Short Research Article

Influence of N-Butanol-Diesel Fuel Blends on the Performance Characteristics of a FourStroke, Compression Ignition Engine.

ABSTRACT

Aims: This study investigates the impact of blending n-butanol with diesel fuel on the performance of a single-cylinder, 4-stroke diesel engine under varying engine loads.

Study design: The performance assessment followed SAE J1349 on a Tec-Quipment TD110-115 4-stroke engine at 1500 rpm with varying loads and fuel samples.

Place and Duration of Study: The study was conducted for a period of 22 months the at Automotive Engineering Technology Workshop, Federal Polytechnic, Bauchi Nigeria

Methodology: The SAE J1349 test protocol was followed, using diesel fuel (D95) and different blended fuel samples (D90, D85, D80, D75, and D70). While diesel fuel generated higher brake power due to its higher calorific value, the D95 blend demonstrated comparable performance to diesel fuel across all parameters.

Results: The brake power of the D95 blend initially decreased by 69.7% and then increased as the load increased to 2500g and 3000g, indicating improved combustion due to oxygenation. The D95 blend exhibited lower fuel consumption compared to diesel fuel, although blends with higher n-butanol percentages showed increased brake-specific fuel consumption due to lower calorific values, densities, and viscosities. Under maximum load, the D95 blend exhibited higher exhaust gas temperature and heat loss, reflecting the increased fuel quantity required for additional power. Lower heat losses at lower loads were attributed to factors such as lower calorific values, n-butanol's heat of vaporization, temperature differentials between the exhaust and ambient conditions, and engine size.

Conclusion: The engine load has diverse effects on parameters across different fuel samples. D95 exhibits similar performance to diesel, yet discrepancies arise, especially with higher n-butanol content at lower loads.

Keywords: Diesel engine, n-butanol, engine performance characteristics, and emissions

1. INTRODUCTION

Due to their high efficiency, versatility and reliability, diesel engines have been globally utilized to produce cheap, economical and dynamic electricity, especially in rural areas where they are connected to a power grid as a backup system or main power source [1,2,3]. Despite the advantages of diesel engines, certain challenges are associated with their use. Combustion of diesel produces carbon dioxide (CO_2), nitrogen oxide (NOx), and particulate matter. These emissions pollute and reduce air quality. Besides the negative environmental impact of diesel, depletion and price uncertainty are other challenges associated with diesel [4]

Biofuels are promising alternative fuels to fossil fuels [5,6,7] This is because of their biodegradability, renewability and green nature. Oxygenated fuels such as alcohols have partially replaced fossil fuels and attracted numerous research interests for many years because their combustion is cleaner [8,9,10,11,12]. Butanol as a versatile renewable fuel could be produced from lignocellulose biomass, or fermentation [13] Among the alcohols, butanol is of particular interest as a versatile renewable biofuel. This is because its properties such as heating value, auto-ignition temperature, cetane number, flowability, and homogeneity are closer to diesel than those of other shorter chain counterparts [14].

The main user end market of this n-butanol is the chemical, petrochemical, textiles, cleaning, and cosmetics industries. At 85% blending mixture, n-butanol can be used in spark ignition engines with no engine modification. This allows for lower fuel consumption than other gasoline alternatives such as ethanol due to the lower oxygen content of n-butanol [15,16] Even though, not much has been reported on N-butanol is an active fuel additive for diesel engines. The sustainable use of the mixture of diesel and n-butanol is being investigated as fuel for in internal combustion engines - as is the case with power plants and transportation vehicles. Hence, the objective of this paper is to evaluate the influence of n-butanol-diesel fuel blends on the performance characteristics of a four-stroke, single-cylinder compression ignition engine under variable loading conditions.

2. MATERIALS AND METHODS

2.1 Materials

The source of materials and properties of n-Butanol used for this study are presented in tables 1 and 2 below.

Table 1. Source of fuel and n-Butanol additive.

S/N	Material	Product Manufacturer /Distributor
1	Diesel	Nigerian National Petroleum Corporation, Nigeria
2	N-Butanol	Solventis, Surrey, UK.

