delivery valve retraction collar geometric circularity revealed the reduction of mean deflection in all sections. The reduction of deflections was caused by running in the details. We may conclude that the operation of the valves in ethanol environment during 100 work hours does not cause significant wear that would lead to major changes in the capacity of the fuel-supply equipment. The same can be said to describe the wear of the plunger pairs. The greatest change in deflection, 1.667 µm, was found in the fourth plunger (Figure 4). The results gained from the measurement of the hydraulic density of plunger pairs did not differ from the initial measurements, and the results corresponded to the factory requirements. Under the microscope one can see barely noticeable scratches on the surface of the plunger. More visible scratches of the work surface, however, are seen on the delivery valve retraction collars (Figure 5), which, according to the measurement results, did not change the hydraulic density according to the factory requirements.



a b c d

Fig. 5. **Work surface of subsystem**: a – unloading collar before testing; b – unloading collar after testing; c – pump plunger before testing; d – pump plunger after testing.

As a result of all measurements we determined average surface roughness of the plungers R_a=0.035 µm and the average distance between the highest and lowest point of surface irregularities R_z=0.6 µm. The average difference in the plunger diameters, measured with micrometre before and after the test, was no more than 0.003 µm and the average difference in the nozzle needle diameters was no more than 0.0005 µm (calculated). The micrometer error limit is 0.0005 µm. The only exception was the third section injector, the nozzle needle diameter of which had reduced to 0.001 µm and hence caused the most significant reduction in the injection pressure.

The main problem when using ethanol in the fuel-injection pump was the possible contact of ethanol with lubricant oil. The problem consists in non-solubility of ethanol and oil, which may cause serious issues in centrally oiled engines with this type of fuel injection pumps. The aforesaid problem should not occur in case of plunger pairs with additional reflux flute, but this was not the main objective of this study. Another problem arises from corrosion generated during the storage of the pump, as it causes damage to the work surfaces of the moving parts.

Conclusions

The aim of the study discussed in this article was to determine the impact of ethanol on the output parameters of the diesel engine fuel injection pump УТН-5А, and the details of subsystem of fuel-supply equipment. The tests revealed that:

1. The pump section capacity with the same work parameters of the fuel-supply equipment shows no significant change when using ethanol in comparison to diesel fuel;
2. When using ethanol, the work surfaces did not have any significant damage that could affect the capacity and reliability of the fuel-supply equipment;
3. The geometric circularity of the measured work parts were generally improved. This leads to the conclusion that ethanol environment is suitable for running in the details indicated in the study;
4. Due to its low viscosity, ethanol comes into contact with lubricant through plunger pairs when using this type of fuel injection pumps;
5. The risk of corrosion of the work surfaces is higher in case of long-term storage of the fuel-supply equipment that has been used with ethanol than in case of equipment operating on diesel fuel.

Based on the previous results and analyses we may conclude that using ethanol in fuel-supply equipment does not cause jamming of precise units and consequent subsystem failure. But these tests do not allow accurate evaluation of the maximum duration of operation of the fuel-supply equipment. The authors recommend using additives that improve lubrication. In the given field further studies shall be carried out with regard to the diesel engine fuel-supply equipment with a different structure, by using ethanol mixtures with various alcohol content based on renewable raw materials.

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