The Impacts of Moisture content on Performance and emissions of a four-cylinder SI engine running with fusel oil –gasoline blends.

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Abstract: - Biofuels from Biomass are meant to decrease significantly dependence on fossil oil and reduce the environmental influences in energy use. Fusel oil one of biofuel that composed of a mixture of alcohols. Fusel oil obtained by-product during fermentation of agricultural products such as beet, cone, sweet molasses, grains, potatoes. According to the high research and motor octane rating also a high density of fusel oil compared with other fuels maybe it will get an essential place in the alternative. The main objective of this study was to determine the impacts of moisture on performance and emissions characteristics of a four-cylinder engine running with fusel oil –gasoline blends.The experiments were performed on spark ignition engine under 4500 rpm engine speed, different engine loads and the different blending ratio of gasoline- fusel oil (G100, FBWE20, and FAWE20). In addition, the effects of test fuels upon brake power, brake thermal efficiency, brake specific fuel consumption, maximum in-cylinder pressure, and emissions (nitrogen oxide NOx, hydrocarbon HC, carbon monoxide CO, and carbon dioxide CO2) were examined. The heating value of fusel oil after water extracted (FAWE) become 33.8 MJ/kg that improved by 13% compared with original one (FBWE) 29.9 MJ/kg. Mostly at all blending of fusel oil –gasoline the brake power is slightly increased than that of gasoline. Also, the brake specific fuel consumption (BSFC) and thermal efficiency improved by reduced the water content of fuel oil. Furthermore, the NOx emission decreased with fusel oil -gasoline blends compared with pure gasoline at all engine loads. However, HC, CO, and CO2 emissions increased with fusel oil -gasoline blends. In general, the higher oxygen content and octane number of fusel oil with reducing water content led to improving the engine performance and NOx emission.

Key-Words: - Fusel Oil, Biofuels, NOx emissions, SI engine, Alternative Fuels, Engine performance

1 Introduction

The growing demands of fossil fuels due to a rapid development of industry and automotive society linked with the environmental pollution issues have encouraged the efforts on exploring alternative fuels for ICE in past decades[1, 2]. Alternative fuels that are obtained from resources other than petroleum. Alcohol based alternative fuels may have regarded one of the renewable solutions, with the potential to be used in a n ear CO2-neutral manner through efficient conversion of biomass [2]. In the generally alcoholic fuels are produced from several sources (biomass, agricultural, etc.) that reduce the energy dependence. Alcohol based fuels, expressly the ethanol, can be produced from renewable energy resources like ammoniac, sugar cane products, barley corn even wastes biomass [3, 4]. Several alcohols can be added to gasoline to improve the engine performance through improving the combustion efficiency due to the high oxygen content of alcohols[3, 4]. However, alcohols have a higher octane number compared with gasoline and can be used as an octane enhancer for gasoline. The addition of high-octane fuel such ethanol, methanol and fusel oil to gasoline is quite significant. Palmer[5] declared that add ethanol to gasoline resulted in an improvement in octane number via five units for each 10% ethanol friction

Bilgin and Sezer.[6]investigated the impact of methanol - gasoline blends on the engine performance. The maximum brake means effective pressure (BMEP) achieved with M5 fuel blend. Dernotte et al. [7]they maintained that the using butanol -gasoline blends at different ratio of butanol Bu20, Bu40, Bu60 and Bu 80% led to improving the combustion stability by decreasing the coefficient of variation of variation(COV) of indicated mean effective pressure (IMEP).

Alcohols as fuels give a b etter trend to reduce the emission of ICE [8, 9]. [8, 9]. Since they have more oxygen content while lower carbon and sulfur content than gasoline. Besides, alcohol fuels give higher evaporative emissions due to higher vapor pressures, and low heating value of alcohol makes a drop in the performance of engine [10]. Rong-Horng et al.[11]studied the impacts of ethanol–gasoline on the engine emissions. Due to the achieved results, being that the ethanol fraction in the blend more than 20% significantly reduces the hydrocarbon (HC) and monoxide CO emissions.

Fusel oil is a by-product of alcohol production after fermentation during the distillation process [12-14]. Fusel oil has the appearance of an efficient alternative fuel for use in a g asoline engine; the composition 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. It consists of about 390 g/L iso amyl 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 [15]. The high research and motor octane number (RON 106 a nd MON 103), high oxygen content (30.23% wt.) and single boiling point of fusel oil that indicate it can be using as additive fuel spark ignition engine[16-18]. On the other hand, the heating value of fusel oil (30 MJ/kg) less than gasoline (43 MJ/kg) by 36% that effect directly on the engine performance and especially the fuel consumption.

