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Influence of N-Butanol Additive on Fuel Property and Emission Behaviour of a 5.6kW Air-Cooled Single Cylinder Compression Ignition Engine

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ABSTRACT: The need to conserve petroleum crude reserve, boost energy security, reduce CO_2 gas emissions, limit global warming to 1.5^{o}C, and mitigate the climate change has become very imperative in line with the Paris agreement. This study is aimed at analyzing the emission levels of a single cylinder compression ignition engine fuelled with diesel and n-butanol blends in various volumetric proportions under constant speed and variable engine loading conditions. The concentrations of various tail pipe emissions , such as; CO_2, carbon monoxide (CO), unburnt hydrocarbons (HC), oxides of nitrogen (NO_X) were obtained and measured using SV-5Q automobile exhaust gas analyzer. The results revealed that increasing n-butanol proportion in the blends caused reduction in CO_2, CO, HC and NO_X emissions. Hence, the application of n-butanol in measured proportions as a diesel fuel extender or fuel additive, would go a long way to reduce of CO2 gases and other anthropogenic gases causing global warming.

KEYWORDS: Global warming, Diesel fuel, N-butanol additive, emissions, compression ignition engine

I. INTRODUCTION

Diesel engines are predominantly utilized by sectors such as; construction, agriculture, transportation, power and industry primarily for the purpose of power generation. Certain factors such as; higher efficiency, versatility, robustness and lower operating cost appear to influence the preference of diesel engines to their spark ignition counterparts [1]. The combustion of petroleum crude and its long carbon chain derivatives in internal combustion engines, releases large amount of carbon dioxide (CO_2) into the air. This greenhouse gas traps heat in our atmosphere, causing global warming. One of the global strategies of curbing challenges of harmful emissions and depletion of fossil fuels is replacement with renewable fuels [2], however the challenge is the issue of long term fuel availability and sustainability. Renewable oxygenated compounds such as, alcohols are viable alternatives in this regard. This is because their combustion is cleaner than that of fossil fuels [3, 4]. Lower alcohols (methanol and ethanol) and higher alcohol (butanol) have been utilized as partial replacement for diesel in diesel engines. Modern production methods has certified butanol inexpensive and eco-friendly option [5]. Besides, some of the advantages which Butanol has over other lower alcohols include; higher cetane number, higher heating value, better miscibility with diesel, and lower heat of vaporization [6].

Butanol or n-butyl alcohol or normal butanol is a primary alcohol surround with four carbon structure and the chemical formula C_4H_9OH that have four structural isomers. N-butanol is a strong competitor as fuel additive for diesel engine, the use of which has rarely been investigated in diesel engines. Unlike shorter chain alcohols, butanol has the potential to perform well as a gasoline surrogate, and has a moderate cetane number, which allows for the incorporation of significant amounts of butanol in diesel fuel. Butanol is of more particular interest as a renewable biofuel, as its properties are much more similar to diesel fuel than are those of ethanol [7].

Butanol is a partly clean burning fuel because it produces black smoke lesser than gasoline but higher than ethanol [8]. The production of butanol from agricultural feedstock and its consumption as a precursor for a diverse set of fuel products may decrease petroleum usage globally. Several literatures have studied the emission characteristics of diesel and n-butanol blends for transportation purpose. The objective of this paper is therefore to analyze the influence of N- butanol fuel additive on the emission behaviour of a compression ignition engines.

II. MATERIALS AND METHODS

Materials

The diesel fuel sample used for this research was purchased at AYM Shaffa- a Nigerian government approved fuel station in Bauchi-Nigeria, while analytical grade n-butanol was purchased from a laboratory equipment supplier.

Preparation of Fuel Samples

Different composition of diesel and n-butanol were mixed and homogenized. The blends were prepared at the ambient temperature of 36^0C, and stirred for an hour to obtain a homogeneous consistency, with a mechanical magnetic stirrer. Each sample was prepared on a volumetric basis of 500ml and marked as B100, D100, D95, D90, D85, D80 and D75.The volumetric proportion of the fuel blends are presented in table 1.

