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Experimental examination of the effects of military aviation fuel JP-8 and biodiesel fuel blends on the engine performance, exhaust emissions and combustion in a direct injection engine

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ABSTRACT

Biodiesels are the most popular fuels which can be used as an alternative fuel instead of diesel fuel in diesel engines. Low emission characteristics and high cetane numbers are the most significant advantages of biodiesels. However, JP-8 military aviation fuel which is a kerosene based fuel has a low viscosity, high lower heating value and very low freezing point. The usage of the fuel blends of biodiesel and JP-8 may be effective in improving the characteristics of biodiesel. In this study, JP-8 aviation fuel and sunflower methyl ester blends were tested at 7.5, 11.25, 15 and 18.75 Nm engine loads and at maximum torque speed (2200 min^{-1}) in a single cylinder, naturally aspirated, and direct injection diesel engine. In-cylinder pressure, ignition delay period, engine performance and exhaust emissions have been examined. As the engine load increases the specific fuel consumptions decrease for all test fuels. It was seen that NO_x emissions increased with the increase of the amount of biodiesel in the test fuels. CO emissions decreased as the amount of biodiesel fuel increased in the test fuels. Consequently, it was observed that JP-8 and biodiesel fuel mixtures can easily and efficiently be used in diesel engine.

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1. Introduction

Energy demand increases each passing day in parallel with the economical and technological developments and increasing population in the world. Today, majority of energy requirement is covered by fossil fuels (petroleum) [1]. Petroleum reserves are rapidly consumed due to increasing requirements. Moreover, the usage of fossil fuels in engine vehicles increasingly threatens the eco-system of the world. So, researchers pay attention towards alternative energy sources. Today, exhaust emissions emitting from gasoline and diesel engines in the vehicles are carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbon (HC), particulate matter (PM), sulfur oxide (SO_x) and lead compounds [2,3]. In order to decrease these emissions, researchers have performed many investigations on the effects of vegetable oils as an alternative fuel in the engines. Rudolph Diesel had used peanut oil as fuel in the diesel engine [4]. Moreover, vegetable oil was used as fuel in many vehicles during World War II, but the most extensive researches on the subject coincide the 1970s when the petroleum crisis occurred [5]. Vegetable oils, which have different chemical structures compared to petroleum based fuels, cause the various problems when used directly as fuel in diesel engines [6]. The viscosity of vegetable oils is about 10 times more than the viscosity of diesel fuel. Their lower heating value is approximately 90% of the diesel fuel. Diesel fuel is substantially composed of paraffins and aromatics. But biodiesel is the ester which fatty acids made with glycerine. The type and amount of unsaturated fatty acids constituted the properties of vegetable oils. Besides biodiesel has higher oxygen content. High viscosity can lead to injection problems, poor atomization and incomplete combustion. While the vegetable oils do not have good properties on injection and ignition, they have high flash point and provide advantage on storage safety [6–8]. Besides the transesterification method was widely used in order to remove the negativities arising from vegetable oils, pyrolysis, microemulsion and refining methods are also used [9–12]. By these methods, vegetable oils are converted to biodiesel. Vegetable oils are esterificated with monohydric alcohol such as methanol and ethanol. This method is called transesterification [13]. The specifications of biodiesel shall be improved or it shall be used along with other fuels in order to expand the operating range in diesel engines [14–16].

At this point, kerosene based aviation fuel JP-8 is used along with biodiesel [17,18]. There are many studies in the literature regarding JP-8 aviation fuel [19–23]. JP-8 does not include naphtha. JP-8 has low cetane number and high boiling point as compared

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to benzen [24]. JP-8 aviation fuel is different from conventional diesel fuel due to its corrosion inhibitor content for fuel system which prevents icing at cold operating conditions. JP-8 aviation fuel can be used in motored vehicles for civil and military purposes because of such chemical specifications [25]. Lee and Bae tested the effects of JP-8 aviation fuel and diesel fuel in a single cylinder, common rail injection system diesel engine under heavy-duty conditions. As the evaporation characteristic of JP-8 aviation fuel is better than the standard diesel fuel. They have observed that it has a wider spray angle and short penetration depth compared to diesel. Moreover, they have observed that the premixed combustion section was improved due to good features of mixture formation of JP-8. The highest heat release of JP-8 aviation fuel was also obtained. While high HC and CO emissions were obtained with JP-8 aviation fuel, they have found that CO emissions decrease [17].

