Effect of n-butanol/diesel blends on performance, emission, noise and vibration characteristics of a diesel engine generator

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ABSTRACT

Simple diesel engine generators in general are noisy and pollute air. It is urgently needed to find alternative fuels applicable for new as well as old engines without structural modifications and along with keeping the environment clean. Diesel-alcohol blends could be such alternatives fuels. For that purpose, in this study tests were carried out using diesel fuel first then, were carried out using three of n-butanol/diesel blends on volume bases with n-butanol concentrations of 5, 10 and 15%, identified as nBu5, nBu10 and nBu15. The engine under study is a single cylinder, four stroke, air cooled diesel engine generator and the tests have been carried out at a fixed 3000 rpm and five different load conditions without any hardware modifications. Total noise, engine block vibration, NOx, HC, CO, BSFC, BTE and EGT have been observed of diesel and n-butanol/diesel blends. The following conclusions can be drawn with n-butanol/diesel fuel blends against diesel fuel; (i) According to engine performance test results; a little higher specific fuel consumption was observed with corresponding slight increase of brake thermal efficiency and little lower exhaust gas temperatures. (ii) According to engine emission test results; the NOx was slightly reduced, this reduction being higher the higher the percentage of butanol in the blend. The CO emissions were reduced, on the contrary, HC emissions were increased, this increase being higher the higher the percentage of butanol in the blend. According to engine vibration and noise test results; Noise and vibration characteristics are somewhat better especially at lesser loads.

Keywords; Butanol-diesel blend. Engine Performance. Vibration. Noise. Diesel engine generator.

Nomenclature

ASTM	American society for testing and materials
DF	Diesel
B	Biodiesel
nBu	n-butanol
D100	100% diesel fuel
nBu5	5% n-butanol with 95% reference diesel
nBu10	10% n-butanol with 90% reference diesel
nBu15	15% n-butanol with 85% reference diesel
$DF/nBu_{5,10,15}$	Diesel/5, 10 and 15% n-butanol blends
BSFC	Brake specific fuel consumption (g/kW h)
BTE	Brake thermal efficiency (%)
CN	Cetane number
CO	Carbon monoxide (% volume)
CO2	Carbon dioxide (% volume)
CV	Calorific value (kJ/kg)
EGT	Exhaust gas temperature (°C)
HC	Hydrocarbons (ppm volume)
kW	Kilowatt
NOx	Nitrogen oxides (ppm)
PM	Particulate matter
ppm	Parts per million
rpm	Revolution per minute

1. INTRODUCTION

Alcohols such as ethanol, methanol and butanol fuels have been widely studied and used in diesel engine. Recent advancements in production techniques have made butanol a cost effective and environmentally friendly alternative (Tashiro et al2007)[1]. Butanol is a good fuel additive for use in diesel engines with several advantages such as higher cetane number, high heating value, better miscibility with diesel and lower heat of vaporization (Lamani et al2017)[2]. It is easy to ship n-butanol in fuel pipelines, due to its low corrosive and low hydrophobic properties, also can be produced from both fossil matter and waste biomass with the same properties, also can be blended with diesel fuel without phase separation (Jang et al2012)[3].

Many investigators compared emission and performance characteristics of n-butanol/diesel blends fueled engine and net diesel fueled engine. Yusri et al(2019)[4]noticed that n-butanol/diesel blends reduce rate of pressure rise and rate of heat release, increase both ignition delay and burn duration, increase engine cyclic variations, reduce NOx, CO and HC. Siva et al(2019)[5] reported that n-butanol/diesel blends reduced CO, NOx, BSFC and smoke emissions, increased both HC and BTE. They used simulation studies of piston bowl geometry to decrease the HC emission. Xinling et al (2019)[6]evaluated four alcohols, ethanol, n-butanol, iso-butanol, and n-pentanol with the same oxygen contenton a diesel engine. They reported that; (i) in comparison with diesel, the alcohol blends have higher peak heat release rate, longer ignition delay, and shorter combustion duration. (ii) All blends showed similar organic carbon emissions and a slight variation or no significant change in regulated gaseous emissions (CO, HC, NOx) at different loads.