The specific objective of this work was to study the effects of moisture reduction on of on performance and emissions of SI engine. The water content of fusel oil was extracted by using rotary evaporator (Bauchi R-210, Switzerland) under 100C and vacuum. The experiments were performed on spark ignition engine under 4500 rpm engine speed, different engine loads and the different blending ratio of gasoline- fusel oil (G100, FBWE20, and FAWE20). In addition, the effects of test fuels upon brake power, brake thermal efficiency, brake specific fuel consumption, maximum in-cylinder pressure, ex and emissions (nitrogen oxide NOx, hydrocarbon HC, carbon monoxide CO, and carbon dioxide CO2) were examined

2 Methodology

2.1. Material

Engine testing was conducted with pure gasoline (G100) as a baseline and fusel oil -gasoline blends. The fusel oil was supplied from Eskişehir sugar refinery, which is producing ethyl alcohol with 99.5% purity. Shell petrol stations in Pahang-Malaysia with octane number 95 provided gasoline fuel. Fusel oil – gasoline blending before extracted water content by different percentage were prepared through mixing (based on volume) FBEW10 (90% gasoline and 10% fusel oil by volume) and FBEW 20 (80% gasoline and 20% fusel oil by volume) Also fusel oil – gasoline blending after extracted water content FAEW10 (90% gasoline and 10% fusel oil by volume) and FAEW 20 (80% gasoline and 20% fusel oil by volume). After that, fuel properties of blends were measured using ASTM standards. The blending

2.2 Fuel Properties Measurement

The HHV the fuel samples were determined according to ASTM D 240, using Oxygen Bomb Calorimeter Model 6772 (Parr Instrument company, USA). The density of the fuel samples measured at 15 C was according to ASTM D 4052 using Density /Specific Gravity Meter, model DA-640. The dynamic viscosities of the fuel samples were determined according to the ASTM 445-01 fuel standards by using a Brookfield DV-II+ Programmable Viscometer, and the kinematic viscosity was calculated. The oxygen, carbon, hydrogen, and sulphur were measured by Intertek laboratories in Kuala Lumper –Malaysia. The carbon, hydrogen, nitrogen and sulphur according to ASTM D5291, ASTM D5291, ASTM D5291 and ASTM D1552 respectively. A ll the fusel oil - gasoline blends, pure fusel oil and pure gasoline listed in Table 2.

2.3 Engine Set Up

In this study, the tests were done on a Mitsubishi 4G93 SOHC 4-cylinder 4-stroke port fuel injection naturally aspirated SI engine. The engine specifications were given in Table 2. Fig. 1 shows a layout of the experimental setup. A 100 kW Dynalec Controls eddy current dynamometer was utilized in the tests. Fuel consumption was measured using an AIC fuel flow meter with an accuracy of 1%. Air. While the air-fuel ratio was measured through a Kane auto 4-1 series exhaust gas analyzers. While the engine emissions and air-fuel ratio was measured through a Kane a Auto plus 5-2 series exhaust gas analyzers. The exhaust gas analyzer determined the exhaust constituents such as NOx, CO, CO2 and HC. The sensitivity and measurement accuracy of the exhaust gas concentration have been described in Tabl4e 3.

Table 1Engine specification

Engine descriptions	
Engine type	Mitsubishi 4G93 SOHC
Bore stroke	81.0mm×89.0mm
Piston displacement	1.834 L
CR	9.5:1
Fuel injection type	ECI-Multi (Electronically Controlled Multi-point) fuel injection
Max power	86kW@5500rpm
Max torque	161Nm@4500rpm

Cylinder pressure was measured using a K astler piezoelectric transducer 6125B spark plug type that fixed on the first piston. The crank angle signal was acquired with a Kastler 2613B1 crank angle encoder, and the in-cylinder combustion pressure was recorded simultaneously using a DEWE-Car Combustion analyzer provided from a DEWE5000 series data acquisition system. The in-cylinder combustion pressure data were collected for 1000 consecutive engine cycles; the ignition timing was optimized by the minimum advance for best torque (MBT) when the friction of fusel oil was used. The test was achieved under steady state conditions and first started with pure gasoline to get the base data of the engine. In additional, the effects of test fuels upon power, brake thermal efficiency, brake specific fuel consumption, maximum in-cylinder pressure, and emissions (nitrogen oxide NOx, hydrocarbon HC, carbon monoxide CO, and carbon dioxide CO2) were examined.

