Experimental Analysis of Gaseous Emission in 2-Stroke Single Cylinder Engine Using Ethanol Gasoline Blends

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Abstract: The emission of Unburnt Hydrocarbon (UHC), Oxides of Nitrogen (NO_x), Carbon Monoxide (CO), and Carbon Dioxide (CO_2) from internal combustion engine have been seen to cause negative environmental impact and a major source of greenhouse effect. This paper provides a better understanding and strategies for use of biofuel ethanol as a blend with gasoline to reduce emissions in 2-stroke engine small power generaor. An experimental study on a single cylinder domestic portable power generating set of fixed speed has been used with gasoline ethanol blends in ratio of 100% gasoline (E0), 50% gasoline ethanol blends (E50) and 100% ethanol (E100) under varying engine loads. The results showed that the CO and HC emission decreases as a result of the leaning effect caused by the ethanol addition. The CO_2 emission was also observed to increase because of the improved combustion as a result of leaning effect of ethanol addition, in particular the E100. The NOx emission for E100 shows the most interesting result of decreasing from idle load to zero at the maximum load.

Keywords: 2-Stroke; ICE; Ethanol; Gaseous Emission; Gasoline

I. Introduction

The increasing demand for energy in the world had led to increase in the consumption of fuels. As a result, access to the conventional fossil fuels is becoming more and more difficult and expensive, and it is also limited in availability. Apart from economic aspects, the main problem is that fossil fuels are non-renewable and have generated great concern globally about its contribution to local emissions and global warming. The global interest in alternative energy or renewable energy sources is due to the mentioned problems in addition to the environmental issues of fossil fuels. Alternative energy is basically a type of energy produced from a source other than conventional fossil fuels, such as, oil, natural gas, and coal. According to the International Energy Agency's (IEA) world energy outlook [1], the total energy consumption in the world will increase by a rate of 1.5% per year until 2030. Fossil fuels such as coal, oil and gas produce huge amounts of CO_2 during combustion,. This gas constitute the key global warming emissiom. To eliminate this environmental effect there is an urgent need for an alternative source to fossil fuel. Presently the best alternative energy resources to replace the fossil fuels are renewable energy carriers such as zero-carbon fuels. When renewable energy sources are used to produce energy in transportation, heat and power they produce little or no carbon dioxide. For this reason, they are often referred to as being neutral- or zero-carbon fuel.

The Biomass, which already has a large percentage of the total renewable energy sources, is expected to have a strong growth in the coming years of this current energy transition period within three key sectors namely, the heat and power generation, transportation biofuels, and other bio-products. The bioenergy energy term is generally used for the energy extracted from biomass resources for the industrial or residential applications, or the extracted liquid fuel (biofuel) to be used in the transportation sector. The consumption of liquid biofuels for road transport was reported to have grew at around 5% per year from 2014-2019 and this growth was concentrated in Europe and North and South America. But it was also reported that the COVID pandemic lead to 5% decline in 2020 [2].

The internal combustion engines (ICE) be it the 2- or 4-stroke has been with us for more than a century [3] are widely use for different applications. But the 2-stroke ICE dominates the smallest and largest power generation applications of the ICE. They are popular in the Marine applications, and the small two-stroke engines are employed widely both in professional and recreational applications due to their simple construction and economical production cost.

The 2-stroke engine also provide a good power-to-weight ratio, as the maximum power output of the two-stroke engines is typically 40–50% higher than that of the four-stroke engines of equal displacement [4]. The most important advantage of 2-stroke over the 4-stroke engines may be that in handheld equipment such as chainsaws and hedge trimmers the two-stroke engines can operate in any position, which is not possible with the four-stokes engines due to the problems associated with the nature of lubrication method. The 2-stroke engines also have a big share in 2-wheelers vehicles such as mopeds, scooters, and motorbikes, especially in the developing countries. In addition, the 2-stroke in the power range of 500W to 1000W dominates the local portable electric power generator set for micro business owner, very low income earners, and the rural settlements, where it is popularly known as “I pass my neighbor” in Nigeria.

Though the 2-stroke portable power generators are banned in the country but they still available in the market. However, one issue the policy makers in the country failed to take into consideration sometimes in enacting policy is how it affects the local populations especially the very low income earners and those in the rural areas. Though the current global trend is towards the renewable energy especially the PV solar system, but the government of Nigeria has failed to critically look at how best to make this engine profitable to users in addition it just being used for electric power generation. In particular, how it will perform in using alternative fuel such as ethanol in blend with gasoline at low to pure ethanol. Since ethanol is locally produced in virtually all the rural settings in Nigeria and government can modify the policy already in place for short-, medium- and long-term ethanol blends in this energy transition period. The portable 2-stroke can serve multi-purpose such as back up for battery charging, salons, for small piece of power and propulsion as well as in a hybrid form. In addition, since the ethanol can readily be produced in all the localities in the country. The users can at the same time be producing the fuel needed locally either from waste crop or farm produce byproducts.

As another alternative fuel, blending ethanol with gasoline is quite promising, studies has confirmed that ethanol in gasoline engine increases the engine efficiency, torque and power compared to baseline gasoline fuel, ethanol is a renewable fuel and can be produced from several biomass. It has unique properties such as high-octane number and it is the largest alternative transportation fuel [5].

Several studies have been carried out by so many researchers on ways to improve engine performance and emission. Comparison has been carried out on 4- and 2- strokes combustion engines using ethanol in varying percentages with gasoline blend using the most advanced engnes and various combustion modes [6-8]. The effect of ethanol in different combustion modes have been analyzed using varying load and speed.

Abdel-Ramah et al [9], carried out an investigation on the effects of different ethanol-gasoline fuel blends up to E40, under variable compression ratio conditions; a varicomp engine was used to study the effect of varying the compression ratio in SI engine. The results show that the engine indicated power improves with the percentage addition of the ethanol in the fuel blend. The maximum improvement occurs at E10 fuel blend.

Hsieh et al [10], experimentally investigated the engine performance and pollutant emission of a commercial SI engine using E0, E5, E10, E20, and E30. Result showed that increasing the ethanol content, the heating value of the blended fuel decreased, while the octane number of the blended fuel increases. The results of the engine test indicated that using ethanol-gasoline blends, torque output and fuel consumption of the engine slightly increases.

Bayraktar [11], investigated the effects of ethanol-gasoline blend on an quasi-dimensional SI engine performance and exhaust emissions using E1.5, E3, E4.5, E6, E7.5, E9, E10.5 and E12 up to E21 at 1500 rpm for each blend with compression ratios of 7.75 and 8.25 and at full throttle setting. Results obtained have shown that among the various blends, E7.5 was the most suitable blend from the engine performance and CO emission. However, theoretical comparisons have shown that the blend containing E16.5 ethanol was the most suited blend for SI engines.

Celik [12], analyzed the effects of E0, E50, and E85 on engine performance and pollutant emissions in a 1-cylinder 4-stroke spark-ignition engine using two compression ratios of10:1 and 11:1. The engine speed was changed from 1500 to 5000 rpm at wide open throttle (WOT). The results of the engine test showed that ethanol addition to gasoline increase the engine torque, power and fuel consumption and reduce CO, NOx, and HC emissions. It was also found that ethanol-gasoline blends allow increasing compression ratio (CR) without knock occurrence.

Najafi et al [13], carried out an investigation on the effects of ethanol-gasoline blends of E0, E5, E10, E15 and E20 performance and the pollutant emissions of a 4-stroke SI engine with the aid of artificial neural network (ANN). The properties of bioethanol were measured based on American Society for Testing and Materials (ASTM) standards. Their experimental result shows that using ethanol-gasoline blends increased the power and torque output of the engine marginally. They also observed that the brake specific fuel consumption (bsfc) decreased while the brake thermal efficiency and the volumetric efficiency (ηv) increase. Their measured concentration of CO and HC emissions in the exhaust pipe decreases in using ethanol blends. This was likely due to the high oxygen percentage in the ethanol. In contrast, the concentration of CO2 and NOx was found to increase when ethanol was introduced.

