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Combustion, performance and emission characteristics of fusel oil in a spark ignition engine

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ABSTRACT

Alcohol based fuels attract the attention of alternative fuel researchers. Many studies have been performed about combustion, performance and emission characteristics of alcohol used in internal combustion engines. Fusel oil is an alcohol based fuel obtained as a by-product during alcohol fermentation. Up to the present there has been no study regarding the combustion characteristics of fusel oil in a spark ignition engine. In this experimental study, performance, emission and combustion characteristics of fusel oil were examined in a spark ignition engine at 2500 rpm and four different engine loads. In-cylinder pressures, heat release rates, flame development and flame propagation durations, crank angles corresponding 50% of total mass fraction burnt, engine torque, brake specific fuel consumptions, CO, HC and NO_x emissions were investigated. The water content and lower heating value of the fusel oil aggravated the combustion. Flame development and flame propagation durations were prolonged. As a result engine performance dropped. In addition, fusel oil usage increased CO and HC emissions up to 21% and 25% respectively. NO_x emissions decreased about 31% due to worse combustion performance of fusel oil.

1. Introduction

A large part of fuel used in the motored vehicles is fossil fuels. However researchers have studied on the alternative fuels owing to both damage on the environment and depletion of fossil fuels [1–3]. Alternative fuels should be environmental, renewable and easily obtained energy source. In addition, they can be used with minimum modifications in the internal combustion engines. It is also possible to say that alternative fuels can improve the combustion and engine efficiency. As known fossil fuels lead to global warming because of their high carbon dioxide (CO_2) release. Besides, carbon monoxide (CO) and hydrocarbon emissions (HC) have carcinogenic and toxic effects that are released when the spark ignition engines operate with inappropriate air/fuel ratios [4]. The reduction of these harmful exhaust emissions depends on the providing the appropriate combustion conditions in a spark ignition engine. Fuels such as ethanol and methanol improve the combustion process and CO emissions are reduced especially [5,6].

Engine efficiency is determined by compression ratio in the internal combustion engines. The ability to increase the compression ratio depends on the octane number of fuel used in the spark ignition engines. Nowadays, limiting the octane number at about 100 prevents the increase of compression ratio in the spark ignition engines. For this reason, the efficiency of spark ignition engines are lower than compression ignition engines. High octane number fuels or improver additives which increase the octane number is essential in order to prevent knocking problem occurred at higher compression ratios [7–12]. Iodine, tel tetra-ethyl lead and alcohol-based additives have been used in order to increase the knocking resistance until now. The researches on the alcohol-based additives increased since the usage of tetra-ethyl lead is forbidden due to harmful effects on health and iodine damages the engine parts [13,14].

Many researchers have studied on usage of alcohols directly as an alternative fuel and fuel additives in the spark ignition engines. Lower heating values of alcohols are lower than gasoline. Therefore, fuel consumption usually increases when alcohol is used as an alternative fuel [15,16]. Bata et al. [17] concluded that the ethanol addition to gasoline reduced the CO and HC emissions. Similar results were obtained in many researches [5,6,18–22]. The reduction in CO and HC emissions was caused by oxygenated characteristic and wide flammability of ethanol. Additionally, similar CO and HC emission reduction trends were seen in use of methanol with gasoline [23–29]. Taljaard et al. conducted a study to investigate the effects of oxygenate in a spark ignition engine. They examined engine performance and exhaust emissions in a single cylinder for stroke engine. It was reported that the CO, NO_x and HC emissions reduced significantly at stoichiometric air/fuel ratio when the oxygenates were used [30]. Bilgin and Sezer [31] reported an increase in brake mean effective pressure with 5% methanol addition to gasoline. Hsieh et al. [21] investigated the effects of 10%, 20% and 30% ethanol–gasoline fuel blends on engine performance in a spark ignition engine. They concluded that the engine torque and fuel consumption slightly increased with ethanol–gasoline blends. They depicted that

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the increase in engine torque and fuel consumption could result from improved combustion efficiency and lower calorific value of ethanol respectively. Similar results were obtained by Al-Hasan [19]. He performed the experiments in a four cylinder four stroke spark ignition engine. He investigated the effects of ten different ethanol–gasoline blends on engine performance and exhaust emissions. It was reported that the engine power, brake thermal efficiency and volumetric efficiency were increased averagely by 8.3%, 9% and 7% respectively. It was reported that the volatility and the latent heat of fuel blend increased while the percentage of ethanol increased in fuel blend. Therefore, charge temperature decreased and volumetric efficiency increased [20,32]. Liu et al. [27] performed a study in a spark ignition engine fuelled with methanol/gasoline fuel blends. They determined start of combustion (SOC) and rapid burning phase (RBP) in case of methanol addition to gasoline. They defined the SOC and RBP from crank angle corresponding 5% and 5%–90% accumulative heat release respectively. They concluded that the SOC was advanced and RBP became shorter with using methanol. A similar result was reported by Hu et al. [28] and Yanju et al. [33]. They were also concluded that the peak cylinder pressures increased when methanol–gasoline blends were used.

Bielaczyc et al. [34] investigated the effects of the blends of ethanol and gasoline (from 5% ethanol–95% gasoline to 50% etanol–50% gasoline in vol.) on the engine performance and exhaust emissions. The experiments were conducted with an unmodified European passenger car on a chassis dynamometer over new European driving cycle. The authors presented the results of both regulated and unregulated emissions. It was reported that the lowest HC and CO emissions were observed with E50 due to improved combustion or improved removal in the after treatment system. Also, the lowest NO_x emission was observed with E25 in urban driving cycle.

