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Improvements to the Composition of Fusel Oil and Analysis of the Effects of Fusel Oil–Gasoline Blends on a Spark-Ignited (SI) Engine's Performance and Emissions

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Abstract: With the increase of energy needs and environmental pollution, alcohol-based alternative fuels are used in spark-ignited (SI) engines. Fusel oil, which is a by-product obtained through distillation of ethanol, contains some valuable alcohols. As alcohols are high-octane, they have an important place among the alternative fuels. Fusel also takes its place among those alternatives as it is high-octane and low on exhaust emissions. In this research, the effects of using blends of unleaded gasoline and improved fusel oil on engine performance and exhaust emissions were analyzed experimentally. A four-stroke, single-cylinder, spark-ignited engine was used in the experiments. The tests were conducted at a fixed speed and under different loads. The test fuels were blended supplying with fusel oil at rates incremented by 10%, up to 50%. Under each load, the engine's performance and emissions were measured. Throughout the experiments, it has been observed that engine torque and specific fuel consumption increases as the amount of fusel oil in the blend is increased. Nitrogen oxide (NO_x), carbon monoxide (CO), and hydrocarbon (HC) emissions are reduced as the amount of fusel oil in the blends is increased.

Keywords: fusel oil; gasoline; distillation; alternative fuel; fusel improvement; exhaust emission; engine performance

1. Introduction

With the technology developing, the world's population growing, and the petroleum reserves depleting and costs increasing, alcohol production by fermentation has become popular as it contributes to national economy directly and significantly. This way, it is also possible to save and better utilize the national resources.

Petroleum, which is the major source of engine fuels, is getting depleted, and the environmental pollution is increasing due to the hazardous exhaust emissions of petroleum-based fuel-operated vehicle engines. These facts have led researchers to study alternative energy sources. Particularly, ethanol, methanol, natural gas, liquefied petroleum gas (LPG), and biofuels, which have lower exhaust emissions, are considered as alternative fuels [1]. Biofuels are the leading ones among the latest alternatives that are rapidly becoming widespread. The fuels to be used for internal combustion engines are required to be cheap, be produced abundantly, have higher heating values, be stored easily, be secured, reduce foreign dependency, and produce less exhaust emissions [2].

Fusel oil is a by-product that is recovered during distillation in industrial ethyl alcohol production by fermentation [3]. This by-product is a liquid with strong odour and colour that ranges from yellow to dark brown, and it is used to generate power in factories, produce methylated spirit, or is disposed [4].

The composition and the amount of fusel oil may change depending on the type and preparation of the carbon source that is used in the process of alcohol production by fermentation, and the method that is used to separate fusel oil from the composition obtained by fermentation. Fusel oil is the only natural source of straight and branched-chain monohydric alcohols with 2–5 carbons [3–5]. Fusel oil is composed of low molecular weight alcohols (such as i-amyl alcohol in particular, and i-butyl alcohol, n-propyl alcohol, n-butyl alcohol, ethyl alcohol, and namyl alcohol), water in small amounts and aldehydes in trace amounts, fatty acids and theirs esters, higher alcohols, and terpenes [6].

Alcohols such as methanol, ethanol, and butanol are colourless, transparent, low-odour, hygroscopic liquids [7,8]. They are produced in industrial scales by hydration of ethylene and fermentation of plants with sugar content (such as potato, grains, sugar cane, and sugar beet) [9]. Using alcohols in engines may have effects on engines as listed below: Alcohols, when compared to gasoline, have lower heating values and higher stoichiometric air–fuel ratios. Therefore, it requires more fuel to achieve the same performance when using alcohol or alcohol–gasoline mixtures instead of gasoline, standalone, in an engine [10,11]. Since alcohols are high-octane, engines may operate at higher compression ratios, and as a result, engine efficiency and fuel consumption can be improved.

Alcohols may have a cooling effect on the drawn fresh mixture due to their lower heating values and higher enthalpy of vaporization, and this leads to an increase in volumetric efficiency of the engine. Due to the higher volumetric efficiency, alcohol-operated engines may have higher torque and horsepower. With fresh charge temperatures dropping and engines operating with poorer mixtures, there may be significant decline in CO and NO_x emissions [11]. However, higher enthalpy of vaporization and lower vapour pressure may lead to vaporization problems in cold weather conditions. To ensure the required vaporization, alcohols or alcohol–gasoline mixtures should be supplied with agents that accelerate vaporization.

Although alcohols have lower vapour pressure, vapour pressure of alcohol–gasoline mixtures increases as the amount of alcohol is incremented [10]. Therefore, vapour lock incident can be encountered in hot weather conditions. As it is well known, alcohols are water absorbers, and this may lead to phase separation in alcohol–gasoline mixtures. This problem can be overcome by supplying substances such as isopropanol, which increase the solubility. On the other, the water that alcohols contain may corrode the mechanical parts. Another material problem is that alcohols lead to a substantial increase in hazardous emissions such as formaldehyde, acetaldehyde, and acetone [10,11]. Should alcohols be produced abundantly and using economical methods, they can be an appealing fuel for spark-ignition (SI) engines. Alcohols can be used in engines as fuel, either standalone or as alcohol–gasoline mixtures. Both options have their advantages and disadvantages in terms of engine performance, fuel economy, and exhaust emissions. Mixtures that contain certain amounts of alcohol can be used in engines, without any modifications to engine design or fuel system [11].

