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Research paper

Investigation of the usability of biodiesel obtained from residual frying oil in a diesel engine with thermal barrier coating

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HIGHLIGHTS

- Performance, combustion and emission of biodiesel blends were tested in a coated diesel engine.
- Initially, 100 μm of NiCrAl lining layer was applied to some parts of the engine.
- The engine was coated with 400 μm a mixture of 88% of ZrO_2, 4% of MgO and 8% of Al_2O_3.
- Test results showed some improvements in performance and combustion parameters.
- Also, the mixture materials of coating process is novel.

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ABSTRACT

In this study, biofuel was produced from residual frying oil of cottonseed and D2, B5 and B100 fuels were prepared in order to use in experiments. These fuels were tested in a single cylinder, four strokes, 3 LD 510 model Lombardini CI engine. Then the top surfaces of the piston and valves were coated with plasma spray coating method by using 100 μm of NiCrAl as lining layer and over this layer the same surfaces were coated with 400 μm of the mixture that consists of %88 ZrO_2, %4 MgO and %8 Al_2O_3. After the coating process, above mentioned fuels were tested in the coated engine. Previously, same fuels had been tested in uncoated engine, at full load and various speeds. Performance, emission and combustion experiments were carried out in coated engine. By coating process, partial increases were observed in power, exhaust manifold temperature and engine noise, while partial decreases were seen in brake specific fuel consumption (Bsfc). Besides, partial reductions were found in carbon monoxide (CO), hydrocarbon (HC) and smoke opacity emissions, but partial increases were observed in nitrogen oxide (NO_x) emissions. Cylinder gas pressure values were higher for coated engine. Moreover, heat releases were close to each other in both engines.

1. Introduction

With increasing trend of modernization and industrialization, the world energy demand is growing at fast rate. Apart from their indigenous production, majority of developing countries import crude oil to cope with their increasing energy demand. A major chunk of their hard earned export earnings is spent for purchase of petroleum products. Along with the energy crisis, the other problem of concern is the degradation of environment due to fossil fuel combustion [1]. Hence, many important alternative fuels have been reviewed and presented in Ref. [2]. Therefore, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, and vegetable oils. Alcohols and biodiesel as biofuel applications for internal combustion engines have been discussed [3]. Performance and combustion characteristics of a direct injection diesel engine fueled with waste palm oil and canola oil methyl esters as biodiesel fuels have been investigated [4]. Safflower oil derived biodiesel has been presented as a probable candidate as fuel for diesel engines [5]. However, direct use of biodiesel and vegetable oils may cause to some problems as well as performance decrease in diesel engines

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[6]. In this point of view, vegetable oils have been used in a thermally insulated diesel engine in order to develop the usability of pure vegetable oils in diesel engines [7]. Also, biodiesel form of vegetable oils has also been introduced in a diesel engine [8]. Another possible way to improve biodiesel usability in diesel engine has been introduced that to increase the injection pressure [9]. Therefore vegetable oils and biodiesel are possible fuel candidates for diesel engines. Besides, it was reported that the differences of the engine power outputs when fueled with various types of fuels (pure biodiesel from recycled cooking fat and vegetable oil) were all less than 1% over the whole test range [10]. It has been reported that used cooking oil biodiesels are usually the same as biodiesel from fresh vegetable oil. So the influence of used cooking oil biodiesel (like biodiesel from neat vegetable oil) on engine performance and combustion characteristics is probably more closely related to the oxygenated nature of biodiesel (which is almost constant for every biodiesel), and also to its higher viscosity and lower calorific value, which have a major bearing on spray formation and initial combustion [11]. Also, it is reported that, utilization of waste cooking oil is a key component in reducing biodiesel production costs up to 60–90% [12].

