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Effects of Engine Speed on Gaseous Emissions of Gasoline and Ethanol Blends in a Production Engine

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ABSTRACT
The emissions 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 has lead to more stringent emission legislation and even a total ban on use of fossil fuel based internal combustion engine, and timeline set by some advanced countries. This investigation is being carried out to provide better understanding and identifying strategies for use of alternative fuel (ethanol) to reduce emissions. Thereby enabling better and more robust advise to the Nigerian government policy makers on use of alternative fuel either in a blend form or complete biofuel use. A Simulation using Ricardo Wave software was initially carried out on a single cylinder spark ignition (SI) engine model using pure gasoline (E0) for better understanding of the process. Then an experiment was carried out on a 4-cylinder production car engine that was popular in Nigerian transportation vehicle, the engine speed was varied using E0 and E15 blend. It was observed from the result obtained using blends of locally produced ethanol and gasoline led to an increase in NOx and CO_2 emissions but decreases the CO and UHC emissions.

Keywords: Gaseous emissions, internal combustion engines, Gasoline, Ethanol, Automotive, Emissions.

I. INTRODUCTION

The internal combustion engine has played a significant role in the course of human development as man has attempted to find means for long distances transportation, portable power generation, and the propulsion of heavy duty marine transportation. The internal combustion engine has been with us for more than 150 years it is an engine whose energy is released by burning or oxidizing the fuel inside the engine [1]. A lot of studies have shown that motor vehicles are the major contributors of local emission, and the major source of greenhouse gases such as carbon dioxide (CO_2), Nitrogen Oxides (NOx), unburnt hydrocarbon (UHC), and carbon monoxide (CO) which result from incomplete combustion of fuel used in engine. The emissions increased the risk of global warming and it also affects society locally in the form of acid rain, and health effect [2]. The limited availability of fossil fuel has necessitated the needs for an alternative and sustainable fuel. There has been a robust research on new generations of combustion engines by the automotive researchers and industries [3]. However, with the stringent emission legislations and the move away from fossil fuel towards electric and fuel cell powertrain, there is an urgent need for an alternative fuel that will be sustainable and readily available in the short term [4]

The key challenge with the internal combustion engine is the exhaust emission which increases day by day due to increasing number of transportation vehicles on the roads. With increasing demand and depletion in fossil fuels reserves there's increased concern for the security of the oil supply and the negative impact of fossil fuels on the environment, particularly greenhouse gas emissions. The CO_2 legislation due to global warming has mandated the development of more efficient IC engines [5]. All these have put pressure on society to find renewable fuel alternatives.

Renewable energy is one of the most efficient ways to achieve sustainable development. Increasing its share in the world matrix will help prolong the existence of fossil fuel reserves, address the threats posed by climate change, and enable better security of the energy supply on a global scale [6].

Engine emissions results from incomplete combustion of fuel used in engine, these can be UHC which are produced during combustion of fossil fuel as a result of incomplete combustion of the hydrocarbon that may results from many of the processes taking place inside the cylinder. The NOx are formed as a result of high temperature combustion in engines. The nitric oxide (NO) and nitrogen dioxide (NO_2) are grouped together as NOx emissions. Nitric oxides are responsible for acid rain and nitrous oxide and contribute directly to global warming. Nitrogen dioxide is toxic and is known to cause and aggravate human respiratory disease. The CO is produced as a result of rich fuel and air mixture preparation in the combustion chamber. The CO formed in combustion process is then oxidized to CO_2 at slower rate. CO is dangerous to human health in many ways mainly by causing respiratory condition and heart disease, and it also combines with the blood and hinders the body ability to absorb oxygen. The CO_2 is nontoxic, high emission of CO_2 is an evidence of good Combustion, but it has environmental effect as it enhances greenhouse effect. The CO_2 constitute 85% of emissions from motor vehicles.However the sources of the above pollutant vary and depend on the engine operating conditions and type of fuel used. There are many ways to realize efficient and less polluting or cleaner transportation, the most common renewable fuel today is ethanol produced from sugar or grain (starch), biodiesel produced from jatropha seed and sea weeds or algae. An alternative fuel like Ethanol has physicochemical properties similar to gasoline but has clean emission as compared to gasoline for same engine output power [7].

