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Application of ceramic coating for improving the usage of cottonseed oil in a diesel engine

Bahattin İŞCAN

Department of Automotive, Vocational School of Higher Education, Batman University, Batman 72060, Turkey

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A B S T R A C T

The development of the usability of a pure vegetable oil of cottonseed in diesel engines was intended in this paper. With this purpose, piston surface and valves of the test engine were coated with zirconium oxide (ZrO_2) ceramic coating material in order to reduce the heat rejected from the mentioned parts. Then waste cottonseed oil was volumetrically blended with petroleum based diesel fuel by 15% cottonseed oil – 85% petroleum diesel (CO15), 35% cottonseed oil – 65% petroleum diesel (CO35) and 65% cottonseed oil – 35% petroleum diesel (CO65). Previously, the petroleum based diesel fuel with number: 2 (D2) fuel was tested in the normal uncoated single cylinder diesel engine. These blend fuels and D2 were then tested in the coated engine. Results were compared with the results of initial test of D2 in uncoated engine operation. The comparison of all the test results showed that the coating process considerably improved the performance of the test engine for all the test fuels. Besides, every measured pollutant emissions were reduced only except for oxides of nitrogen (NO_x). This may certify that the coating process is a reasonable method for using pure vegetable oils in diesel engines provided that the injection process runs well for so long.

1. Introduction

The ever increasing energy demands with the limited availability of fossil fuels and the environmental pollution resulting from their usage have derived researchers in exploring alternative fuels in order to gradually substitute conventional fuels [1,2]. The concerns have focused attention on biofuels [3,4]. Vegetable oils are an important alternative bio-based fuel sources for diesel engines [5,6]. However, high viscosity and low evaporation of vegetable oil-base fuels make their use as fuel more difficult [7]. Direct use of crude vegetable oils without modification in diesel engines causes some damage to parts of the engine and also, the performance is negatively affected [8,9]. Without engine or oil modification some problems such as poor atomization, injector sticking and blocking which prevent engine operation occurs when using pure vegetable oils in diesel engines. Direct use of crude vegetable oils in diesel engines causes some damage to parts of the engine and also, the performance is negatively affected [8,9]. Besides, using these kinds of fuel in diesel engines result in worse performance parameters than that of diesel fuel. It has been reported by many researchers that when crude vegetable oils are used as diesel engine fuel, declines can be seen in performance parameters with reductions in emission values [10–16].

Temperature and thermal stress analyses of a ceramic-coated aluminum alloy piston used in a diesel engine have been investigated [17]. It was reported that increase in the maximum temperature according to the uncoated piston is 64.3% for 1.0 mm thick coating. The higher combustion chamber temperature provided by means of coating results in the better thermal efficiency of the engine. Since in-combustion chamber temperatures of coated engines are higher than those of uncoated engines, it may be possible to use a fuel with a large distillation range and lower quality fuels such as pure vegetable oils or biodiesel [18]. Combustion characteristics of low heat rejection (LHR) diesel engines are different from standard diesel engines in four ways [19]. Ignition delay period shortens; Diffusion burning period increases while premixed burning period decreases; Total combustion duration increases; Heat release rate in diffusion burning period decreases. It was reported that higher temperatures in the combustion chamber can also have positive effects on diesel engines due to the drop in self-ignition delay [20,21].

In a conventional diesel engine, about 30% of the total energy is rejected to the coolant and it was reported that the engine coating may be a good solution [22]. Thermal barrier coatings are generally applied on the cylinder head, piston and valves by plasma spray method. Coating

E-mail address: bahattin.iscan@batman.edu.tr.

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these parts with ceramic also limits the negative effects of wear, friction, heating, corrosion and oxidation. It was also reported in a theoretical diesel cycle analysis that the more the heat transfer decreases, the less energy will be lost, thus the work output and the thermal efficiency increase [23]. In another study, with engine coating an increase in engine power and decrease in specific fuel consumption, as well as significant improvements in exhaust gas emissions and smoke density have been addressed in comparison to the uncoated engine [24].

Because the combustion chamber temperatures of ceramic coated engines are higher than those of uncoated engines, it is possible to use a fuel with a large distillation range and lower quality fuels. Furthermore, because heat losses going to the cooling system are reduced and gas temperatures after compression are increased in diesel engines, starting is easier in cold weather. In addition, noisy running caused by uncontrolled combustion decreases [25]. In various studies, it has been reported that engine performance and exhaust emissions were improved in diesel engines where all or some elements of their combustion chambers were coated with ceramic [26,27].

Therefore, in the present study, piston surface and valves of the test engine were coated with ZrO_2 ceramic coating material in order to perform low heat rejection aim. Then the cottonseed oil blends with standard diesel fuel were tested in the coated engine in order to investigate the possibility of using pure vegetable oils as fuel in diesel engines. The formation of the coating material and their usage ration along with the blends of cottonseed oil with diesel fuel are different in comparison to the other studies.

2. Experimental procedure and test materials

Performance and emission tests were carried out at the engine test laboratory of Automotive Department of vocational school of higher education at University of Batman. Fig. 1 shows the experimental test installations.

Schematic diagram of experimental setup is presented in Fig. 2. A BT-140 model hydraulic dynamometer was used for performance tests. The test engine specifications are presented in Table 1.

Exhaust emission test were carried out with a Capellec CAP 3200 model emission analysis device. Technical properties of emission test device are given in Table 2. CAPELEC 3200 brand emission test device was used for determining exhaust emission. This device was coupled with a NO_x sensor. This device is complying with standards of OIML R99, ISO 3930 and BAR97. The response time for each parameters is bellow 5 s. The device is also able to measure the smoke opacity with an second probe linked to the opacimeter unit of the analyzer using the same software, and same LED screen that shows the measured values. The technical specifications and measurement resolutions of the analyzer with opacimeter are given in Table 2.

The test conditions were various speeds and fully loaded engine operation conditions. In order to have full loading conditions the engine was loaded until speed reduced for 1000 rpm and the stable accelerator position. For example, before engine was loaded the accelerator was fixed at 2500 rpm. Then the engine was loaded until speed was reduced to 1500 rpm at a fixed accelerator position. The same procedure was performed for each specified speed and fuel test. All tests were repeated for 5 times and the average values were presented in this manuscript. These average values of all test parameters represent the average of 5 data points that obtained at 8 different engine speeds. The engine speed was kept constant during the tests. Therefore when the test fuels and other conditions except for speed are varied, the comparison can easily be made. Also, each test was repeated for 5 times and average values were used for drawing the graphs. The fuel consumption was measured in burettes with 50 and 100 ml volumes and a stopwatch.

The test engine's piston surface with combustion chamber and both exhaust and intake valves were coated with a ZrO_2 layer with the method of spray plasma teqnique. The thickness of coating layer on the piston surface and valves of the engine was 500 μm. Before coating was applied the surfaces of the selected parts were grinded. After the grinding process, the thicknesses of coated parts were reduced for 500 μm. Hence, the compression ratio of the test engine was kept the same as the catalog value. Then, the parts mentioned were coated with the 100 μm NiCrAl as lining layer. Afterwards, the same parts were coated with 400 μm material of coating that was %100 of ZrO_2. The photo of coated and uncoted forms of the mentioned parts of the test engine was presented in Fig. 3.

3. Results and discussions

3.1. Performance results

The variation of power values with engine speed for different fuels in coated engine operation and uncoated engine diesel operation are illustrated in Fig. 4. It is clear from the figure that when compared with the result of normal engine operation the coated D2 operation

Fig. 1. Image of the experimental test installations.