Dev et al (2018)[7] used various blends of n-butanol/diesel to study a single-cylinder 4-stroke diesel genset engine. Results showed that; blends were better for CO, NOx, smoke, noise and vibration however, the same may not be said for hydrocarbon emissions and engine efficiency. Nurun et al(2017)[8]investigated that the n-butanol/diesel blends under the European Stationary Cycle (ESC)reduce power, peak pressure, particulate matter (PM) and particle number (PN) emissions as well as increase BSFC, exhaust blow-by, HC, NOx emissions.

Venkatesh et al (2017)[9] reported reduction of smoke opacity, NOx and carbon monoxide emissions with the increasing n-butanol percentage in diesel fuel. Ashish et al (2017)[10] reported that n-butanol/diesel blends reduce smoke, NOx, CO and engine performance as well as increase CO2 and HC. Zhang et al (2016)[11] conducted an experimental study on the influence of using the effect of n-butanol/diesel blends on particle emissions of diesel engine and indicated that the concentration of total particle emissions reduces.

Ibrahim et al (2016)[12] observed that the blending of 20% n-butanol/diesel blend resulted in significant reduction in PM with a negligible change in engine performance. Zheng et al (2015)[13] reported that when neat n-butanol was injected in a diesel engine, the emissions of NO_x and smoke reduced substantially but HC and CO emissions were increased. Sahin et al (2015)[14] investigated experimentally that; maximum smoke reduction of 21.75% was observed with 4% n-butanol blend, and maximum NOx reduction of 5.03% was observed for 2% n-butanol blend.

Choi et al (2015)[15] showed that; (i) Blending of n-butanol should be equal to or less than 10% for reduced emissions. (ii) For B5 and B10, PM size under 50 nm is reduced to 18.5 and 31.1%, respectively, whereas for B20 it increased to 20.5%. (iii) On a positive note, these blends have resulted in improved engine performance. Zehra et al (2015)[16] investigated the effects of the using of low ratio n-butanol/diesel fuel blends on a diesel engine. The test results showed that engine characteristics and NOx emission improve for nB2 and nB4 at selected engine speeds and loads. However, they deteriorate for nB6. At the end, nB2 was determined as the most favorite blend for engine characteristics and NOx. Smoke reduce for nB2, nB4 and nB6 at all of the selected engine speeds.

Huang et al (2015)[17] concluded that BSFC increase and BTE decreases. However, variations in BSFC and BTE also depend on base fuel and operating parameters. Also, reduce smoke significantly, reduces CO, reduce NO_x marginally, and increase HC.Sahin et al (2015)[18] investigated experimentally that; maximum smoke reduction of 21.75% was observed with 4% butanol/diesel blends, and maximum NOx reduction of 5.03% was observed for 2% n-butanol blend.

1. 1 Current Research

According to the above literature review and authors' best knowledge, the simultaneously characteristics evaluations of diesel engine generators are rather limited. As is known, these engines are noisy, generate vibrations, and pollute air so, there is more pressing need to explore and compare these simultaneously characteristics when working with net diesel and other fuel blends which, could be alternatives for new as well as old engines without structural modifications.
For that purpose, in this study tests were carried out using three of n-butanol/diesel blends on volume bases with concentrations of 5, 10 and 15%, identified as nBu5, nBu10 and nBu15.

2. MATERIALS and METHODOLOGY

Three different nBu/DF blends having 5% nBu with 95% reference diesel (DF), 10% nBu with 90% DF and 15% nBu with 85% DF, identified as nBu5, nBu10 and nBu15, denoted as nBu5, nBu10 and nBu15. Properties of n-butanol are listed in Table 1 together with the Egyptian diesel specifications (Ahmed et al **2019**)[19].