Using an alternative fuel such as ethanol and gasoline blends will result to a significant drop in greenhouse gas emissions as well as creating wealth for the locals involved in the production of the biofuel. The ethanol fuel has the potential to mitigate greenhouse gases as it has physicochemical properties similar to gasoline but improved emissions compared to gasoline for same engine output power. In addition, it extends the knocking limit of the engine due to its high octane number, and the high latent heat of vaporization lowers the combustion temperature. Ethanol has high octane number, high latent heat of vaporization than that of gasoline (which lowers the combustion temperature), high flame speed, higher oxygen content, low sulphur content, less calorific value which means high fuel air ratio required for complete combustion. Therefore it has positive influence on engine performance and reduces exhaust emissions according to [8]. But the specific fuel consumption increases because ethanol has less calorific value as compared to gasoline. Hence, more ethanol is required for usage to cover the same mileage or load compared to using pure gasoline.

Hsieh et al [9], experimentally investigated the engine performance and pollutant emission of a commercial SI engine using E0, E5, E10, E20, and E30. Their 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. But the CO and UHC emission decreases, which they attributed to the leaning effect caused by the ethanol addition. They also observed the CO_2 emission to have increased because of the improved combustion. In addition, they observed that NOx emission depends on the engine operating condition rather than the ethanol content.

Al-Hassan [10], investigated the effect of using gasoline-ethanol blends on a 4-stroke 4 cylinder Toyota Tercel-3A SI engine. The performance test and the emissions of CO, CO_2 using different percentages of fuel blend at 75% throttle opening position were analyzed. The engine speed was varied from 1000 to 4000 rpm. The results showed that blending unleaded gasoline with ethanol increases the brake power, torque, volumetric and brake thermal efficiencies, and the fuel consumption. The CO and HC emissions concentrations in the engine exhaust decrease, while the CO2 concentration increases. The use of E20 gave the best results for all measured parameters at all engine operational speeds used.

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. The obtained results showed 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], investigated the effects of E0, E50, and E85 on engine performance and pollutant emissions in a single cylinder 4-stroke SI engine using two compression ratios of 10:1 and 11:1. The engine speed was changed from 1500 to 5000 rpm at wide open throttle (WOT) position. The results of the engine test showed that ethanol addition to gasoline increase the engine torque, power and fuel consumption but reduced the CO, NOx, and HC emissions. It was also observed that ethanol-gasoline blends allow increasing compression ratio (CR) without knocking combustion occurrence.

Turner et al [13], investigated the effects of using different blending-ratios of bio-ethanol and gasoline with respect to spark and injection timing strategies on a direct injection spark ignition (DISI) 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.

Canakci et al [14], investigated the effect of ethanol-gasoline and methanol-gasoline blends of E5, E10, M5, and M10 using a vehicle having a 4-stroke, 4-cylinder, multi-point fuel injection (MPFI) system gasoline engine on a chassis dynamometer. The vehicle was operated at two different speeds of 80 km/h and 100 km/h, and four different wheel powers (5, 10, 15, and 20 kW). The experimental results revealed that CO, CO_2, UHC and NOx emissions decreased for all wheel powers at the speed of 80 km/h. However, when the vehicle speed was increased to 100 km/h, more complex trends occurred in the exhaust emissions for the fuel blends, especially for the wheel power of 15 kW this could be as a result of the various effect on the emission. In addition, the air-fuel equivalence ratio increased with the increase of ethanol and methanol percentages in fuel blends when compared to pure gasoline case.