Turner et al [14], investigated the effects of using different blending-ratios of bio-ethanol/gasoline with respect to spark timing and injection strategies on a direct injection spark ignition engine at a part load and speed condition. The result showed that adding ethanol into gasoline reduces engine emissions and increased efficiency, and the addition of ethanol modifies the evaporation properties of the fuel blend which increases the vapour pressure for low blends and reduces the heavy fractions for high blends.

Yao et al [15], carried out an experiment on the effects E15 ethanol-gasoline blend on a 2- and 4- stroke motorcycles equipped with carburetor and fuel-injected engine respectively, with a chassis dynamometer on CO, UHC, and NOx exhaust emission. The results showed that CO from E15 decreased by 32% (carburetor) and 10% (fuel-injection), respectively. UHC emissions also showed a reduction by 10% for fuel-injected engine, but did not reduce emissions from carburetor engine. No significant decrement of NOx emission was observed as using E15. The ozone-forming potential of motorcycle engine exhaust also reduced as using E15 blend instead of commercial gasoline.

Elfasakhany [16], analyzed the effects of performance and exhaust emissions from SI engine fueled with ethanol–methanol–gasoline blends. Ethanol–methanol blends (3–10 vol. %) in gasoline was compared to ethanol–gasoline blends, methanol–gasoline blends and pure gasoline. Results showed that when the vehicle was fueled with ethanol–methanol–gasoline blends, the concentrations of CO and UHC emissions were significantly decreased, this means that ethanol–gasoline blend provides the highest brake power.

Ojapah M Moore [17], reported the effects of E15 and E85 on both 4- and 2-Stroke controlled auto ignition (CAI) combustion processes with a range of load varied from 2.2bar to 8.6bar IMEP at 1500rpm. It was observed that E15 resulted in lower emissions of HC and NOx. The reduction of NOx was due to lower combustion temperature of E15, a higher CO emission was observed. The combustion efficiency was reduced as ethanol blend was increased to 85% resulting in the highest fuel consumption and CO emission.

Phuangwongtrakul et al [18], evaluated the effects of various ethanol-gasoline blend E10, E20, E30, E40, E50, E60, E70, E85, and E100 conducted at different engine speeds and percentages of intake-throttle opening at a constant compression ratio. The relative air-fuel ratio was tuned to unity and the ignition timing was tuned for maximum engine torque. The experimental results indicated that the appropriate ethanol-gasoline mixing ratio can enhance engine torque output, especially at low engine speed. The brake thermal efficiency is maximum when the engine operates at 58-73% of WOT with an engine speed of 2000-2500 rpm, using E40 and E50 fuels.

Akansu et al [19], carried an experimental investigation into the engine performance and emission values of gasoline, gasoline-ethanol and gasoline-ethanol-hydrogen blends, respectively and it was shown that E20 worsened the engine performance and emissions. However, the engine performance and emission values have been improved with the adding of hydrogen to blend. The results showed that the addition of hydrogen to the gasoline-ethanol blend improved the combustion process and improved the combustion efficiency, expanded the combustibility range of the gasoline-ethanol blend, reduced emissions. But, nitrogen oxide emission values increased with the addition of hydrogen.

Masum B M et al [20], they investigated the effect of ethanol-gasoline blend on NOx emission in SI engine. He discussed extensively the physicochemical properties of gasoline and ethanol, that the slight difference in properties between ethanol and gasoline are enough to create considerable change to combustion system as well as the engine behavior. In addition, he stated that these effects lead to several complex and interacting mechanism that makes it difficult to identify how ethanol affects NOx emissions. They however said the key factor that lead to NOx emissions is that due to thermal. Lastly, further emphasize that hydrous ethanol will be best option as the water contained in it will lower the combustion temperature that will lead to reduction in NOx emission.

The NOx emission which is one of the key pollutant from internal combustion engine because of the effect on the environment as well as health has also been examined under varying alcohol blends to see if alcohol blending can mitigate this emission. The ethanol which is branded as the low level alcohol has been researched by many and there has been many reports that the addition leads to increase in NOx emission. But some researcher also observed decrease of the NOx emission. In using ethanol in SI engine, NOx emission decrease with increasing ethanol. In using E85 lead to a reduction in NOx due to reduction in flame speed. Increasing it to E100, the NOx emission increases due to advanced combustion Phasing. This advanced combustion leads to increase of in-cylinder temperature and pressure, when compared to E85. It was also observed in by some researcher that when the percentage of ethanol increases from 10% to 85% NOx decreases. This can be summarized as when using alcohol fuel in an engine, due to the higher latent heat of evaporatuion and lower calorific value. This will lead to a decrease in NOx emission. Sometimes, the NOx emissions of ethanol will increase because of the high pressure and high temperature at the combustion chamber [21].

However, very little or no experimental research so far been conducted on this class of engines. With the energy transition currently going on globally and Nigeria government policies to decarbonizes the power and transport sector. In addition, with increasing level of poverty in the rural sector, which is dominated by the peasant farmers coupled with high unemployment among the Nigerian youth. There is presently no available incentives for those that are interested in bioenergy production especially at the rural and peri-urban areas. These challenges on renewable energy availability and accessibility, and the economic gain associated with bioenergy prompted this research so as to be in a better position to advise the policy makers and as well sensitize the locals about the opportunity in biofuel production and utilization locally to replace gasoline in this transition period.

Experimental set up and emission measurement

The experimental set up comprises of a single cylinder, 2-stroke spark ignition (SI) engine of 850Watts. The engine was slightly modified to provide space for the exhaust gas analyzer, the engine loading was through the use of inhouse loading system using electric appliances similar to type of load the engine are put to use when in operation. This portable electric generator set is popular among low income earners, small business holders, and rural settlements. The exhaust gas was sampled from the modified exhaust port using Nanhua model NH4-506EN 5-gas analyzer capable of measuring the UHC, NOx, CO, CO_2, O_2, lambda, engine speed, as well as the engine lubrication oil temperature. The instrument is composed of the instrument host, short tube, pre filter, sampling probe and embedded micro-computer printer. The engine specification is in Table 1, and Table 2 is the exhaust gas analyzer specification. The sampling probe was connected and tested for leakage, then inserted into exhaust outlet as show in Figure 1 and the speed measuring pliers was clamped on the high tension cable of the spark plug. The power is turned on and the instrument is allowed to warm up for 10 minutes the seal of the sampling probe was removed and the instrument automatically enter the interface of leak check after warm up by popping up a display cover the probe with the cap" and leak checking is carried out in 10 seconds and OK prompt appears on the instrument display screen when there is no leakage detected. Zeroing starts automatically when leak test is completed and the main menu display appears. The engine loading is then started and the time taken. Readings were taken every 10 min for increasing engine loads. The gaseous emissions and corresponding lambda (λ) in using blends of E0, E50 and E100 were measured. The fuel blends were prepared before starting the experiment to ensure that the fuel mixture is homogenous.