Methanol was used as vehicle fuel during the 1930s to replace gasoline supplies for high-performance engines. Chemically, methanol (CH_3OH) is the simplest alcohol, with single carbon atom per molecule. Methanol is a toxic, tasteless, and colorless liquid, and is generally known as "wood alcohol". It has many benefits that distinguish it as an attractive alternative fuel over oil fuels. The first is its low cost and that it can be produced from several ways such as synthesis gas (mixture of hydrogen and carbon monoxide) that is produced by steam reforming of natural gas, gasification of coal, as well as a production of biomass, all of which are available in abundance or regeneration. The production cost of methanol is around half of the cost of petroleum fuels in Canada. Even though the value is in comparison with the equivalent energy, it is quite lower than that of gasoline. The second is low exhaust emission. In addition, due to the lower boiling point of methanol, the fuel will evaporate faster and this is advantageous to engine combustion and, thereby, hydrocarbon emissions will be decreased. Furthermore, the high oxygen content of methanol and simple chemical structure can lead to lower emissions and better engine combustion in spark-ignition engines [12].

Butanol or butyl alcohol is a four-carbon atom alcohol (C_4H_9OH) that can be used in non-modified spark-ignition engines. It is miscible with most solvents and sparingly soluble in water. Butanol is generally produced using fossil fuels, but can also be produced from biomass, in which case it is called bio-butanol. Both bio-butanol and petro-butanol have the same chemical properties [12,13]. Butanol is quite similar to gasoline due to its longer hydrocarbon chain, lower oxygen content, and higher heating value, compared to methanol and ethanol [12,14]. Furthermore, butanol, as a promising fuel candidate, has attracted more attention recently. Butanol has several more benefits than methanol and ethanol, and includes high tolerance to water contamination, which permits the use of the existing distribution pipelines [15,16].

Ethanol is a high-octane rating fuel with a broad range of sources, which has been widely regarded as a promising alternative fuel for SI engines. However, because of the high latent heat of vaporization, low net calorific value, and other negative features of ethanol, it is hard for vehicular SI engines to be only powered by ethanol under all running conditions. Thus, to further popularize the application of SI ethanol engines, it is necessary to improve the burning condition and thermal efficiency of the ethanol engines [17].

İçingür and Calam [18] analysed the engine performance and emission figures using gasoline–fusel oil blend in a single-cylinder, spark-ignited, injection engine under full-load conditions. They conducted experiments at various engine speeds and at power stroke, which provides maximum engine torque. They have found that engine torque increases upon supplying fusel oil, and this increase is determined to be 3.4% at its maximum, using F30 blend. Engine speeds have been found to increase in specific fuel consumption, as the amount of fusel oil in the mixture increases. This increase is determined to be 7.7% at its maximum, using F30 blend. They have also found out that nitrogen oxide (NO_x) emissions decline, whereas hydrocarbon (HC) and carbon monoxide emissions increase as the amount of fusel oil in the mixtures increases.

Solmaz [19] analysed the performances, emissions, and combustion characteristics of F0, F50, and F100 fusel blends in 2500 rpm and under four different loads applied. It has been found out that water contained in fusel fuel reduces the engine performance, and using fusel oil increases CO by 21% and HC by 25%, whereas it reduces NO_x by 31%.

In his research, Çelik [20] used ethanol fuel to increase the engine performance at a high compression ratio and to reduce the emissions of small gasoline engines. Initially, he tested the engine, which had a compression ratio of 6/1, with a constant load and at a constant speed using E25 (75% gasoline + 25% ethanol), E50, E75, and E100. As a result of the experiment, he found out that E50 is the most favourable fuel regarding the performance and emissions, and continued his experiments incrementing the compression ratio from 6/1 to 10/1. The engine was tested using E0 with a compression ratio of 6/1, and using E50 with a compression ratio of 10/1, under full-load and at various speeds, without any knocking.

The first study concerning fusel oil was conducted by Wetherill in 1853 [21]. It has been seen that since that year, there have not been many studies concerning fusel oil [22], and the existing ones are concerning the hazardous effects of fusel oil [23], method of reducing fusel oil in alcoholic beverages [24], analysis [25], and dehydration of fusel oil and ethanol contained in alcoholic beverages [26–28], with HPLC (High performance liquid chromatography), production of lubricants from fusel oil using enzymatic method [29], and biodiesel production [30].

The aim of this study is that waste fusel oil can be used as a potential fuel in internal combustion engines. It has been observed that waste fusel oil contains valuable alcohols by analyzing its chemical and physical characteristics. Besides gum and water within waste fusel oil having been minimized so that it can be used as fuel in engines, the effects of waste fusel oil have been investigated on engine performance (brake thermal efficiency, specific fuel consumption (BSFC), torque) and emission values (CO, HC, NO_x). Moreover, with the limited number of studies concerning the analysis of waste fusel oil, it is believed that this study may fill the gap in the literature.