Table 1

Properties of n-butanol and Egyptian diesel fuel

property	Diesel	n-Butanol
Specific gravity at 15.56 °C Density (kg/ m^3)	840[b]	810[a]
Latent heat of evaporation (MJ/ kg)	0.27	0.43
Calorific value (kJ/kg)	Min 42.7[b]	33.1[a]
Cetane index	55.6[b]	25[a]
Boiling point (°C)	187–343	117
Kinematic Viscosity @ 40 _C	3.21[b]	2.22[a]

[a] Data have been provided by the supplier

[b] Data have been provided by the Egyptian diesel fuel specification

2. 1 Measured and Computed Parameters

Total noise, CO_2, NO_X, CO, HC and EGT of each test blend were measured. The engine block top RMS vibration (g), fuel consumption (FC), BSFC, BTE, %, CV and CN were computed according to the following equations (Ashish et al **2017**)[20].

$$g_{total}=\sqrt{g_x^2+g_y^2+g_z^2} \qquad 1$$

Where; $g_{x,y,z}$ = vibration for vertical, lateral, longitudinal direction respectively

g_{total} = total acceleration of engine vibration

$$FC = \frac{3600\ \rho m}{1000\,T}\,\frac{kg}{hr} \qquad 2$$

ρ = density of fuel in gram/cc, m = burette reading in cm^3, T = time taken in seconds.

$$BSFC = \frac{FC}{P}\,\frac{kg}{kW\,hr} \qquad 3$$

P is the output power in kW

$$BTE\ \% = \frac{3600\ P}{FC\ CV} \qquad 4$$

$$CV\ of\ blends = \frac{\left(\rho_{nBu} CV_{nBu}\frac{V_{nBu}}{V}\right)+\left(\rho_{DF} CV_{DF}\frac{V_{DF}}{V}\right)}{\left(\rho_{nBu}\frac{V_{nBu}}{V}\right)+\left(\rho_{DF}\frac{V_{DF}}{V}\right)}\,\frac{kj}{kg} \qquad 5$$

ρ density, $\rho_{nBu,DF}$ density of butanol and diesel respectively

CV . calorific value, $CV_{nBu,d}$ the CV of butanol and diesel respectively

V . total volume of blend, $V_{nBu,d}$ volume ratio of butanol and diesel respectively

$$CN = CN_{nBu}\frac{V_{nBu}}{V}+CN_{DF}\frac{V_{DF}}{V} \qquad 6$$

$CN_{nBu,DF}$ is cetane number of butanol and diesel respectively

Fuel Blends properties and calculations are listed in Table 2.

Table 2

Fuel Blends and its Properties Calculation

Fuel blend in vol.	Diesel (%v/v)	n-butanol	Cetane Number[a]	Calorific value[b]
Diesel fuel	100	-	55.00	44.30
nBu5	95	5	53.50	43.76
nBu10	90	10	52.00	43.21
nBu15	85	15	50.50	42.67

[a, b] Data have been computed by Ref. (20)

2. 2 Engine Under Study

The technical specifications of genset engine are given in Table 3 and layout of the test bed constructed in the automotive laboratory, faculty of engineering, Minia University, Figure 1.

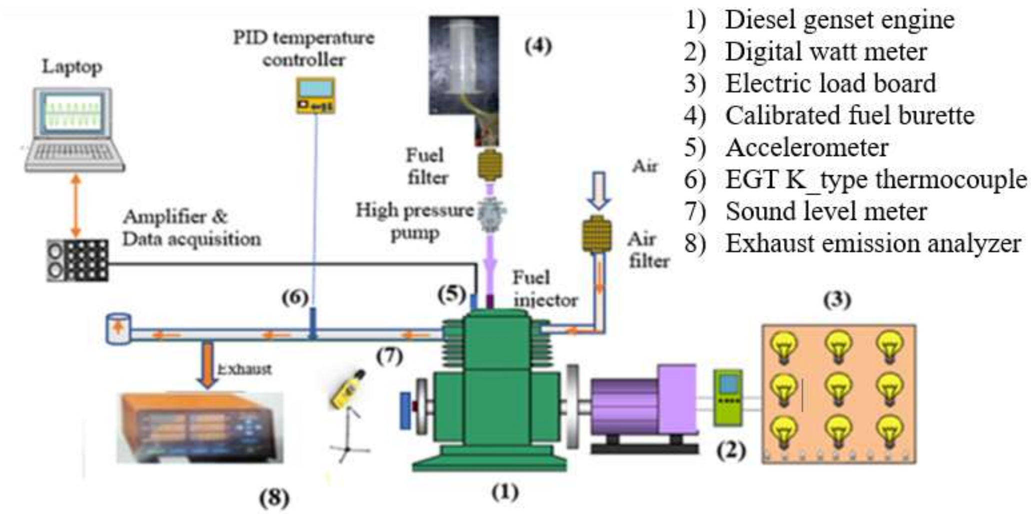

Fig. 1. A schematic diagram of experimental setup.