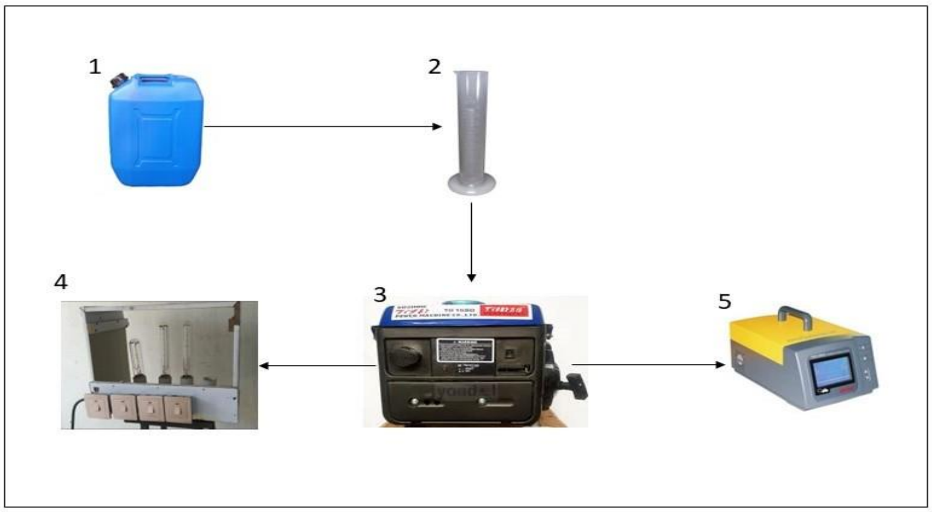

Figure 1 Experimental Setup

Table 1: General specification of test engine

Model	TG 950
Displacement	63cc
Rated frequency	50Hz
Rated RPM	3600rpm
Rated Voltage	230V
Rated Amperage	2.3A
Rated Power	450Watts
Max power	850Watts
Fuel tank capacity	4L
Full load continuum running time	5.0h
Exhaust gas analyzer	NH4-506EN Gas analyzer
Number of cylinder	1

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Table 2: General specification of the gas analyzer

Measured Quality	Measurement range
CO	0… 10 (*10^{-2}) %
CO2	0… 18(*10^{-2}) %
O2	0… 25(*10^{-2}) %
HC	0… 10000 (*10^{-6}) ppm
NO	0… 5000(*10^{-6}) ppm
RPM	300rpm-8000rpm

The experiment was started with no load, which implies the engine was idling conditions and then gradually increased the load to the maximum possible loading condition of the engine. The CO, CO_2, UHC, and NO_x emissions in using fuel blends were measured by the analyzer and recorded for further analysis and comparisons of the results. When using new blends the engine was operated for some time so that all residual fuel in the lines is used up before the readings are taken. The engine load used are 0W (idling or no load), 100W, 200W, 300W, 400W, 500Wand 600W.

II. Results and discussions

Emissions of CO, CO_2 and O_2.

The emissions of carbon monoxide results from the incomplete combustion of hydrocarbons due to a lack of oxygen. It is a poison to humans and animals that breathe it. Once carbon monoxide reaches the blood cells, it fixes to the hemoglobin in place of oxygen, thus diminishing the quantity of oxygen that reaches the organs and reducing the physical and mental abilities of the affected living beings. Dizziness is the first symptom of carbon monoxide poisoning, which can rapidly lead to death. Carbon monoxide binds more strongly to hemoglobin than oxygen. The bonds are so strong that normal body functions cannot break them. Persons intoxicated by carbon monoxide must be treated in pressurized chambers, where the pressure makes carbon monoxide hemoglobin bonds easier to break. The carbon dioxide (CO_2) is the result of the combustion of hydrocarbons and coal. In a complete combustion of gasoline fuel CO_2 and water are the expected results. It is important to note that carbon dioxide is indeed digested by plants and sequestrated by the oceans in the form of carbonates. However, these natural assimilation processes are limited and cannot assimilate all of the emitted carbon dioxide, resulting in an accumulation of carbon dioxide in the atmosphere [22].

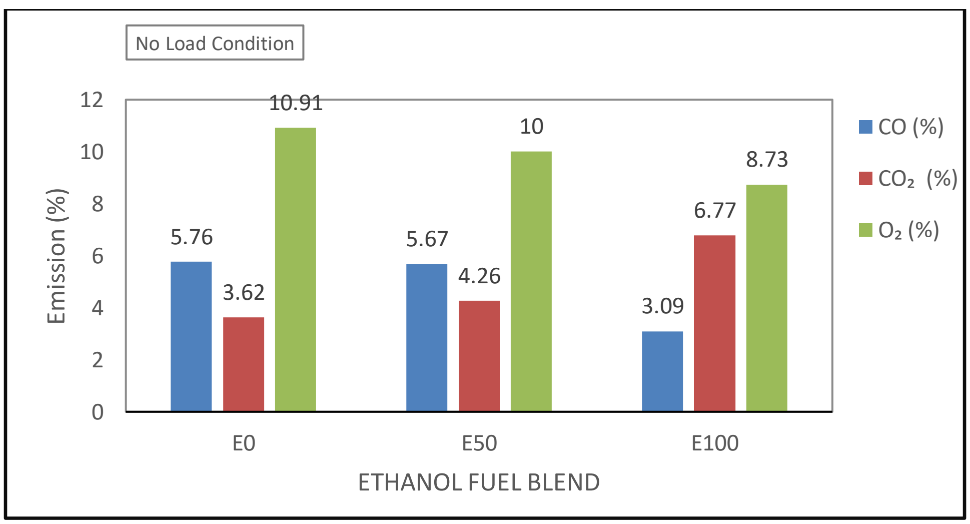

Figure 2 CO CO_2 O_2 Emission at No load for different ethanol fuel blend

From Figure 2 at no load condition, the E0 (Pure gasoline) has the highest emissions of CO which is 5.76%, and using E50 it was 5.67% with E100 emitting the least amount of CO which is 3.09%. For the CO_2 emissions the trend was as the blend increases the CO_2 emssions was equally increasing with the highest amount of 6.77% for E100, this highest amount recorded for E100 also implies that using E100 display an improved combustion and at the same time the CO_2 emitted was that absorbed by the plant

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during the course of its growth. Hence, it is environmentally neutral carbon fuel. But the least O_2 emitted was recorded for E100 under this no load condition, this is also an indication of improved combustion. The high CO recorded for E0 and E50 may likely be due to the rich nature of the mixture as recorded in the lambda value.

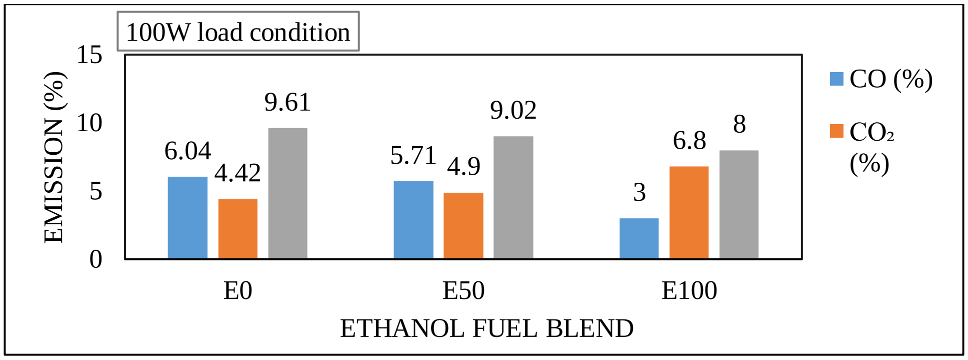

Figure 3 CO CO_2 O_2 Emission at 100W load for different ethanol fuel blend

In Figure 3, when the engine was loaded at 100W, the amount of CO emissions was similar in trend to the no load conditions but the lowest value of 3% in using E100 was recorded which was about half of what was obtained in E0 and E50. For the CO_2 the trend was also similar to the no load conditions but it was higher in all the blends and for E100 it was 6.8%. The O2 emission also display similar trend but decreases across all the blends. Under this load for all the blends the lambda value was less than 1.0 which implies rich mixture and this may likely be responsible for the high CO emission recorded across E0 and E50.

