Fuel 221 (2018) 44–60

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Experimental investigation on combustion, noise, vibrations, performance and emissions characteristics of diesel/n-butanol blends driven genset engine

Dev Prakash Satsangi, Nachiketa Tiwari*

Dhwani (Acoustics) Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Kanpur, Kanpur 208016, India

A R T I C L E I N F O

Keywords:
A-weighting (dBA)
One-third octave band
Compression ignition engine
Engine vibrations
Root mean square
Decibel
Diesohols
n-Butanol
Performance
Emissions

A B S T R A C T

Several emerging economies, including India, use diesel widely to produce electric power. This is accomplished through millions of small or medium sized generators driven by diesel engines. These engine-alternator combinations, or gensets, are extremely noisy, generate vibrations, and pollute air. There is a pressing need to find alternatives to diesel for such applications. Diesel-alcohol blends (diesohols) could be such alternatives. However, not much effort has been made till so far to evaluate their noise, vibration, emissions, performance, and combustion characteristics. This work fills such a gap by comprehensively investigating the efficacy of four different diesel/n-butanol blends. For this, a single-cylinder 4-stroke naturally aspirated direct injection diesel genset engine was operated at a fixed rpm and at six different load conditions. Detailed measurements of combustion noise, exhaust noise, total noise from the engine, engine vibrations, emissions (NO_x, HC, CO, and smoke), engine pressure, and fuel consumption were made. Data from these measurements were used to establish inter-relationships between engine's noise, vibration, emission, combustion and performance parameters. Linkages between these parameters, and key physical and chemical properties of test fuels were explored. Results show that noise and vibration characteristics of test diesohols are somewhat better especially at lesser loads. However, this trend reverses at higher loads. Analyses of results show strong correlation between combustion noise, rate of pressure rise, and vibration characteristics of test fuels. This work provides a detailed phenomenological explanation for such correlations in terms of fuel properties. Diesohols were also found to perform better for CO, NO_x, and smoke emissions. However, the same may not be said for hydrocarbon emissions and engine efficiency particularly for diesohols with high n-butanol content. Finally, this work establishes that blends of n-butanol and diesel are viable alternatives for diesel for genset applications.

1. Introduction

Compression engines are widely used in automotive as well in genset applications. These engines convert fuel energy into mechanical and electrical energy, respectively. Unlike automotive diesel engines, genset engines are in general simpler in design, run at constant speed, and are stationary. They are rarely electronically controlled, and may or may not be held to ground through foundation bolts. In emerging economies like India, there are millions of such engines in operation. These engines are in general noisy, pollute, and generate vibrations, which gets transmitted to neighboring structures and machines. They also contribute significant amounts of greenhouse gasses. Thus, there is a need to find alternative fuels for these engines, which do not necessitate significant design changes to engine.

Over last several years, substantial attempts have been made globally to identify alternatives to diesel fuel. These alternatives can be grouped in two groups; blends of diesel and biodiesel or oils, and blends of diesel and alcohol. Some works on performance, emissions and combustion of biodiesel-diesel blends in stationary and genset engines are [1–5]. Alcohol-diesel blends can be a promising solution as they are cleaner fuels, combust better, and generate cooler engine temperatures [6–8]. Alcohols can be used in compression ignition engines either through alcohol fumigation, or through dual fuel injection, or as blends of alcohol and diesel or as alcohol-diesel emulsion. Amongst these

Abbreviations: BSCO, brake specific carbon monoxide; BSFC, brake specific fuel consumption; BSHC, brake specific hydrocarbon; $BSNO_x$, brake specific nitrogen oxides; BTE, brake thermal efficiency; CAD, crank angle degree; CI, compression ignition; EGT, exhaust gas temperature; EoC, end of combustion; FFT, fast Fourier transform; HC, hydrocarbons; HRR, heat release rate; *n*-Butanol, normal-butanol; NO_x, nitrogen oxides; P_{rel}, peak in-cylinder pressure relative to diesel; RoPR, rate of pressure rise; Rpm, rotations per minute; SoC, start of combustion

* Corresponding author.
E-mail address: ntiwari@iitk.ac.in (N. Tiwari).

https://doi.org/10.1016/j.fuel.2018.02.060
Received 30 September 2017; Received in revised form 14 December 2017; Accepted 8 February 2018

methods, the first two methods require some modifications in the engine and fuel delivery system [6,9]. However, usage of alcohol-diesel blends or emulsion do not necessitate changes to the engine system. Amongst primary alcohols, use of butanol in blends offers several advantages. Its blends reportedly produce lesser NO_x emissions on account of its higher cetane numbers [10,11]. Further, butanol has higher energy content relative to methanol and ethanol, is less volatile, absorbs lesser moisture and has better corrosive properties. Butanol is easily miscible with diesel unlike methanol and ethanol. Butanol also has similar viscosity and density as that of diesel [12]. Rakopoulos et al. [10] have investigated performance and emissions characteristics of a high speed direct injection diesel engine using n-butanol blends. They reported an increase in BSFC and BTE due to lower calorific value of n-butanol blends compared to diesel. Also, exhaust gas temperature (EGT) reduced for n-butanol blends compared to diesel. This was attributed to high latent heat of vaporization of n-butanol. Emissions for smoke, CO and NO_x were reduced while those for HC increased for n-butanol blends compared to diesel. Yao et al. [13] have studied performance and emissions characteristics of a turbocharged intercooled heavy duty direct injection diesel engine using n-butanol blends. They reported an increase in BSFC for n-butanol blends and attributed this to lower calorific value of n-butanol blends compared to diesel. Reduction in soot and CO emission levels were also reported for n-butanol blends. Such a reduction was attributed to relatively longer injection duration compared to that for diesel.