2. Materials and Methods

2.1. Improvements to Fusel Oil to Be Used in the Experiments

The waste fusel oil used in the experiments was procured from Eskişehir Şeker Fabrikası (Eskişehir Sugar Production Plant) and Konya Şeker Fabrikası (Konya Sugar Production Plant), which produce ethyl alcohol of 99.5% purity, in compliance with TS 1810 standard. Characteristics of physical and chemical composition of the waste fusel oil that was used in this study as an alternative fuel, were tested in chemistry and energy laboratories of TUBITAK's Marmara Research Center (MRC), and the results thereof are shown in Table 1.

Table 1. Characteristics of fusel oil composition.

Amyl Alcohol	Chemical Formula	Molecular Weight (g/mol)	Density (g/cm^3)	Boiling Point (°C)	Melting Point (°C)	Volumetric (%)	Viscosity (cp)	Specific Heat (kal/g °C)
2-Methyl 1-Butanol	$C_5H_{12}O$	88.148	0.815	129	−70	0.22	4	0.57
4-Methyl 2-Pentanol	$C_6H_{14}O$	102	0.8079	131.8	−90	0.27	-	-
i-amyl alcohol (3-Methyl 1-Butanol)	$C_5H_{12}O$	88	0.809	132	−117.2	62.29	3.86	0.535
n-Hexanol (1-Hexyl Alcohol)	$C_6H_{14}O$	102	0.8186	157.2	−51.6	0.51	-	-
n-Heptanol (1-Heptyl Alcohol)	$C_7H_{16}O$	116	0.824	175	−34.6	0.08	-	-
i-Butanol	$C_4H_{10}O$	74	0.805	108	−108	8.71	3.5	0.59
n-Butanol	$C_4H_{10}O$	74	0.81	117	−79.9	0.12	2.6	0.687
n-Propanol	C_3H_8O	60	0.804	97.2	−127	0.738	2.256	0.59
i-Propanol	C_3H_8O	60	0.789	82.5	−85.8	8.06	2.1	0.66
ethanol	C_2H_6O	46	0.789	78	−112	11.09	1.41	0.68
water	H_2O	18	1	100	0	10.3	1	1

Fusel oil, as factory waste, cannot be used as fuel in engines as it contains gum and water. The gum the fusel oil contains prevents it from mixing homogeneously with gasoline. It is considered that high amount of water it contains also leads the extra vapor pressure to have an effect on piston head during power stroke. Therefore, it needs to be processed to reduce the gum, and to be separated from water it contains. Thus, fusel oil can be used for experiments on engines.

The fundamental method used to separate the liquid mixtures is the distillation method. The principle in this method is to separate the liquids exploiting the difference between their boiling points. As the higher alcohols in fusel oil cause azeotrope, a simple distillation process is carried out [31–34]. Figure 1 shows the distillation temperatures of fusel oil.

Molasses fusel oil was used for this analysis. This substance is a greasy liquid of 818.6 kg/m^3 at 15 °C, with coloring from green to yellow or brown. It has been found out that it contains 240 mg/kg water, and its flash point is determined to be 39.5 °C in distillation analysis.

According to the results obtained through petroleum products analysis tests, the distillation efficiency of fusel oil at its final boiling point has been found to be 96.5%, and the limit defined in TS EN 228 for existent gum content is 26.6 mg/100 mL. Using gum inhibitor only, existent gum content was reduced to 13.4 mg/100 mL. It has been observed that gum content of fusel increases when fusel is stored in fuel tanks. At the end of the experiments, existent gum content is reduced to 0.8 mg/100 mL using gum inhibitor and desiccant together, without letting fusel oil, which is obtained by fermentation, settle. Removing water from fusel oil enables distillation of alcohols at lower temperatures, however, it doesn't lead to any notable changes in the amount of alcohols.

For that reason, the fusel oil was supplied with 5 lt/2 kg molecular sieve Z4-01(2.5–5 mm) desiccant, and upon stirring the fusel oil, the gas accumulated inside was discharged. This process was repeated at least twice every other day, and the fusel oil was settled for 2 more days. The settled fusel oil was filtered by cotton and ordinary paper, and supplying it with 1 kg molecular sieve Z4-01(2.5–5 mm) desiccant, it was left for settling for 1 more night. The analysis after re-filtering process showed that water contained in fusel oil was removed substantially (approximately 96.9%). Figure 2 shows the changes in the amount of gum content in fusel oil that was obtained as a result of the improvements.