3 Results and discussion

The specific purpose of this work was to study the effects of water content (moisture) reduction on o f on performance and emissions of SI engine. T he experiments were performed on spark ignition engine under 4500 r pm engine speed, different engine loads and a different blending ratio of gasoline- fusel oil (G100, FBWE20, and FAWE20). The lower heating value of fusel oil (almost 31% is lower than unleaded gasoline) that lead to the lower heating value of the test fuels by adding fusel oil into gasoline. Hence, the amount of fuel mass taken into the cylinder rises with the increase of the amount of fusel oil in the blending fuel.

The heating value of fusel oil affected by several factors such as the oxygen, hydrogen, carbon, and water content as mentioned in the introduction [4, 19, 20].By extracted water content (moisture) of fusel oil from 13.5% to 6.5% through using rotary evaporator (Bauchi R-210, Switzerland). The heating value of fusel oil after water extracted (FAWE) become 33.8 MJ/kg that enhanced by 13% compared with fusel oil before water extracted (FBWE) 29.9 MJ/kg as shown in Fig 2. The oxygen content decreased while the carbon content increased thereby heating value enhanced. The increasing in carbon-hydrogen was respectively while the decreasing in was as shown the Fig3. The change in the oxygen, carbon, and hydrogen content agreed with refs [21, 22]. The water content of any fuel such as hydrous ethanol or fusel oil effects of the combustion negatively also the higher dissolved water content decrease the heating value of the fuel thereby will effect on engine performance [23]. Also, the brake specific fuel consumption (BSFC) and thermal efficiency improved by reduced the water content of fuel oil.

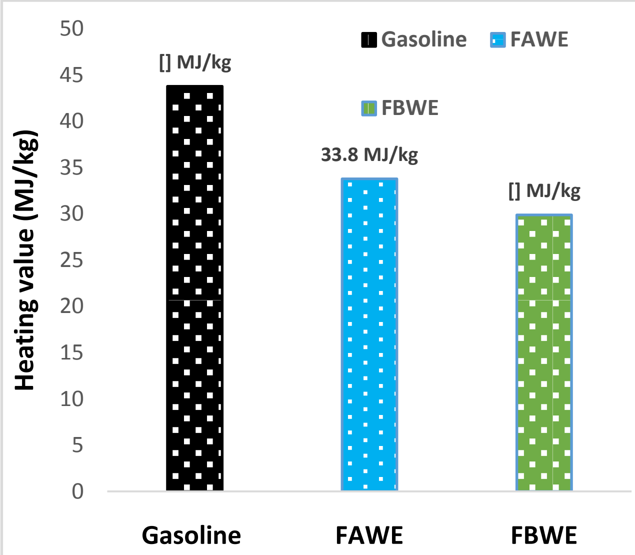

Figure 2. The higher heating value of fusel oil and gasoline

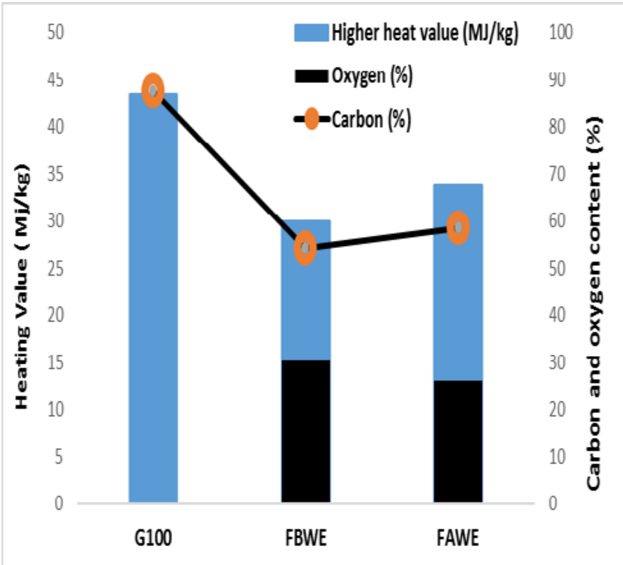

Figure 1 Relationship between oxygen content, carbon content and heating value of fusel oil and gasoline

