Performance and Emission Characteristics of Spark Ignition Engine Running With Gasoline, Blends of Ethanol and Blends of Ethiopian Arekie

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Received: 21-08-2022, Received in Revised form: 17-11-2022, Accepted: 16-12-2022, Published: 31-12-2022

Abstract

This research intends to introduce Ethiopian locally produced alcohol as an alternative in the blended form with gasoline to use in spark ignition engines. The traditionally distilled Arekie was purchased from a local producer and purified using fractional distillation. Then five Arekie-gasoline blends were prepared with the proportion of 5, 10,15,20, and 25%v/v (A5, A10, A15, A20, and A25, respectively). Also, absolute ethanol was purchased from a local supplier, and ethanol-gasoline blends were prepared with a similar proportion as Arekie-gasoline blends (E5, E10, E15, E20, and E25). Then an experiment was conducted on a single cylinder, 4-stroke, spark-ignition engine running at a constant speed of 2500 rpm and variable loads to investigate the performance and emission characteristics. Results showed that the performance and emission parameters are significantly improved as the ratio of Arekie and ethanol in gasoline increases at all loads. Among all tested fuels, E20 exhibited better performance, and E25 exhibited better emission. A20 provided a slightly lower performance than E20 but much improved compared to pure gasoline. A25 provided comparable emissions with E25 and was much better than pure gasoline. Generally, adding up to 20%v/v Ethiopian Arekie in gasoline could make a better, renewable alternative to spark ignition engines.

Keywords: Alcohol fuels, Alternative fuels, Pollutant emissions, Spark-ignition Engine, Arekie-Gasoline Blends.

Introduction

We live in a world that is in extreme danger nowadays than before. It will only be even worse in the future if we do not apply significant precautions very soon. Mainly developed countries are badly experiencing an energy crisis because of increased population, expansion of industrialization, improved transportation, and rapid continuous exploitation of fossil fuels [1]. Since developing countries are also transforming their economy into industry-based, our world will suffer too much from environmental change and global warming. That is why we are noticing that even America, Australia, India, and other countries are losing control of the wildfire this time because of the hot and dry environmental conditions. Therefore, it is no surprise that the world has become more concerned about reducing the use of fossil fuels. They have become a threat to the world because of their toxic emissions. Besides, it is unknown how long they will last. The only known fact is that they are depleting rapidly and will not last long. So the world's concern about finding environmentally friendly alternative fuels has increased recently. Hence alcohol fuels are found to be the most convenient alternatives to use in internal combustion engines. That is why almost every country sets its plan and alternative energy policies. They have been encouraging researchers to find renewable alternative energy sources. As a result, bio-fuels are found to be a convenient alternative to fossil fuels due to their low emission contaminants, renewability, and oxygenation [2][3]. Mainly, ethanol is one of the most known alternative fuels. It has the potential to replace fossil fuels in internal combustion engines, because it has a comparative physio-chemical property to that of regular gasoline [4]. Ethanol can be easily produced at home from renewable energy sources such as farm serials, vegetables, and fruits [5][6]. One of the best examples of homemade ones is Ethiopian locally produced alcohol (Arekie). Arekie is a clear, colorless traditional alcoholic beverage produced by distillation [7][8].

Numerous studies have been conducted on the possibility of using different alcohols as an alternative fuel for SI engines by blending them with gasoline. Mohammed et al. [4] blended ethanol with gasoline in 10, 20, 30, and 40 %v/v proportions utilizing an ultrasonic bath to ensure perfect mixing. A single cylinder, four-stroke, spark ignition engine was used to study and analyze the effect of ethanol-gasoline blends on engine performance and exhaust gas emission. Results showed that performance characteristics are improved with the increase of ethanol concentration and harmed volumetric efficiency. It is also reported that adding ethanol reduced harmful exhaust gas emissions (CO, HC, NOx). Dhande et al. [1] extracted ethanol from pomegranates fruits waste and used it as bio-fuel. Four different blends, namely PE10, PE15, PE20, and PE25, were prepared and experimented on a Kirloskar type single cylinder, four strokes, and variable compression ratio spark ignition engine at various operating speeds. The results show that adding ethanol enhanced fuel consumption and braking capacity while reducing thermal performance. PE15 blend exhibited optimum brake thermal efficiency (BTE) at full load condition compared to gasoline. Brake specific fuel consumption (BSFC) of PE15 was lower at different operating speeds among all the blends. As the ratio of ethanol increases in the blend, the NOx and CO_2 emissions increase. In contrast, the HC and CO emissions were reduced. Dur˜ao et al. [9] produced pyro-gasoline from used cooking oils unfit to produce bio-diesel and added it to fossil gasoline. Binary and ternary mixtures of gasoline with 0, 2.5, and 5 % of pyro-gasoline and ethanol were tested on a spark-ignition engine, operated at full load between 2000 and 6000 rpm while recording engine performance and exhaust gases pollutants. The results showed that binary mixtures with pyro-gasoline did not improve or worsen the engine's performance. However, the ternary mixtures (gasoline + pyro-gasoline + ethanol) improved the performance with torque gains between 0.8 and 3.1 percent compared to gasoline. Balki et al. [10]