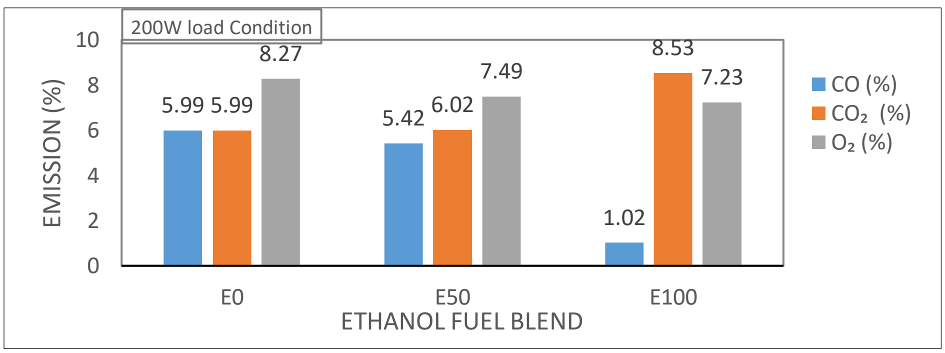

Figure 4 CO CO_2 O_2 Emission 200 no load for different ethanol fuel blend

For 200W load in Figure 4, in E0 the CO and CO_2 emission was same at 5.99%, but the emissions still show the same trend as in the earlier lower loads. The CO_2 was still highest in E100, which is 8.53% and this increase may be as a result of the increased in load and the corresponding increase in fuel admitted into the engine. But the CO emission was also lowest in using E100 which further indicates a better and improved combustion under this low load in using pure ethanol. Under this load the value of lambda for E100 was 1.0, for E0 and E50 the value of lambda was leaner and this was likely the key reason why CO emission was greater than in E100. Since NOx maximum value is usually recorded within the window of lambda 1.0. E100 also display the highest level of O_2 emission.

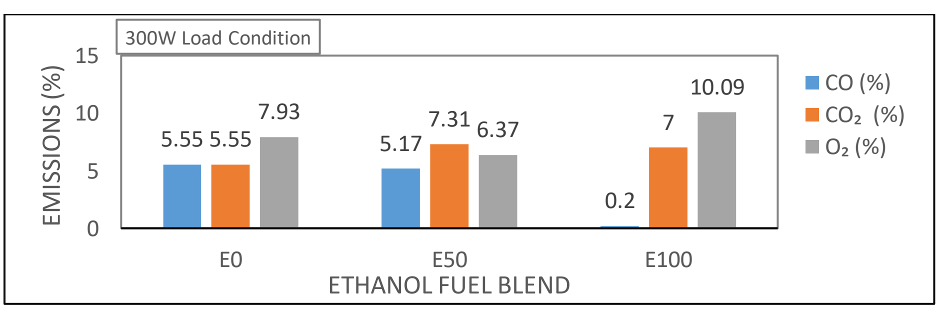

Figure 5 CO CO_2 O_2 Emission at 300W load for different ethanol fuel blend

In Figure 5 at 300W load, the CO emission was 5.55% which was highest for E0, and the lowest of 0.2% was recorded for E100. But for the CO_2 emission, the highest value of 7.31% was recorded for E50, and this value decreases to 7% in using E100. The O_2 emission value of 10.09% which was the highest was also obtained in using E100. In using E100 at this loading the value of lambda was 1.17. The reduction in CO_2 under this load compared to the previous load of 200W may be as a result of the cool charging effect of the oxygenation of ethanol and this was reflected in the high O_2 emissions and low value of CO emission, all these can be as a result of improved combustion in using E100. The high level of CO recorded for E0, and the higher CO for E50 was also due to the mixture as shown by the value of Lambda. The value of E0 was slightly richer than E50 (0.83), but E50 was rich (lambda 0.88), this may likely be the reason the NOx emission was highest in E50.

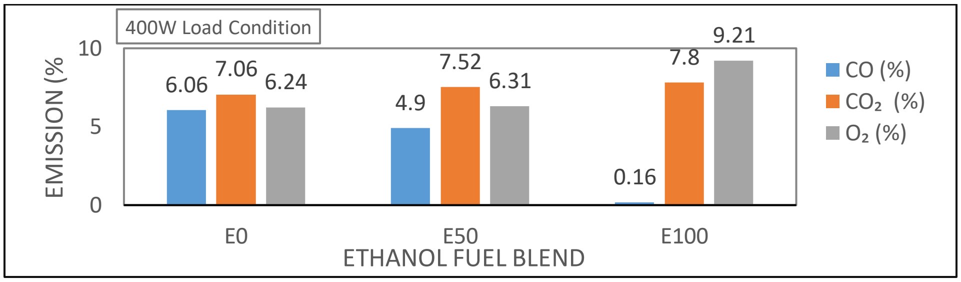

Figure 6 CO CO_2 O_2 Emission at 400W load for different ethanol fuel blend

At 400W engine load in Figure 6 in all the fuel blends the highest value of 6.06% for CO emission was obtained in E0, and for E100 it was 0.16%, which was far lower than in E50 and E0. But for the CO_2 emission, the highest value of 7.8% was obtained for E100. The higher values of CO obtained for E0 and E50 indicates that there was high level of incomplete combustion in those blends at this load range. The E100 display a better and improved combustion compared to E0 and E50.

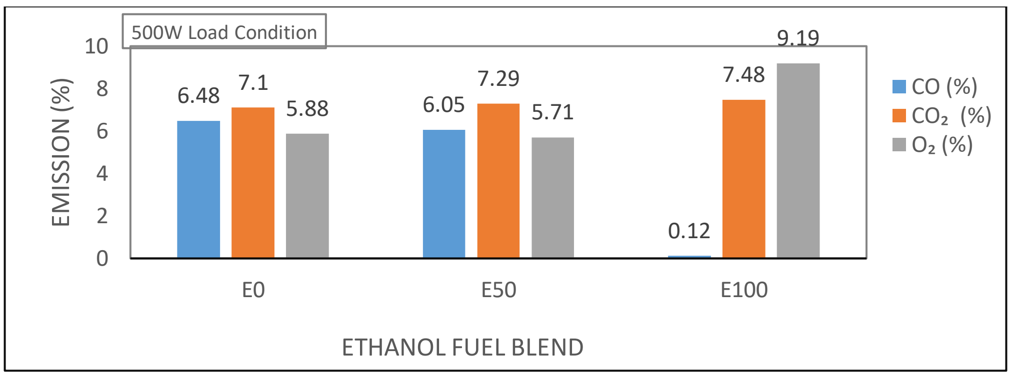

Figure 7 CO CO_2 O_2 Emission at 500W for different ethanol fuel blend

From Figure 7 at 500W load the emissions are similar to the load of 400W, but the CO was higher in E0 and E50 and lowest in E100 (0.12%). The CO_2 emission was similar to the load of 400W. But it was still obvious that under this load the E100 displayed a better and improved combustion and emission foot print. The high value of CO emissions under this loading can still be attributed to the rich nature of E0 and E50 from the value of lambda which was 0.81 for E0 and E50. In using E100 the value of lambda was 1.16 which is a lean mixture and the high level of CO_2 an indication of complete combustion.