Table 1: Volumetric proportion of N-butanol -Diesel Blends

S/N	**Samples**	**Fuel Constituents (%)**	
		N-butanol	**Diesel**
1	D100	0	100
2	D95	5	95
3	D90	90	10
4	D85	85	15
5	D80	80	20
6	D75	75	25

ASTM Standard methods were used to conduct the tests, and the fuel properties for the 6 fuel samples under study are presented in table 2.

Table 2: ASTM D975 test specifications for fuel samples

Fuel Property	**ASTM Specifications**
Density at 40^oC (kg/m^3)	ASTM D4052
Specific gravity	ASTM D4052
Kinematic viscosity at 40^0C (mm^2/s)	ASTM D445
Flash Point (^{o}C)	ASTM D93
Cloud Point (^{o}C)	ASTM D2500
Derived Cetane Number	ASTM D613
Calorific Value (kJ/Kg)	ASTM D975

III. EXPERIMENTATION

The Set up for the experiment consists of a water cooled eddy current dynamometer coupled to Tec-Quipment TD110-115 horizontal single cylinder, 4-stroke air-cooled, and 5.6KW engine. Refer to figure 1 and table 4 for the block diagram of the test rig and engine specifications. The engine was coupled to a manometer and eddy current dynamometer with rated power of 5.6Kw at 3600 rpm. The engine was operated at a constant speed of 1500 rpm with variable loads of 500g, 1000g, 1500g, 2000g, 2500g and 3000g. Concentration of emissions of carbon dioxide (CO_2), carbon monoxide (CO), unburnt hydrocarbons (HC), oxides of nitrogen (NO_X) were measured using SV-5Q automobile exhaust gas analyzer by fixing the probe tip of the exhaust gas analyser to the exhaust tail pipe of the engine test bed. The same test procedure was employed for each set of the blends.

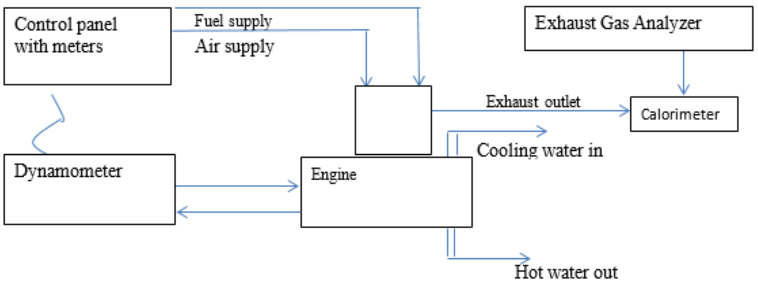

Figure 1. A block diagram of TD 110-115 engine test bed

Table 3: Test Engine Technical Specifications

Parameters	Specifications
Model	TD110-115
Number of cylinders	1
Method of starting	Manual starting
Engine type	Single cylinder, 4-stroke diesel
Bore	79.5× 95.5 mm
Piston stroke	115mm
Displacement	1896mm
Rated speed	3600 rpm
Maximum output	5.6kW
Compression ratio	12:1 to 17.5:1
Maximum MEP	1400kPa
Cooling method	Air cooled
Fuel and Lube oil	filter Present
Injection pump	Bosh VE VP 37

IV. RESULTS AND DISCUSSIONS

Fuel Properties

The results of the physico-chemical properties of the various fuel samples presented in table 4, are briefly discussed as follows:

Diesel fuel sample demonstrated a comparatively higher fuel density and relative density at room temperature, with a value of 0.8367. While the fuel samples D95, D90, D85, D80, and D75 exhibited relative density values of 0.83379,0.83278, 0.83103, 0.82962 and 0.82870 respectively, and B100 fuel sample showed the lowest relative density value of 0.813. It could be seen that the density of the fuel samples decreases as the proportion of N-butanol additive in the fuel mixture increases.