https://doi.org/10.24949/njes.v15i2.713

experimentally studied the effect of methanol and ethanol on the performance, emissions, and combustion characteristics of a 2 kW power single-cylinder engine and compared the results with conventional gasoline operation. The tests were performed at full load and variable engine speeds. The results showed that using alcohol fuels improved the performance and combustion characteristics of the engine. The amount of CO_2 emission increased while HC, CO, and NOx emissions decreased because of the improved combustion properties. Sasongko and Wijayanti [11] investigated the effect of ethanol addition on the engine performance and exhaust emissions of a spark ignition engine. An experiment was conducted on a 4 - stroke, single-cylinder engine having a capacity of 124.8cc and compression ratio of 9.3:1. It was performed at eight different engine speeds ranging from 1500 rpm to 5000 rpm with ten types of ethanol-gasoline blends (E10 to E100). Results showed that the effective power decreased with the increase of ethanol in the fuel blends for all variations of engine speeds. Gasoline engines fueled with pure ethanol reduced the CO emission by more than 60 percent by volume compared to gasoline. The maximum power with fuel blends was obtained at an engine speed of around 2500 to 3000 rpm. Finally, it is concluded that engines operating with ethanol blends performed better at the lower engine speed. Koten et al. [12] experimented on a four-stroke, naturally aspirated, single-cylinder, spark ignition engine to study performance and emission characteristics at full load and a constant engine speed of 2400-r/min. Different levels of ethanol addition (2.5, 5, 10, 15, and 20 %v/v) into gasoline were analyzed and compared with neat gasoline-fueled conditions. Obtained results showed NOx emissions increased with the increment of the amount of ethanol. The CO and total HC emissions decreased while the performance parameters were unaffected.

Almost all the previous studies show that alcohol-blended fuels might have improved or not affected the performance and emission characteristics of the engine. The current study intends to investigate the effects caused by the addition of a small fraction of purified Ethiopian locally produced alcohol (Arekie) on the performance and emission characteristics of spark ignition engines.

Materials and Methods

Fuel Preparation

Directly blending the purchased Arekie with gasoline did not go well. It sunk to make a phase separation; hence fractional distillation was undergone to purify it. After the fractional distillation, the properties of Arekie became much improved (Table 1). Hence the proposed Arekie-gasoline blends were prepared with the proportion of 5, 10, 15, 20, and 25 %v/v and represented as E5, E10, E15, E20, E25. Ethanol-gasoline blends were prepared with similar proportions to that of Arekie-gasoline blends for comparison. The properties of both blends were improved (Table 2).

Table 1. Some Properties of Arekie before and after fractional distillation

Property	Before Fractional Distillation		After Fractional Distillation
	Sample 1	Sample 2	
Alcoholic Content (%v/v)	48	51	95
Density, ρ (g/m^3)	896.8	890.35	798.975

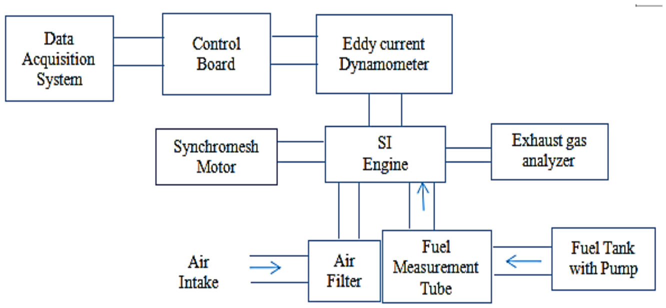
Experimental Setup

A water-cooled, four-stroke, single-cylinder spark ignition engine was used (Table 3). A constant speed of 2500 rpm and variable loading conditions were considered while experimenting. The test engine generates maximum torque at 2200 rpm and maximum power at 3000 rpm, so that nearly average engine speed was considered to have average effects since we are keeping it constant. The test engine was connected to a synchronous motor that operated as a dynamometer to enable load control. The test stand was equipped with a measuring tube for fuel measurements and with a measuring orifice for air consumption measurements. It is also integrated into a data acquisition computer with specific software and an exhaust gas calorimeter to analyze the emission (Figure-1).