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

Elfasakhany [16], investigated the effects of performance and exhaust emissions from an SI engine fueled with ethanol–methanol–gasoline blends. The ethanol–methanol blends (3–10 vol %) in gasoline was compared to ethanol–gasoline blends, methanol–gasoline blends and pure gasoline. The results showed that using ethanol–methanol–gasoline blends, the concentrations of CO and UHC emissions were significantly decreased, but the ethanol–gasoline blend displayed the highest brake power.

Costagliola et al [17], investigated the effect of bioethanol–gasoline blends on the exhaust emissions and engine combustion of a 4-stroke motorcycle fuelled with E5 and E30 on chassis-dynamometer tests based on Euro 3. They observed that a significant reduction in carbon monoxide and particle number was associated with the ethanol content of the fuel. But the volatile organic compounds (VOC), mainly alkanes and aromatics, are not substantially influenced by the ethanol content of the fuel.

Iodice Paolo and Adolfore Senatore [18], investigated the effect of ethanol and gasoline blends on CO and HC cold start emissions of 4-stroke SI engines using E10, E20, and E30 on a motorcycle engine. The motorcycle was operated on a chassis dynamometer for exhaust emission measurements without change to the engine design. Results of the experimental tests indicated that CO and HC in cold start emissions decreased compared to the use of pure gasoline, with the E20 ethanol blend achieving the highest emission reduction.

Phuangwongtrakul et al [19], investigated the effects of various ethanol-gasoline blends 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 one (lambda=1) and the ignition timing was tuned for maximum engine torque (MBT). The experimental results indicated that the appropriate ethanol-gasoline mixing ratio can enhance engine torque output, especially at low engine speed. The maximum brake thermal efficiency was obtained when the engine operates at 58-73% of WOT with an engine speed in the range of 2000-2500 rpm, using E40 and E50 fuels.

Akansu et al [20], investigated the engine performance and emission using gasoline, gasoline-ethanol, and gasoline-ethanol-hydrogen blends. The E20 blend display the worst engine performance and emissions. However, the engine performance and emission value was improved with the addition of hydrogen to the 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.

Juan E. Tibaquira et al [21], investigated the effect of using ethanol-gasoline blends on the mechanical, energy and environmental performance of in-use vehicles. This was to address the worries

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of the environmental authorities in large urban areas on the true effect of using E20 without any modification to the engine control unit (ECU), and on the variations of these effects over the years of operations. However, their main concern was the potential increase in the emissions of volatile organic compounds with high ozone formation potentials. In their work they tested a carbureted and fuel-injected engine using E20 and measured the power, torque, fuel consumptions, CO_2, CO, NOx, UHC and VOC that are considered key ozone precursors. Their obtained result does not show any significant differences in these variables in using E20 instead of pure gasoline. They also observed that in using E20 at high engine loads, the value of lambda was higher for E20 when compared to their operation with gasoline. In their conclusion, the use of E20 reduces the VOCs (acetaldehyde, formaldehyde, benzene, and 1,3-butadiene) as their results equally showed that ethane, formaldehyde, ethylene and ethanol are the most relevant VOC emitted. Hence, the use of E20 reduced 20-40% of those emissions. This translated to an average reduction of 17% in the ozone formation potentials.

Shamil Ahmed flamarz Al-Arkawazi [22], carried out an experimental investigation on the impact of fuel quality on the consumption, lambda, and emissions of gasoline engines. In his investigation he observed a direct impact of the fuel quality on the listed parameters including CO_2 emissions as well as the UHC. In addition, he emphasized that the result can assist in charting a pathway to reducing fuel consumption, the combustion quality and reducing emissions. This is similar in a way to blending gasoline with biofuel, as the blend will obviously change the fuel properties and the corresponding emissions, in particular the carbon footprint of the fuel.

Adewale Adewuyi [23], carried out an extensive study on the use of biofuel in Nigeria to meet the SDG 7 as a means of mitigating the current energy crises the country is facing as a consequences of our over dependent on foreign refined products. He emphasized on the use of waste materials and non-edible underutilized seed oil such as jatropha curcas so as to curb the controversies associated with using food materials as feedstock for biofuel production. In addition, he further stressed that more attention should be focused on Nigerian waste as the feedstock, because it has the potential of generating sufficient energy that will drive the economy and also serve as means of employment creation. However, he stressed the need to create more awareness on the importance of the biofuel and at the same time to create a suitable business model for local and international investors.