Table 2. Technical properties of n-Butanol

Properties	Specifications
Description	Colourless liquid, medium volatility, banana-like odour
Synonyms:	butan-1-ol, 1-butanol, normal butanol, and n-butyl alcohol
Cas Number	71-36-3
Molecular Formula	$C_4H_{10}O$
Molecular Mass	74.12
Flashpoint (closed cup)	29 °C (84.2 °F) - 35 °C
Autoignition temperature	343 °C (649.4 °F)
Boiling Point	117 °C (242.6 °F)
Melting Point	-90 °C (-130 °F)
Vapour Pressure	0.58 kPa at 20 °C (68 °F)
Density	0.81 at 20 °C (68 °F)
Log P	0.88

Source: [15

The use of personal protective equipment, such as; gloves, coveralls, and recommended respirators of >20ppm –full face piece APR with organic vapor cartridges, >200ppm-supplied air to deal with health and safety concerns against; inhalation, and eyes and skin contact would be encouraged when handling n-butanol and preparing fuel samples in the laboratory [17]

2.2 Preparation of Fuel Samples.

In order to prepare the samples for the study, different composition of diesel and n-butanol were mixed with the aid of mechanical magnetic stirrer. The blends were prepared at an ambient temperature of 36^0C, and stirred for 60 minutes to obtain a homogeneous consistency. Each blended fuel sample was prepared on volumetric basis of 500ml using the prescribed volumetric proportion of the mixtures in table 3.

Table 3: N-butanol -Diesel Blends

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

2.3 Fuel Characterizations.

ASTM Standard test protocols as prescribed in table 4 below were used for the fuel property determination [18].

Table 4. ASTM D975 test specifications for fuel samples.

Fuel Property	**ASTM Specification**
Density at 40^{o}C (kg/m^{3})	ASTM D4052
Specific gravity	ASTM D4052
Kinematic viscosity at 40^{0}C (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
Autoignition temperature (^{o}C/^{o}F)	ASTME659-14

2.4 Engine Performance Test.

The performance test was conducted in conformity with the SAE J1349 [19] test protocol on a Tec-Quipment TD110-115 single-cylinder, 4-stroke air-cooled engine test rig coupled to a horizontal hydraulic dynamometer (refer to figure 1 and table 4 for schematic diagram and technical specifications of the engine test rig). The engine was operated at a constant speed of 1500 rpm with variable loads of 500g, 1000g, 1500g, 2000g, 2500g and 3000g. The time taken by an engine to consume 8 ml of fuel, torque, exhaust temperature and barometric pressure for all fuel samples were recorded. Engine performance test on diesel fuel was also conducted as a basis for comparison. As the percentage of blend and load were varied, engine performance measurements such as brake specific fuel consumption, air flow rate, brake power, volumetric efficiency, brake thermal efficiency, percentage heat loss and air/fuel ratio were computed and recorded.

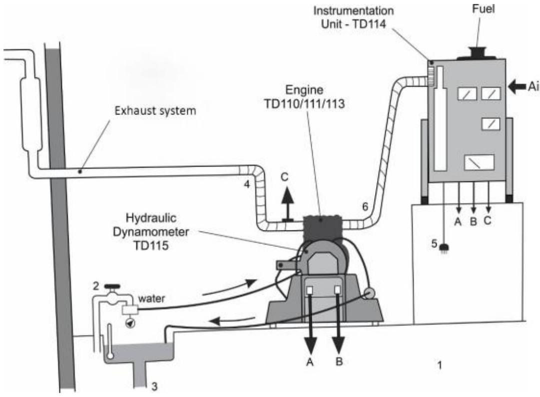

Fig.1. An illustration of a complete TD110-TD115 TQ small engine test rig [20]..

Table 5: 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

Source: [20].

3.0 RESULTS AND DISCUSSIONS

3.1 Fuel properties of fuel and blended samples.

The result of the properties of the fuel samples are presented in table 4 and are briefly discussed in the ensuing paragraph.

The result in table 4 has shown that Diesel fuel sample demonstrated a relatively higher fuel density and relative density at room temperature, with a value of 0.8367. 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. The lower the fuel viscosity, the more efficient fuel injection, 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 ^oC), 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. The cloud point of fuel samples analyzed revealed that Diesel fuel samples exhibited the highest pour point (-24 ^{o}C), and the value decreases as the volumetric proportion on-butanol increases in the fuel mixture. It is important to note that low temperature behavior is required for engine at cold start and low load conditions.

Cetane number (CN) is one of the most important parameters affecting diesel fuel behavior. It is related to the time that elapses between fuel injection and beginning of combustion [2, 21]. It generally depends on fuel composition and can influence engine stability, noise level and exhaust emissions [22, 23].. 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 [24]. 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 pour points 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).