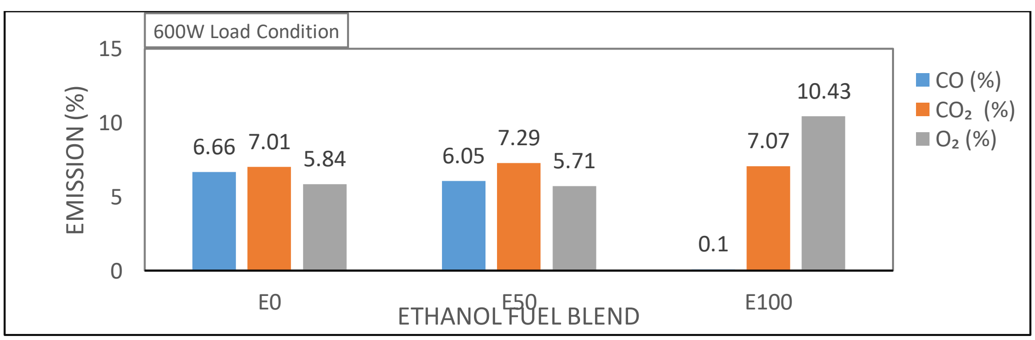

Figure 8 CO CO_2 O_2 Emission at 600W load for different ethanol fuel blend

In Figure 8 at 600W, the maximum loading of the engine, the E100 still display the best improve combustion as shown with the values of CO, CO_2, and O_2 emissions. It can be seen that E0 and E50 display similar trends with the high CO and CO_2 and low O_2 emissions. The mixture was still in rich condition for E0 and E50, but for E100 it was in lean condition and this further confirmed by the CO and CO_2 emissions.

Emissions of NOx and UHC

Nitrogen Oxides (NOx) result from the reaction between nitrogen in the air and oxygen. Theoretically, nitrogen is an inert gas. The NOx result from the reaction between nitrogen in the air and oxygen. Theoretically, nitrogen is an inert gas. But the high combustion temperatures and pressures in engines create favorable conditions for the formation of nitrogen oxides. Temperature is the key most important parameter in nitrogen oxide formation. The most commonly found nitrogen oxide is the nitric oxide (NO), although small amounts of nitric dioxide (NO_2) and traces of nitrous oxide (N_2O) are present. Once released in the atmosphere, NO reacts with oxygen to form NO_2. This is later decomposed by the sun's ultraviolet radiation back to NO and highly reactive oxygen atoms that attack the membranes of living cells. Nitrogen dioxide is partly responsible for smog; its brownish color makes smog visible. It also reacts with atmospheric water to form nitric acid (HNO_3), which dilutes in rain. This resulted in acid rain that is responsible for the destruction of forests in industrialized countries. Acid rain also contributes to the degradation of historical monuments made of marble. NOx reacts with hemoglobin in the blood stream forming methemoglobin, and this reduces the bloods capacity to carry oxygen. In addition, increased exposure to the emission of NOx can result in genetic disorders, breathing difficulty, tiredness, and the formation of fluid in the lungs as well as reduces fertility in females (NOx Text). The formation of NOx are greater when the mixture is slightly leaner. In addition, under complete or near complete combustion also enhances NOx emission due to increased combustion temperature. Unburnt Hydrocarbons (UHC) are a result of the incomplete or partial combustion and evaporation of hydrocarbon fuel, and it is also carcinogeic [22]. They are mainly formed as a result of the gas exchange or scavenging process in 2-stroke engine. This formation strongly depends on the type of lambda value. In rich mixture the fuel cannot get enough oxygen to sustain combustion hence an increase in UHC emission. The NOx reported here is the thermal NOx not the prompt type.

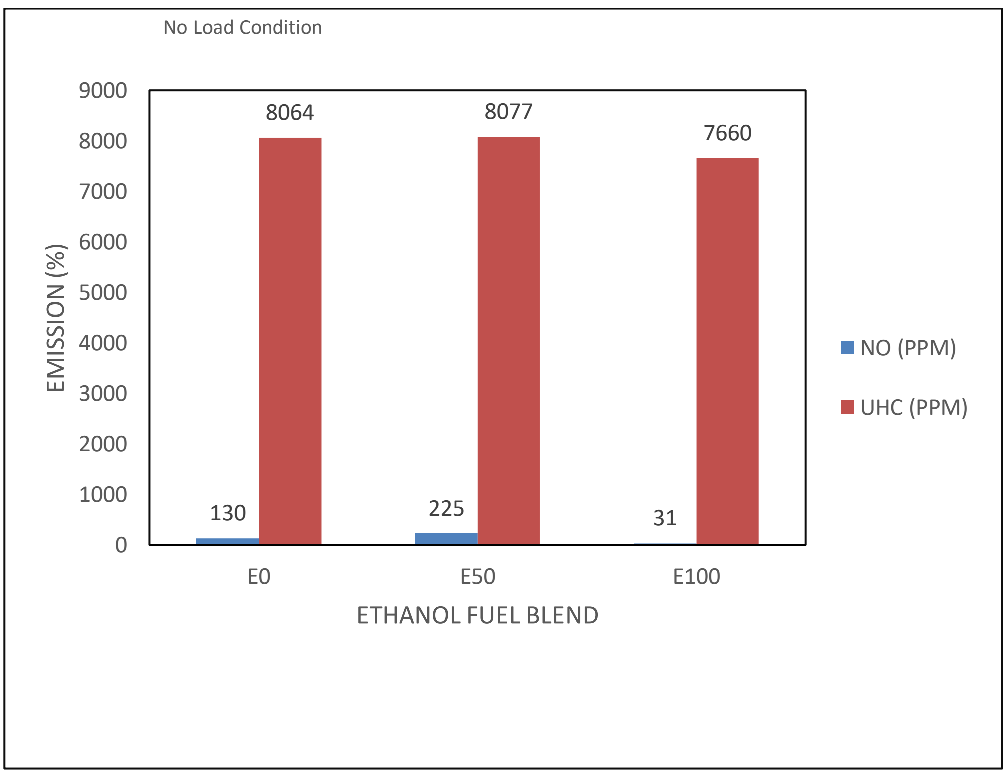

Figure 9 NO_x and UHC Emission at no load for different ethanol fuel blend

From Figure 9, at no load the E100 has the lowest NOx and UHC emission, and this was expected and in agreement with some literature as it does not contain fossil fuel and cool charging effect of ethanol contributes to the very low NOx emission and this is further confirmed by the obtained value of lambda. The reduced UHC was also as a result of the E100 containing no fossil fuel characterized by high level of carbon. Though all the mixtures of E0, E50 and E100 have lambda values of below 1.0..

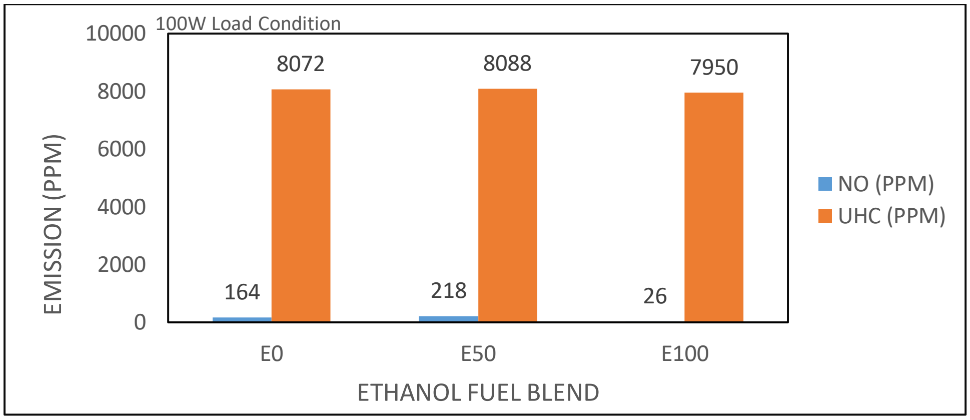

Figure 10 NO_x and UHC Emission at 100W load for different ethanol fuel blend

For 100W in Figure 10 the emission characteristics was similar to the no load condition, the NOx was observed to be lowest with E100. The charge cooling effect of pure ethanol and the value of lambda must have been responsible for this value of NOx. In E0 and E50 the value of lambda was less than 1.0 which is a rich mixture but for E100 it was 1.0 which is stoichiometric hence the low value of NOx obtained.

