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Effect of fuel oil - gasoline fusel blends on the performance and emission characteristics of spark ignition engine: A review

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Abstract: Alcohol-based as alternative fuels attract the attention of many researchers. Many kinds of research have been conducted on performance, combustion and emission characteristics of alcohol utilized in spark ignition engines. Fusel oil is an alcohol based fuel obtained as a by-product of alcohol fermentation from agricultural such as beet, cone, potatoes, rice, etc. The calorific value, higher evaporation heat and octane number of fuel oil close to other alternative fuels. Despite that, there is limited number of studies refer on the usage of fusel oil as fuel in spark ignition engines. This paper reviews the works done 'effects of fusel oil as a fuel blends on performance (brake torque, brake power, BSFC, effective efficiency, EGT) and emissions (CO, NOx, HC) characteristics in spark ignition engine. It was seen that when fusel oil – gasoline blend used at almost the engine torque and specific fuel consumption increased, Also HC and CO emissions averagely increased. Furthermore knocking and nitrogen oxides NOx were decreased .Moreover volumetric efficiency and octane number increases with the increase in percentage of fusel oil in blend tests. In other hand the negative effects that happened in engine performance caused by the higher water content in fusel oil.

Key words: Fusel oil; Alternative fuels; Spark ignition engine; Exhaust emissions

1. Introduction

A huge part of fuel used in the engine cars is fossil fuels. However researchers have studied on the alternative fuels owing to both damage on the environment and depletion of fossil fuels (Uyumaz et al., 2014). Alternative fuels should be environmental, renewable and easily obtained energy source. Alcohols have been recommended as an alternative engine fuel almost since automobile was invented (Wagner et al., 1979). Several researchers have achieved on using of alcohols directly as an alternative fuel or fuel additives in IC engines. Due the chemical properties of alcohol such as the heat value the fuel consumption usually increases when alcohol is used as an alternative fuel (Chen et al., 2010; Gravalos et al., 2013; Scragg, 2009). Gasoline – alcohol blend can be used with or without water. Depending on the ambient temperature, the chemical structures of the components and purity of the chemical components, phase differentiation problems can be observed. As a result of phase differentiation, differences between each cycle and difficulties in combustion and initial movement problems can be observed

Alcoholic fuels, particularly the ethanol, can be gotten from renewable energy resources such as ammoniac, sugar cane, waste biomass products, barley and corn (Astbury, 2008; Moka et al., 2014). The ethanol that is manufactured in Brazil in 99.3% purity is added to gasoline in concentrations varying between 20 and 25% in order to increase the ant-knocking resistance. (Costa and Sodre, 2010; Icingur and Calam, 2012; Jehlik et al., 1999) Also the oxygen content(O2) of alcohol improves the combustion performance, and allows for reduction the emissions of carbon-monoxide (CO) and hydro-carbon (HC) (Cairns et al., 2009; Yeliana et al., 2008). It is known that the octane values of alcohol-based alternative fuels such as methanol and ethanol that can be used in IC engines are high. The alcohol-based combustibles having high octane values which allow to reduce the knocking in SI engines when increase the compression ratio. The increment in compression ratio leads to improvements engine performance, brake specific fuel consumption BSFC (Cerri et al., 2013; Goswami and Vashist, 2015; Koç et al., 2009; Mack et al., 2014; Rothamer and Jennings, 2012). On the other hand, when compared alcohol with gasoline fuel, many researchers have revealed that alcohols reduce the exhaust emissions. But the low energy values of alcohol may be lead to increase the specific in engine performance. For same engines the fuel consumption and output power, decreases when alcohol-based combustibles are used (Gravalos et al., 2013; Yüksel and Yüksel, 2004).

