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Vibration analysis of a diesel engine using biodiesel fuel blended with nano particles by dual fueling of hydrogen

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ABSTRACT

In pursuit of environmental friendly alternative fuels for diesel engines, biodiesel is a promising alternative. Efforts are on in utilizing the biodiesel with diesel in Internal Combustion (IC) engines, because of its reduced pollution characteristics. Long-term effects of these biofuels in IC engines have not been explored earnestly. Enduring effects of which are high noise & vibration and irregular & erratic combustion leading to knocking. Few researches on vibration analysis of biodiesel blends have been reported. Hence, an effort is made to study the vibration characteristics of biodiesel blends amidst Zinc Oxide (ZnO) nano particles with hydrogen in dual fuel mode. Initially, experimentation is carried out to record vibration signatures with 100 ppm concentration of ZnO particles of 20 & 40 nm sizes suspended in Jatropha Methyl Ester (JME) biodiesel along with hydrogen as secondary fuel. In order to avoid strenuous experimentation Artificial Neural Network (ANN) model was developed to predict Root Mean Square (RMS) of velocity. ANN predictions are found to be scrupulously matching with the experimental values as manifested by the regression values of 0.97185, 0.98574 & 0.96913 for prediction of RMS velocities in horizontal, vertical & axial directions respectively. It is found that the best fuel blend with least vibration is B30 & B20 with nano particle of size 40 nm for hydrogen flow rates of 0.5, 1.0 & 1.5 l/min.

1. Introduction

In the quest for an alternative fuel for a diesel engine, biofuel is considered to be a potential candidate. Researchers have pondered on the study of biofuels as an alternative fuel. Senthil Kumar (2003) has experimentally investigated the use of jatropha with methanol on Compression Ignition (CI) engine and reported performance enhancement and reduction in NO_X levels. Ramadhas et al. (2005) recorded the feasibility of rubber seed oil on a diesel engine and found it to be a viable alternative to diesel. Yusaf et al. (2011) examined the practicability of crude palm oil with an enhancement in Brake Specific Fuel Consumption (BSFC) and reduction in NO_X. Ignition delay period and performance of a jatropha biodiesel were experimentally examined by EL-Kasaby and Nemit-allah (2013). The peak pressure for 50% of biodiesel blend was obtained for a speed of 1750 rpm and that for 10% of biodiesel blend at 1000 rpm. The increase in peak pressure causes a decrease in ignition delay period with an increase in efficiency. Sonar et al. (2014) probed the feasibility of using mahua oil blended with diesel and found fuel properties similar to diesel.

Biodiesel, a renewable and clean substitute for diesel carry the disadvantage of an increase in NO_X, poor atomization, high viscosity, carbon deposition and incomplete combustion. A viable alternative to reduce the ill effects of using biodiesel through the addition of nano particles to the fuel blends was investigated by Shaafi et al. (2015). Studies on nano metal particle combustion revealed that metal powders have high specific surface area, higher thermal conductivity and high reactivity (Dreizin, 2000, Yetter et al., 2009). The addition of cerium oxide nano particles to the biofuels caused an increase in Cetane number, thus improving the overall fuel efficiency of IC engine (Roger, 2006). Combustion rate of nano-sized metal particles is higher when compared to micro-sized particles. Moreover, the addition of nano particles in the fuel blend does not alter the density or the viscosity as compared to micro-sized particles (Gan and Qiao, 2011). Combustion behavior examination of aluminum and aluminum oxide nano particles suspended in biofuels revealed that the amount of heat release increased linearly with nano particle concentration (Jones et al., 2011). Sadhik Basha and Anand (2011) investigated the role of aluminum oxide

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nano additive and reported enhancement in performance and reduction in emissions. The addition of nano particles caused a reduction in ignition delay, peak pressure and heat release rate in turn increase in BTE, reduction in NO_X and smoke. Koc and Abdullah (2013) studied the performance and NO_X emissions with biodiesel, diesel and water nano emulsions. Biodiesel nano emulsions produce lower NO_X and increase BSFC and CO emissions. When volume concentration of water was increased from 10 to 15%, rate of NO_X reduction was greater than the rate of CO increase. Mehta et al. (2014) tested performance and emission characteristics of diesel with water, aluminum nano with diesel and silicon nano with diesel. BSFC of diesel with water was marginally high when compared to neat diesel. BSFC decreases by 21 & 37% and Brake Thermal Efficiency (BTE) increases by 16 & 14% for aluminum and silicon nano biodiesel respectively when compared to diesel with water.

Enhancement of conventional engine performance and emission reduction by adding hydrogen has been investigated by several researchers and the outcomes are propitious. Saravanan and Nagarajan (2009) addressed the use of hydrogen in diesel fuelled engines and reported a decrease in NO_X emission by five and half times, while other emissions increased by 1.4 times as compared with neat diesel. Lilik et al. (2010) experimentally studied diesel hydrogen dual fuelled combustion characteristics. It is found that increase in hydrogen substitution on energy basis causes an increase in NO_2 emission and decrease in NO, CO & CO_2 emissions. Zhou et al. (2014) examined with hydrogen and reported a reduction in CO emission with lowest NO_X compared to baseline diesel engine.