Table 3

Specifications for lister generator, Model GF-KM3

Type	Single cylinder, 4 strokes, air cooled
Bore x stroke	86x70 mm
Displacement	406 cm3
Max. Output Power	9.0/3000 hp/rpm
Rated voltage	220 v
Rated Frequency	50 Hz
Rated Output	5000 W
Max. Output Power	5500 W

2. 3 Measured Instruments

Total noise of engine is measured by B&K sound level meter, engine vibration is measured by B&K accelerometer, CO, CO_2, HC and NO_X is measured by an exhaust emission analyzer model - GA4000XD, EGT is measured by K type thermocouple and fuel consumption is measured by a calibrated fuel burette with a valve.

2. 4 Error Analysis

The uncertainty range of BSFC and BTE comes from the errors in the measurement of FC, brake power and calorific value. Accuracy of instruments are shown in Table 4.

Table 4
Description and accuracy of instruments

Sensor/type	Description	Accuracy
Digital thermometer	EGT	± 0.1 °C
Accelerometer	Vibration	0.3%
Sound level meter	Noise	0.2 dB
Emission analyzer	Exhaust gases	CO ±0.01 %, CO_2 ± 0.1 % NOx ±1 ppm, HC ±1 ppm

2. 5 Experimental Precautions

The blends mixing were not at rate cause turbulence or bubbles. The thermocouple and analyzer gas sampling probe are placed in fixed position. The engine was warmed up. The first tests were carried out using diesel fuel at different loads and rated speed 3000 rpm then, the rest of the tests were carried out using all the fuel blends under the same conditions. Before running the engine to another fuel, it was permitted to keep running to consume the rest of fuel from the past experiment. For each test, three readings were taken to increase confidence.

3. RESULTS AND DISCUSSION

3.1 Variation of Engine Body Vibration

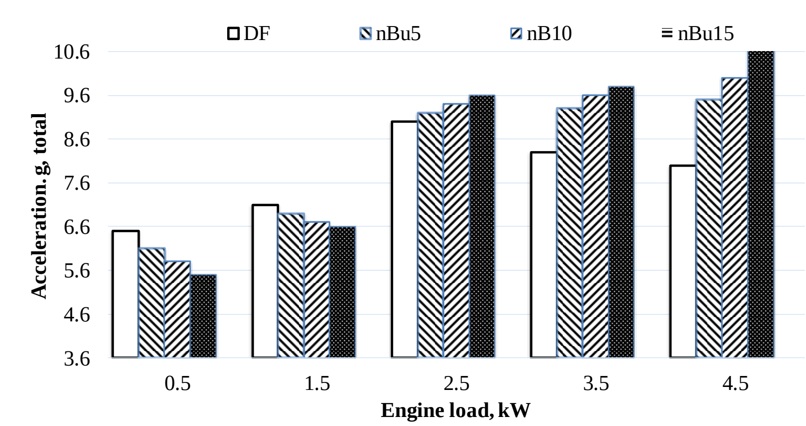

Fig. 2. Variation of vibration vs. engine load

The top of engine block is the highest sensitivity place to vibrations derived from combustion process and the lowest sensitivity place to vibrations derived from mechanical parts, thus the accelerometer is placed on the engine cylinder head cover to measure the vibration resulted of combustion process(Chiati et al 2014)[21]. The vibration measured for three directions, vertical (x), lateral (y), and longitudinal (z). The resultant (g_{Total}) was computed, according to:

$$g_{total}=\sqrt{g_x^2+g_y^2+g_z^2}$$

Fig. 2 showed at different engine loads, the effect of diesel and n-butanol/diesel blends on engine vibration.

