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Spray characterization, combustion, noise and vibrations investigations of Jatropha biodiesel fuelled genset engine

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HIGHLIGHTS

- Spray characteristics and engine experiments for Jatropha biodiesel.
- Spray penetration & cone angles strongly influenced by ambient pressure.
- HRR_{max} and CD correlated very well with combustion noise.
- Noise and vibrations signatures were closely coupled in engines.
- JB20 showed higher combustion noise & vibrations in all three directions.

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ABSTRACT

There is an urgent need for detailed comparative engine performance assessment of alternative fuels such as biofuels vis-à-vis conventional gasoline and diesel. Single cylinder genset engines are widely used in developing countries in very large numbers in agriculture and decentralized power generation sectors, therefore such a detailed understanding becomes even more important. In this study, the effects of change in fuel on noise, vibrations, and engine combustion characteristics of a single cylinder genset engine are investigated. Three different test fuels; mineral diesel, Jatropha biodiesel (JB100), and Jatropha biodiesel-diesel blend (JB20) were used. Spray characterization studies were also conducted and it was found that the spray penetration length, and spray cone angle are strongly influenced by ambient pressure for all the three test fuels. These parameters are not significantly different, especially at higher ambient pressures (1 MPa, and 2 MPa) for different test fuels. The study shows that the variation of HRR_{max} and combustion duration for test fuels correlates well with our measurements of combustion noise and vibrations. A higher value of HRR_{max} corresponds to higher levels of combustion noise.

1. Introduction

Frequent power cuts and inefficient electrical distribution network drives a very large number of people in developing countries to use single cylinder direct injection diesel engines for generation of electrical power. India heavily depends on the import of crude oil to meet its energy needs therefore it is important for her to look for alternative fuels which are economical, as well functionally comparable, if not better than mineral diesel. In this context, Karanja and Jatropha biodiesels offer a distinct possibility, since their respective vegetable oils can be easily produced in India. In this experimental study, we have conducted a detailed comparative study of Jatropha biodiesel (JB100), Jatropha biodiesel-diesel blend (JB20), and mineral diesel. Our study captures the role of these three different fuels on noise, vibrations, and combustion characteristics of a single cylinder genset engine. Further, we have also characterized these fuels in terms of their properties, as well as their spray parameters. The study of fuel properties was important, because they eventually affect fuel's atomization, combustion, noise and vibration characteristics. Further, these properties play an important role on diverse spray characteristics including its penetration and cone angle, thereby influencing combustion characteristics. In past, several studies have been conducted to understand the interplay between fuel and engine's noise and vibrations characteristics. However, most of these studies have focused on specific dimensions of the problem. While some studies have

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focused only on spray characteristics, others have devoted themselves to investigating engine's operating parameters such as brake thermal efficiency (BTE), heat release rate (HRR), and brake specific fuel consumption (BSFC); while some others have focused on noise aspects. Hence, there is limited information available on the measurement and interplay of *all* of parameters; viz. fuel properties, spray characteristics, and its environmental impact on engine (noise and vibrations).

1.1. Review of past studies

Several researchers in the past have investigated the relationship between fuel properties and spray characteristics for a variety of biodiesels and biodiesel-diesel blends. Lee et al. [1] have experimentally investigated the effect of biodiesel-blend ratio on spray atomization and combustion characteristics. They found that increased viscosity of biodiesel is the main reason for reduction in fuel injection velocity of biodiesels, leading to relatively poorer atomization. They also reported that Sauter Mean Diameter (SMD) of biodiesel was higher due to its higher surface tension. However, they also reported that this had only marginal influence on fuel's spray tip penetration. Similar results were also reported by Gao et al. [2]. However, they reported higher spray penetration and spray tip speed, and reduced spray cone angle for biodiesels. Observations made by Zhao el al. [3] were consistent with those of Gao et al. [2]. Through their spray visualization experiments, they also concluded that increasing ambient pressure led to reduction in spray penetration and increase in spray cone angle. To compare relative influence of different fuel properties on spray characteristics of biodiesels and mineral diesel, Som et al. [4] conducted numerical simulation study. They reported that the differences in spray characteristics between biodiesel and mineral diesel were more pronounced in evaporated state of fuels compared to liquid state. Based on their simulation study results, they argued that vaporization properties such as heat of vaporization and boiling temperature influence spray characteristics to a far greater extent than fuel's physical properties, such as density, viscosity, and surface tension. Further, they argued that as these properties become only relevant post vaporization, spray characteristics for biodiesel and diesel show significant differences only in evaporated state of test fuels.