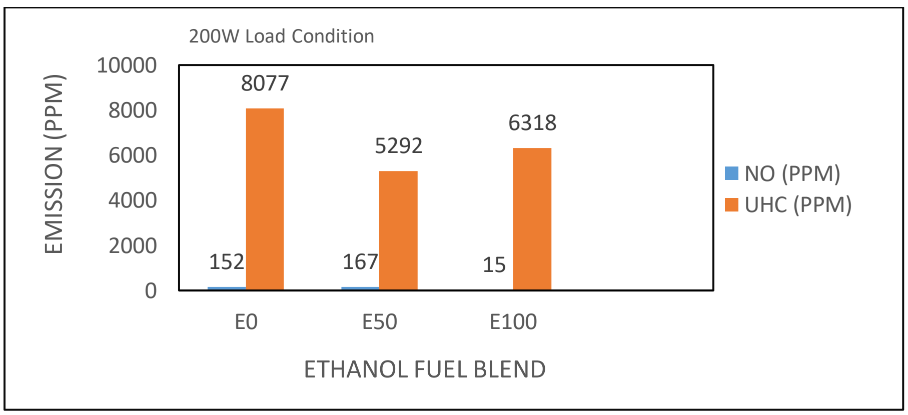

Figure 11 NO_x and UHC Emission at 200W load for different ethanol fuel blend

But as the load increases to 200W, it was observed that there was reduction in NOx for all the three fuel used with E100 still having the lowest NOx emissions. But the UHC emission was highest for E0 and lowest for E50, which may be due to increased fuel admitted into the engine, but the higher value of UHC in E100 compared to E50 may likely be due to reduced fuel evaporation due to the higher charge cooling effect of the E100 compared to the E50. For all the blends the value of lambda was less than 1.0, but E0 and E50 was rich mixture with lambda less than 1.0.

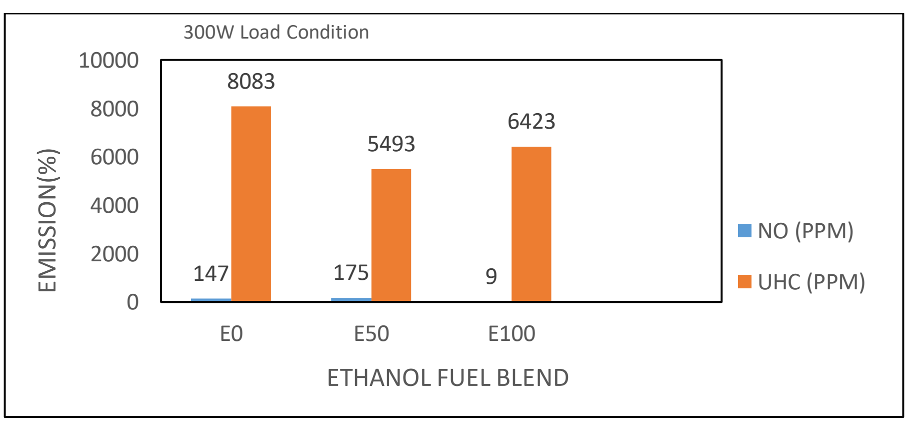

Figure 12 NO_x and UHC Emission at 300W load for different ethanol fuel blend

For Figure 12 at 300W load, the UHC emission was higher compared to the 200W load which may be due to increased fuel addition as the load increases. But the UHC emissions for E0 was highest for this fuel, and for E100 it was second highest, and the least was in E50. The E0 and E50 are all rich mixture which implies not enough oxygen to completely oxidized the fuel. But in E100 it was higher than E50 this may be due to cooling charge effect of the increased amount of E100 admitted into the cylinder. But the NOx recorded for E100 was still the lowest peaking at 9ppm.

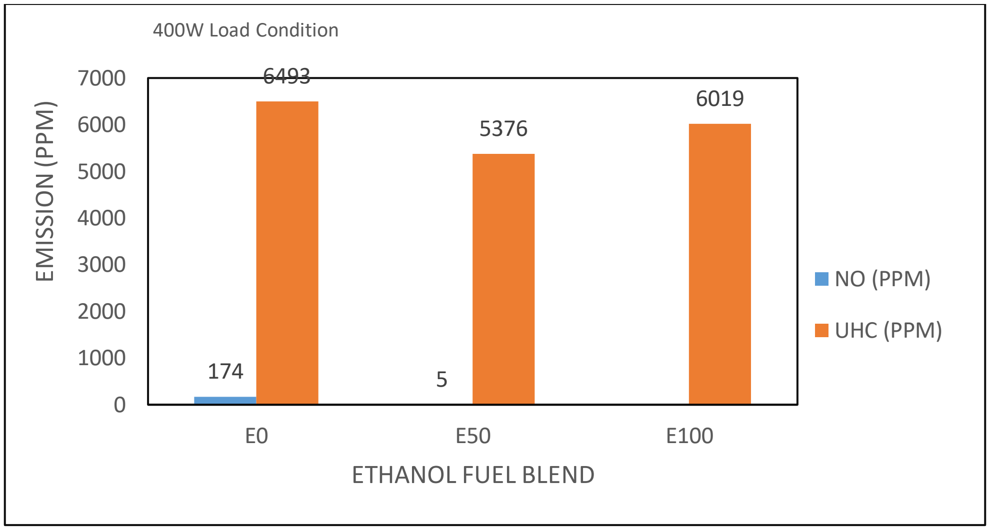

Figure 13 NO_x and UHC Emission at 400W load for different ethanol fuel blend

Increasing the load to 400W in Figure 13 the UHC and NOx emissions was highest for E0, but for the E50 NOx was 5ppm and the UHC was 5376ppm. For E100 no NOx was recorded but the UHC was 6019ppm. The low NOx for E50 and none recorded for E100 may likely be due to the fact that this is a small engine, with the increased load of 400W and the high blending of E50 and E100 may have resulted in reduced in-cylinder temperature that have lead to very low and no NOx formation.

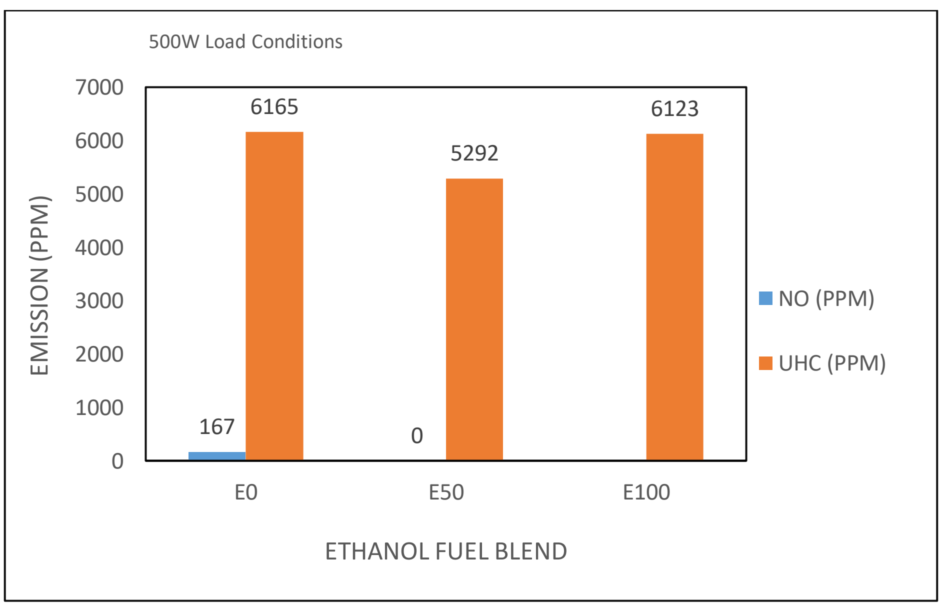

Figure 14 NO_x and UHC Emission at 500W load for different ethanol fuel blend

In Figure 14, at 500W load the UHC emission of 6165ppm was recorded for E0, 5292ppm for E50 and 6123ppm for E100. For the NOx emission the highest value of 167ppm was recorded for E0 and in using none was recorded. This zero NOx emission may have resulted from the charge cooling effect of ethanol and coupled with the fact that the calorific value of E50 and E100 is lower than E0, higher quantity of fuel must have been admitted for E0 and E100. This increased amount of fuel quantity in E50 and E100 must have lead to increased charge cooling effect which had caused zero NOx emissions.