Fig. 4 illustration the brake power of gasoline –fusel oil blends at 4500 rpm and different engine loads. The brake power was increased as the engine load increased. It was observed at all fusel oil –gasoline blends the power is slightly higher than that of pure gasoline. These results are in agreement with a previous study[15, 16]. Also, it was seen the fusel oil after water extracted (FAWE20) has slightly higher power compared with fusel oil before water extracted (FBWE20) and pour gasoline that it was higher by 0.3% and 0.78% respectively. The water content may be restricted the engine combustion thereby the decrease in water content led to better engine combustion. Moreover, the greatest power was obtained FAWE20 at 60 engine load. As a conclusion, the engine power improved by extracted the water content and the highest power was with FAWE20.

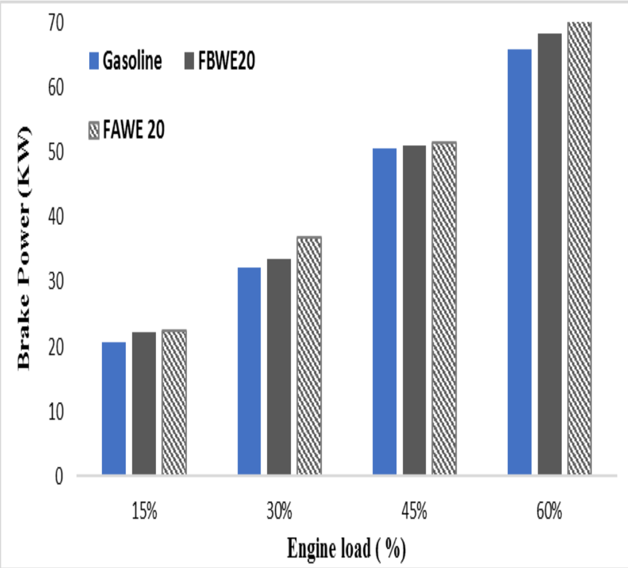

Figure 4. Various of the brake power gasoline –fusel oil blends

The brake specific fuel combustion(BSFC) is the ratio between fuel mass consumption and the engine brake power, as well as for a given fuel. Fig. 5 illustration the BSFC of gasoline –fusel oil blends at 4500 rpm and different engine loads. The BSFC was decreased as the engine load increased due to the brake power. Furthermore, it was detected the BSFC was higher with fusel oil –gasoline blends at all engine loads due to the lower heating value of fusel oil. Also, it was seen the fusel oil after water extracted (FAWE20) has slightly lower BSFC compared with fusel oil before water extracted (FBWE20). This could be explained by the improvement in heating value after water extracted from fusel oil and due the higher brake power with FAWE20.

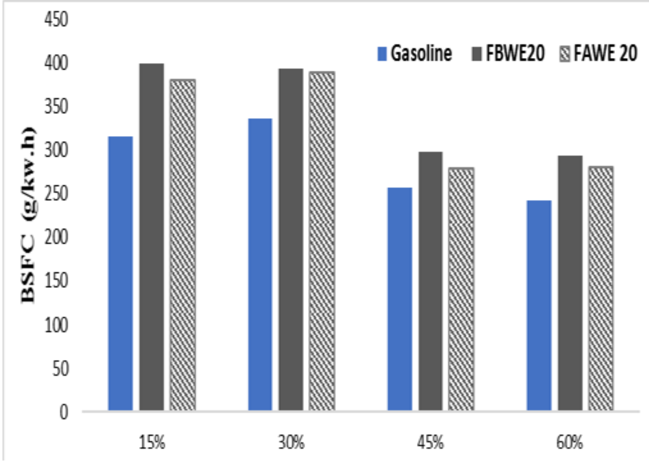

Figure 5 Various of the brake specific fuel combustion (BSFC) of gasoline –fusel oil blends

Brake thermal efficiency (BTE) is a measure of fuel conversion efficiency which indicates the engine operation with the tested fuel. It is defined as the ratio fuel thermal efficiency to the engine output power delivered to the crankshaft. Fig. 5 shows comparisons of brake thermal efficiency (BTE) for gasoline -fusel oil blends at 4500 rpm and different engine loads averaged over 1000 c onsecutive cycles. The BTE was with fusel oil -gasoline was higher compared with gasoline at all engine loads. Also, it was seen the fusel oil after water extracted (FAWE20) has slightly higher BTE compared with fusel oil before water extracted (FBWE20) and pour gasoline. The best BTE happens when with FAWE20 at 60 % engine load.