In another study Rakopoulos et al. [14] investigated performance and emissions characteristics of a six cylinder, turbocharged, after-cooled direct injection diesel engine using n-butanol blends. BSFC and BTE reportedly increased for n-butanol blends compared to diesel due to blend's lesser calorific value. Smoke opacity, CO and NO_x emissions reduced while HC emissions increased for n-butanol blends compared to diesel. Doğan [11] has investigated engine performance and emissions characteristics using a small high speed diesel engine run on n-butanol blends. He has reported an increase in BTE and BSFC for these blends compared to diesel. He attributed this to lesser calorific value of n-butanol and the presence of inherent oxygen in fuel. EGT was also reportedly less for n-butanol blends than that for diesel due to blends lesser calorific value, presence of inherent oxygen content in it and its higher latent heat of vaporization. Similar to the previous work, he also reported a reduction in smoke opacity, CO and NO_x but an increase in HC emission for n-butanol blends.

Siwale et al. [15] have investigated combustion and emissions characteristics of n-butanol blends using a turbocharged compression ignition engine. They reported minor changes in peak in-cylinder pressure for n-butanol blends vis-à-vis diesel. However, the observed increase in heat release rate for n-butanol blends relative to diesel and attributed it to longer ignition delay. They also reported an increase in NO_x, CO, and HC emissions but lesser soot emissions for n-butanol blends. In another investigation Siwale et al. [16] reported an increase in BSFC and BTE for n-butanol blends compared to diesel. They attributed this to combined effects of butanol's lesser calorific value, lesser cetane number, and higher heat of evaporation. Not many studies have been conducted on diesohols run diesel engine's noise and vibrations characteristics. However, there are some works which explore these characteristics for diesel engines run on blends of bio-diesel and diesel. Uludamar et al. [17] have investigated noise and vibrations characteristics using an unmodified diesel engine run on several biodiesel blends. They conducted a regression analysis to predict the relationship between fuel properties and engine's vibration characteristics. They reported a reduction in engine vibrations for diesel–biodiesel blends and attributed this to the presence of inherent oxygen in fuel. Patel et al. [18] investigated noise and vibrations for a single cylinder diesel engine fuelled by preheated Jatropha oil-diesel blends. Results showed reduction in combustion noise, and total noise in range of 1–3 dBA for Jatropha oil-diesel blend relative to diesel. Diesel showed highest vibrations amongst all test fuels in all the three i.e. vertical, horizontal and lateral direction.

Taghizadeh-Alisaraei et al. [19] have investigated vibrations for a diesel engine using canola and soybean biodiesel blends. They reported lesser vibrations in the engine running on pure diesel vis-à-vis one run on biodiesel. Lee et al. [20] have studied correlation between maximum heat release rate and vibration for a diesel engine. They reported vibrations in 0.3–5 and 1.5–2.5 kHz frequency bands attributable to combustion process and piston slap, respectively. In another study How et al. [21] conducted vibration investigations on biodiesel and diesel blends driven diesel engine equipped with high pressure common rail system. They observed a reduction of 13.7% in vibrations for biodiesel-diesel blends relative to diesel. Such a reduction in vibrations was attributed to lesser cylinder pressures for biodiesel-diesel blends. In another study Patel et al. [22] investigated the role of Karanja biodiesel as a fuel in diesel gensets. They reported that 20% blend of biodiesel blend produces maximum combustion noise and heat release rate among all tested fuels. Vibrations were also reported highest for 20% blend of biodiesel blend especially in vertical direction.

Fattah et al. [23] have investigated the effect of biodiesel fuel on engine noise. They observed that chemical and physical properties of fuels play an important role in noise production. They reported a reduction in engine noise while using biodiesel, and correlated this reduction to the lesser cylinder peak pressure relative to diesel. Torregrosa et al. [24] have investigated combustion noise characteristics of synthetic and vegetable oils driven direct injection diesel engine. They reported deterioration in combustion noise with increase in percentage of biodiesel or synthetic oil content in fuel. In both cases, noise deterioration was attributed to difference in combustion phasing and rate of fuel injection. Redel-Macias et al. [25] have studied noise from a diesel engine run on blends of diesel and olive pomace oil methyl ester. They reported a reduction in engine noise while using biodiesel as a fuel and attributed it to its high cetane number.

It is seen that a significant amount of research work has been conducted on performance and emissions of diesel engines fuelled by n-butanol/diesel blends. However there is a scarcity of works which explore combustion, noise, vibrations, performance and emissions in totality for CI engine. Further, there is very little knowledge on the performance of n-butanol run CI engine from noise and vibration standpoints. Given n-butanol's potential as an alternative to diesel, this gap needs to be filled. This work seeks to fill this gap by assessing the behavior of a CI engine comprehensively. The work address engine performance, combustion, noise, vibrations and emissions aspects of the diesel engine for different diesel/n-butanol blends.

2. Test fuels and their characterizations

In this work, four different blends of diesel and n-butanol, as well as diesel, were evaluated. Table 1 shows compositional details of these test fuels. Important properties such as density, kinematic viscosity, and calorific value of test fuels were measured by portable density meter (Kyoto Electronics; DA130N), kinematic viscometer (Stanhope-Seta; 83541-3), and bomb calorimeter (Parr; 6200), respectively. These instruments and the associated fuel characterization methodology are compliant with standards ASTM D4052, ASTM D445, and ASTM D4809, respectively. Table 2 lists these properties of test fuels.

Table 1
Composition of test fuel.

Test fuel	Diesel (%v/v)	n-Butanol (%v/v)	Oxygen (%w/w)
Diesel	100	–	0
DB1	95.1	4.9	1
DB2	90.2	9.8	2
DB3	85.4	14.6	3
DB4	80.5	19.5	4