Table 2. Properties of fuel blends after fractional distillation

No	Fuel Grades	Fuel Properties: Heating value (kJ/kg)	Density (g/m^3)	Octane Number
1	Gasoline	44200	742	87.5
2	Ethanol	29500	785	99.96
3	E5	43191	744.15	88.125
4	E10	42185	746.3	88.746
5	E15	41235	748.75	89.369
6	E20	40430	750.6	89.992
7	E25	39578	752.75	90.615
8	Arekie	32100	798.975	95
9	A5	43595	744.84	87.875
10	A10	42990	748	88.25
11	A15	42385	751	88.625
12	A20	41780	753.4	89
13	A25	41175	756.24	89.375

Figure 1(a): Actual experimental setup (Test Stand).



b) Schematic diagram

Figure 1(b): Schematic diagram of Actual experimental setup

Table 3. Test engine technical details

Engine Type	Air-cooled, single cylinder, 4 - stroke petrol engine
Manufacturer	GUNT
Dimensions (LxWxH)	500mm x 345mm x 410mm
Weight	Approx. 34 kg
Compression ratio	8.5:1
bore	89 mm
Stroke	63 mm
Connecting rod length	110 mm
Crank throw	31.5 mm
Maximum Power	7.5 kW @ 3000 rpm
Maximum Speed	3600 rpm
Maximum Torque	24.6 Nm @ 2200 rpm
Oil Capacity	1.4 litters
Ignition	Magneto ignition
Sound level (distance 1m)	96 dB(A)

The engine was started and allowed to run for at least 10 minutes to warm up before starting the test. After realizing the engine had warmed up, and a constant speed of 2500 rpm was achieved, gasoline fuel was fed, and the records of performance parameters such as brake torque, brake power, brake specific fuel consumption, and thermal efficiency were taken by the data acquisition system, and the CO, CO_2 and HC emissions results were captured from the emission analyzer display screen at no load, 25%, 50%, 75% and full load conditions. The remaining fuel was drawn out through the return unit, and the engine was allowed to run for 2 minutes without fuel before jumping to the next experiment. Similar procedures were taken for all Arekie-Gasoline blends (A5, A10, A15, A20, and A25) and Ethanol-Gasoline blends (E5, E10, E15, E20, E25).

Table 4: Emission analyzer technical details

Model	Infralyt smart	
Measuring Principle	NADIR	
Dimensions (LxWxH)	570mm X 570mm X 1300mm Weight = Approx. 105 kg	
Temperature measurement	Sensor: Thermocouple type K Measuring range = 0 - 1000 °C	
Water flow-rate measurement	Variable - area flow meter Measuring range = 30 - 300 liter/h	
Display unit power supply	230 V, -50 Hz	
Exhaust gas measuring range		**Uncertainty**
CO	0 to 10 %vol.	± 0.01%
CO_2	0 to 20 %vol.	± 0.1%
UHC	0 to 10000 ppm vol.	± 10 ppm
O_2	0 to 25 %vol.	-

The exhaust gas analyzer measurement technique is based on infrared rays energy transmitted to a detector through the flow of exhaust gases. The rotating wheels interrupt the rays to produce a sequence of signals. Those signals are then analyzed automatically by a microprocessor, and the results are presented.

Results and Discussions

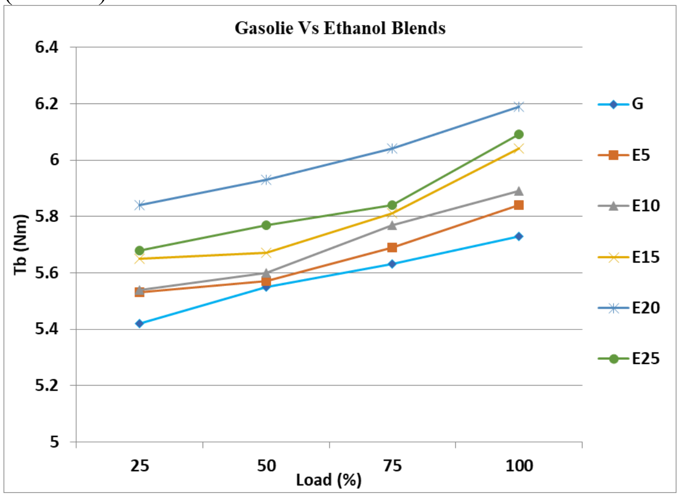
The performance parameters such as: - brake torque (Tb), brake power (Pb), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and the emission parameters such as - CO, CO_2, and UHC emissions are analyzed, the results are presented and discussed in this section.