Fusel oil is a by-product of ethyl alcohol production with fermentation during the distillation process and is a natural source of amyl alcohols (Dörmő et al., 2004; Ferreira et al., 2013; Özgülsün et al., 2000). Fusel oil has a bad smell and dark brown color. It consists of about 390 g/L iso amyl alcohol, 158 g/L isobutyl alcohol, 28.4 g/L ethyl alcohol, 16.6

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g/L methyl alcohol and 11.9 g/L n-propyl(R.P. Eduardo) as shown in Table 1.In Brazil, fusel oil is generally produced in the proportion of 2.5 L per 1000 L of ethanol. Also in Turkey 2–3.5 L fusel oil is obtained per 1000 L alcohol (Anonymous, 2013; Ferreira et al., 2013). Fusel oil is not widely-used in the industry .The direct use of fusel oil as a solvent. Also in some countries it uses as supply energy by burned for processing plants (Qi et al., 2005). However, both the physical and chemical properties of fusel oil indicate that it can be used as an alternative fuel for SI engines as shown in the Tables 1, 2.

Fusel oil has the appearance of an alternative fuel for use in a spark ignition engine, The composition and amount of the fusel oil depends on the type of carbon used in the alcohol production, fermentation process, preparation method, and decomposition method of the fusel oil in the mixture (Calam et al., 2014). The performance and emission engine levels improved by used fusel oil as an additive with methanol gasoline blended. Improvements have been detected in the torque engine at all of the loads and engine speeds compared to pure gasoline(Karaosmanoğlu et al., 1997).

There are a limited number of literatures and researches on engine performances, emissions and combustion characteristics using fusel oil as fuel additive or blend. This paper was investigated the effects of performance (brake torque, brake power, BSFC, effective efficiency, EGT) and emissions (CO, NOx, HC) characteristics of spark ignition engine with fusel oil as fuel blends.

2. Literature review

The chemical and physical properties refer the quality of fuel to be combusted in an engine. Engine performance, combustion quality and emission characteristics are related to them. The important properties of fusel oil are shown in Table 2. One of the most significant properties of fusel oil is the oxygenated atoms in their molecular compounds. Nonetheless, the lower LHV and a higher latent heat of evaporation of the fusel oil will cause same problem on flame development. Moreover, the water content of the fusel oil can reduce the flame development.(Solmaz, 2015). Also, the density of the fusel oil is higher than gasoline. This property can present an advantage in terms of engine performance. Due the higher density of the fusel oil the mass flow rate of the fuel will increase. Thereby, the negative influence of the lower LHV can decrease.

Icingur and Calam (Icingur and Calam, 2012) worked on the performance and exhaust emission of an SI engine using fusel oil blends (F0, F5, F10, F20 and F30). The Test was achieved by four strokes; single cylinder at full load conditions also with different engine speeds. The results of this work showed the specific fuel consumption and torque were increased and the highest increase was obtained at F30 as 7.7%and %3.4 respectively. Also the hydrocarbon monoxide (CO) and (HC) carbon emissions have increased and decreased in NOx depending on the quantity of oil blends Fusel.

In this study (Karaosmanoğlu et al., 1997) that performed by Karaosmanoglu on four-cylinder spark ignition engine with deferent engine speeds of 1750,2500,3250, and 4000 rpm .The phase separation temperature (PST) of ethanol-gasoline blends reduced according to an increased in the amount of fusel oil as a new blending agent.

3. Results Of experiment conducted By Calam et al. (2014)

The experiments have been achieved in a four-stroke, single cylinder, SI Hydra engine. The experiments were carried out under deferent engine speeds (1500, 2500, 3500 and 5000 rpm) and deferent engine loads 25%, 50%, 75%, and 100% N m. Also deferent test fuels (F0, F10, F20 and F30) have been performed in the experiments.

The torque was increased in all loads and engine speeds when the amounts of fusel oil in the test fuels have increased. The highest engine torque has been determined at 2500 rpm for F30 as shown in the Fig. 1. The lower calorific heat values of fusel oil (almost 30% is lower than unleaded gasoline) led to lower calorific heat values of the test fuels by adding fusel oil into gasoline. Hence, amount of fuel mass taken into the cylinder rises with the increase of amount of fusel oil in the test fuel. As a result of the increase this quantity of fusel oil the brake specific fuel consumption increased. Evaluating the maximum engine torque speed the SFC has increased by 2.4%, 2.7%, and 3.1% compared to pure gasoline when F10, F20 and F30 test fuels have been used, respectively.