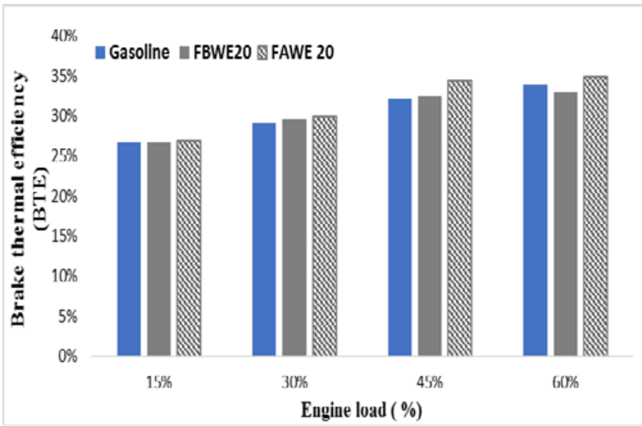

Figure 2. Brake thermal efficiency (BTE) of gasoline –fusel oil blends

The impact of gasoline -fusel oil blends on the maximum in-cylinder pressure (MCP) as presented in Fig 6. It is clear that MCP increased as engine load increased due to the increasing in cylinder pressure. The best MCP happens with FAWE20 at 60 % engine load. This increase is attributable mainly to the higher volumetric efficiency that occurs from the higher latent heat of vaporization of fusel oil, which cools the air in the engine to a larger extent, therefore increasing air density and providing more air Inside, resulting in a greater mass density of the fuel-air mixture.

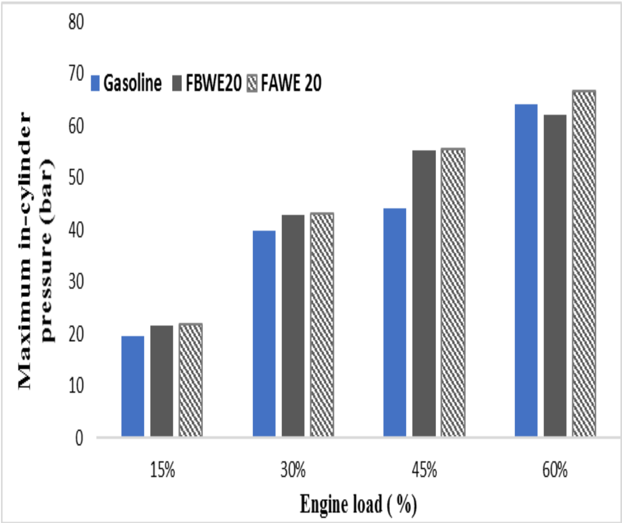

Figure 3. Maximum in-cylinder pressure (MCP) of gasoline –fusel oil blends

Engine emissions such hydrocarbon (HC) Carbon monoxide (CO), carbon dioxide CO2 and nitrogen oxides (NOx) in spark ignition engines are related to engine operating condition, the homogeneity of the fuel with air and fuel properties. Many studies have revealed that the NOx emission reduces with the rise in friction of alcoholic fuel [18, 24-26]. Fig. 7 shows comparisons of nitrogen oxides (NOx) for gasoline - fusel oil blends at 4500 rpm and different engine loads. The NOx was higher with gasoline compared with gasoline -fusel oil blends at all engine loads. Also the NOx emission of FAWE 20was slightly higher than that of FBWE20. This could be explained by the water and oxygen content of fuels. The NOx emission has a strong correlation with exhaust temperature. The exhaust temperature as shown in Fig 8 was higher with gasoline compared with fusel oil this could explain the NOx behavior.