In terms of kinematic viscosity, Diesel fuel samples demonstrated the highest viscosity (2.98 mm^2/s), while N- butanol blended fuel samples D95, D90, D85, D80, and D75 exhibited relative lower viscosities with values of 2.895 mm^2/s, 2.817 mm^2/s, 2.798 mm^2/s, 2.776 mm^2/s, and 2.762 mm^2/s respectively, and B100 fuel sample exhibited the lowest viscosity value of 2.22 mm^2/s. The lower the fuel viscosity the more efficient the fuel injection and atomization, and combustion behavior of the fuel samples.

From the results presented in table 4, Diesel fuel samples could be seen to demonstrate the highest flash point (54 ^{o}C), while the blended fuel samples; B100, D95, D90, D85, D80, and D75 progressively drops from 37^{o}C, 34^{o}C, 32^{o}C, 31^{o}C,31^{o}C, to 30^{o}C accordingly. Even though Diesel fuel tend to be more flammable with a higher flash point as presented in table 4, it could nonetheless be safely handled.

The pour point of oils analyzed revealed that diesel fuel samples exhibited the highest pour point (-24 ^oC), while n-butanol blended fuel samples D95, D90, D85, D80, and D75 exhibited relative lower pour points with values of -34 ^oC, -35 ^oC, -36 ^oC, -37 ^oC, and -37 ^oCrespectively, and the pour point of B100 fuel sample was hardly measurable. It is important to note that low temperature behaviour is required for engine at cold start and low load conditions [9].

The cetane number results showed that Diesel fuel samples exhibited the highest cetane number (56.9), while n-butanol blended fuel samples D95, D90, D85, D80, and D75 exhibited relative lower cetane numbers with values of 52.7, 49.9, 49.1, 44.1, and 41.9respectively, and the cetane number of B100 fuel sample was observed as the least (i.e. 17.6).Cetane number (CN) is one of the most important parameters affecting diesel fuel behaviour. It is related to the time that elapses between fuel injection and beginning of combustion [10, 11] It generally depends on fuel composition and can influence engine stability, noise level and exhaust emissions [12, 13]. A fuel with high CN depicts short ignition delay, which causes the combustion to begin shortly after being injected into the combustion chamber, thereby increasing its efficiency [13].

The calorific (heating) value of the fuel samples under consideration showed that diesel fuel samples exhibited the highest heating value of 45530.6kJ, while n-butanol blended fuel samples D95, D90, D85, D80, and D75 exhibited relative lower heating values of 44728.4 kJ, 44728.4 kJ, 44126.9 kJ, 43532.0 kJ, 43321.5 kJ, and 42579.7 kJrespectively, and the heating value of B100 fuel sample was observed as the least (37025 kJ).

Table 4: Fuel properties of N-butanol and Diesel fuel blends

Fuel Property	D100	B100	D95	D90	D85	D80	D75
Density at 40^{0}C (kg/m^3)	835.6	813	833.79	832.78	831.03	829.62	828.70
Specific gravity	0.8367	0.813	0.83379	0.83278	0.83103	0.82962	0.82870
Kinematic viscosity at 40^{0}C (mm^2/s)	2.980	2.22	2.895	2.817	2.798	2.776	2.762
Flash Point (^{o}C)	54	37	34	32	31	31	30
Cloud Point (^{o}C)	-24	-	-34	-35	-36	-37	-37
Derived Cetane Number	56.70	17.6	52.70	49.90	47.10	44.10	41.90
Calorific value (KJ/Kg)	45530.6	37025	44728.4	44126.9	43532.0	43321.5	42579.7