The results show that; At lower engine load, both the total vibration level of diesel and diesel/n-butanol blends rapidly increase with increasing engine load but, during this diesel produces highest vibration level and diesel/n-butanol blends burn smoothly and produce less vibration due to both its inherent fuel oxygen content and lean fuel–air mixture. At higher engine load, diesel vibration level does not show a significant increase but, diesel/n-butanol blends start generating higher vibration. The reasons may be that, fuel–air mixture becomes richer in high loads, so the effect of lower fuel viscosity of diesel/n-butanol blends becomes significant and increase the ignition delay and cancel the moderating effect of inherent fuel oxygen content. Consequently, the vibration level continues to rise, albeit slowly, even further due to the amount of fuel injected leading to higher cylinder pressures.

3. 2 Variation of Noise Emission

Fig. 3 showed at different engine loads, the effect of diesel and n-butanol/diesel blends on total noise.The results show that; At lower engine load, both the total noise level of diesel and diesel/n-butanol blends rapidly increase with increasing engine load but, diesel produces highest combustion noise and diesel/n-butanol blends burn smoothly and produce less noise due to both its inherent fuel oxygen content and lean fuel–air mixture. At higher engine load, diesel combustion noise level does not show a significant increase but, diesel/n-butanol blends start generating higher combustion noise and become the noisiest at 100% engine load. The reasons behind that, fuel–air mixture becomes richer, so the effect of lower fuel viscosity of diesel/n-butanol blends become significant and increase the ignition delay and cancel the moderating effect of inherent fuel oxygen content. Consequently, the noise level continues to rise, albeit slowly, even further due to the amount of fuel injected leading to higher cylinder pressures.

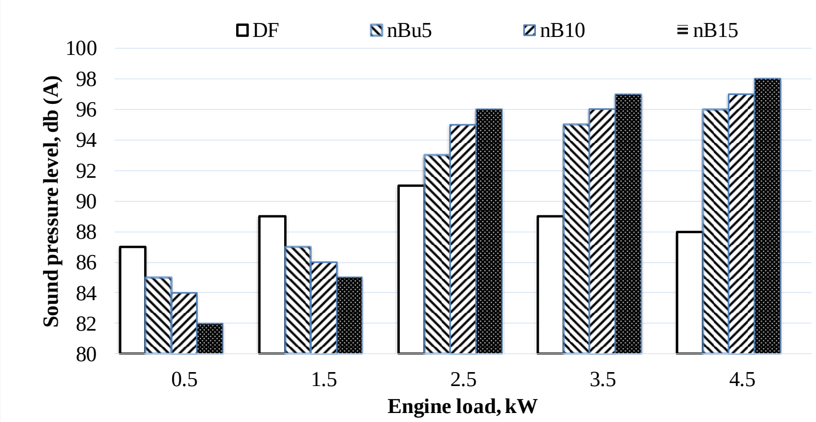

Fig. 3. Variation of noise vs. engine load

3. 3 Variation of BSFC

Fig. 4 shows at different engine loads, the effect of diesel and n-butanol/diesel blends on BSFC.The results show that; Irrespective of fuel used, due to the very large ratio of frictional losses to the brake power at low engine loads, BSFC consumption is greater and due to incomplete combustion at high engine loads, BSFC increase. Adding butanol to diesel increase BSFC consumption and increase more with butanol addition to diesel, itmay be due to lower heating value of butanol (Atmanli et al 2015)[22] and lower cetane number which lead to ignition delay increase and therefor fuel increase before combustion. Like it, the time duration of combustion at higher temperature increase and heat transfer to engine parts increases, the effective energy conversion into brake power decreases.