Performance

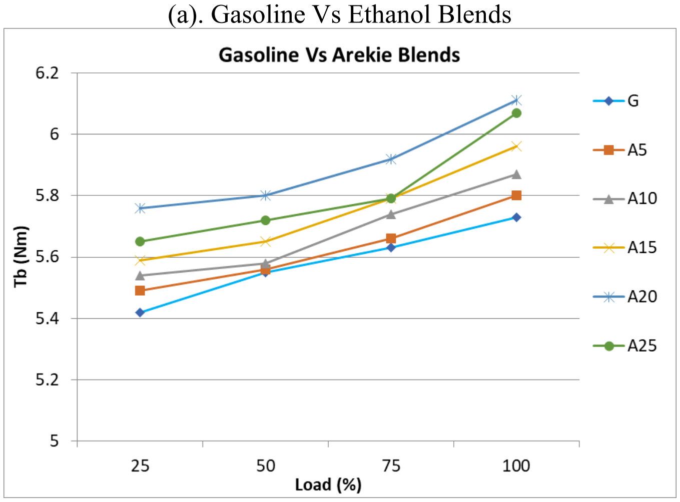
Brake Torque (Tb)

Figure 2 (a and b) presents a comparison of the brake torque (Tb) for fuels (Gasoline and Ethanol Blends, and Gasoline and Arekie Blends, respectively.) running the engine at constant engine speed (2500 rpm) and variable loads. According to the obtained experimental results, the generated brake torque of the test engine was significantly improved with the addition of both Arekie and Ethanol at all loading conditions. However, Arekie blends have shown a slightly reduced or comparative result to ethanol blends throughout the experiment. At full loading condition, the provided improvement in engine torque was recorded as 0.11, 0.16, 0.31, 0.46 and 0.36 Nm (which is 1.92, 2.79, 5.41, 8.028, and 6.28% improvement) running with E5, E10, E15, E20 and E25, respectively. A5, A10, A15, A20 and A25 also improved the torque by 0.07, 0.14, 0.23, 0.38

and 0.34 Nm (which is 1.22, 2.44, 4.01, 6.63 and 5.93%, respectively). This shows that the maximum torque is obtained running the engine with E20 (6.19 Nm) followed by A20 (6.11Nm) at full load.