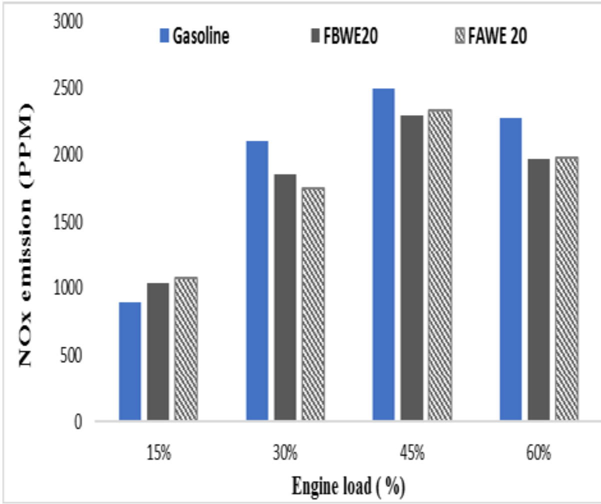

Figure 4 variation of NOx emissions for fusel oil - gasoline blends

Moreover, the highest exhaust temperature was with gasoline compared with blends. The most influential parameters for the rise of the largest exhaust with the blends could be the oxygen content, heating value and the air-fuel ratio of the mixture. In addition, fusel oil based alcohols have a higher latent heat of vaporization than that of gasoline that led to decreased highest exhaust as referred to by the Refs [27, 28].Furthermore, the water content and high oxygen content of fusel oil played the main role to limited the combustion and decreased exhaust temperature. Thus the exhaust temperature increased with FAWE20 compared with FBWE20. As a result, of the reduction in exhaust temperature with fusel oil the NOx emission increased.

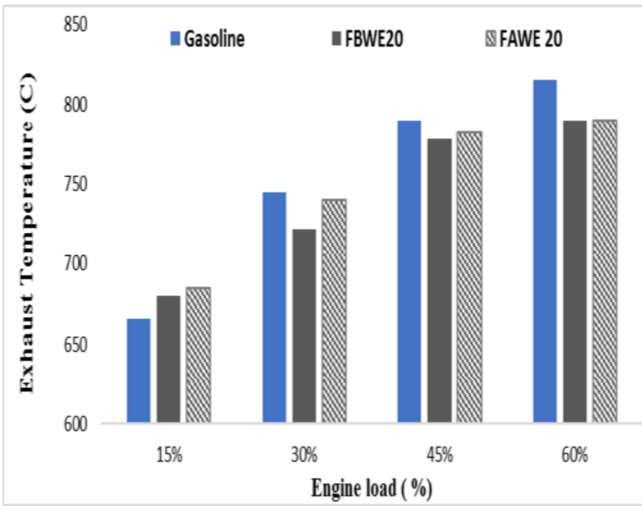

Figure 5 variation of exhaust temperature emissions for fusel oil - gasoline blends

Fig. 10 represents the emission of hydrocarbons (HC) for gasoline-fusel oil blends. HC is emission that occurs from incomplete combustion of the fuel–air mixture[29]. It was observed the HC emissions increased with fusel oil -gasoline FBWE20 and FAWE20 blends compared with pure gasoline at all engine loads by 11% and 14 % respectively. Furthermore, the HC emission FAWE20 were slightly higher than FBWE20 that was around 5%. As well as due to the reduce the water content the engine e t he combustion temperature increased thereby the HC emission increased. Besides, high viscosity makes longer spray diffusion and fuel impingement onto the in-cylinder, which also outcomes in higher HC emissions[30]

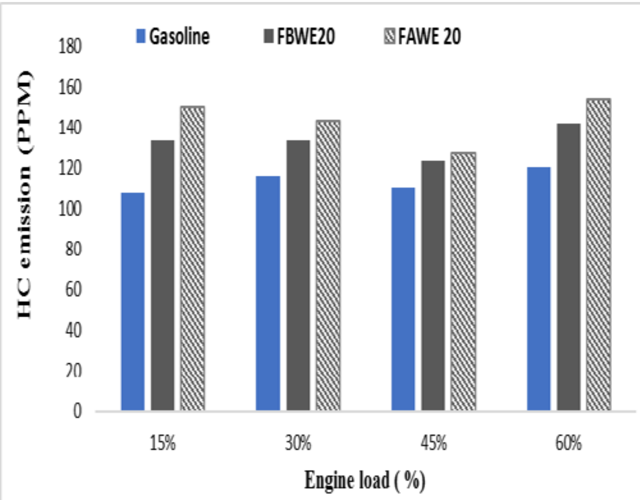

Figure 6 variation of HC emissions for fusel oil - gasoline blends

Fig. 11 represents the emission of carbon monoxide (CO) for gasoline-fusel oil blends. It was observed the CO emissions increased with fusel oil -gasoline FBWE20 and FAWE20 blends compared with pure gasoline at all engine loads by 18% and 19 % respectively. Furthermore, the CO emission FAWE20 were slightly higher than FBWE20 that was around 1%. This is could due to the high viscosity of fusel oil resulted in poor atomization and locally rich mixtures into the engine cylinder, which produces higher CO generated through the combustion due to the local lack of oxygen[31]. However, a higher heat of vaporization could produce lower combustion temperature and burning speed, and then higher CO and HC emissions.