Thermal barrier coatings (TBCs) are applied to diesel engines in order to improve the performance of the engine and reduction of pollutant emissions [13]. TBCs are also applied in adiabatic engines for possible reduction of engine emissions [14]. Thermal barrier coatings are used to improve reliability and durability of hot section metal components and enhance engine performance and efficiency in internal combustion engines. It is reported that constructional problems evolved concerning the compatibility of the new ceramic materials used as insulation along with the conventional ones [14]. Different composites like SiCa, silicon nitride, Al, $MgSiO_2$ and other ceramic materials were used in low hear rejection engine concept [15]. TBCs can also be composed of a bond coat (NiCrAl) as an oxidation resistant layer and stabilized zirconia as a top coat that provides thermal insulation toward metallic substrate. The thermal barrier coated engine parts are piston, cylinder head, and cylinder liners and exhaust valves. The engine with thermal barrier coating is also called low heat rejection (LHR) engine. Insulating the combustion chamber components of LHR engine can reduce heat transfer between in-cylinder gas and cylinder liner. The LHR concept is based on suppressing heat rejection to the coolant and recovering the energy in form of useful work. Some important advantages of LHR engines are improved fuel economy, reduced engine noise, higher energy in exhaust gases and multi-fuel capability of operating low cetane fuels [16,17]. Besides, cold start HC emissions considerably decrease compared to the standard engine without any degradation in engine performance [18].

Although, transesterification makes the fuel properties of vegetable oil closer to petroleum diesel fuel, the viscosity of vegetable oil esters (biodiesel) is still higher (approximately 2 times) than that of petroleum diesel fuel. The concept of an LHR engine is believed to be useful in this regard. The increased in-cylinder gas and cylinder liner temperatures of the LHR engine make possible the usage of biodiesel without preheating. So the energy of biodiesel can be released more efficiently. Literature reviews reveal that insulation of the engine combustion chamber reduces heat rejection, improves thermal efficiency and increases energy availability in the exhaust. But some researchers reported that they observed no considerable improvement in thermal efficiency [19,20].

Higher thermal efficiency, lower emissions, lower fuel consumption, and elimination of the cooling system from engine are the major promises of LHR engine [21]. The objectives of higher efficiency, improved fuel economy, and lower emissions are accomplishable but much more investigations with improved engine and coatings modification, and design are required to explore full potentiality of LHR engine [22]. In this study, blend fuels of waste cooking oil biodiesel with petroleum based diesel fuel by volumes of 5% biodiesel-95% diesel fuel (B5), 100% biodiesel (B100) and D2 (diesel fuel) were tested in a single cylinder compression ignition engine. The usability and stability of biodiesel as fuel in a thermally insulated diesel engine coated with the mixture of 88% of ZrO_2, 4% of MgO and 8% of Al_2O_3 were investigated. Performance, combustion and emission comparisons were made between blends of biodiesel and diesel fuel and between coated and uncoated diesel engines.

2. Materials and test method

2.1. Experimental installations

Experiments were carried out at the Engine Test Laboratory of Automotive Department of Engineering Faculty of Batman University. Schematic diagram of experimental setup is seen in Fig. 1. A single cylinder air cooled and four strokes diesel engine that have a cylinder volume of 510 cc and 9 kW engine output power have been used. Technical specifications of the test engine are presented in Table 1.

Substitutes of the piston and valves of the Lambardini 3 LD 510 single cylinder diesel engine were prepared for coating process. 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. Afterward, the same parts were coated with 400 μm material of coating that was the mixture of 88% of ZrO_2, 4% of MgO and 8% of Al_2O_3.

Tests were carried out at fully loaded operation for each of the test fuels both in coated and uncoated engine operations. BT-140 model hydraulic dynamometer was used for engine performance tests. Technical specifications of the dynamometer and the control unit are given at Table 2.

The FEBRİS combustion analysis software [23] was used in data collecting and analysis. The heat release rate, heat release and cylinder gas pressure values versus crank angle (CA) have been collected by this software.

The CAPELEC CAP 3200 brand exhaust gas analyzer was used to measure emissions of the test fuels. The technical specifications of the device have been presented in Table 3.

The Raytek Rraynger ST4, a non-contact infrared temperature measurement device was used to specify exhaust gas temperature. The exhaust temperatures were measured on the exhaust manifold at the nearest point to the combustion chamber. The technical specifications of this device are presented in Table 4. Engine noise values were also tested for each fuels and engine operation by Digital Sound Level Meter AZ-8921 noise device.

Blend fuels of waste cooking oil biodiesel B5, B100 and D2 were prepared for experiments. These fuels were tested in both coated and normal uncoated engine operations. Testing these fuels in the coated engine operation is symbolized with “C” while the normal engine operation of these fuels is symbolized as “U”. Eventually, for 3 fuels 6 curves are presented for each testing parameters. These curves are for coated engine experiments as CB5, CB100 and CD2, and uncoated engine experiments as UB5, UB100 and UD2. Chemical and physical properties of test fuels are presented in Table 5.