(a). Gasoline Vs Ethanol Blends

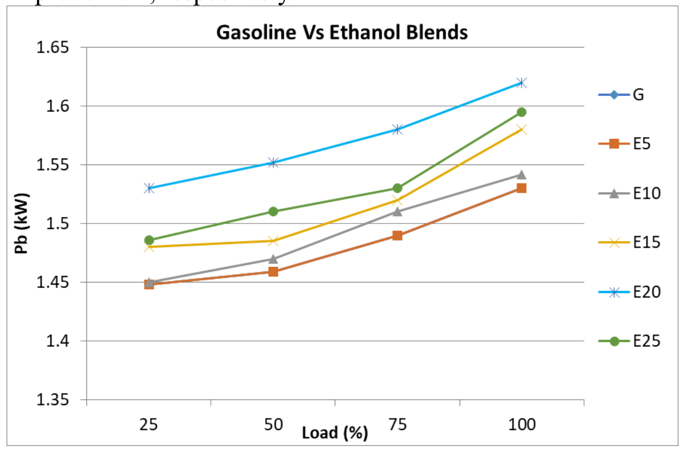


(b). Gasoline and Arekie Blends

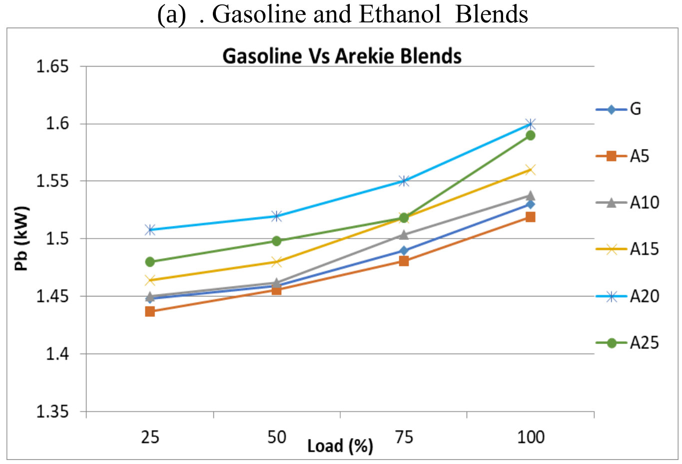
Figure 2. Tb Comparison

Brake Power, (Pb)

As for brake torque, improvements are noticed in the brake power of the test engine at all loading conditions, as shown in Figure 3 (a and b). The engine's power extends its improvement proportionally as the blending ratio increases up to 20%v/v. However, further increment of the blending proportion caused a reduction in the brake power (Pb). According to the recorded results from the experiment, the engine was able to generate greater power running with a relatively higher blending ratio at higher loads, withE25 being the exception. It was because the addition of increased blending ratios of oxygenated Arekie and Ethanol in gasoline increases the oxygen content in the combustion chamber, leading to complete combustion, hence increased power. The results of Pb for E5 and gasoline became similar at all loads, whereas A5 caused a negligible reduction. That is why we only see five lines in Figure 3 (a) while the legends are six, as the results for ethanol blends and gasoline coincide. However, all fuels performed well and improved brake power as the load and blending ratios increased. Among all, maximum power generation is exhibited running the engine with E20 followed by A20 at full load. They showed 5.50 and 4.38% improvement, respectively.



(a) . Gasoline and Ethanol Blends



(b) . Gasoline and Arekie Blends

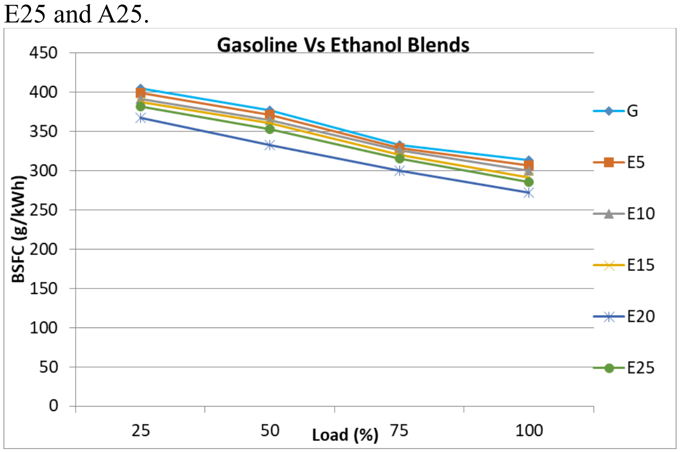
Figure 3. Pb Comparison

Brake-Specific Fuel Consumption (BSFC)

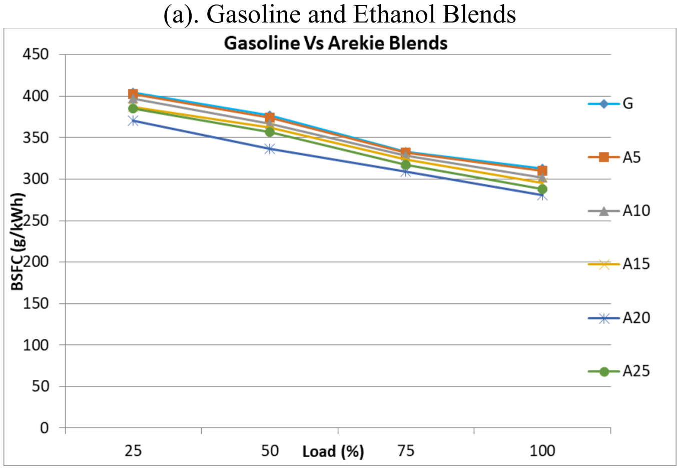
Brake-specific fuel consumption is defined as the amount of fuel consumed to generate one kW of power within an hour. The BSFC of the test engine was recorded using the integrated computer software intended for such a specific task. The engine was set to operate at a constant speed of 2500 rpm and variable loads. The effects of Ethanol-Gasoline blends and Arekie-Gasoline blends compared to neat gasoline on BSFC of the engine are obtained as presented in Figure 4 (a and b). It is observed that the BSFC of the test engine was gradually reduced with the addition of both Arekie and ethanol at all loads. At full load and constant engine speed of 2500rpm, E5, E10, E15, E20 and E25, showed 1.98, 4.15, 7.03, 13.20 , 8.86% reduction, and A5, A10, A15, A20, and A25 exhibited 1.02, 3.45, 5.72, 10.41, and 7.9% reduction respectively compared to the engine's BSFC running with gasoline. For all fuels, more than 22% reduction is noticed between 25% - 100% loads. However, E20 gave the most reduced amount of BSFC, followed by A20 with 13.20 and 10.41% improvement at full load. The improvement is due to the enhancement of fuel's cetane number and volatility with the addition of Ethanol/Arekie that led to improved combustion, which further resulted in better brake thermal efficiency.