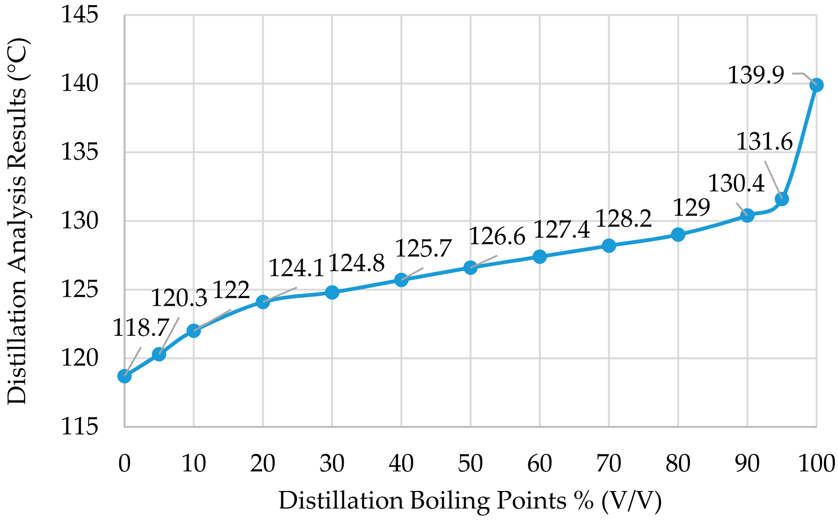

Figure 1. Results of distillation analysis.

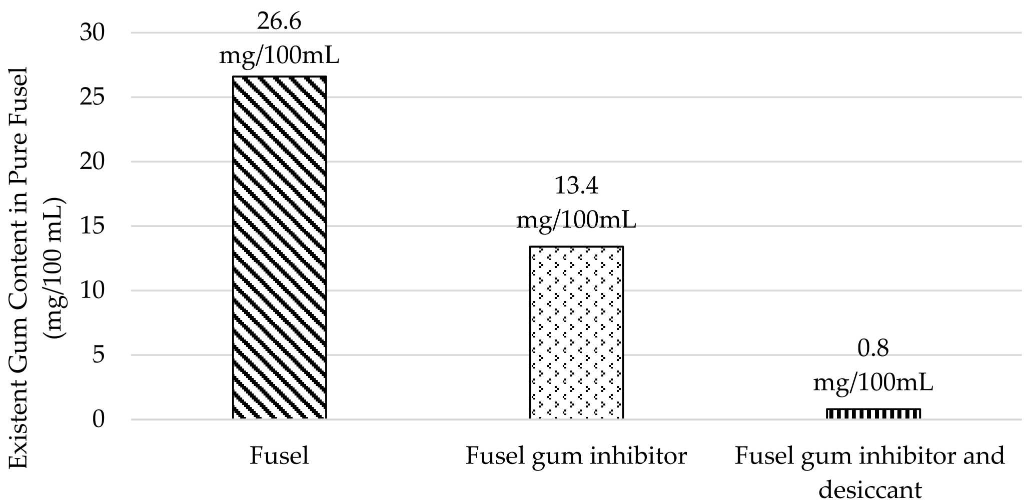

Figure 2. Reducing water gum content in pure fusel oil.

2.2. Experiment Fuels

Five fuel blends were prepared using different unleaded gasoline to fusel ratios. These are F0 (0% fusel oil + 100% unleaded gasoline), F10 (10% fusel oil + 90% unleaded gasoline), F20 (20% fusel oil + 80% unleaded gasoline), F30 (30% fusel oil + 70% unleaded gasoline), F40 (40% fusel oil + 60% unleaded gasoline), and F50 (50% fusel oil + 50% unleaded gasoline). Analysis of fusel oil fuel blends were conducted by TUBITAK MRC, and the results are shown in Table 2.

Table 2. Characteristics of the experiment fuels.

Fusel	F0	F10	F20	F30	F40	F50	F100
Density (kg/m^3)	721.79	726.03	735.13	750.55	758.54	764.83	852.1
Lower heating value (kJ/kg)	43,580	42,449.60	41,319.20	40,188.81	39,058.41	37,928.02	32,276.04
MON	86.51	87.08	87.12	87.17	88.50	89.30	103.61
RON	96.33	97.80	97.84	98.30	98.34	98.38	106.82
Freezing point (°C)	−53	>50	>50	>50	>50	>50	>50

2.3. Experiment Procedure

A single-cylinder, spark-ignited, four stroke power generator with carburetor, Honda HK 5500 MS, was used in the experiments. Technical specifications of the engine and the power generator connected thereto, which were used in the experiments, are shown in Table 3.

Table 3. Technical specifications of experiment engine.

Engine Specifications	
Model	Honda GX390
Engine Type	4-Stroke, overhead camshaft, single-cylinder
Compression Ratio	8.0:1
Cooling System	Air-cooled
Engine Displacement (cm^3) (Bore x Stroke) (mm)	389 (86.0 × 64.0)
Net Horsepower	11.8/11.7 HP
(According to SAE 1349) (kW @ rpm)	(8.7) @ 3600
Net Torque	2.70 kg/m
(According to SAE 1349) (N/m @ rpm)	(26.5) @ 2500
Power Generator Specifications	
Model	Honda HK 550 M/MS
Max. Power Output (kW)	5.5
Voltage (V)	230
Phase	Single phase
Frequency (Hz)	50
Power Factor (kW @ rpm)	13.0 @ 3600
AC Circuit Breaker	Yes

To determine the instantaneous fuel consumption, an electronic weighing scale with a weight accuracy of 0.01 g to 2 kg was used. Revolute per minute (RPM), engine oil temperature, and exhaust gas temperature sensors were mounted on the power generator. As fusel oil has a lower heating value when compared to gasoline, the main nozzle on the carburetor was extended in order to set Excess Air Coefficient to 1. Using a cone point carburetor adjustment screw, the nozzle was modified and set as $\lambda = 1$ for all experiments. In order to apply different loads on the fixed-speed power generator for dynamometer purposes, eight projector lamps of 1000 W were used. The experimental setup is shown in Figure 3.

