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Full Length Article

Determination of vibration characteristics of a compression ignition engine operated by hydrogen enriched diesel and biodiesel fuels

Ahmet Çalık

Mersin University, Ciftlikkoy Campus, 33343, Yenisehir, Mersin, Turkey

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ABSTRACT

Biodiesel is a renewable fuel that is produced from vegetable oils and animal fats. The main advantage of biodiesel is its cleaner characteristic after the combustion. Due to its promising effect on the environment, the use of biodiesel is increasing day by day. Therefore, other effects of biodiesel fuels on internal combustion engine must be investigated by researchers. Mechanical vibration of a machine is a highly important phenomenon for safety. Moreover, in some applications, it directly influences human comfort. The vibration of a vehicle through its internal combustion engine has gained great importance due to the effect on vehicle structure parts and passenger comfort as well as driving safety. In this study, a diesel engine was fuelled with alternative fuel and conventional diesel fuels. Pure conventional diesel fuel was selected as reference fuel to compare vibration characteristics of the engine with respect to various biodiesel fuels. In the study, biodiesel was produced from waste cooking oil. Hydrogen was also added through intake air through experiments. The results indicated that addition of biodiesel in conventional diesel fuel lowered the engine block vibration. Moreover, the addition of hydrogen gas further decreased the engine vibration both with conventional diesel engine and biodiesel blend.

1. Introduction

Internal combustion engines have widely been using in many areas from transportation to power production. Especially diesel engines have prominent advantages such as high energy efficiency, high stability and being flexible for various operating conditions [1,2].

In today's world, ICEs highly depend on conventional petroleum-based fuels. This dependency creates inevitable problems since conventional fuels face with scarcity issue due to growing populations and industrialization. Therefore, scientists are trying to find renewable, sustainable and clean alternatives to fossil fuels. Beside depletion of fossil fuels, strict emission regulations have also forced scientists to search new alternatives [3–6].

Biodiesel can be produced from various feedstocks. Generally, feedstocks can be classified as edible or non-edible vegetable oil, waste or recycled oil and animal fats [7]. Environmental and agricultural conditions, availability of soil, geographical locations are main factors for selection of feedstocks [8]. Especially, waste cooking oil (WCO) is prominent among other feedstocks with its being relatively cheaper for biodiesel production [9]. Feedstock cost can be reduced and removal of waste oil problem can be achieved by converting WCO into biodiesel. WCO is a very big problem in hotels and public eateries [7]. There are various studies which deal with performance, emission and fuel properties of WCO biodiesel operated internal combustion engines as an alternative potential fuel [10–14].

Another potential energy source to replace conventional fossil fuels is hydrogen. Hydrogen is well-known for its being clean and environmentally friendly energy. It generates water after combustion [15]. Hydrogen is naturally available and it can also be produced from different sources [16]. In literature, various studies can be found in which hydrogen gas is used as an additive to main fuel [4,17–20].

Besides usability of alternative fuels such as biodiesel, hydrogen etc. from the perspective of their performance, combustion and emission characteristics, vibration produced by the engine is another important phenomenon [21,22]. Recently, scientists have been trying to reduce vibration of engines since it is very crucial for comfort conditions and mechanical damages. Therefore, automotive manufacturers have forced to develop their products to be able to meet customer demands for high competition in the sector [23]. In this respect, researchers have studied vibration behaviour of internal combustion engines supplied by various fuels. Uludamar et al. (2017) evaluated vibration behaviour of a hydroxyl (HHO) gas generator installed compression ignition engine operated with different diesel-biodiesel mixtures. The experiment resulted showed that the HHO addition was improved the vibration acceleration of engine block [24]. Çelebi et al. (2017) determined noise and vibration characteristic of a diesel engine fuelled with diesel fuel-biodiesel blends with the addition of natural gas. Their results indicated that both biodiesel and natural gas addition decreased engine vibration severity

E-mail address: ac@mersin.edu.tr.

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[25]. Torregrosa et al. (2017) studied the impact of gasoline and diesel blends on combustion noise and emissions in premixed charge compression ignition (PCCI) engines [26]. Taghizadeh-Alisaraei et al. (2012) performed vibration analysis of a compression ignition engine operated with biodiesel and petrodiesel fuel mixtures. In their experiments, effect of biodiesel changed with engine speed [27]. Heidary et al. (2013) made vibration analysis of a diesel engine which uses diesel-biodiesel mixtures. Their intent was to find fuels with minimum vibration level [28].

In this study, a diesel engine was fuelled with alternative fuel and conventional diesel fuel. WCO was used as a feedstock for biodiesel production. Hydrogen gas was also supplied with intake air through experiments. Biodiesel and hydrogen gas effect on a vibration characteristic of the engine were investigated. The engine was operated with diesel, biodiesel, conventional diesel-hydrogen, biodiesel-hydrogen fuels. Here, conventional diesel fuel was used as reference fuel to compare with others.

2. Material and method

In this study, vibration characteristic of conventional diesel and WCO biodiesel fuelled compression ignition engine was determined. The experiments were also repeated with hydrogen addition into intake manifold to see how hydrogen gas affects vibration of the engine.