Brake Thermal Efficiency (BTE)

Brake thermal efficiency (BTE) is a parameter obtainable from the input energy. It is determined in terms of brake torque (Tb), brake power (Pb), and brake-specific fuel consumption (BSFC). The BTE of the test engine was measured by running the engine at constant engine speed and variable loading conditions. Figure 5 (a and b) shows the variation of brake-thermal efficiency (BTE) for different fuels (Gasoline, Ethanol-Gasoline blends, and Arekie-Gasoline blends) at constant engine speed (2500 rpm) and variable loads. It is observed that the brake-thermal efficiency of the test engine increases with the increment of the concentration of Ethanol/Arekie in the blend for all loading conditions. At full load, the BTE obtained running the engine with E20 and A20 is 32.78% and 30.73%, which is a significant improvement compared to the 26% BTE obtained from running the engine with gasoline at similar operating conditions. The efficiency running with blends of Arekie and Ethanol was similarly affected because of the raised load from 25% - 50% - 75%. For varying load from 25% - full load, fuels have registered from 5.88% improvement with gasoline to the maximum of 8.54% improvement with E20. Maximum efficiency of 32.78% was recorded with E20, followed by A20's 30.37% at full load. However, increasing the blending ratio of both Arekie and ethanol by more than 20%v/v in gasoline affected the air-fuel ratio. The BTE started to fall back, as noticed with E25 and A25.

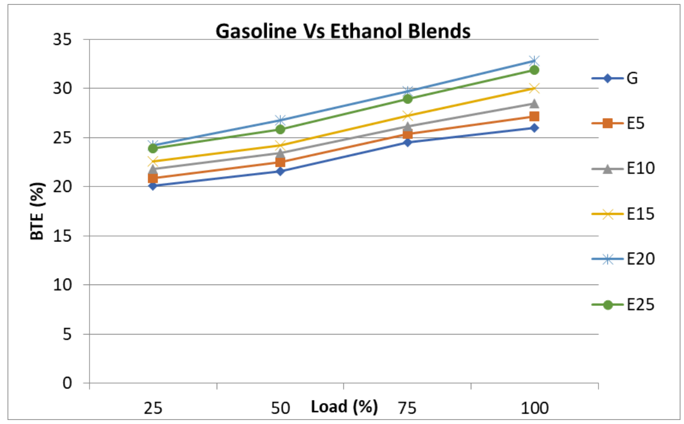


(a). Gasoline and Ethanol Blends

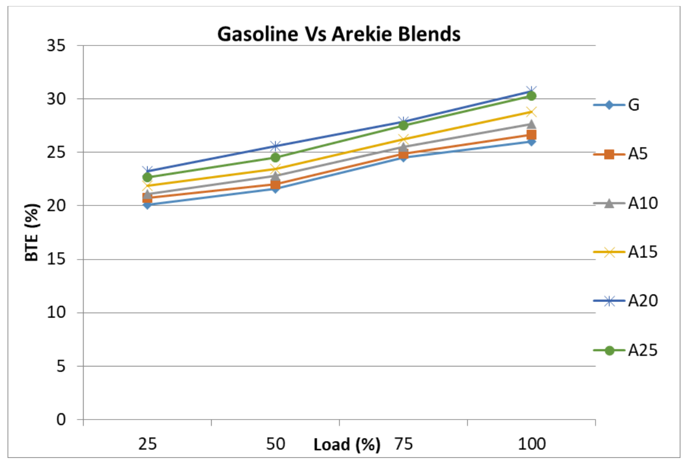


(b). Gasoline and Arekie Blends

Figure 4. BSFC Comparison



(a) . Gasoline and Ethanol Blends



(b) . Gasoline and Arekie Blends

Figure 5. BTE Comparison

Exhaust Emissions

Carbon monoxide (CO)