Using Bilsa MOD 2210 WINXP-K exhaust gas analyzer, CO, HC, CO_2, O_2, NO_x emissions, and lambda were measured at precisions shown in Table 4.

Table 4. Exhaust gas analyzer measurement range.

Parameters	Measurement Limit	Precision
CO	0–10.0% vol.	0.001%
CO_2	0–20.0% vol.	0.001%
HC	0–10,000 PPM vol.	1 PPM
O_2	0–10% vol.	0.01%
NO_x	0–5000	1 PPM
Lambda	0.5–2.00	0.001
RPM	0–9990 rpm.	10 rpm.

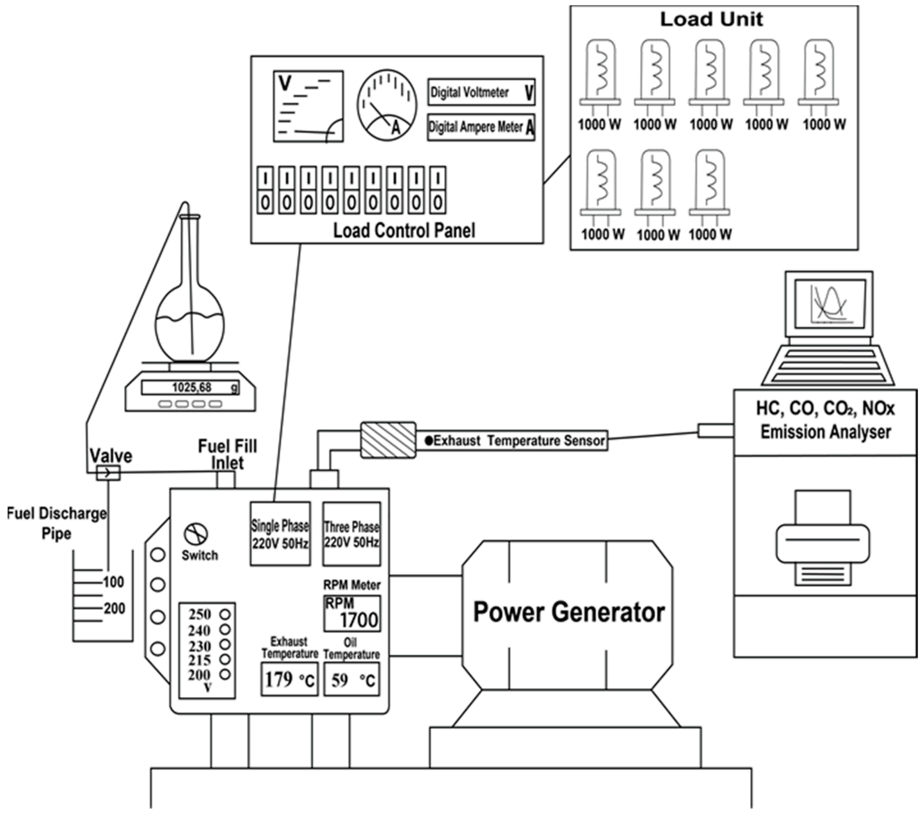

Figure 3. Overview of experimental setup.

Before the data collection stage, the experiment engine was run until it reached engine operating temperature with experiment fuel. Experiments were conducted on stable operation modes by loading with various halogen lamps of 1000 W, 2000 W, 3000 W, 4000 W, 5000 W, 6000 W, 7000 W, and 8000 W. For each fuel blend (F0, F10, F20, F30, F40, and F50) used in experiments, the engine was loaded with those lamps, and using those fuel blends, engine performance and emissions were recorded. In the experiments, brake thermal efficiency, engine torque, specific fuel consumption, and exhaust emissions (CO, HC, CO_2, NO_x) were measured.

3. Results and Discussion

3.1. Brake Thermal Efficiency

Brake thermal efficiency is the ratio of the useful mechanical power obtained from the engine and the energy content of the fuel consumed in unit time. Figure 4 shows the brake thermal efficiency achieved by using F0, F10, F20, F30, F40, and F50 fuel blends in the experiment engine, in fixed-speed and constant Excess Air Coefficient. As fusel oil contains oxygen, it increases combustion efficiency. Brake thermal efficiency was increased by 3.98% with F30 fuel blend, when compared to gasoline. The lower heating value of fusel oil is lower than gasoline. Brake thermal efficiency was reduced as the density of fusel oil increased in the F40 and F50 fuel mixtures. These results are in concordance with other studies [2,18,35].

