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Investigation of usability of the fusel oil in a single cylinder spark ignition engine

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A B S T R A C T

In order to decrease the dependency on petrol-originated energy resources, the utilization of different energy resources in internal combustion engines has been the center of interest of researchers. The main renewable alternative combustible species are ethanol, methanol, hydrogen, biodiesel, and biogas. On the other hand, appearing as a by-product during alcohol production via fermentation, the fusel oil is another alternative energy resource which can be used in internal combustion engines. Containing high alcohols, fusel oil is dark brown colored alcohol mixture, and has a strong odor. The calorific value of fusel oil close to other alternative combustible types ones and the limited number of researches on utilization of fusel oil, an alcohol derivative, in internal combustion engines constitute the base of this research. In this study, the effects of the mixture of unleaded gasoline and fusel oil on engine torque, brake specific fuel consumption and exhaust emissions in a single cylinder, spark ignition engine having port-type fuel infection system at various engine speeds and loads have been investigated. As a result of research carried out, as the amount of fusel oil in mixture increased, the improvements have been observed in engine torque at all of engine speeds and loads compared to pure unleaded gasoline. It has been determined that the brake specific fuel consumption and carbon monoxide (CO) and hydro-carbon (HC) emissions have increased while nitrogen-oxide (NO_x) emissions have decreased.

1. Introduction

The most of energy requirement of world is met from fossil-based combustibles. The engines manufactured until 1970 have been designed for working with fossil fuels. Especially after 1973 petrol crisis and the increase in prices of petrol after Gulf War, and as a result of continuously increasing number of vehicles, the difficulties occurred in meeting the fuel requirements of countries [1]. Also, the negative circumstances of fossil-based fuels on environment and human health have become more important day by day. The usage of petrol and petrol-derivative fuels leads to release of gases called sera-gas. The leading one among emission resources leading to sera gas release is shown to be internal combustion engines [2].

Considering the fuel consumption tendencies, it can be said that oil reserves reduce [3]. In order to avoid from energy crises due to short of fossil fuels, the researches are carried out on alternative energy resources. Also getting rid of external dependency of countries in such an important strategic field as energy is economically very important. While establishing the new energy policies, the main constituents are usage of local, renewable and more environment-friendly resources, improving the efficiency, and ensuring the resource diversity. At this point, the automotive sector, which is the leading sector of countries in terms of economy, is one of the most important industries where the

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liquid and gas combustibles are consumed. As an alternative to unleaded gasoline and diesel, many studies on usage of combustibles such as hydrogen, various alcohol species, liquid petroleum gas (LPG), compressed natural gas (CNG), vegetable oil esters and etc. in vehicles as fuel have been carried out [4–7].

Alcoholic fuels, especially the ethanol, can be obtained from renewable energy resources such as sugar cane, ammoniac, waste biomass products, corn, and barley. The ethanol which produced in Brazil in 99.3% purity is added into unleaded fuel in concentrations varying between 20 and 25% in order to improve the knocking resistance. The oxygen (O_2) content of ethanol improves the combustion performance, and allows to decrease the emissions of hydro-carbon (HC) and carbon-monoxide (CO) seen in exhaust emissions. Since it is a liquid combustible, its storage and even its transfer between regions are similar with those of fuel [8–11].

It is known that the octane values of alcohol-based alternative fuels such as ethanol and methanol which can be used in internal combustion engines are high but their cetane values are low. The alcohol-based combustibles having high octane values allow knocking in spark-ignition engines to be decreased, and they allow the thermal efficiency to be improved due to working on higher pressure rates. But alcohols are not suitable for using directly in diesel engines due to their low cetane values [12]. On the other hand, when compared with gasoline fuel, many researchers have revealed that alcohols decrease the exhaust emissions. But the low lower calorific values of alcohol may lead to losses in engine performance. For same engine output power, the fuel consumption increases when alcohol-based combustibles are used [13–17].