Exhaust Emission Behaviour

Carbon dioxide (CO_2) emission behaviour

The variation of CO_2 emissions level for diesel and its blends with n-butanol at different loads is presented in Figure 2. It could be observed that CO_2 emissions for all blends were lower as compared to the diesel fuel samples under different engine loading conditions. However, CO_2 emissions levels increased with load increase for all tested fuel samples. Diesel fuel displayed higher CO_2 emission levels than the fuel blends in the category. While, D95 blended fuel sample exhibited minimum CO_2 emission within 14.2% - 20.8% lower that of diesel fuel sample under consideration at 500g (minimum) and 3000g (maximum) engine loads. Nonetheless, the maximum CO_2 emission was observed in D90 blended fuel sample dropped within the range of 18.6%-34.4% lower than diesel fuel at minimum and maximum engine loads.The rising trend of CO_2 emissions with increased loading conditions results in higher fuel consumption. This in turn could be attributed to the fact that n-butanol has a lower carbon chain length and lower elemental carbon to hydrogen ratio than diesel fuel [14]. Even though, a slight increase of CO_2 emissions for D85, D80 and D75 fuel samples were also observed in the course of the test, this however, could be explained in terms of proper combustion of fuel [15]. In other words, the oxygenated nature of n-butanol a encourages the engine to operate under lean mixture conditions thereby converting more CO to CO_2 gases [16], as graphically presented in figure 2 for varying engine loads.

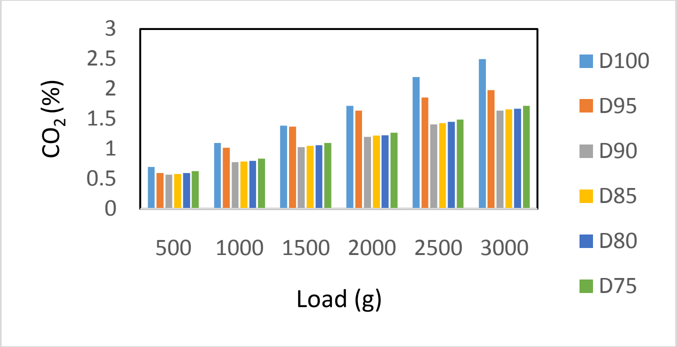

Figure 2: Variation of CO_2 emissions under varying engine load

Carbon monoxide (CO) emission behaviour

CO is formed mainly due to incomplete combustion of fuel [17]. CO is converted to CO_2 during a complete combustion. Incomplete combustion could be due to shortage of air or low gas temperature; thereby leading to the formation of CO. The variation of CO emission levels s for diesel and blends with n-butanol under consideration at different engine loads are illustrated in the plot figure 3. It could be seen from the plot that the engine emits more CO for diesel under all engine loading conditions when compared with the emission arising from the combustion of blended fuel samples. Secondly, the exhibited CO emission behaviour also dropped with increase in engine load for all tested fuel samples, even though a noticeable increase was observed at maximum engine load. Minimum reduction in CO emission was recorded for D95 blended fuel samples within a range of 8.3%- 9.5% lower than diesel fuel benchmark under all engine loads. Nonetheless, the maximum CO emission reduction of 54.1% - 76.2% lower than the diesel fuel benchmark was recorded for D75 blended fuel sample at minimum and maximum engine loads. However, as the proportion of n-butanol in the blend increases, the percentage of CO emission levels decreases owing to higher oxygen content and lower carbon to hydrogen ratio in n-butanol compared to diesel [18].These lower CO emissions of n-butanol blends could be attributed to the presence of oxygen in the blends allowing for partial reduction of the CO gas emissions through the formation of CO_2 thereby enhancing fuel oxidation than in diesel fuel sample during combustion [19].

From Figure 3, it was also observed that the CO initially decreased at 2500g load and increased at the higher load of 3000 g. This trend was observed for both diesel fuel and the blended fuel samples. Initially, at low load condition, cylinder temperature might be too low, which increases with loading due to more fuel injected inside the cylinder. Also, at high load condition, more fuel is consumed and relatively lowering the level of oxygen required for fuel combustion resulting in slightly higher carbon monoxide emission levels. The interpretation of the results obtained is indicative of rising n-butanol content in the fuel blends, and this consequently reduces the levels of CO emissions.