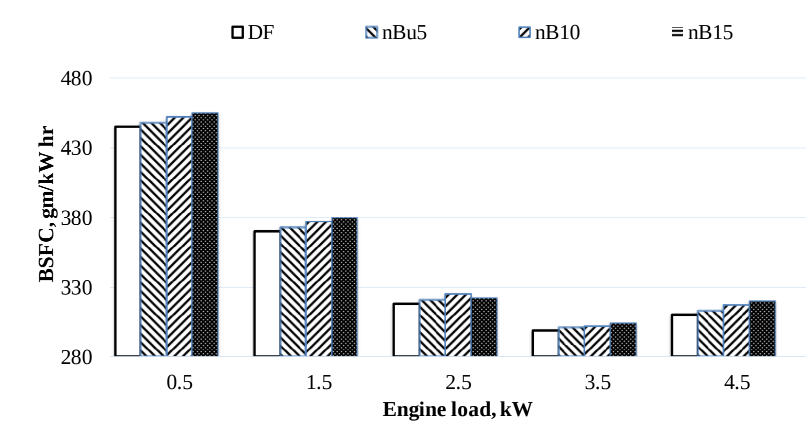

Fig. 4. Variation of BSFC vs. engine load

3. 4 Variation of Brake thermal efficiency (BTE)

Fig. 5 shows variation of brake thermal efficiency for all test fuels at varying engine loads. Fig. 5 shows at different engine loads, the effect of diesel and n-butanol/diesel blends on BTE. The results show that; Irrespective of fuel used, at low loads BTE reduce due to low BMEP, which degrades the combustibility of fuel then BTE, increase as a result of good combustion then BTE, decrease due to bad fuel utilization (Emiroğlu et al 2018)[23]. Adding butanol to diesel reduce BTE emission and reduce more with butanol addition, it may be due to release more heat in the expansion stroke due to delayed combustion resulted from low CN, high latent heat vaporization and low calorific value of butanol.

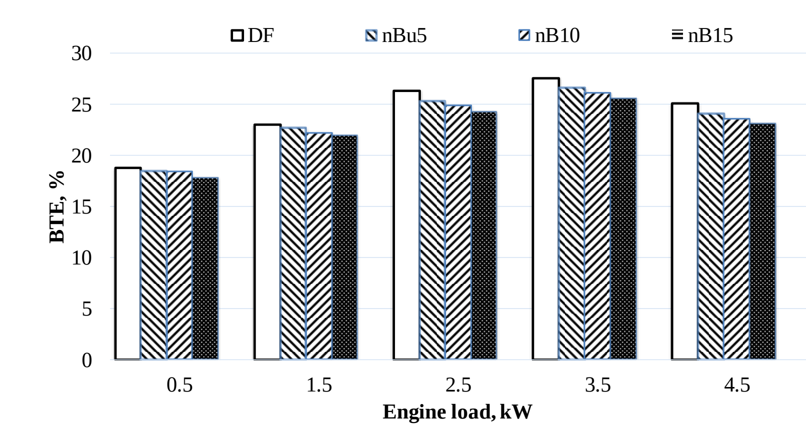

Fig. 5. Variation of BTE vs. engine load

3. 5 Variation of EGT

Fig. 6 shows at different engine loads, the effect of n-butanol/diesel blends on EGT. The results show that; Irrespective of fuel used, EGT increased with increasing engine load, this is attributed to combustion of maximum amount of fuel at highest engine load. Adding butanol to diesel reduce EGT emission and reduce more with butanol addition, it may be due to; Oxygen content enhances leanerand cooler combustion.Higher latent heat of vaporization of n-butanol reduce peak cylinder temperature, which in turn reduce EGT(Işık MZ et al 2017)[24].

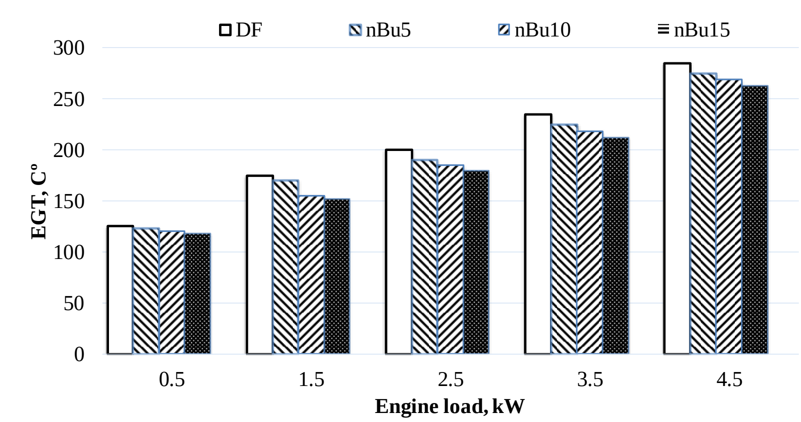

Fig. 4. Variation of EGT vs. engine load

3. 6 Variation of Nitrogen oxides (NOx)