Nigeria renewable energy roadmap [24], had emphasized the Nigerian government desires to see to the use of bioethanol and biodiesel in transportation sector as a means of gradually disengaging from the over dependence on imported road vehicle as measure towards mitigating the environmental and global effects of the use of fossil fuel. It equally highlighted the need to shift from the current first generation production of bioethanol and biodiesel, and the challenge of producing enough of the biofuel for blending as this is a big challenge currently. In response to the above challenges this investigation is to experimentally study the emission from gasoline ethanol fuel blend in low percentages using mid-size multi-cylinder production engine that is popular in public and personal transportation across the six geopolitical regions of Nigeria. In addition, the ethanol used in this investigation was obtained locally.

1.1 EXPERIMENTAL SET UP AND TEST PROCEDURE

The experimental setup consists of 4-cylinder 4-stroke spark ignition 1.8 liter Mazda premacy MPFI production engine. The detail and specification of the engine is given in Table. A single-cylinder model of an engine was built using the Ricardo Wave software. Then the experimental test was carried out using pure gasoline (E0) and 15% ethanol-gasoline blend (E15), this percentage was chosen so as to meet the Nigerian Renewable Energy Roadmap for medium term plan for 2020 to 2030 plans [], to blend gasoline with 15% ethanol (E15) based on the projected demands and local ethanol production. This blend ratio does not really require engine modification and can be used with the present fleet of road vehicles and even domestic power generating engines. All experiments have been carried out at varying throttle opening to correspond with varying speed. This speed variation was chosen as it was difficult to measure the load. When switching to E15 fuel mode, the engine was operated for some time so as to exhaust all the residual fuel in the pipeline. This was to enable accurate and precise error free readings to be taken. The experiment was started under varying engine speed conditions, the speed was varied from 1000, 1500, 2000, 2500, 3000, 3500, and 4000rpm. The CO, CO_2, UHC, and NO_x emissions of the various fuel blends measured by the analyzer were recorded for further analysis and comparisons of the results.

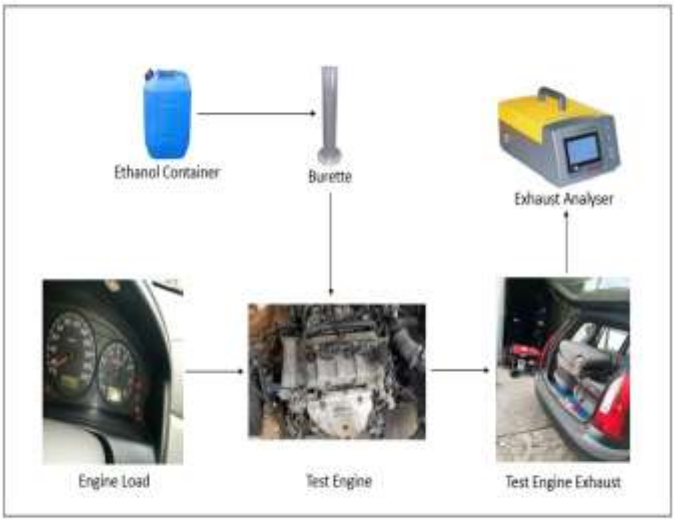

Figure 1 Experimental Set Up

Table 1 General specification of test engine and exhaust gas analyzer

Engine type	**Spark ignition engine 4-stroke**
Fuel type	**Gasoline (Petrol)**
Fuel system	**MPI (indirect injection)**
Valves per cylinder	**4**
Cylinders alignment	**Line 4**
Bore *Stroke	**83.0 * 85.0mm**
Compression ratio	**9.7**
Engine alignment	**Transverse**
Max torque	**152Nm @3500rpm**
Max power	**74kW @5500rpm**
Fuel tank capacity	**58L**
Number of valves	**16 valves**
Exhaust gas analyzer	**NH4-506EN Gas analyzer**