Agarwal et al. [23] investigated the effects of M10 (10% methanol and 90% gasoline) and M20 (20% methanol and 80% gasoline) the blends of methanol and gasoline fuels on the performance, emissions and combustion in a medium duty spark ignition engine. The test results showed that thermal efficiency obtained by the blends of methanol–gasoline test fuels were higher than gasoline. They also determined that CO, nitrogen oxides (NO_x) and soot emissions decreased when compared to gasoline fuel. It was also found that there was a slight difference in cylinder pressure compared to the gasoline fuel. They noticed that the heat release rate obtained with gasoline started to increase earlier compared to the blends of methanol–gasoline test fuels. Moreover, it was shown that combustion duration decreased with increasing engine load.

Maurya and Agarwal [24] examined the ethanol, methanol and gasoline fuels in a four stroke, port type fuel injection system homogeneous charged compression ignition (HCCI) engine and investigated the performance, emissions and combustion characteristics. They investigated the effects of inlet air temperature and air/fuel ratio on thermal efficiency, combustion efficiency and emissions. It was shown that ethanol and methanol fuels could be used instead of gasoline in HCCI combustion mode. They realized that the ethanol and methanol fuels could be ignited at lower inlet air temperature compared to gasoline. They obtained higher indicated mean effective pressure (imep) with ethanol and methanol fuels at all constant air/fuel ratio.

Siwale et al. [25] examined the performance and combustion characteristics of gasoline, M53b17 (53% methanol, 17% n-butanol and 30% gasoline in vol.), M20 and M70 test fuels in a spark ignition engine. They pointed out to increase the thermal efficiency but decrease the exhaust gas temperature with blends. They saw that the combustion duration decreased with M53b17 due to higher energy content. Furthermore, it was determined that CO emissions increased with M53b17 test fuel compared to M70 test fuel.

Fusel oil is obtained as by product in the production of alcohol after the distillation process. Fusel oil has a bad smell and dark brown color. It consists of about 390 g/L isoamyl alcohol, 158 g/L isobutyl alcohol, 28.4 g/L ethyl alcohol, 16.6 g/L methyl alcohol and 11.9 g/L n-propyl alcohol [35]. It also includes the aldehite, esters and water by about 15% in vol. [33,36–42]. The first study on fusel oil was performed by Wetherill in 1853 [43]. Reduction of the harmful effects of fusel oil, reduction of the fusel oil in the alcohol drinks, the lubricating production from the fusel oil and biodiesel production with fusel oil are the researches that have been conducted on the fusel oil up to the present [44–47]. Fusel oil has not been used effectively apart from the compensating the small part of energy demand in the factories. In Turkey 0.4–0.7 L fusel oil is obtained per 100 L alcohol production [47]. According to data given by Turkish Tobacco and Alcohol Market Regulatory Authority, approximately 73,140,000 L ethanol was produced in 2013 in Turkey [48]. It equals about 512,000 L fusel oil production. When it is taken into consideration that the fusel oil has not been used effectively, it is obvious there will be enormous environmental pollution. Using fusel oil even only in agricultural activities will reduce this pollution and cause to decrease cost of agricultural production.

There are limited numbers of studies on the usage of fusel oil in the spark ignition engines in the literature. Calam and İçingür [41] investigated the effects of the blends of fusel oil and gasoline fuels on performance and exhaust emissions. They obtained the maximum engine brake torque with F30 test fuel (30% fusel oil and 70% gasoline test fuel in vol.). Specific fuel consumption increased by the increase of fusel oil fraction in the test fuels at all engine speed and full load. The highest increase was obtained by F30 test fuel about 7.7%. NO_x emissions decreased with the increase of fusel oil fraction in the test fuel but HC and CO emissions increased in the experiments. They determined that the reason of increase of HC and CO was the decrease of the in-cylinder temperature when fusel oil was used. In another study, Calam ve et al. [49] investigated the effects of the variations of ignition timing on the usage of fusel oil. They saw that engine brake torque and fuel consumption increased by the addition of fusel oil to gasoline in the experiments conducted at 3500 rpm engine speed. In addition, HC and CO emissions increased by about 40% and 10% respectively when fusel oil was used.

The usage of fusel oil in the internal combustion engines as an alternative fuel may be advantageous in terms of using a new energy source for internal combustion engines. However, a detailed study on the combustion characteristics of fusel oil is not be found in literature. In this study, the effects of the blends of fusel oil–gasoline test fuels (F0, F50 and F100) on engine performance, exhaust emissions and combustion characteristics were investigated in a single cylinder, four stroke gasoline research engine having port fuel injection system. The experiments were performed at 2500 rpm engine speed, $\lambda = 1$ and four different engine loads (25%, 50, 75% and 100%). The effects of test fuels on cylinder pressure, heat release rate, maximum pressure rise rate, combustion durations, engine brake torque, specific fuel consumption and exhaust emissions were investigated.

2. Experimental apparatus and procedure

2.1. Research engine test bed and test fuels

In this study single cylinder, four stroke, port fuel injected gasoline research engine Ricardo Hydra was used. The technical specifications of the test engine are given in Table 1. Premixed gasoline and fusel oil were provided by port type fuel injector mounted in the intake manifold. Fuel injection pulse width was controlled electronically to keep $\lambda = 1$ at constant value. Compression ratio of the test engine can be adjusted between 5:1–13:1. Also, the ignition advance can be switched between 70° before top dead center (BTDC) and 20° after top dead center (ATDC). In this study, experiments were conducted at 9:1 compression ratio and the ignition advance was fixed to 20° BTDC. The test system was also equipped with torque measurement, exhaust gas temperature, ignition timing, injection pulse, coolant and engine oil temperature, air mass flow meter, intake air heater, DC dynamometer and exhaust gas analyzer. Meriam Laminar Flow Element Z50MC2-4F