It is observed that the CO emissions increases with engine load increases .Also the CO emissions of F10, F20 and F30 have increased compared with pure gasoline (F0), 7.4%, 8.1% and 9.9%, respectively.

Table 1: Composition of fusel oil (Calam et al., 2014; Icingur and Calam, 2012)

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 alkyl	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

Table 2: Composition of gasoline _fusel oil Blends (Calam et al., 2014; Icingur and Calam, 2012)

	Test standard	gasoline	Fusel oil	F10	F20	F30	F50
Density [kg/m3]	ASTM D 4052	746	847	755	761	768	785
Low heating value[kJ/kg	ASTM D 240	43,594	29,536	42,63	42,125	41,798	39,585
Engine octane number	ASTM D 2700	86.59	103,72	87.28	87.09	87.1	89.8
Research octane number	ASTM D 2699	96.47	106.85	97.85	97.89	98.3	98.7
Freezing point [°C]	ASTM D 6749	−52	≤50	≤50	≤50	≤50	≤50

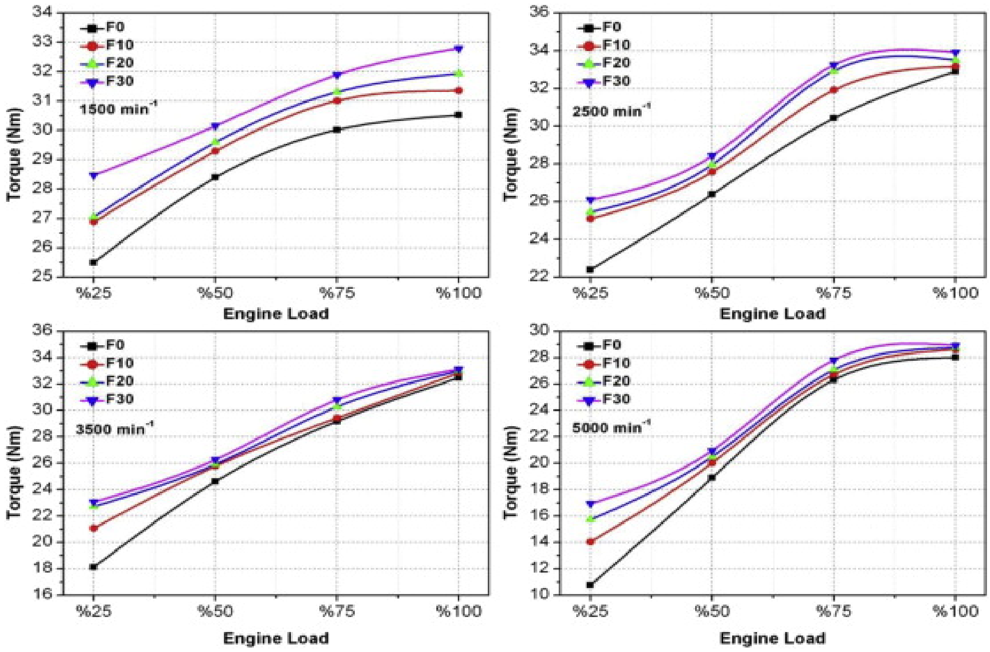

Fig. 1: The difference of engine torques with versus engine load at four different engine speeds (Calam et al., 2014)

Moreover in this study HC emissions have increased with the increase of engine load at all engine speeds. HC emissions for F30, F20 and F10have increased by 5.2%, 6.7% and 7.7% respectively at the maximum engine torque speed (2500 rpm) with test fuels. NOx emissions are the produce of exhaust gas happening inside the cylinder depending on temperature and pressure at the end of combustion. Also, NOx emissions are released as a result of a reaction of oxygen and nitrogen content of air gotten into the cylinder, particularly above 1800 °C. Also, the actuality of certain amount of water content in fusel oil has been effective on a reduction of NOx emissions. The decreases in NOx emissions of F10, F20 and F30 test fuels compared to gasoline (F0) were 1%, 2% and 3.1%, respectively at the maximum engine speed.