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**

II. RESULTS AND DISCUSSION

The Ricardo wave displays the result in the post processor for a single cylinder, 4-stroke, PFI SI engine for pure gasoline E0. The result of this simulation is to show the engine torque and power characteristics and relationship with the engine speed. The simulation was performed using Ricardo Wave and the built model was validated using experfimental the results obtained from state of the art advanced Ricardo single cylinder electrohydraulic camless engine [3] after building the model and test run it before the simulation runs. Figure 2(a and b) shows the variation of power and torque against engine speed, it was observed that as engine speed increases the indicated power increases continuously with increasing speed which was in agreement with expectations, theories and literature. The torque was seen to increase with speed up to 2000rpm and start to decrease which was in agreement with the literature.

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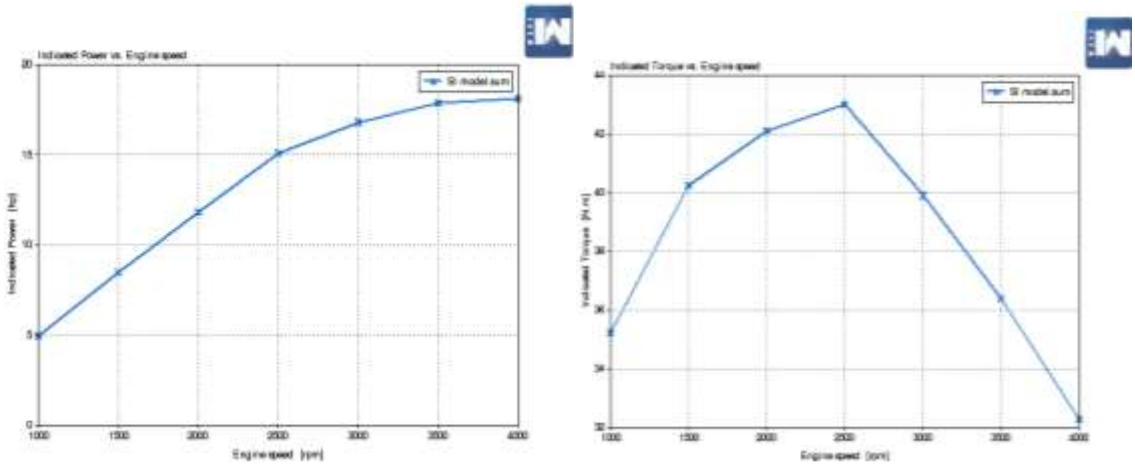
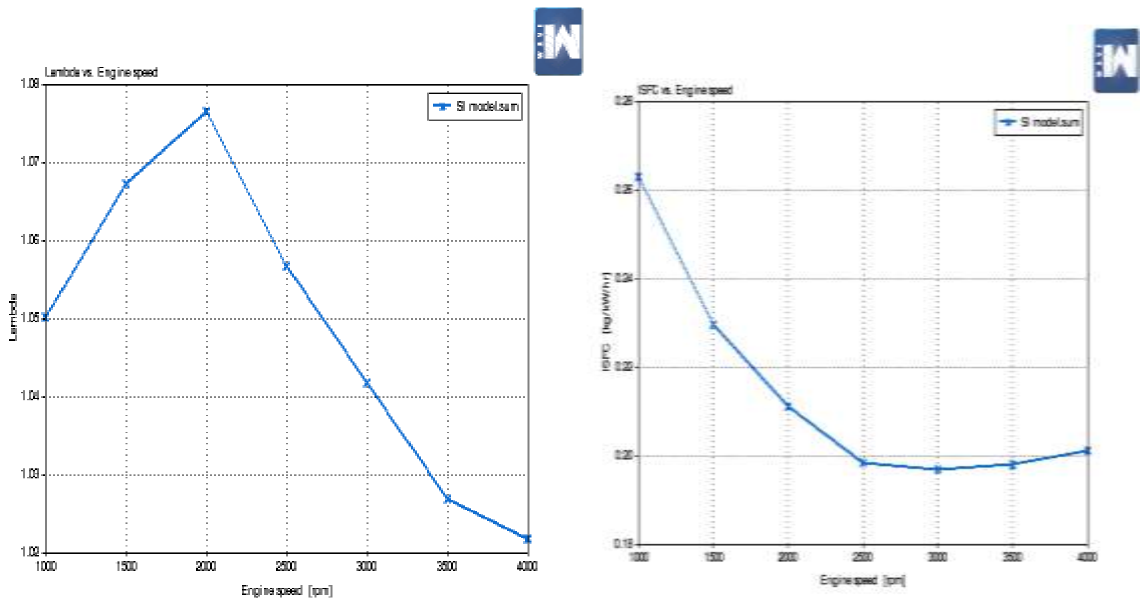