NO_X formation is mainly influenced by oxygen content, in-cylinder temperature, and reactions (palash et al 2013)[25]. Fig. 7 shows at different engine loads, the effect of diesel and n-butanol/diesel blends on NOx. The results show that; Irrespective of fuel used oxides of nitrogen increase with engine load due to higher combustion temperature. Adding butanol to diesel reduce NOx emission and reduce more with butanol addition, due to the leaner engine running and the temperature lowering effect of the butanol, due to its lower calorific value and its higher heat of evaporation. Similar trends were found in Miers et al (2008)[26].

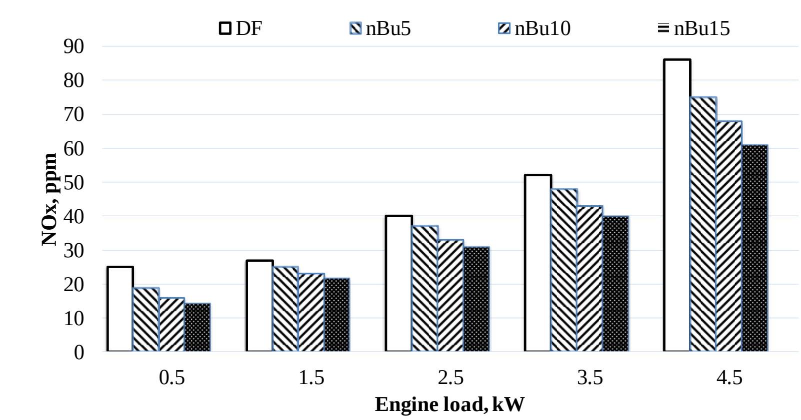

Fig. 6. Variation of NOx vs. engine load

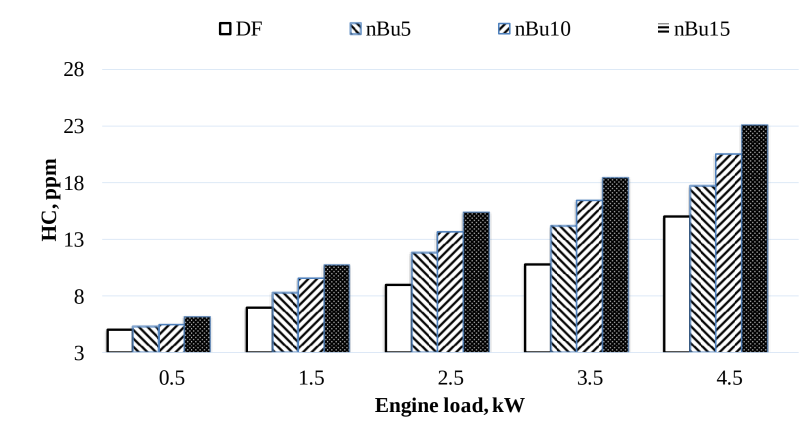

Fig. 7. Variation of HC vs. engine load

3. 7 Variation of Hydrocarbons (HC)

Fig. 8 shows at different engine loads, the effect of diesel and n-butanol/diesel blends on HC. Irrespective of fuel used at low loads HC decrease but increase at high loads due to less oxygen and more fuel (Kalam et al 2011)[27]. Adding butanol to diesel increase HC emission and increase more with butanol addition, thistrend may be due to; (i) Lower cetane number and delay the ignition timing which disturb the combustion.(ii) The higher heat of butanol evaporation (Racopoulus et al 2010)[28].

3. 8 Variation of CO

Fig. 9 showed at different engine loads, the effect of diesel and n-butanol/diesel blends on CO.The results show that;Irrespective of fuel used, CO increase as the engine load increase due to the unstable combustion. Adding butanol to diesel reduce CO and reduce more with butanol addition. This trend may be due to the higher oxygen content of blends which, enhance the complete combustion(Yao et al 2010)[29].