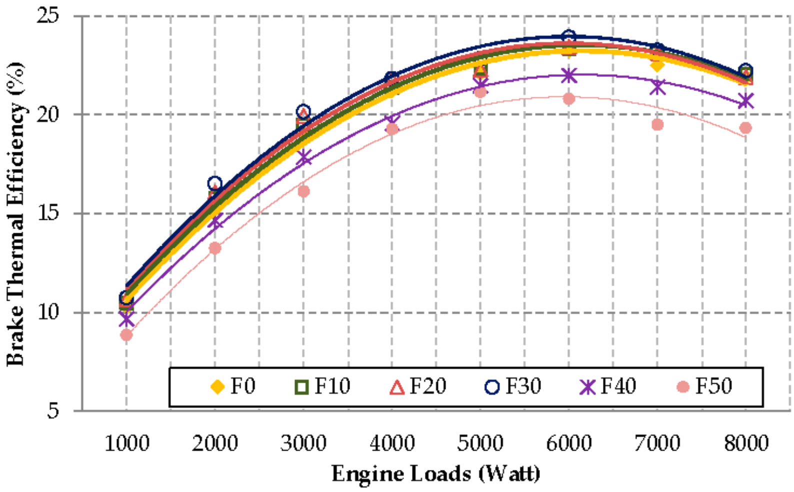

Figure 4. Brake thermal efficiency changes with engine loads.

3.2. Engine Torque

Figure 5 shows the engine torque per load increase in fixed engine speed, for each fusel oil blend of 10%, 20%, 30%, 40%, and 50% with unleaded gasoline (F0). Despite the fact that lower heat values of fuels obtained by blending unleaded gasoline with fusel oil are less than that of unleaded gasoline, the engine torque shows, even a little, increase. That combustion occurs better due to the oxygen contained in fusel oil, which can be considered as the reason why the engine torque increases as the amount of fusel oil increases. However, for the same engine displacement, when compared to that of unleaded gasoline, the consumption of fusel-blended fuels increases as the fuel density increases. This leads to certain increases in engine torque and effective power. Volumetric efficiency also increases due to high latent heat of vaporization of fusel-blended fuels, when compared to unleaded gasoline. The increase of charge in the cylinder has direct effects on engine torque and effective power. When compared to F0, for all engine loads, it has been observed that engine torque is increased by 2.72% using F10; 3.29% using F20, and 3.95% using F30, whereas it is reduced while using F40 and F50. The reason for such reduction is considered to be that the brake thermal efficiency and engine torque reduce as the in-cylinder combustion temperature reduces, due to lower heat values decreasing as the amount of water in fusel oil increases. There is a satisfactory concordance between the engine torque and changes in power recorded in this research and that of other researchers [18,20,35].

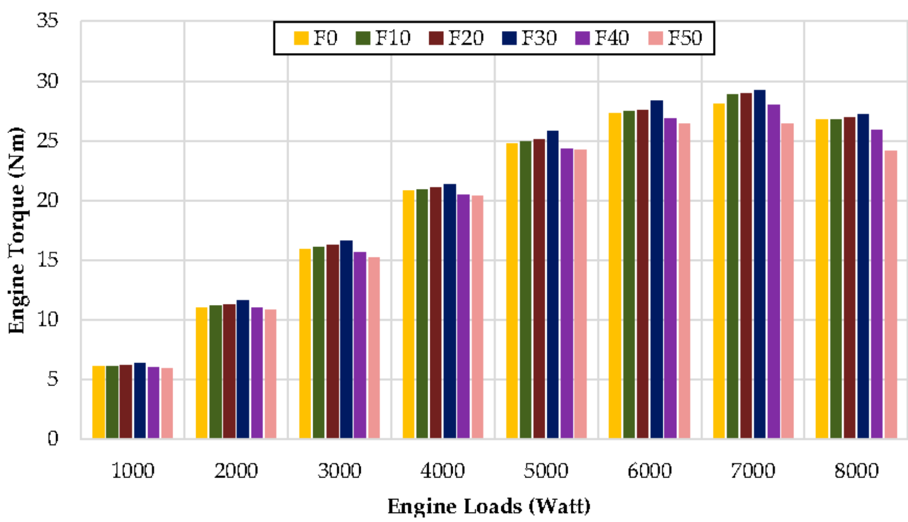

Figure 5. Engine torque changes with engine loads.

3.3. Specific Fuel Consumption

Figure 6 shows the graph of specific fuel consumption vs. power drawn at fixed-speed per fusel oil blend. Lower heating value of fusel oil is below that of gasoline, therefore, as the amount of fusel oil in the blend increases the lower heating value declines. With respect to specific fuel consumption, as the lower heating value declines the amount of fuel consumed increases. With the constant Excess Air Coefficient of experiment engine, in comparison to F0, fuel consumption increased as the amount of fusel in the blend increased. In comparison to F0, and for all engine loads, fuel consumption increased by an average of 1.72% for F10, 3.33% for F20, 10.53% for F30, 18.53% for F40, and 30.44% for F50. Specific fuel consumption results are in concordance with those of other researchers [18,20,36].