CO emission resulted in IC engines because of incomplete combustion and slow-burning of the air-fuel mixture in a combustion chamber. According to this study, the CO emissions reduced as the load increased, which was due to the increase in combustion temperature that resulted in complete combustion at higher loads. In addition, it was found that the CO emission of the test engine was reduced as the blending ratio of both absolute ethanol and Ethiopian Arekie increased in the fuel. It was because of the increased oxygen content and lower carbon to hydrogen ratio compared to pure gasoline. The addition of either ethanol or Arekie in gasoline increased the cetane number of the blended fuel, which boosted the combustion behavior of the fuel and prevented the formation of a rich fuel zone, hence reduced the CO emission. (Figure 6).

Carbon dioxide (CO_2)

Since CO_2 is the byproduct of complete combustion, its emission noticed in this study is increased as the engine load increases for all tested fuels, as shown in Figure 7. Since bio-fuels are highly oxygenated (have high oxygen content) and contain lower carbon to hydrogen ratio, it improves the combustion behavior of the fuels and the CO_2 emission of the test engine increases. Among all the tested fuels, E20, E25, A20, and A25 registered the maximum and nearly similar CO_2 emission at full load. This shows that adding purified (fractionally distilled) Arekie or ethanol has improved the combustion characteristics of the fuel and resulted in complete combustion compared to pure gasoline. (Figure 7).