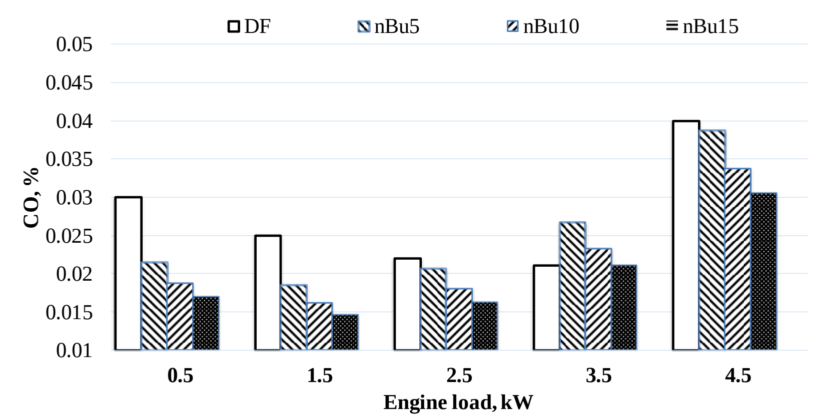

Fig. 8. Variation of CO vs. engine load

3. 9 Variation of CO2

Fig. 10 shows at different engine loads, the effect of diesel and n-butanol/diesel blends on CO_2. The results show that;D100 produced higher CO_2 compared to all the blended fuels. Adding butanol to diesel increase CO_2 and

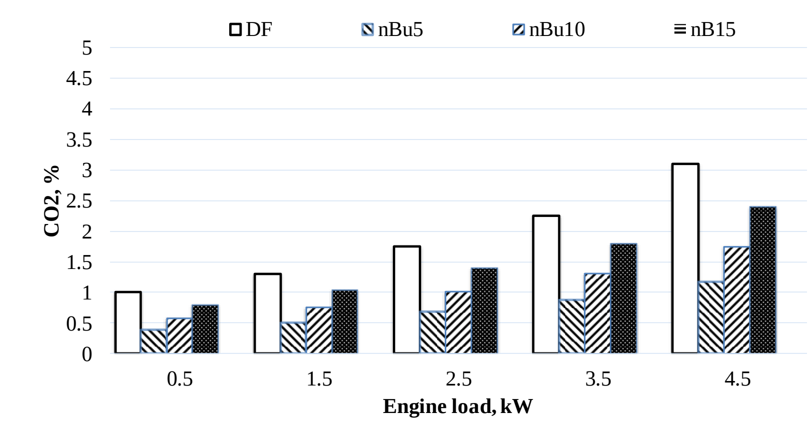

Fig. 9. Variation of CO2 vs. engine load

increase more with butanol addition, due to the engine operating at a leaner air-fuel mixture. This finding is inagreement with Jeevahan et al (2018)[30] which attributed that to the butanol being an oxygenated additive that turns CO into CO_2 exhaust emissions.

Conclusions

An experimental investigation was conducted to evaluate the use of n-butanol as supplement to the conventional diesel fuel at blending ratios of 5/95, 10/90 and 15/85(by volume) in a diesel genset engine. The series of tests were conducted using each of the above fuel blends, with the engine working at a constant speed of 3000 rpm and five different loads. When working with neat diesel or fuel blends measurements of total noise from the engine, cylinder block vibrations, emissions (NOx, HC, CO, EGT) and fuel consumption were made at the same conditions. BSFC and BTE were computed. The following conclusions can bedrawn with n-butanol/diesel fuel blends against diesel fuel; (i) According to engine performance test results; a little higher specific fuel consumption was observed with corresponding slight increase of brake thermal efficiency and little lower exhaust gas temperatures. (ii) According to engine emission test results; the NOx was slightly reduced, this reduction being higher the higher the percentage of butanol in the blend. The CO emissions were reduced, on the contrary, HC emissions were increased, this increase being higher the higher the percentage of butanol in the blend. (iii) According to engine vibration and noise test results; Noise and vibration characteristics are somewhat better especially at lesser loads.

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