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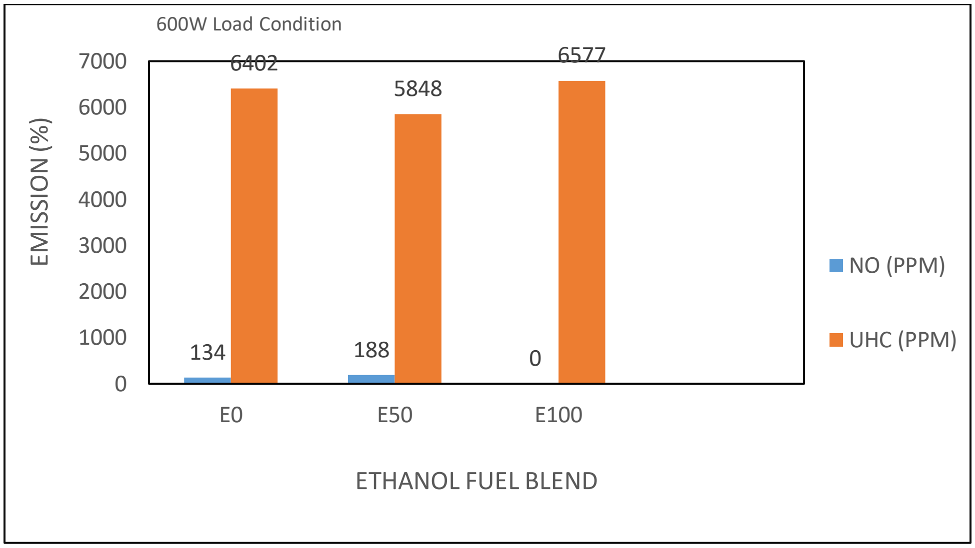

Figure 15 NO and UHC Emission at 600W load for different ethanol fuel blend

For the highest load of 600W in Figure 15, the E100 there was still no NOx recorded but the highest UHC was recorded for this fuel blend. It was observed that at this load the NOx measured was highest for E50. Most plausible result was the highest NOx recorded for E50, this may likely be due to the physiochemical properties of E50 and the high load. This behavior will better be understood through in-cylinder visualization using an optical engine.

Emission variation at different load condition for different ethanol fuel blend

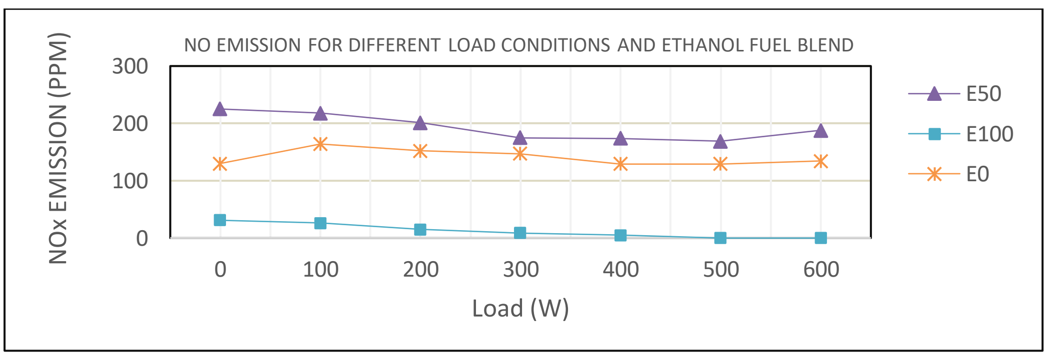

Figure 16 $\boldsymbol{NO_x}$ Emission for different load conditions and ethanol fuel blend

To better understand the behavior of the emissions with increasing loads for the various fuel blends we went further to plot the NOx emission against load for the fuel blend as shown in Figure 16. It was observed that as the load increases the NOx emission for E100 continuously decreases from 31ppm at no load to zero at 500W and 600W loads. The E50 display the highest NOx emission across the engine operational loads. This behavior may likely be due to the physiochemical nature of E50, in using this blend with the same combustion parameters may likely have resulted in maximum combustion temperature, which is the major factor for increased NOx formation. as it its completely different from E100 and E0. This result of NOx emission is interesting as NOx emissions in SI engines is expected to decrease with increasing load when speed decreases with decreasing load. However, in 2-stroke carburetor engine such as the engine used in this experiment, the scavenge air purges the exhaust gas. In the course of this process, some part of the unreacted fuel can also escape the exhaust. If this purging is not complete, then some exhaust gases will be retained inside the engine cylinder. This is known as internal exhaust gas recirculation (iEGR). This iEGR may likely have assist in lowering the in-cylinder temperature by absorbing the combustion energy, thereby lowering the NOx emissions. In addition, the fuel was mixed with the lubricant and this may have also contributed to the reduced temperature in the combustion chamber. In addition, the lower energy density of ethanol of E100 must have lead to massive decrease of NOx as the load increases. From the lambda value, we can also see from figure 20, that E0 and E50 display similar trend of lambda across all the load range, but E50 was nearer stoichiometric than E0, and E100 was leaner as load increases. The E50 must have attained complete combustion, and this would have raised the combustion temperature, as a result, the NOx emissions also increases. Hence, the low blend of ethanol

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will increase combustion temperature and hence NOx emission also increases, due to enhanced combustion, resulting in a higher incylinder temperature. A high ratio of E100 lower NOx because of reduced incylinder temperature. This is as a result of ethanol high latent of heat of evaporation, which reduces the incylinder temperature.

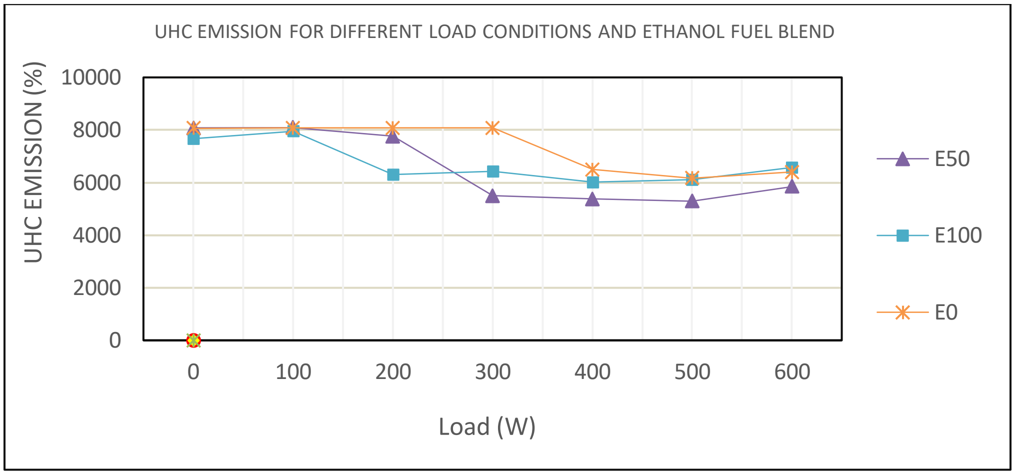

Figure 17 UHC Emission for different load conditions and ethanol fuel blend

Figure 17 shows the behavior of UHC emissions in all the fuel blends as the load increases from no load to the highest load of 600W. E0 display the highest emissions in all the engine operational loads, with E100 slightly higher at 600W. The lowest value was observed for E50 from 300W to 600W. The value of lambda in all loads for E0 and E50 was rich mixture, hence the highest value recorded for E0 may likely be due to the rich mixture.