4. The results of the experiments conducted byCalam et al., (2013)

According to the experiment performed by (Calam et al., 2013) with a Hydra brand, four cylinders spark ignition engine with compression rate of 11/1 also the experiment was conducted under full load conditions of 3500 1/min maximum engine torque with varying advance values. The specifications of the test engine are shown in Table 3. Also with deferent fusel oil blends (B0, F5, F10, F20, F30 and F50.

Table 3: Specifications of the test engine (Calam et al., 2013)

Engine Type	Hydra, s Ignition Engine
Number of Cylinders	1
Bore × Stroke	80.26 × 88.9 (mm)
Max. Speed	5400 (1/min)
Max. Output	15 (kW)
Compression Ratio	5/1–13/1
Fuel System	Fuel Injection
Spark Timing Range	70° BTDC–20° ATDC

The result concluded that on increasing the amount of fusel oil in gasoline fuel blend there was an increase in torque when compared to pure gasoline. An optimum engine torque was observed 33.53 Nm at 24° ignition timing for F10 (Fig. 2).

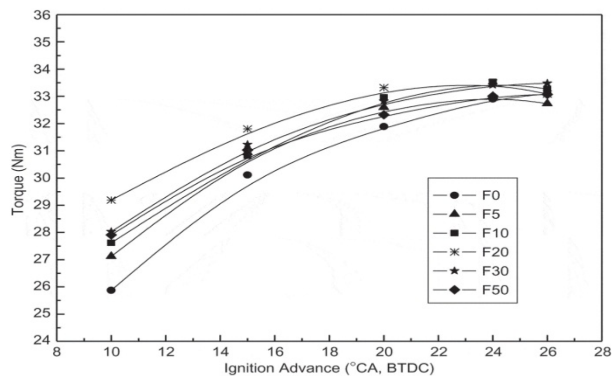

Fig. 2: Difference of engine torque with ignition timing (Calam et al., 2013)

When increased fusel oil the specific fuel consumption increased. Also was noted CO and HC emission reduced. As the ignition advance increases, the decreases and NOx decreased due to low exhaust gas temperature (Fig. 3).

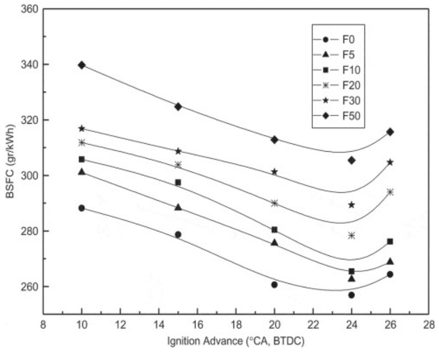

Fig. 3: Difference of engine torque with ignition timing (Calam et al., 2013)

5. The results of the experiments conducted by Solmaz (2015)

The experiments have been achieved in a single cylinder, four stroke, port fuel injected gasoline research engine Ricardo Hydra. The performance, combustion characteristics and emission of deferent fusel oil blending were measured in four different engine loads and 2500 rpm .Also compression ratio ignition advance were 9:1 and 20° BTDC.

It is achieved that the heat release rates and in-cylinder pressure decrease when used fusel oil. This reduction cussed by worse combustion characteristic of fusel oil due to its high water content (10–15%). The maximum indicated mean effective pressure value was achieved at 100% engine load with gasoline fuel (F0) as 8.05 bar (Fig. 4).

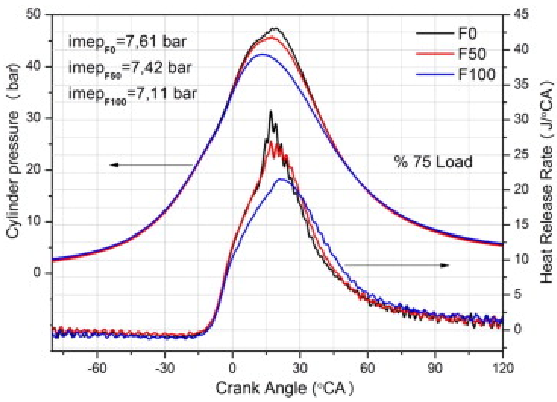

Fig. 4: Impacts of fusel oil on in-cylinder pressure and heat release rate at 100% engine load and 2200 rpm engine speed (Solmaz, 2015)

The CO and HC emissions averagely increased 6.7% and 21% and 10% and 25% when using F50 and F100 fuels respectively. The increment in CO emissions related with decreased in in-cylinder temperatures which caused by the water content of fusel oil. The decreased in NOx emissions were observed when used F50 and F100 15% and 31% respectively as shown in Fig. 5.