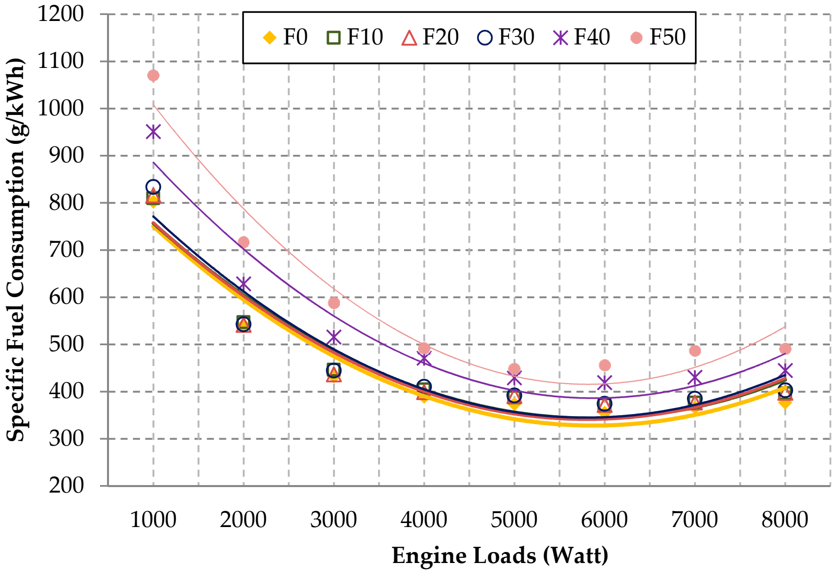

Figure 6. Specific fuel consumption changes with engine loads.

3.4. Exhaust Emissions

3.4.1. Carbon Monoxide (CO)

Figure 7 shows changes in CO emissions per engine load. CO emission concentration depends heavily on the engine's operation and air/fuel ratio. CO emissions occur due to incomplete combustion when there is not enough time for combustion, or due to insufficient oxygen that is required for full combustion of rich air/fuel mixtures in the cylinder. It has been seen that fusel oil containing oxygen improves the combustion and reduces CO emission levels. In comparison to F0, CO emissions were observed to reduce as the amount of fusel in the blend increased. For all engine loads, CO emissions are reduced by an average of 13.10% for F10, 25.53% for F20, 62.89% for F30, 72.84% for F40, and 81.9% for F50. These results are in concordance with other studies [37–39].

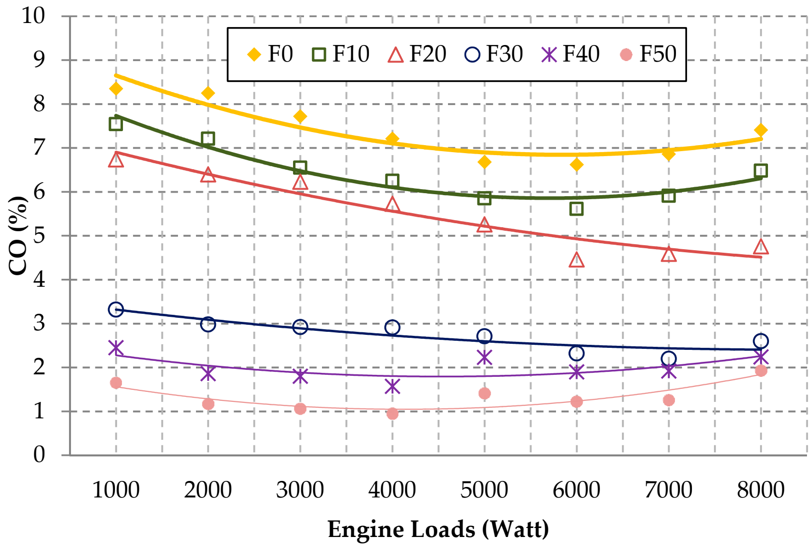

Figure 7. CO emission changes with engine loads.

3.4.2. Hydrocarbon (HC)

Figure 8 shows HC emissions that different fusel oil blends eject to the atmosphere under different engine loads. HC emissions occur due to incomplete combustion when there is not enough air and oxygen in the cylinder. HC emissions are fuel conveyed out unburned. As can be seen in Figure 8, HC emissions reduce as the amount of fusel oil in the blend and the engine load increase. This reduction occurs due to the fusel oil containing oxygen and therefore due to the increase in combustion temperature as the engine load increases. When Excess Air Coefficient is set to ($\lambda = 1$), the cylinder is charged with more fusel oil–gasoline blend to achieve stoichiometric mixture, and this is considered to increase the cooling effect of fusel oil within the cylinder. As the amount of fusel oil in the blend increases, HC emissions are reduced. For all engine loads, HC emissions is reduced by an average of 20.84% for F10, 25.26% for F20, 31.81% for F30, 45.98% for F40, and 50.78% for F50. These results are in concordance with other studies [39–42].