The fusel oil is obtained as by-product during the distillation process in alcohol production [18–20]. The studies on fusel oil have generally focused on obtaining the amyl alcohol and iso-amyl acetate production [21]. The amount and quality of fusel oil is determined by the type and quality of resource used for fermentation. The fusel oil is obtained while purifying the alcohol. In general, 1–11 L of fusel oil is obtained as by-product during production of 1000 L of alcohol [22].

The composition and amount of fusel oil depend on the type of carbon used in alcohol production process through fermentation, the preparation method, and the method used for separating the fusel oil from fermentation mixture. Fusel oil consists of main low molecular weight alcohols (all kinds of I-butyl alcohol, n-propyl alcohol, n-butyl alcohol, ethyl alcohol and n-amyl alcohol, but especially i-amyl), trace amount of water, trace amount of aldehydes, free acids and their esters, high alcohols, and terpenes [22]. The chemical properties of fusel oil are represented in Table 1.

In this study, fusel oil has been added into unleaded gasoline at concentrations of 10% (F10), 20% (F20) and 30% (F30). The experiments have been carried out at different loads and engine speeds, where the maximum engine torque is acquired. Obtained performance and exhaust emission values have been compared with reference unleaded gasoline (F0) usage values.

2. Material and method

The experiments have been carried out in a four-stroke, single cylinder, spark-ignition Hydra engine the technical specifications of which are shown in Table 2. The test engine was loaded with a McClure brand electrical DC dynamometer which is rated 30 kW at 6500 rpm. The schematic view of experimental setup is represented in Fig. 1. In order to measure the fuel consumption, a Dikomsan JS-B brand electronic scale having 30 kg capacity with 1 g sensitivity and the Rucanor brand chronometer with 0.01 s sensitivity have been used. In order to measure the exhaust emissions, a SUN MGA 1500 exhaust gas analysis device has been utilized, and its technical specifications are given in Table 3. The calibrations of all devices have been completed before experiment, and controlled periodically.

The experiments were conducted at 1500, 2500, 3500 and 5000 min^{-1} engine speeds. The tests were performed at 25%, 50%, 75%, and 100% engine loads. Four test fuels (F0, F10, F20 and F30) have been used in the experiments. The properties of the test fuels are shown in Table 4 [20]. Fusel oil contains approximately 10% water. Also, its lower calorific value is lower than that of unleaded gasoline. All experiments have been conducted at stoichiometric air/fuel ratio. Stoichiometric air/fuel ratio of fusel oil was calculated as 9.65/1 when the water content was neglected. The results indicate that more fusel oil is needed under same conditions in the experiments which conducted at this stoichiometric air/fuel ratio ($\lambda = 1$). The engine torque, fuel consumption and exhaust emissions (HC, CO and NO_x) have been measured in experiments. Before starting the experiments, it has been waited for the stabilization of engine oil and cooling water temperatures.

For calculating the effective power, Eq. (1) was used. Where, M indicated the engine torque, n indicates the engine speed, and P_e indicates the effective power.

$$P_e = \frac{2*\pi*M*n}{60*1000} \tag{1}$$

The specific fuel consumption represents the amount of consumed fuel per unit time for unit power. The amount of specific fuel consumption has been calculated with Eq. (2).

$$bsfc = \frac{\dot{m}_f}{P_e} \tag{2}$$

where, bsfc represents the specific fuel consumption, and $\dot{m}_f$ indicates the fuel consumption.

Table 1
Physical properties of fusel oil composition [19].

Constituent	Chemical formula	Molecular weight (g/mol)	Density (g/cm^3)	Boiling point (°C)	Freezing point (°C)	% Volumetrical	% Molar
i-amyl alcohol	$C_5H_{12}O$	88.148	0.8104	131.1	−117.2	63.93	61.52
i-butyl alcohol	$C_4H_{10}O$	74.122	0.802	108	−108	16.66	15.87
n-butyl alcohol	$C_4H_{10}O$	74.122	0.8098	117.73	−89.5	0.736	0.708
n-propyl alkol	C_3H_8O	60.09	0.8034	97.1	−126.5	0.738	0.704
Ethanol	C_2H_6O	46.07	0.789	78.4	−114.3	9.58	8.98
Water	H_2O	18	1	100	0	10.3	12.23