Table 6: Fuel properties of n-butanol and Diesel fuel blends

Fuel Property	D100	B100	D95	D90	D85	D80	D75
Density at 40^{o}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
Autoignition temperature (^{o}C/^{o}F)	210 °C (410 °F)	343 °C (649.4 °F)	-	-	-	-	-

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 calorific value of B100 fuel sample was observed as the least (37025 kJ).

In terms, of auto ignition temperature (AIT)- i.e., the lowest temperature at which the fuel will ignite spontaneously under ambient conditions without an external source of ignition such as spark or flame, it could also be seen that the AIT value is higher for butanol (343 °C /649.4 °F) than diesel fuel sample (210 °C /410 °F). The implication is that the temperature required to supply the activation energy needed for combustion is higher for butanol and its blend than Diesel fuel sample. Hence, more rapid compression is required to raise the temperature of the butanol and blends to self-initiate combustion of the fuel samples, as such, butanol and its blended samples are much safer to handle in terms of storage and transportation.

3.2 Influence of Fuel Samples on Engine Performance.

3.2.1 Effect on brake power.

The variation of brake power (BP) with load increase for diesel and its blends with n-butanol is presented in figure 2. An increase in BP was observed for both diesel and its blends as load increased to maximum load [25].. The comparatively higher BP supplied by engine running diesel fuel is attributed to its higher calorific (heating) values (refer to table 4). The BP performance of D95 was comparable to diesel fuel. At the load of 2500g the BP for D95 reduced by 69.7% and peaks further to 72.8% at 3000 g, but lower than diesel fuel sample. The relatively higher BP increased to maximum load [26]. The comparatively higher BP supplied by engine running diesel fuel is attributed to its higher calorific (heating) values (refer to table 4). The BP performance of D95 was comparable to diesel fuel. At the load of 2500g the BP for D95 reduced by 69.7% and peaks further to 72.8% at 3000 g, but lower than diesel fuel sample. The relatively higher BP can be attributed to the improved calorific value of n-butanol when blended with diesel. D85, D80 and D75 blends showed decreased BP as a consequence of decrease in heat release due to their low calorific values. This can also be attributed to higher heat of vaporization of n-butanol which causes decrease in power and torque [26, 22]

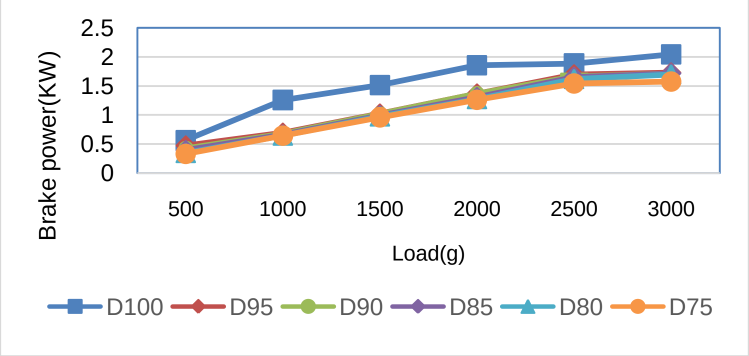

Fig 2: Variation of BP with load increase for fuel samples

3.2.2. Effect on brake specific fuel consumption.

It could be observed form figure 3 that as load increased, brake specific fuel consumption (BSFC) decreased to a minimum value at 3000g engine load. The BSFC of the blended samples are also closely comparable to Diesel fuel at loads at 2000g, 2500g and 3000g engine loads. At a load of 1000g the BSFC for D95 rose above diesel fuel sample by 11.17%, and drops below diesel fuel sample fuel at 3000g by 0.024%. This improvement in BSFC can be attributed to efficient combustion due to the presence of additional oxygen molecules in the n-butanol in the blended fuel samples [27].. The BSFC values of Diesel fuel was noticed to be lower when compared with the blended samples. In other words, BSFC increased as the n-butanol percentage in the blends increased. The increased BSFC in blends with higher n-butanol percentage can be linked to the combined effects of lower calorific values, densities and viscosities resulting to low fuel flow rate (refer to table 4). Though, Kuszewski, [28] had opined that a slight decrease in the density of n-butanol -diesel blends with the increase in the n-butanol fraction could in itself create a marginal problem in modern Diesel engines. Hence, mass fuel delivery at lower fuel density can easily be increased by modifying the control system. surmount this challenge.