Rakopoulos et al. tested the effects of JP-8 aviation fuel and diesel fuel in direct and pre-chamber diesel engines on exhaust emissions [21]. Arkoudeas et al. experimented and compared biodiesel fuel obtained from the sunflower methyl ester and olive oil ester, (10%, 20% and 50% mixtures with the JP-8 aviation fuel) and the JP-8 aviation fuel in a diesel engine. They determined that biodiesel fuel has shown similar characteristics, and they have observed improvement in the particulate matter emissions with JP-8 fuel [26]. Anastopoulos et al. have tried to improve the lubrication characteristics of kerosene. In their study, they have tested 10 different mono-carboxylic acid esters and kerosene in a direct injection diesel engine. They have concluded that all the tested esters improve the lubrication characteristic of kerosene [27]. Kouremenos et al. investigated the effects of diesel fuel and JP-8 in high speed ordinary four-cycle engine. They have found that no significant differences occurred in the generated emission levels for both fuels. Moreover, they have specified that combustion pressure, intensity increased and combustion stability deteriorated when they used the JP-8 aviation fuel. When JP-8 and diesel fuel were compared, they have observed that JP-8 caused pressure fluctuations (oscillations) in the fuel injection systems depending on the different physical specifications of JP-8 [20]. Durbin et al. tested different fuels (low sulfur diesel fuel, vegetable oil/yellow-grease biodiesel fuel, yellow-grease biodiesel, soy-based biodiesel and military JP-8 fuel) in order to determine the effects on HC, CO, PM and NO_x emissions. They have seen that higher biodiesel blends of fuels showed higher unburned hydrocarbons and CO. But PM emissions reduced with higher biodiesel blends of fuels. Moreover THC and CO emissions increased using JP-8 fuel compared to low sulfur diesel fuel. They used the cetane improver with biodiesel. But they observed that the effects of cetane improver were negligible [28]. Labeckas et al. studied on four-stroke, four-cylinder, and naturally aspirated diesel engine fuelled with diesel fuel and its 5 vol.% (E5), 10 vol.% (E10), and 15 vol.% (E15) blends with anhydrous (99.8%) ethanol (E). In addition, they prepared the blends of ethanol–diesel–biodiesel (E15B) including 15 vol.% of ethanol, 5 vol.% of biodiesel and 80 vol.% of diesel fuel. They researched the effects of ethanol and RME addition to diesel fuel on combustion, engine performance, start of injection and emissions. They showed to develop brake thermal efficiency of 0.362 when the engine fuelled with E15B. Furthermore, NO_x and HC emissions reduced with the addition of ethanol to diesel fuel for richer mixtures [29]. Adaileh and AlQdah experimented the diesel, B5 and B20 test fuels (including 5%, 20% biodiesel respectively) in a diesel engine fuelled with waste vegetable oil at engine speed of 1200–2600 rpm. They have seen that biodiesel showed significant reductions in CO and HC emissions except for NOx. It was also seen that specific fuel consumption increased by 5.95% with biodiesel owing to low heating value. NO_x emissions increased when B5 and B20 are used instead of diesel fuel [30]. Keskin et al. investigated the effects of cotton oil soapstock biodiesel–diesel fuel blends in a diesel engine. They determined that engine torque and power output decreased with cotton oil soapstock biodiesel–diesel fuel blends by 5.8% and 6.2%, respectively. It was also observed that specific fuel consumption increased up to 10.5% when cotton oil soapstock–diesel fuel blends used. Smoke emissions decreased up to 46.6% with blend fuels depending on the amount of biodiesel at maximum engine torque speed [31]. Lee et al. performed an experimental study to analyze the combustion process of JP-8 and diesel fuel in a heavy duty diesel engine. ıt was shown that JP-9 emitted less smoke emissions compared to NO_x and HC emissions. They characterized combustion process by means of image analysis focusing on the luminosity intensity and its spatial distribution. According to test results JP-8 had a longer inition delay compared to diesel fuel. They have seen that flame luminosity of diesel fuel was stronger than JP-8 fuel. They have also implied that diesel fuel had more diffusion dominant combustion [32]. Allen et al. investigated the autoignition characteristics JP-8 and camelina hydroprocessed renewable jet fuel in a rapid compression machine. They measured ignition delays at 670–750 K and low pressures (7 and 10 bar). It was shown that ignition properties of renewable jet fuel were distinct from JP-8. In addition ignition delay for hydroprocessed renewable jet fuel was shorter than JP-8 fuel. Hydroprocessed renewable jet fuel had earlier onset of ignition and more vigorous heat release compared to JP-8. They explained the reason of this case by contenting full paraffinic of hydroprocessed renewable jet fuel [33].

Biodiesel and JP-8 fuel mixtures can be used efficiently in diesel engines. The purpose of this study is to analyze the combustion using biodiesel and JP-8 fuel mixtures and diesel fuel. In this study, the experiments were conducted in a single cylinder, four-stroke, direct injection diesel engine fuelled with biodiesel based sunflower seed oil methyl ester and JP-8 fuel mixtures and diesel fuel at 7.5, 11.25, 15 and 18.75 Nm engine loads at maximum torque speed. The effects of different test fuels on combustion, engine performance and exhaust emissions were investigated at different engine loads.

2. Material and method

In this study, six different test fuels have been tested. The mixture percentages of test fuels are given in Table 1. Test fuels have been obtained by mixing sunflower methyl ester based biodiesel and JP-8 aviation fuel by volume. In order to determine the test fuels on combustion, engine performance and exhaust emission in a single cylinder, four-stroke, and direct injection diesel engine were used. For this purpose, the test engine was operated at a maximum engine torque speed of 2200 min^{-1} and 7.5, 11.25, 15, and 18.75 Nm engine loads. The experiments were performed at constant engine coolant and oil temperature. They were kept constant in order to provide stable operating conditions during the tests. The technical specifications of the test engine are given in Table 2.

High viscosity of biodiesel and low lubrication characteristics are the most significant disadvantages of JP-8 aviation fuel. Insufficient lubrication properties of the JP-8 aviation fuel may damage the engine parts and fuel injection system. Some characteristics of test fuels are given in Table 3. The measurements of the characteristics of fuels have been performed at the laboratories of Turkish Petroleum Refineries (TUPRAS).

The schematic view of the experimental set-up is shown in Fig. 1. Cussons P8160 DC dynamometer was used which can absorb a power of 10 kW in 4000 min^{-1} in the control of engine speed and loads. Engine

Table 1
Percentages of test fuels and their abbreviations.

Abbreviation	Percentages of fuel
B25	25% biodiesel + 75% JP-8
B50	50% biodiesel + 50% JP-8
B75	75% biodiesel + 25% JP-8
B100	100% biodiesel
J100	100% JP-8
Diesel	100% diesel

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