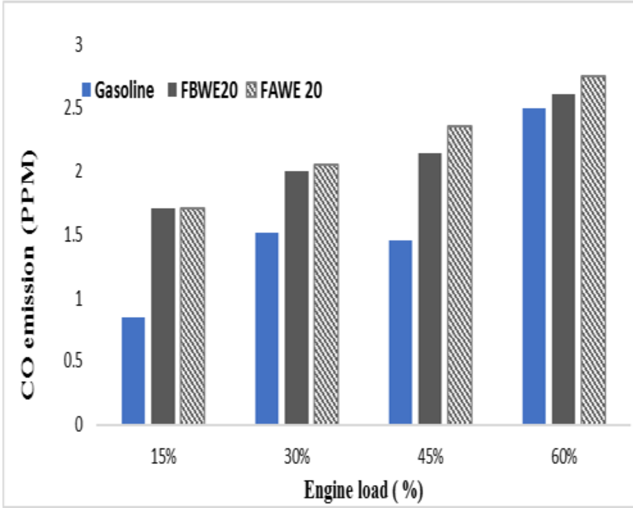

Figure 7 variation of CO emissions for fusel oil - gasoline blends

Although carbon dioxide (CO2) is a non-toxic gas and is not classified as an engine pollutant, it is one of the substances that is responsible for rising global temperature through the greenhouse effect [32]. Fig. 12 represents the emission of carbon monoxide (CO2) for gasoline-fusel oil blends. It was observed the CO2 emissions increased with fusel oil -gasoline FBWE20 and FAWE20 blends compared with pure gasoline at all engine loads. The increment in CO2 with FBWE20 and FAWE20 compared with gasoline 30% Furthermore, the CO emission FAWE20 were slightly higher than FBWE20 that was around 2%.

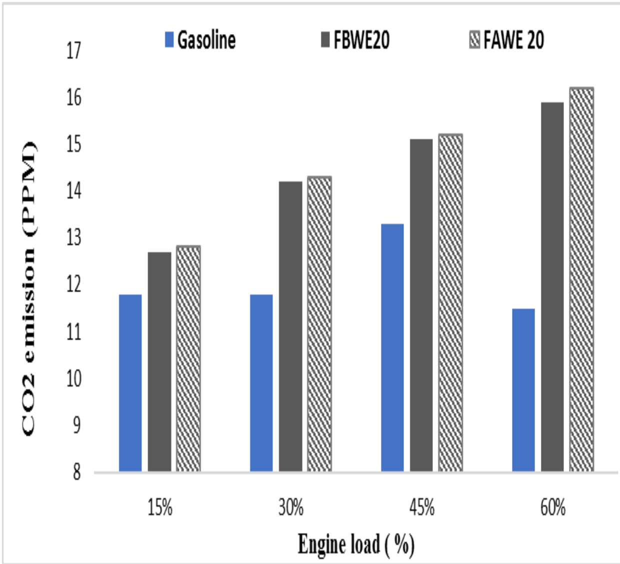

Figure 8 Variation of CO2 emissions for fusel oil - gasoline blends

4 Conclusion

A comprehensive analysis of the performance and emissions of fusel oil -gasoline blends were completed. The experimental was achieved direct injection SI engine run with fusel oil-gasoline blends and pure gasoline as b aseline fuel. The engine was run at different engine loads and 4500 rpm engine speed.

Regarding the water content reduction of fusel oil, there was very slightly changed in viscosity and density while was significant changes in heating value, oxygen, and carbon content of fusel oil. However, when the fusel oil blends with gasoline all the properties were improved except heating value and carbon content. The heating value of fusel oil after water extracted (FAWE) become 33.8 MJ/kg that improved by 13% compared with original one (FBWE) 29.9 MJ/kg. The carbon content increased by 7.9% from 54.2 to 58.45%. While the oxygen content reduced by 14% from30.32to 26.1% thereby heating value enhanced. Accordingly, the higher fusel oil density at FBWE and FAWE will slightly compensate for their lower heating value compared with gasoline

Mostly at all blending of fusel oil –gasoline the brake power is slightly increased than that of gasoline. Furthermore, it was observed that the fusel oil after water extracted (FAWE20) has slightly higher power compared with fusel oil before water extracted (FBWE20).Also, the brake specific fuel consumption (BSFC) and thermal efficiency improved by reduced the water content of fuel oil..