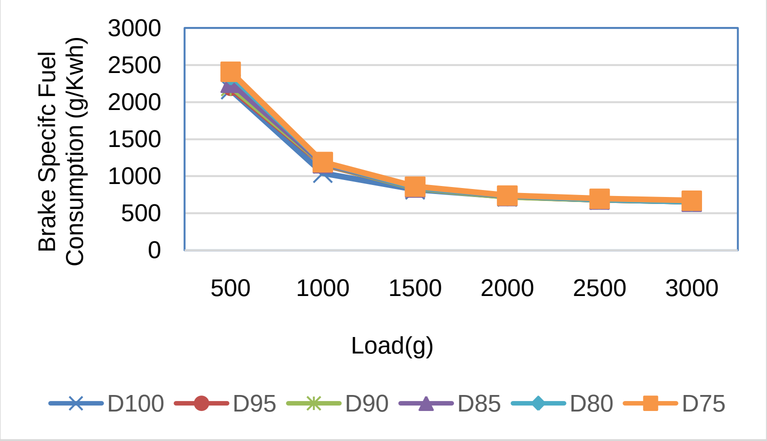

Fig 3: Variation of BSFC with load increase for fuel samples

3.3.3 Effect on air fuel ratio

With increase in engine load an increase in air fuel ratio (AFR) was observed for all tested fuel samples (refer to figure 4). Blends with low n-butanol percentage i.e., D95 and D90 exhibited higher AFR values than Diesel fuel at all engine loading conditions. At a load of 2500g the brake power for D95 increased by 0.21% and peaks further at 3000g to 0.53 % and higher than diesel fuel sample. This implies that blending n-butanol oxidizes the fuel samples thereby inducing a lean effect on the stoichiometric values of the mixture in blended fuel samples [30, 29, 30,31]. Blends with higher n-butanol percentage i.e., D85, D80 and D75 exhibited lower AFR in comparison to Diesel fuel. This too could be linked to the poor auto-ignition property of n-butanol which causes ignition delay thereby lowering cylinder walls and combustion temperatures. This performance could have been compensated by the higher oxygenation behavior, lower density and viscosity of n-butanol blended fuel samples to enhance the combustibility of the fuel samples under study.

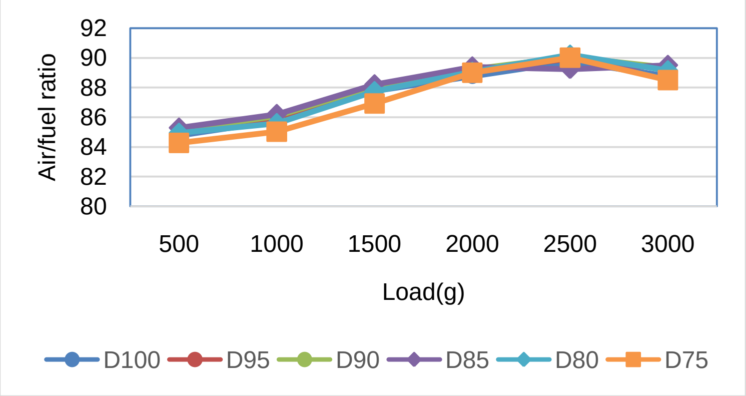

Fig 4: Variation of air fuel ratio with load increase for fuel samples

3.3.4 Effect on exhaust gas temperature.

The exhaust gas temperature (EGT) increases with an increase in load for both Diesel fuel and the blended fuel sample (refer to figure 5). This increase in EGT with load is obvious from the simple fact that more amount of fuel was required in the engine to generate that extra power needed to take up the additional

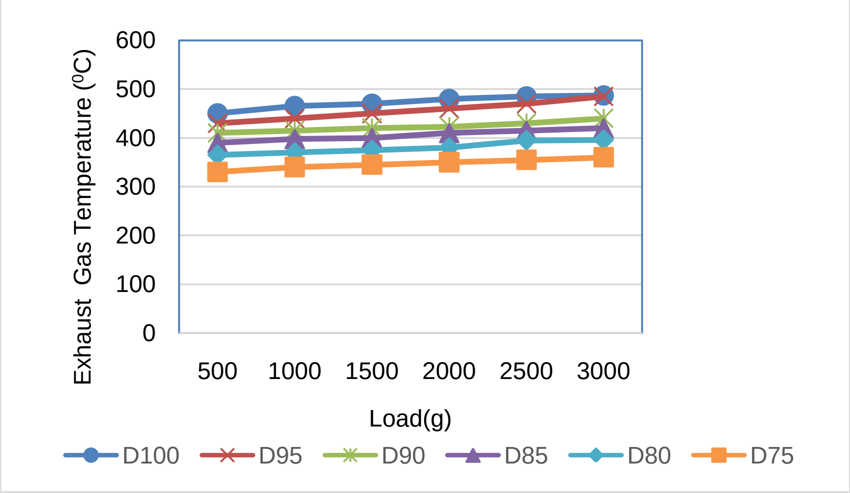

Fig 5: Variation of EGT with load increase for fuel samples.