Biodiesel was produced by using waste cooking oil. If there is high FFA content in triglyceride, alkali-catalyzed transesterification reaction will not be able to occur efficiently [29]. Since oil has high free fatty acid (FFA) value, it was reduced by use of acid catalysis which is a pretreatment method firstly. In transesterification method, sodium hydroxide and methanol were selected as catalyst and alcohol, respectively. Then, oil was mixed with alcohol and catalyst and was heated until the thermometer showed a temperature of 60 °C before the reaction. The mixture was stirred 1 h at the same temperature. Crude methyl ester was held at funnel for 8 h to separate the glycerine from methyl ester. The separated crude methyl ester was washed in warm water and then it is subjected to drying process at 105 °C for 1 h. At the last, methyl ester was passed through a filter and pure biodiesel was obtained. After the production of the biodiesel fuel, some critical fuel properties were measured according to European Standards to determine the usability of the experimental fuel in the test engine. Kyoto electronics DA-130, Zeltex ZX440, IKA-Werke C2000 Bomb Calorimeter, AKV-202 Auto Kinematic Viscosity were used to measure the density, cetane, heating value (calorific value) and viscosity and for cetane number, of the test fuels, respectively. Fuel properties of conventional diesel and WCO biodiesel fuels were given in Table 1.

Experimental studies were performed on a 4-stroke, 4-cylinder, naturally aspirated compression ignition engine (Mitsubishi Canter 4D34-2A). The other specification of the experimental engine was presented in Table 2. H_2 gas was supplied to the intake manifold with a flow rate of 5 L per minute (l/min) and sent to the engine with the air charge. Experiments were conducted at 1200–2400 rpm range under full load condition and the data was collected at 300 rpm intervals. Schematic of the experimental engine was shown in Fig. 1.

The accelerometer of PCB Electronics (Triaxial ICP®, Model No: 356A33) was used to measure vibration. The sensor was bonded to engine support with quick adherent gel. Data was recorded in 3 orthogonal axes (x-longitudinal axis, y-lateral axis, z-vertical axis) (see Fig. 2). The vibration data was gathered via the universal portable measuring system of SINUS Messtechnik GmbH (Soundbook™) operated by SAMURAI v2.6 software and the Toughbook™ CF-18 portable Panasonic computer.

RMS values were used for vibration results which are related with a measure of vibration level providing an amplitude value with respect to the time history of the wave. RMS value was calculated by use of following formula:

$$a_w = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)dt}$$

Table 1
Fuel properties of test fuels.

Fuel Properties	Diesel	EN590	WCO Biodiesel	EN 14,214
Density (20 °C) (kg/m^3)	831	820–845	891	860–900
Cetane Number	55	Min 51	52.34	Min 51
Calorific Value, (Mj/kg)	44.824	–	38.192	–
Kinematic Viscosity (40 °C) (mm^2/s)	2.65	2.00–4.5	4.81	3.5–5.00

Table 2
Specifications of the test engine.

Configuration	In line 4
Firing order	1–3–4–2
Type	3907 cc
Bore	104 mm
Stroke	115 mm
Power	89 kW at 3200 rpm
Torque	295 Nm at 1800 rpm
Oil cooler	Water cooled
Weight	325 kg

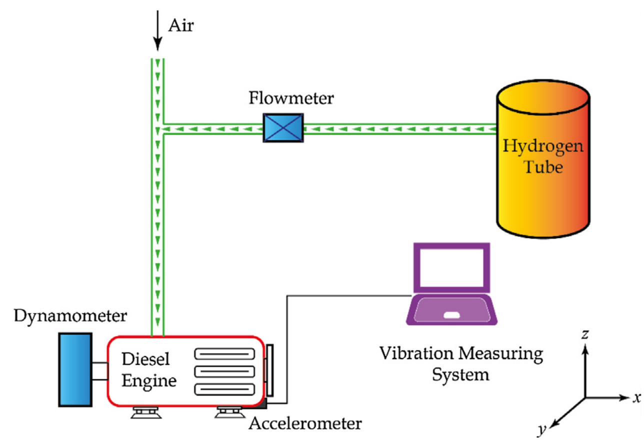

Fig. 1. Schematic of experimental layout.

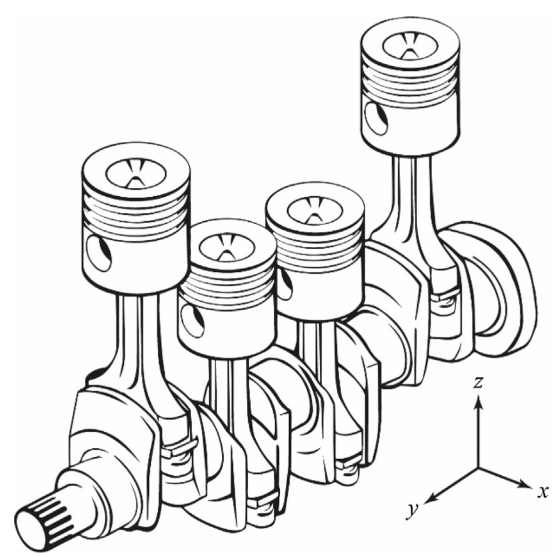

Fig. 2. Vibration axes on engine.

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