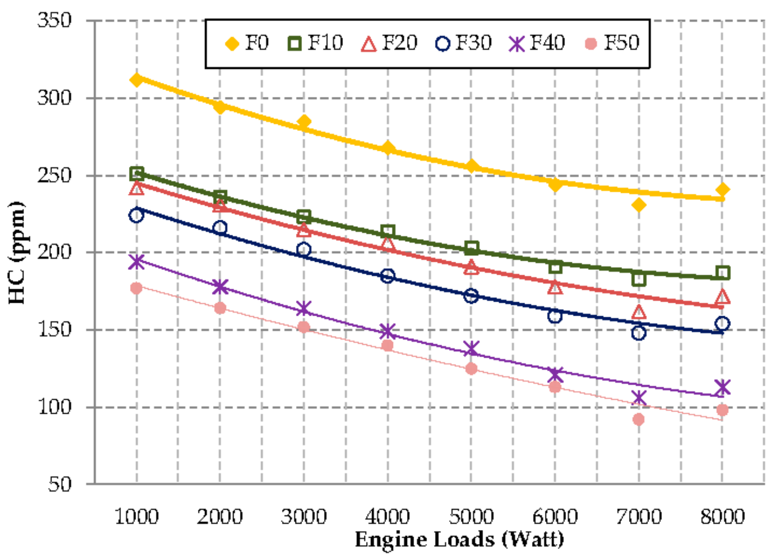

Figure 8. Hydrocarbon (HC) emission changes with engine loads.

3.4.3. Nitrogen Oxide (NO_x)

NO_x is an exhaust emission formed due to in-cylinder temperatures. NO_x emissions are formed especially when temperatures exceed 1500 °C. Another parameter most essential to NO_x is the oxygen concentration within the cylinder. Figure 9 shows the NO_x emissions increasing as the engine load increases. In comparison to F0, with all fusel oil blends, the NO_x emissions are reduced. Due to higher latent heats of vaporization of alcohols that form fusel oil, the flame temperatures, and therefore the NO_x emissions, are reduced. Hence, the NO_x emissions may change depending on the conditions the engine operates, and the amount of fusel oil in the blends. For all engine loads, NO_x emissions is reduced by an average of 53.91% for F10, 66.57% for F20, 70.73% for F30, 76.49% for F40, and 83.04% for F50. These results are in concordance with other studies [18,19,35,39,42,43].

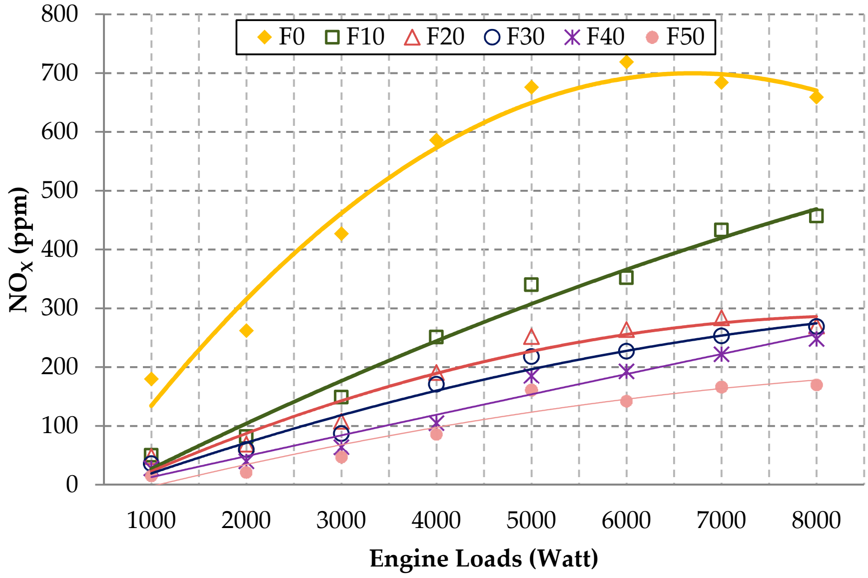

Figure 9. NOx emission changes with engine loads.

4. Conclusions

In this research, using fusel oil–gasoline blends as fuel in a spark-ignited, fixed-speed power generator, engine performance and exhaust emissions were analyzed under different engine loads, and the following results were obtained:

- Fusel oil is a by-product formed as a result of the fermentation of ethanol. The distillation efficiency of fusel oil is 96.5%. Existent gum content of 26.6 mg/100 mL in pure fusel was reduced to 0.8 mg/100 mL as a result of improvements (by using gum inhibitor and desiccant) and brought in compliance with TS EN 228 standard. The reason for these improvements is that fusel oil, due to the large amount of existent gum content it contains, does not blend with gasoline homogeneously. Facilitating a homogeneous blend of heavy alcohols contained in fusel oil, with gasoline, the alternative fuel was brought in compliance with TS EN 228 standard.
- Due to higher latent heat of vaporization of fusel oil–gasoline blends, when compared to standalone gasoline, F10, F20, F30 blends increased engine torque, whereas F40 and F50 reduced it.
- The fusel oil having lower heating values below that of unleaded gasoline led to an increase in specific fuel consumption as the amount of fusel oil in the blends increased.
- With fusel oil's stoichiometric air/fuel ratio below that of gasoline, in order to create heat equivalent to that gasoline creates and obtain the stoichiometric mixture, the cylinder was charged with more fuel. This increased the cooling effect of fusel within the cylinder and the increasing amount of fusel within the cylinder led to lower NO_x emissions, when compared to unleaded gasoline.

- As fusel oil contains a high amount of oxygen, CO an HC emissions were reduced.
- Experiment results prove that fusel oil can be utilized as fuel in a gasoline-operated engine. Moreover, upon using fusel oil–gasoline blends, CO, HC, and NO_x emissions were reduced.

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