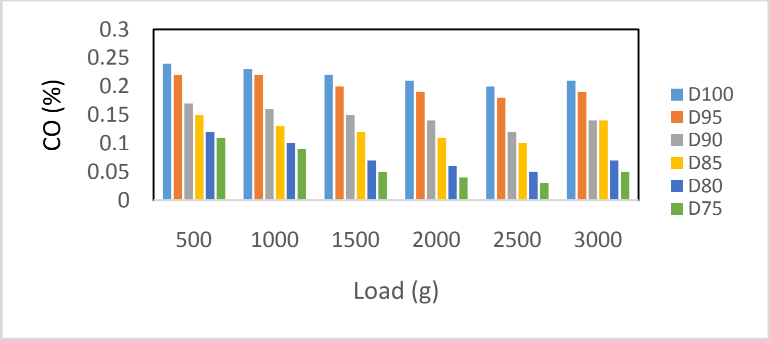

Figure 3: Variation of CO emissions under varying engine loads

Unburnt hydrocarbon (HC) emission behviour

Hydrocarbon (HC) emission in exhaust are a result of incomplete burning of the carbon compounds in the fuel. Figure 4 presents HC emissions variation for diesel fuel and blended fuel samples with n-butanol under varying engine loads.

HC emission reduces with increase in engine loads for all tested fuel samples. Diesel fuel samples exhibited a correspondingly higher HC emission levels than all tested blended fuel samples. The minimum reduction in HC emission was noticeable for the D95 blended fuel sample at a range of 2% - 1.6% lower than diesel at minimum and maximum engine loads. In addition, the D75 blended fuel sample demonstrated maximum HC emission reduction within the range of 10.8% - 5.4% lower than diesel fuel sample at minimum and maximum engine loads. All blended fuel samples exhibited lower HC emission levels than diesel fuel benchmark. This trend is could be credited to the higher fuel oxygenation and the richer combustible mixture of n-butanol, thus improving the combustion properties of the blended fuel samples [20, 21] From the foregoing, it is apparent that increasing n-butanol content oxygenates the fuel mixtures and consequently lowers HC emissions [22].

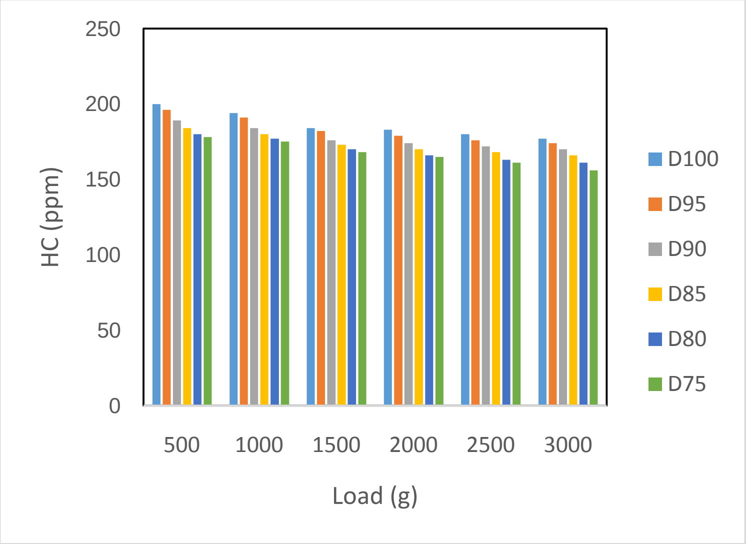

Figure 4: Variation of HC emissions under varying engine load

Nitrogen oxide (NO_x) emission behaviour

Figure 5 shows NO_x emissions variation for diesel fuel and its n-butanol blended fuel samples under varying engine loads. NO_x emission increased with increase in load for all samples. Diesel fuel exhibited higher level of NO_x emission than other blended fuel samples understudy. Minimum NO_x reduction was noticed in D95 blended fuel samples, and are within the range of 3.1% -1.2% lower than that of diesel fuel at minimum and maximum engine loads. While, D75 blended fuel sample showed maximum NO_x reduction within the range of 10.8% - 5.4% lower than that of diesel fuel samples at minimum and maximum engine loads. The combustion behavior of the blended fuel samples exhibited lowerNO_x emissions than diesel fuel, and by increasing n-butanol content in the blends brings about reduction in NO_x emission. This behaviorcould be attributed to the combined effects of; lower exhaust gas temperatures, and higher latent heat of vaporization of n-butanol that in turn causes evaporative cooling of the blended fuel samples in the engine cylinder. Thus, agreeing with explanation provided in existing literature within the context of the fact that the alcohol in fuel samples tends to lower flame temperature, and consequently lowers the level of the hitherto dominant thermal NO_x formation at higher engine temperature[1, 20, 23]. It was noticed too from the preceeding tests that NO_x emission levels increases under varying engine loads for all tested fuel samples. At higher loads, due to increased quantity of fuel injection, and the consequent rise in combustion temperature and oxygen availability, more NO_x emission levels are likely to occur at higher engine loads [24].