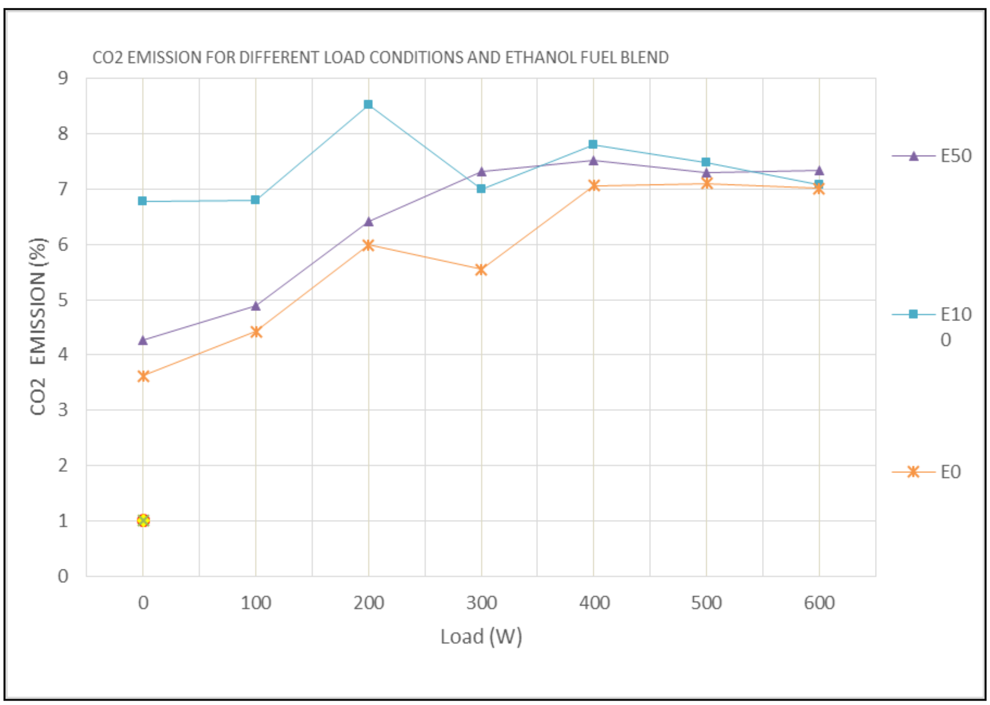

Figure 18 CO_2 Emission for different load conditions and ethanol fuel blend

In Figure 18 is the emission of CO_2 for all the fuel blends with increasing loads. The E100 display the highest emission of CO_2 at low and high loads, but it was slightly lower than that of E50 at 300W. The CO_2 was also observed to be increasing with increasing loads for all the blends. But E0 display the lowest CO_2 emissions across all the operational loads. Hence, in using E100 the combustion is more complete than using E50 and E0. Pure gasoline display the highest level of incomplete combustion which may also be due to the lubricant addition to the fuel.

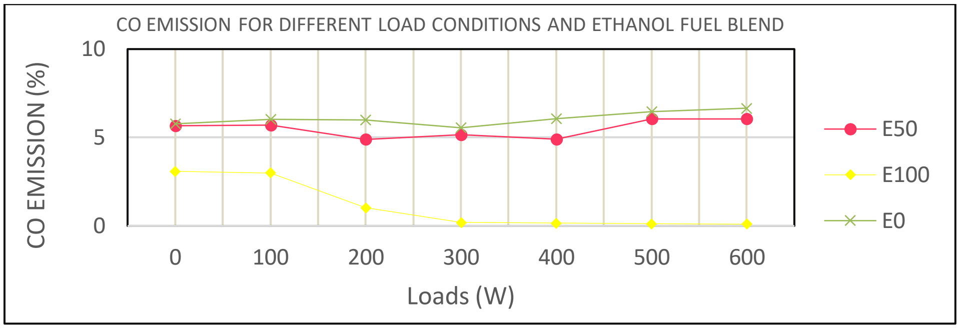

Figure 19 CO Emission for different load conditions and ethanol fuel blend

The CO emission for the blends is shown in Figure 19. The emission of CO was lowest in E100 for all the operational loads with maximum value of 3.09% recorded for the no load condition and 100W load and thereby continue to decrease to the lowest value of 0.15 at 600W. The value for E0 was similar to E50 but slightly higher for E10 compared to E50 at all operational loads.

Lambda variation at different load condition for different ethanol fuel blend

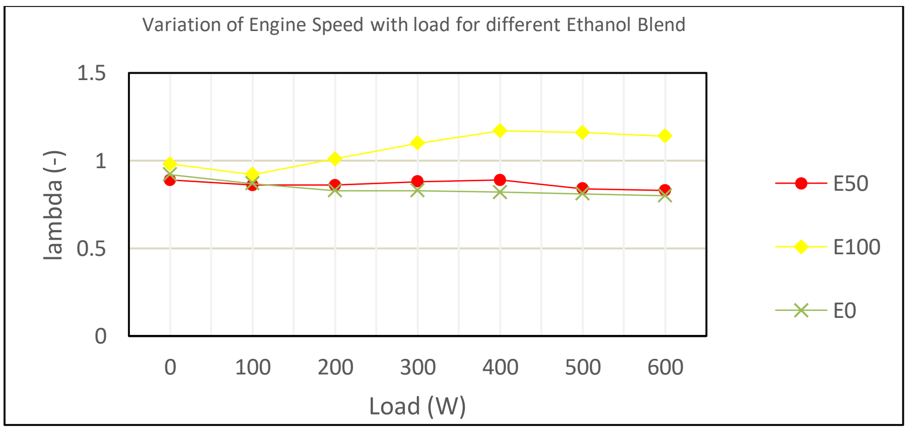

Figure 20 Variation of lambda with load for different ethanol blend

The values of lambda for all the blends across the loads in Figure 20, clearly shows that in all the operational above 200W for E100 blend lambda value was largely greater than 1.0, except in no load condition of 0W where it was 0.98, and in 100W it was 0.92. From 200W it was above 1.0 which implies leaner combustion. But for E0 and E50 the value of lambda was similar and varies between 0.89 at no load condition to 0.8 at 600W load. This means that during the entire engine operational load the mixture was rich which was responsible for the higher CO emissions recorded for both E0 and E50 and this was shown from the values of lambda in Figure 20.

III. Conclusion and Recommendations

In this research, the CO and NOx emissions were observed to decrease massively for the E100 as a result of the leaning effect caused by the pure ethanol fuel. The CO_2 emission was seen to be higher for the E100 and E50 compared to the E0 because of the improved combustion as a result of leaning effect characterized by the improved combustion in using ethanol fuel. Also there was increase in fuel consumption in using E50 and E100 compared to E0. The following recommendations could be considered for further research. Ethanol has the added advantage of been a relatively sustainable fuel source that can be made locally, the effect of long term usage on engine life was not considered, but there are numerous work currently existing which can be applied. More attention need to be put into sensitizing the citizens on the importance in terms of economic and environmental gains associated with alternative fuel such as ethanol. Lastly there is need for a well developed engine test bed for further investigation on how ethanol and liquefied petroleum gas (LPG) can be combined in total replacement of gasoline.

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