(a) (b)

Figure 2 Simulation plots of indicated power and Torque against speed

The variation of lambda against engine speed in Figure 3a using pure gasoline varies between 1.02 and 1.08 within the operational speed range on a gasoline engine, the lambda values increases up to the speed of 2000rpm then start to decrease as the speed further increases, The specific fuel consumption (SFC) decreases with the increasing speed, which is in agreement with the reviewed literature. The simulation is necessary as the vehicle used for this experiment was not calibrated to measure the torque, power and the SFC.



(a) (b)

Figure 3 Simulation plots of indicated power and Torque against speed

Experimental results on UHC and NOx Emissions

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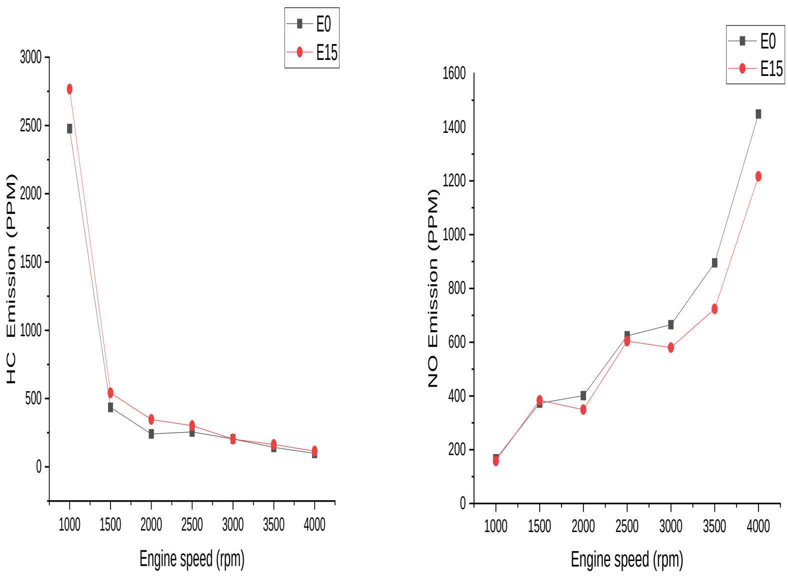

(a) (b)

Figure 4: HC and NOx Emissions against engine speed

From figure 4a, it was observed that the UHC emission at 1000rpm for E0 and E15 were 2477 PPM and 2766 PPM, respectively. The UHC concentration at E15 was increased by 289 PPM in comparison to gasoline. But the UHC concentration in the exhaust gas emission at 1500rpm for E0 and E15 were 435 PPM and 574 PPM, respectively, the UHC concentration for E15 blend was observed to have increased by 107 PPM in comparison to gasoline. At 2000rpm the measure UHC for E0 and E15 were 241PPM and 347PPM, with an increase in UHC concentration of 106PPM in using E15 compared to E0. For 2500rpm, the UHC concentration for E0 and E15 were 256PPM and 302 PPM. With an increase in the UHC concentration of E15 of 46 PPM compared to gasoline. From 3000-4000 the UHC emission for E0 and E15 were similar and display continual decrease.