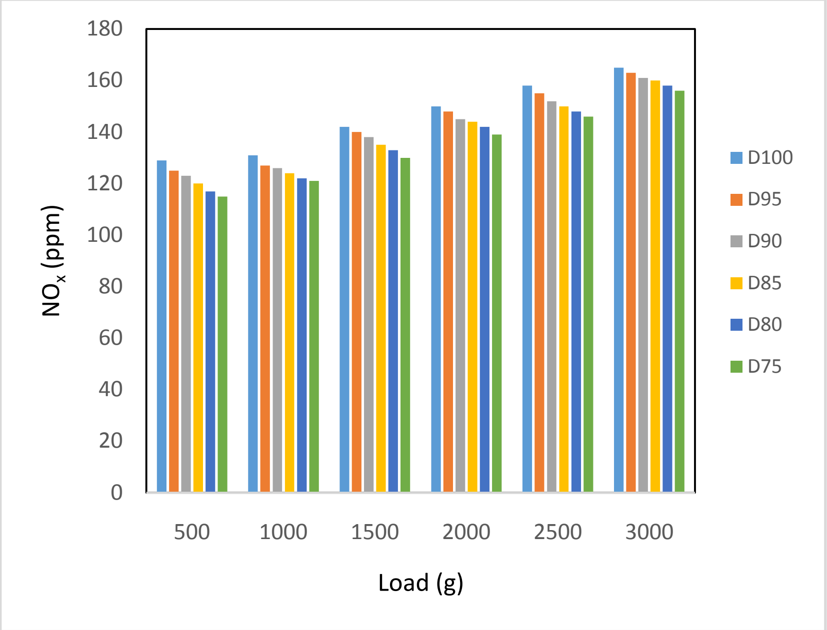

Figure 5: Variation of NOx emissions under varying engine load

V. CONCLUSION

In this study, the emission of diesel fuel, and fuel samples blended with n-butanol were studied at constant speed and variable load conditions. The following could be concluded from the research:

i. Diesel fuel sample demonstrated a comparatively higher fuel density and relative density at room temperature, viscosity, flash point, cloud point, cetane number, calorific value than the D95, D90, D85, D80, and D75 blended fuel samples.

ii. CO_2 emission levels increases with load increase. Increasing n-butanol in the blended samples lowers CO_2 emission due to the lean mixture condition in the engine. The maximum CO_2 emission was observed in D90 blended fuel sample dropped within the range of 18.6%-34.4% lower than diesel fuel at minimum and maximum engine loads.

iii.Higher emission levels of CO was noticed for diesel fuel than other blended samples. Raising the n-butanol content lowers CO emission levels. Maximum CO emission reduction of 54.1% - 76.2% lower than the diesel fuel benchmark was recorded for D75 blended fuel sample at minimum and maximum engine loads

iv.HC emission levels is lowered for all tested fuel samples as the load increases. By increasing n-butanol in the blends causes HC emission levels to fall. In addition, the D75 blended fuel sample demonstrated maximum HC emission reduction within the range of 10.8% - 5.4% lower than diesel fuel sample at minimum and maximum engine loads.

v.NOx emission levels increases for all tested fuel samples with increase in engine load. Hence, increasing n-butanol proportion in the fuel blends caused NOx emission levels to decrease due to the combined effects of lower exhaust gas temperatures, and higher latent heat of vaporization of n-butanol. While, D75 blended fuel sample showed maximum NO_x reduction within the range of 10.8% - 5.4% lower than that of diesel fuel samples at minimum and maximum engine loads.

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