The researchers have instigated feasibility of biofuels from performance and emission perspective. The enduring effects of using biofuels are yet to be investigated, the effects of which are frequent maintenance, irregular and erratic combustion arising to knocking, erosion of combustion chamber and piston head, vibration of structure and CI engine. An efficient biofuel may not have good enduring characteristics because of vibrations. Engine knock and detonation during combustion of an engine may degrade thermal efficiency. Excessive engine vibrations will reduce the life of the engine. Hence, vibration analysis of ingenious latest fuels reported need to be inquisited.

Barelli et al. (2009) utilized vibration signals for the diagnosis of IC engines and found a viable correlation to predict mean effective pressure inside the cylinders. They also reported greater vibration signal peaks with an increase in load; the amplitude value is strongly decreasing with increase in frequency. Knock detection using vibration signature of a single cylinder diesel engine in three perpendicular directions was reported by Murthy (2011). The long term effect of using biodiesel blends (B0, B10, B20, B30, B40, B50, B75 and B100) at five different compression ratios (16, 16.5, 17, 17.5 and 18) and four injection pressures (100, 150, 200 and 250 bar) was explored by Jindal (2012). B50 fuel blend had better vibration characteristics. Taghizadeh-Alisaraei et al. (2012) investigated with nine different fuel blends at seven different speeds on a six cylinder tractor engine. Lowest vibration was found for B40 & B20 fuels and highest for B15, B30 & B50. On the contrary, B100 & B5 possess lowest vibrations and B10 highest as illustrated by Heidary et al. (2013).

Dehkordi et al. (2013) designed a neural network model with fuel blends and engine speeds as inputs to predict RMS value of vibration. Blends of ethanol (E2, E5, E10, E15 and E20), for speeds (1200, 1600, 2000 and 2400 rpm) and concluded that lowest vibrations were recorded for E10 and highest for E20. Ilić et al. (2013) discovered the impact of changing quality of air-fuel mixture during a flight of an aircraft. The lowest measured values of RMS acceleration for vibrations in all three axes correspond to the maximum value of EGT. Gravalos et al. (2013) systematically designed an experimentation to detect fuel type from vibration behavior on a spark ignition engine. During the course of experimentation, three different fuels (unleaded gasoline, blends of ethanol (E10, E20 &E30) and methanol (M10, M20 &M30)) and different speeds (1000, 1300, 1600 and 1900 rpm) were explored. Engine vibrations were not influenced by the percentage of ethanol or methanol mixed into gasoline, a 10% blend of methanol or ethanol makes nearly the same variation in vibration level as 30% blend. Change in engine speed does not affect engine vibration level.

In this research work, the vibration effects of fuels prepared by trapping the advantage of JME blended with ZnO nano particles and hydrogen is investigated. Initially, an experimental investigation on a single cylinder diesel engine with different; blends of JME, flow rates of hydrogen & sizes of nano particles at various loads is carried out. Experimental data recorded is used to develop an ANN model for predicting RMS of velocity. Lastly, vibration data acquired for the mentioned fuels is analyzed, and the best fuel with least vibrations is figured out.

2. Fuels and experimentation

2.1. Fuels

Fuels used for the experimentation was prepared in home. Crude jatropha oil was degummed, and then transesterification was done with sodium hydroxide to obtain jatropha methyl ester (Berchmans and Hirata, 2008). JME-biodiesel blends were prepared based on the volumetric ratio. ZnO nano particles at a concentration of 100 ppm of 20 & 40 nm sizes were suspended in JME-biodiesel blends by ultrasonication process. Nomenclature adopted for various fuel blends combinations with nano particles are represented in Table 1.

2.2. Experimentation methodology

For the present work, experimentation was conducted on a four stroke single cylinder direct injection diesel engine test rig. Detailed specifications of the test setup are mentioned in Table 2. Hydrogen as a secondary fuel was inducted through an enrichment chamber and as hydrogen possesses a potential risk of back fire propagation, flame arrester and flash arresters were added to the test rig.

Phase-1: Engine was run on standard diesel as a primary fuel. Subsequently hydrogen in dual fuel mode with flow rates of 0.5, 1.0 & 1.5 l/min were introduced at 1 bar pressure.

Phase-2: Engine was run on B100 and hydrogen as a secondary fuel was introduced at flow rates similar to phase-1.

Table 1
Nomenclature and specifications of fuels tested.

Fuel	JME (Vol %)	Diesel (Vol %)	Nano size (nm)
B5JME20	5	95	20
B5JME40			40
B10JME20	10	90	20
B10JME40			40
B15JME20	15	85	20
B15JME40			40
B20JME20	20	80	20
B20JME40			40
B30JME20	30	70	20
B30JME40			40
B100	100	–	–
Standard diesel	–	100	–