Hence it can be concluded that UHC emission decreases for both E0 and E15 as the engine speed increases because for increasing speed the throttle is opened wider and more air is inducted and the mixture becomes fully stoichiometric (lambda = 1) indicating an improved combustion. In addition, the use of E15 provides more oxygen for the combustion process and leads to the so-called oxygenation. This indicates that the engine tends to operate in leaner conditions especially at lower speed when the engine was in idling mode the highest UHC was recorded as indicated by the value of lambda which may have resulted in increased UHC emission, this is in agreement with the SFC with maximum value at 1000rpm.

In figure 4b it was observed that the NOx emissions at 1000rpm for E0 and E15 were similar up to 1500rpm, and at 1000rpm and it was 166PPM for E0 and 158PPM for E15. The NOx concentration for E15 was 8 PPM lower in comparison to gasoline. While at 1500rpm, the NOx concentration in the exhaust gas for E0 and E15 were 373PPM and 384PPM. This increase in the NOx concentration in using E15 was increased by 11PPM in comparison to gasoline. However, from the speed of 1500rpm to 4000rpm the NOx emissions for E0 was higher compared to E15, but they display the same trend. The NOx concentration in the exhaust gas emission at 4000rpm for E0 and E15 were 1449 PPM and 1217 PPM. The NOx emission in using E15 was 232 PPM lower compared to E0.

The concentration decrease in NOx emissions as engine speed increases in E15 compared to E0 may be due to charge cooling effect of ethanol which may have reduced the incylinder maximum combustion temperature, the key enabler for NOx emissions.

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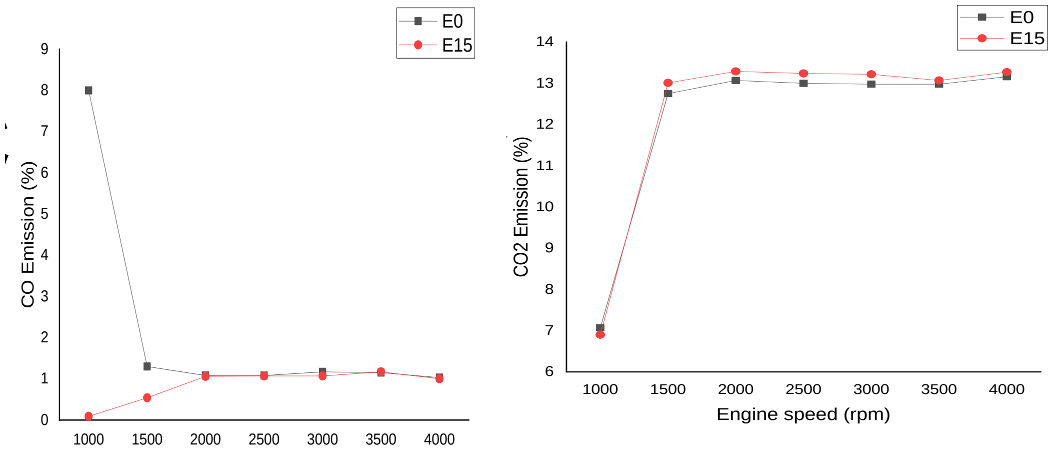
Experimental results on CO and CO_2 Concentration



(a) **(b)**

Figure 5: CO and CO_2 Emissions against engine speed

From Figure 5a, it was observed that the CO emission in the exhaust at 1000rpm for E0 and E15 were 8% and 0.09%. The CO emissions then decreased for E0 to about 1.3% at 1500rpm then maintain a constant value of about 1.0% from the speed of 2000 rpm to 3500rpm and decreases slightly by about 0.03%. But for E15, the value increases from 1000rpm to 2000 rpm and maintained this value of about 1.0% same as the E0 up to 3500rpm and thereafter decreases same as the E0. The carbon monoxide is as a result of rich mixtures reducing the available oxygen to participate in slow oxidation process of CO to CO_2 due to insufficient amount of air in the mixture preparation.