There have been several studies pertaining to engine performance attributes of diesel engines fuelled with biodiesels. Chauhan et al. [5] observed lower peak cylinder pressure and heat release rate for Karanja biodiesel vis-à-vis mineral diesel. Gumus [6] conducted similar tests using hazelnut oil biodiesel and blends on a direct injection compression ignition engine. They reported that as biodiesel content increased in the blends, it led to increase in combustion duration, reduction in cumulative heat release (CHR) and reduction in rate of pressure rise (RoPR). Tesfa et al. [7] conducted similar experiments on a 4-cylinder, 4-stroke direct injection turbocharged diesel engine using biodiesels made from waste cooking oil, rapeseed oil, and corn oil as well as regular diesel. They observed slightly higher cylinder pressure and heat release rates for biodiesels vis-a-vis baseline mineral diesel. Kegl [8] conducted similar tests on a four-stroke, six-cylinder engine and reported that biodiesel showed lower HRR vis-a-vis mineral diesel. Ozturk [9] conducted similar studies on a single-cylinder diesel engine running on diesel and diesel-biodiesel blends. He observed that ignition delay and maximum HRR decreased with increasing biodiesel content in the test blend.

There have been some investigations to understand the influence of fuel on engine noise and vibration characteristics. Usually, engine noise is attributable to three key sources: combustion noise, exhaust noise, and mechanical noise due to reciprocating, vibrating and rotary motion of various engine parts. It is generally recognized that combustion noise is the most significant component of engine noise.

To understand the role of fuel on engine noise, Li et al. [10] conducted tests on a Euro-4 engine using different blends of waste cooking oil biodiesel. They reported that increasing biodiesel content up to 20% increased combustion noise by 0.5 dB, but reduced vibration levels by 0.25 dB. Patel et al. [11] conducted tests on a single cylinder genset engine using 20% straight vegetable oil (SVO) blended with diesel and reported that SVO blends tend to generate lesser combustion noise as well as external noise vis-à-vis diesel fuelled engine. These reductions were reported to be in the range of 1–3 dB(A). They also reported that such reduced noise levels were accompanied by reduced vibrations in the direction of cylinder axis. Sanjid et al. [12] conducted tests on a single cylinder diesel engine at different engine speeds and reported that combustion noise was positively correlated to the maximum pressure rise rate. As a shorter ignition delay period reduced this value, noise in the engine with shorter ignition delay period was observed to be lesser. They also noted that biodiesel enhanced lubricity and damping, which led to reduced noise levels. However, Torregrosa et al. [13] reported that combustion noise increased with increasing biodiesel content in the test fuel. Spessert et al. [14] conducted experiments using an air-cooled single-cylinder diesel engine operated using rapeseed methyl ester (RME). They reported as much as 2.7 dB(A) increase in sound pressure level (SPL) at part-load condition, compared to noise levels from a mineral diesel fuelled engine. Lee et al. [15] reported a positive correlation between the changes in maximum HRR and the magnitude of engine vibrations. In another work, Sivash et al. [16] reported that single-cylinder diesel engine fuelled with biodiesel-diesel blends generated noise having peak spectral content in the neighborhood of 315 Hz, and this engine noise was lower for blends with lesser biodiesel content. Bao and He [17] conducted tests on a single cylinder diesel engine using 30% rapeseed oil blended with diesel and determined the effect of four engine operating parameters (intake valve closing angle, fuel delivery angle, exhaust valve opening angle and fuel injection pressure) on the engine noise. By optimizing these parameters, they were able to reduce engine noise by 2–4 dB(A). Uludamar et al. [18] observed that sound pressure level and vibrations decreased with increasing percentage of biodiesel in the test fuel. Elshaib et al. [19] reported reduction in noise levels when biodiesel was blended with mineral diesel.

This experimental study was carried out with an objective to understand the interplay of vital parameters; viz. fuel properties, spray characteristics, engine combustion characteristics and their impact on engine noise and vibrations, while using Jatropha biodiesel and its blends in a single cylinder engine, which is using mechanical fuel injection equipment.

2. Experimental setup

Two different experimental setups were designed to conduct this study. The first setup was designed to visualize and characterize the fuel sprays. The second setup was developed to conduct engine combustion, noise and vibrations measurements in a single cylinder diesel engine. In these experiments, three test fuels were used namely: JB100 and JB20 and mineral diesel. The important properties of these test fuels are given in Table 1.

Table 2 shows the distillation characteristics of JB100 and baseline mineral diesel.

2.1. Spray visualization setup

To compare the effect of fuel's physical properties on spray characteristics, we performed spray visualization experiments at