. Furthermore, the NOx emission decreased with fusel oil -gasoline blends compared with pure gasoline at all engine loads. However, HC, CO, and CO2 emissions increased with fusel oil -gasoline blends compared with pure gasoline at all engine loads. In general, the higher oxygen content and octane number of fusel oil with reduce water content led to improve the engine combustion and performance.

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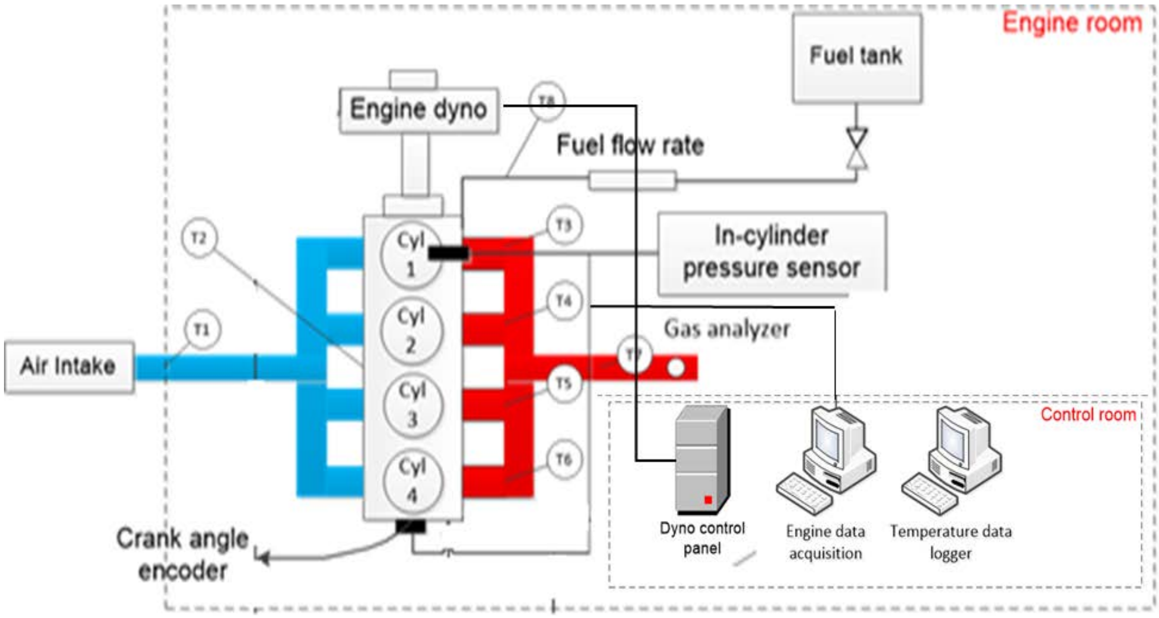

Figure 1 Schematic of the experimental setup

Table 2Fusel oil properties before and after water extracted

Property	Test method	G100	FBWE	FAWE	FBWE20	FAWE20
Higher heat value (MJ/kg)	ASTM D 240	43.5	29.93	33.8	40.854	41.624
boiling point (°C)	ASTM D 2887	27-225 [33]	98.4	90.6	-	-
Moisture content (%)	ASTM D6304	0	13.5	6.5	2.7	1.3
Density (Kg/m3)	ASTM D 4052	769	844	843	785	783
Research octane number (RON)	ASTM D 2699	95	106	106	97.2	97.2
Oxygen (%)		0	30.32	26.1	6.064	5.22
Carbon (%)	ASTM D5291	87.5	54.2	58.45	80.84	81.69
Hydrogen (%)	ASTM D5291	12.5	15.1	15.1	13.02	13.02
Sulphur	ASTM D1552	0.1	0.38	0.28	0.156	0.136
Kinematic viscosity(mm2/s)		0.49	4.1588	4.1637	1.22696	1.22794

Table 3Sensitivity and measurement accuracy of instruments used for measuring the exhaust gas concentration

Exhaust gas	Measurements range	Measurement Resolution
NOx	0–5000ppm	1 ppm
CO	0–9.99%	0.1%
CO2	0–16%	0.1%
HC	0–5000ppm	1 ppm
λ	0 ~ 2.000	0.001