The emission of CO_2 is shown in figure 5b, it is observed that the CO_2 concentration in the exhaust gas at 1000rpm for E0 and E15 were 7.07% and 6.9%, respectively. This was an increment of 0.26% of CO_2 in using E15 compared to gasoline. At 1500rpm the CO_2 emissions for E0 and E15 were 12.15 % and 13.01%. This was an increment of 0.26% of CO_2 in using E15 compared to using E0. It continues in this pattern up to the speed of 4000rpm, showing E15 to emit more CO_2 compared to E0. The CO_2 is a greenhouse gas, and it is absorbed by plant during photosynthesis, hence the increase in CO_2 emissions in using E15 is actually the CO_2 absorbed by the plant from the atmosphere. Hence, the use of E15 is a positive effect to reducing CO_2 emissions from the ICE.

Effect of Speed on Lambda

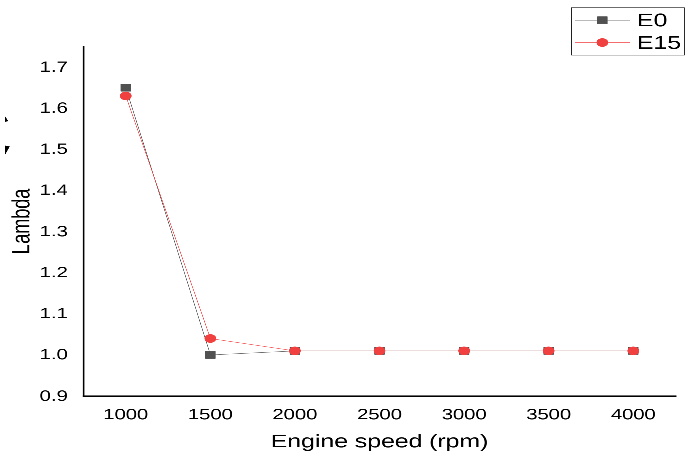


Figure 6: A graph of lambda verses Engine speed

From figure 6, it can be seen that as the engine speed increases the values of lambda reduces from ultra lean to stoichiometric at 2000rpm and this value was maintained for both the E0 and E15 blend, In addition, as lambda decreases from leaner mixture to stoichiometric, NOx increases with increasing speed for both E0 and E15.

III. CONCLUSION

An experimental and simulation analysis has been performed on a production engine in compliance with Nigeria government medium term plans of blending gasoline with 15% ethanol in transportation sector as a part of transition step towards decarbonization of the automotive sector and to generate employment and at the same time create wealth for the local farmers. The use of E15 was done without any modification to the engine fueling system and this implies that this can be applied to the current fleet of vehicle without any modification. On the emissions, the UHC is a product of incomplete combustion which is related to lambda. It can be concluded that that adding ethanol to the blends will reduces the UHC emission because of oxygen enhancement. However, there was no appreciable observed decrease in UHC when using E15 in all the operational speed. The only observable emission decrease was in NOx. The use of E15 blend displayed nearly the same emission characteristics with E0. In conclusion, for the Nigerian government biofuel plan not to fail there is an urgent need to sensitize the masses on the need for decarbonization of the transport sector as our contribution towards the SDG 7 and 13. Currently first generation ethanol production method should be discontinued with so as to avoid conflict with food production. There is vast land for cultivating dedicated crops for biofuel. Presently the jatropha curcas oil is being produced in large quantities in the North Western part of the country. Though, it is currently being used for soap production and other local uses, more research needs to be done on its use as a biofuel and biolubricant. By so doing more farmers can go into the cultivation as part of their farming activities. There is also the need for government incentives to those in agricultural sector on further research in how to increase the oil yield of dedicated crops to biofuel as well as incentives to farmers be it on small, medium or large scale biofuel plant cultivation. Lastly, the government needs to invest in advanced engine research facilities for a robust research in advanced powertrain and biofuel research.

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