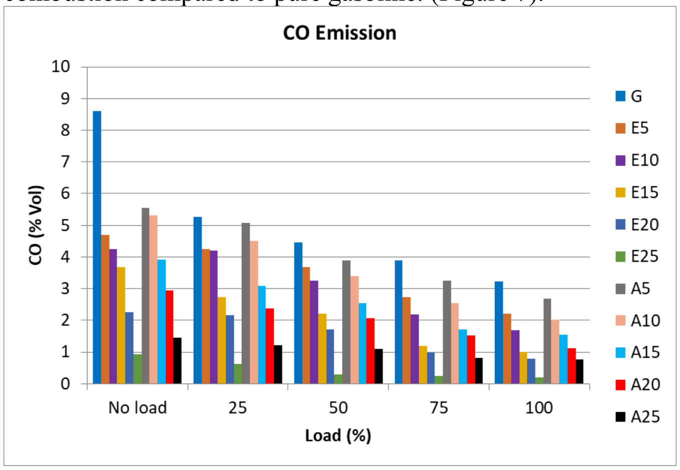


Figure 6. CO emission

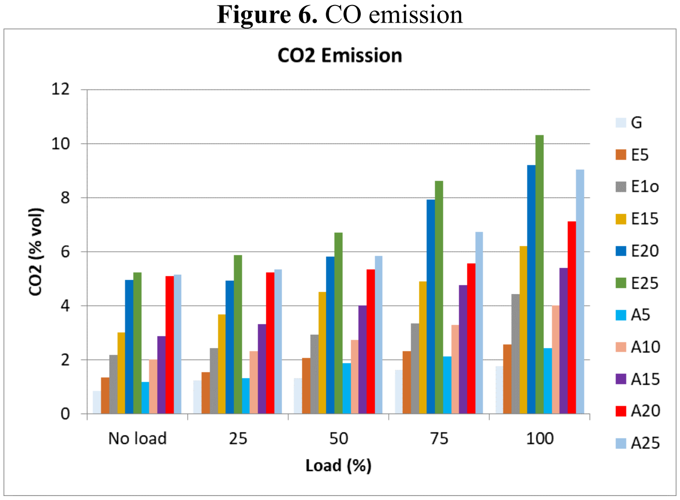


Figure 7. CO_2 emission

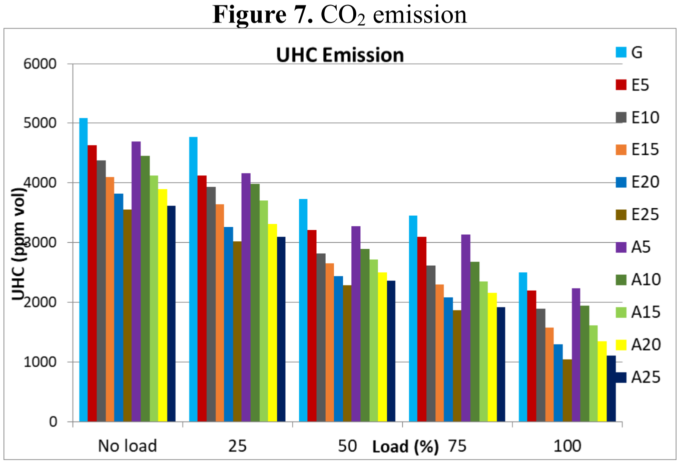


Figure 8. UHC emission

Unburnt Hydrocarbon (UHC)

Blending gasoline with Arekie or ethanol improved the combustion characteristics of the test fuels. An increased load also raised the combustion temperature. So it results in the completeness of the combustion process. The possibility that we could have UHC as a byproduct of the combustion is too low for the engine running with ethanol-gasoline or Arekie-gasoline blends compared to regular gasoline. According to this study, the UHC emission of the test engine running with neat gasoline is improved by about 49.15percent because of the load variation from 0 (no load) to 100% (full load). Increment in the blending ratio too reduced the toxic emissions. Among the blended fuels, E25 has shown less UHC emission followed by A25 than other tested fuels. (Figure 8).

Economic Advantage

Absolute ethanol was purchased from a local supplier with 450 ETB (Ethiopian Birr) per litter, whereas Ethiopian Arekie having 51% alcoholic content before fractional distillation, from which we produced one litter purified using two litter unpurified, was purchased with 150 ETB/liter for the study. That means we can have Ethiopian Arekie having a comparable property with absolute ethanol just for 150 ETB/litter less cost. That means we could save one third (33.33%) of total fuel cost by using Arekie blends instead of Ethanol blends.

Conclusion

In this Study, Ethiopian locally produced alcohol (Arekie), previously used for drinking only, is introduced as an alternative fuel in blended form with neat gasoline for the SI engine. Homemade Arekie was purchased from a local producer, purified using fractional distillation and blended with gasoline in smaller proportions starting from 5%-25% v/v in a fraction of 5% (i.e., A5, A10, A15, A20, and A25). Then the performance and emission characteristics of the test engine were investigated by conducting an experiment on a single cylinder spark ignition engine running at a constant speed of 2500 rpm and variable loads. Pure gasoline (E0, A0) and ethanol blends (E5, E10, E15, E20, E25) were tested to compare the results. The following significant conclusions are drawn from this study.

The engine running with Ethanol-Gasoline blends and Arekie-Gasoline blends has produced better Tb, Pb, and BTE. It consumed less fuel to generate a kW of power in an hour (reduced BSFC) than running with neat gasoline. It also has generated maximum brake power (Pb) running with E20 followed by A20 at full load, which is 5.88 and 4.57% greater compared to the power generated running with pure gasoline at the same operating condition. The power generated with E5 coincided with neat gasoline, while A5 reduced it with a negligible amount at all loads. Brake torque (Tb) also was improved by about 7.99 and 6.63% with E20 and A20, respectively, compared to neat gasoline at full load. BSFC is observed that it reduced by adding ethanol or Arekie to gasoline. It improved by about 13.20 and 10.40% running the engine with E20 and A20 respectively instead of gasoline at full load. The maximum brake thermal efficiency of 32.78% is achieved by running the engine with E20 at a constant speed of 2500 rpm and full load. The efficiency achieved operating with A20 (30.73%) was less compared to E20, but it is much more efficient compared to the efficiency exhibited running with neat gasoline, which is 26% at the same operating condition. As the concentration of ethanol or Arekie increases up to 25%v/v (E25, A25) in pure gasoline; the CO emission is reduced up to (75.85%, 65.65%), CO_2 emission was increased by about (80.87%, 75.26%), and UHC emission is reduced by (58.56%, 55.68%) respectively, compared to gasoline. A20 exhibited comparable results with E20, better performance compared to neat gasoline in terms of the performance and emission parameters, and cost-effective (33.33% reduced) compared to E20. Therefore, it can be used as an alternative fuel in SI engines if blended with gasoline up to 20%v/v.

Acknowledgments

The authors are highly thankful to Addis Ababa Science and Technology University, Addis Ababa, Ethiopia, and Debre Birhan University, Debre Birhan, Ethiopia, for providing a laboratory facility to experiment.

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