The reduction in engine torque when used F50 and F100 fuel were averagely 2% and 6% respectively Also it is observed the increment in BSFC when the fusel oil was used. Nonetheless, while the engine load was increased, BSFC reduced due to the increasing power at the same engine speed of 2500 rpm. BTEs were decreased averagely 3.3% and 8.6% when F50 and F100 respectively was used as shown in Fig. 6.

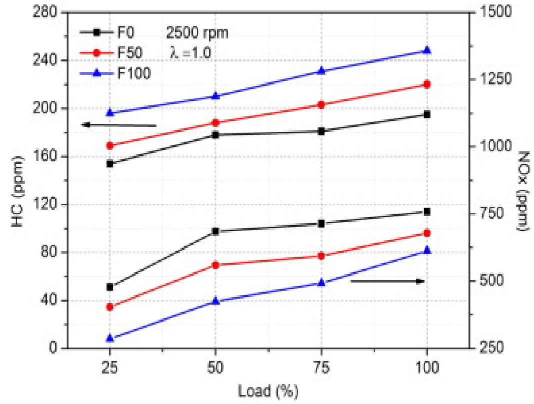

Fig. 5: Impacts of fusel oil on NOx and HC emissions at 2500 rpm engine speed and four different engine load(Solmaz, 2015)

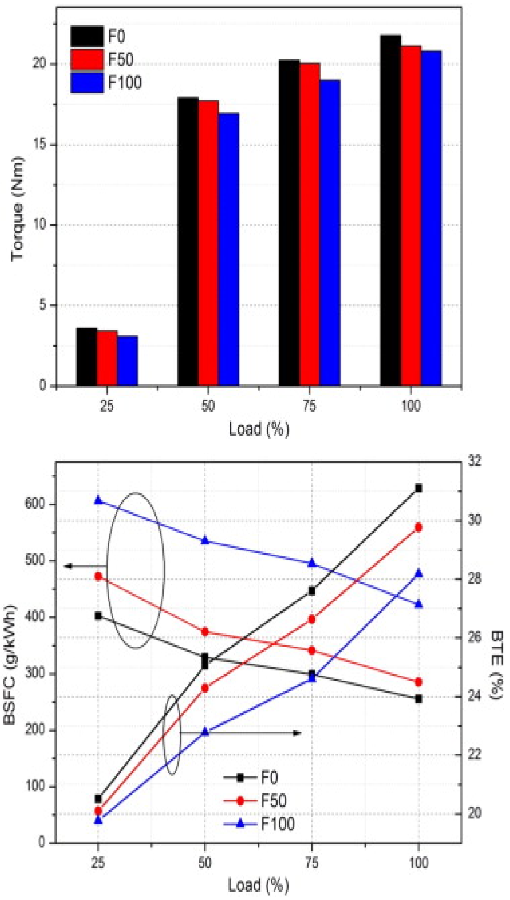

Fig. 2: Torque, brake thermal efficiency and brake specific fuel consumption differences between fusel oil (F0, F50 and F100) and four different engine load at 2500 rpm engine speed(Solmaz, 2015).

6. Conclusion

Fusel oil is a by-product gotten from agricultural product such as, sugar beet, cone, grains, potatoes, rice, wheat, etc. Fusel oil contains mainly three alcohols: ethyl alcohol, i-butyl alcohol and i-amyl alcohols. Based on the reviewed paper for the performance and emissions, it's concluded that fusel oil represents as alternative fuel for gasoline and accordingly must be used into in the future for carrier purpose. Also, different properties of fusel oil that is essential for the evaluation the performance and emission characteristics of spark ignition engine have been reviewed and compared with pure gasoline.

According to the mentioned in the literature review the torque averagely increased except the (SFC) specific fuel consumption, HC and CO emissions averagely.

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