loading. The Diesel fuel sample exhibited higher EGT compared to blended fuel samples. The EGT of D95 blend is comparable with Diesel fuel sample. The EGT for D95 rose from 4.44% for 500 g to 0.41% at maximum load (3000g) but lower than diesel fuel sample as the most comparable in the group. This implies that increasing the n-butanol content in the blends leads to a decrease in EGT values due to the effect of its diminishing calorific values in the blends (refer to table 4). This shows that the n-butanol – like any alcohol-absorbs more heat in order to evaporate and burn, consequently decreases the in-cylinder temperature at the end of compression stroke and so the EGT at the end of combustion process [14,]. Agarwal [32] had reported that by increasing the concentration of n-butanol in a blended fuel sample is likely lower the EGT in an operational internal combustion engine, and could probably explain the cause of the drop in4] the EGT values in this case.

3.3.5 Effect on brake thermal efficiency.

It could be seen from figure 5 that for all tested fuel samples, the brake thermal efficiency (BTE) increases with increase in load. This could be attributed to the consequent increase in brake power occasioned by the improved combustion behavior with increase in engine load to a maximum of 3000g. Oxygen present in the blends could have enhanced the combustion of fuel samples at low engine load. At high loading conditions the change of state from molecule oxygen to atomic oxygen perhaps led to a decrease in BTE [32]. The BTE provides an idea of the output generated by the engine with respect to heat supplied by the fuel.

Diesel fuel showed higher BTE than other tested blends under varying load conditions (refer to figure 6). This could be attributed to the higher calorific value of the Diesel fuel (refer to table 4). At a load of 2500g the BTE for D95 reduced drastically by 1.67% and drops further to 0.11% but higher than diesel fuel sample at an engine load of 3000g. The fact that the BTE values at loads of 2000g, 2500g and 3000g for D95 is closely comparable to Diesel fuel, it does suggest improved stoichiometric mixture and enhanced combustion behavior of the fuel samples in the combustion chamber due to the further oxygenation effect of n-butanol in the fuel mixtures. The lower BTE obtained in of D80 and D75 blends could probably be attributed to the obvious drop in their calorific values on one hand (refer to table 4), and increase in fuel

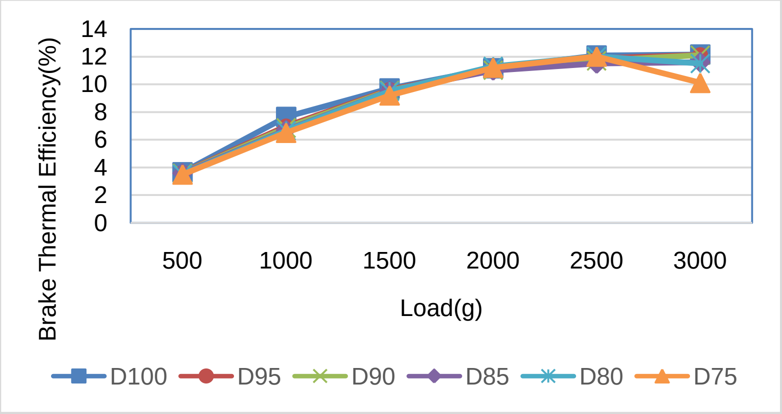

Fig 6: Variation of BTE with load increase for fuel samples

consumption on the other. The higher latent heat of vaporization of n-butanol might also be responsible for inhibiting proper air-fuel mixing, thereby leading to inferior fuel combustion and lowering of the BTE values [33].

3.3.6 Effect on brake specific energy consumption

Figure 7 presents the variation of brake specific energy consumption (BSEC) for diesel and its blends with n-butanol with increase in load. At a load of 1000g the BSEC for D95 rose drastically to 9.22 %, and drops further to 1.78 % lower than diesel fuel sample at a load of 3000g. Decrease in BSEC with increase in load were observed up to 2500g load, after which a slight increase was experienced at 3000g load. This could be due to percentage increase in fuel required to operate the engine is less than the percentage increase in brake power. The initial decrease in BSEC could be attributed to the complete and improved combustion of the fuel. Above 2500g engine load, the time taken for complete combustion of fuel decreased, hence a slight increase in BSEC was observed. It was also observed that the increase in n-butanol percentage in the blends due to the decrease of calorific values of tested fuel samples, while the specific fuel consumption increased, this is responsible for the lower BSEC of all blends than that of diesel. The further oxygenation of the n-butanol blended fuel samples might as well explain the progressive lowering of the BSEC values from D95 to D75 fuel samples. Topgül[34] mentioned that BSEC expressed as the total energy supplied by fuel to generate per engine power over an hour. The BSEC is also related to thermal efficiency, the result showed that improved thermal efficiency was found with decreased energy consumption.

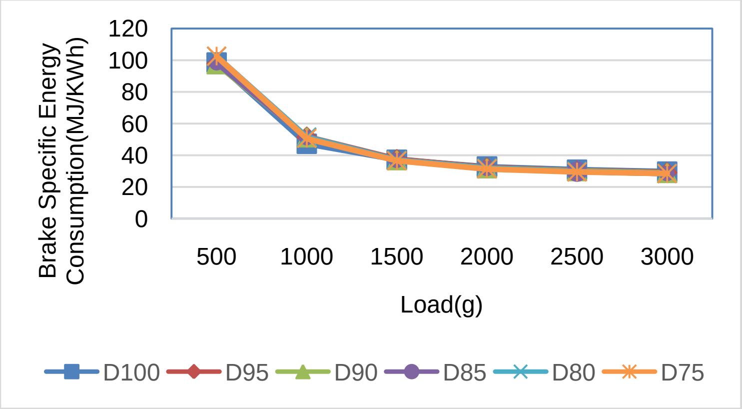

Fig 7: Variation of BSEC with load increase for fuel sample.

3.3.7 Effect on percentage heat loss

The variation of percentage heat loss (PHL) for diesel and n-butanol blended fuel samples with increase in load is presented in Figure 8. All tested fuel blends showed evidence of lower heat loss in the engine than neat diesel fuel. At a load of 2500 g the PHL for D95 increased marginally dropped by 1.35 %, and rose further to 1.89 % higher than diesel fuel sample at the load of 3000 g. The lower heat loss recorded in the blends at lower loading conditions can be explained in terms of lower calorific values, heat of vaporization of n-butanol, the difference between the exhaust and ambient temperatures and the size of the engine. However, heat unaccounted for due thermal losses is partly a function of the engine size. Hence, for smaller engines, considerable conductive and radiative heat losses are usually caused by inefficient combustion [35, 36].

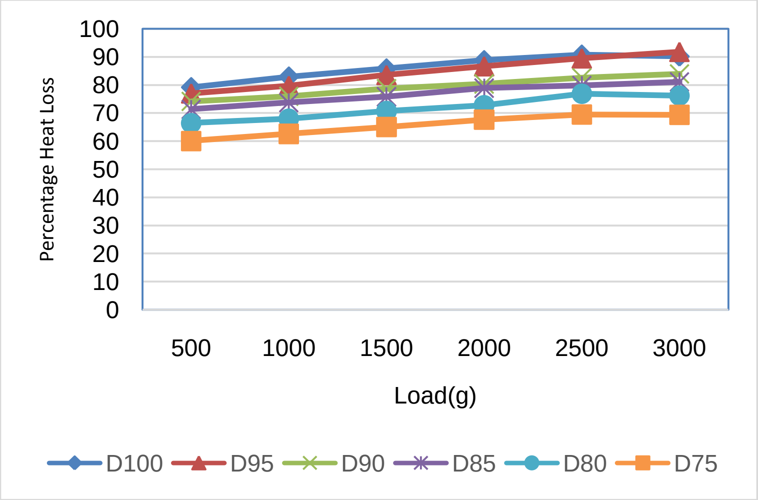

Fig 8: Variation of PHL with Load Increase for Fuel Samples

4.0 CONCLUSION

In all. this study sheds light on the intricate relationship between different fuel blends, and engine performance, and the following could be concluded:

i. Engine parameters such as BP, air-fuel ratio, EGT, BTE, and PHL increased as engine load increased.
ii. It was noted that blends with higher n-butanol content exhibited increased BSFC due to factors like additional oxygen molecules and lower calorific values, densities, and viscosities, resulting in a lower fuel flow rate.
iii. Despite these differences, the performance of the D95 fuel mixture closely resembled that of the diesel fuel sample, albeit with slightly lower BP, BTE, and BSEC values at higher loads.
iv. The EGT for D95 showed a slight increase at the maximum load, while at lower loads, increasing n-butanol content led to decreased EGT values.

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