Vibration Analysis of a Diesel Engine Fuelled with Sunflower and Canola Biodiesels

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Abstract

Biodiesel is one of the most popular alternative fuels. The usage of biodiesel is increasing day by day. Therefore, all effects of biodiesel on internal combustion engines must be known. In this study, vibration effect of canola (rapeseed), sunflower biodiesel and their blends with low sulphur diesel fuel was investigated. Fuels were tested in a four cylinder four stroke diesel engine at 1300, 1600, 1900, 2200, 2500 and 2800 rpm engine speed. The results showed that with the use of biodiesel blend with low sulphur diesel fuel up to 40% proportions, vibration values get significantly lower at all engine speed. The least vibration value for most of the fuel was observed with the use of 60% biodiesel blend. The results were also individually interpreted in longitude, vertical and lateral axes.

Keywords: Vibration; Canola biodiesel; Sunflower biodiesel; Internal combustion engine

Introduction

Alternative fuels become more important day by day due to depletion of petroleum based fuels. Many countries are mandate by legislations and support the interest in biofuels such as European union (EU) countries which are aim to get 10% of the transport fuel of every EU country from renewable sources [1]. Because of its many advantages, biodiesel is the most prominent alternative fuel. Biodiesel becomes important for compression ignition engines due to reduction of unburned hydrocarbons, particulars, carbon monoxide, and sulphur oxide exhaust emissions and ease of production [2,3].

Moreover it is renewable, non-toxic and biodegradable fuel [4]. Biodiesel can be derived from plants oil or animal fats via a transesterification reaction with alcohols such as methanol and ethanol [5,6]. Recently, the usage amount of biodiesel dramatically increases mainly due to its unlimited source and modification on diesel engines are unnecessary for the usage of biodiesel as a fuel [7].

The effect of biodiesel fuel must be well known for further engine development and engine maintenance. There is limited study about vibration effect of biodiesel fuels on diesel engines.

In vehicles, engines can generate disturbing forces at different frequencies and causes passenger discomfort [8]. Vibration of internal combustion engine is influenced by burning pressure, the movement of piston-crank mechanism, input from the timing gear system, inputs resulting from the work of the fittings of the engine, inputs transmitted from the motor body, flow of cooling factor, inlet and outlet gases, inlet and outlet of fuel through injector, inertia of cam unit’s parts, impacts of head’s parts [9,10].

Some researchers examined the vibration characteristic of internal combustion engines which were fuelled with alternative fuels. How et al. investigated combustion, vibration characteristics, performance and emissions of a high pressured common rail diesel engine which is fuelled with coconut biodiesel blends [11]. Gravalos et al. presented a paper about vibration behaviour of a spark engine fuelled with unleaded gasoline, ethanol, and methanol blends [12].

Taghizadeh-Alisraei et al. studied vibration effect of a biodiesel and its blends on four- stroke six cylinders diesel engine at different rpms [13]. Since canola and sunflower oil is the principal feedstock of Europe, in this paper vibration effect of canola and sunflower biodiesels at different engine speeds were investigated in longitudinal, vertical and lateral axes. In literature, researchers gathered vibration data from engine block, which is far from the chassis connection of a vehicle. Therefore, in this study, accelerometer was adhered on engine support to observe engine vibration just before transmitted to chassis.

Material and Methods

Test fuels

In this study, commercial low sulphur diesel (D), sunflower biodiesel (S100), canola biodiesel (C100) and their blends 20%, 40%, 60% and 80% by volume with diesel fuel (S20, C20, S40, C40, S60 and S80, C80 respectively) were used to conduct the engine experiments.

Commercial sunflower and canola oil were supplied from a local market and used without any further purification. Biodiesels were produced via the transesterification method. In this reaction, methanol and sodium hydroxide were used as reactant and catalyst. The mixture was heated up to 60°C and kept at this temperature for 90 minutes by stirring. After the reaction period, the crude methyl ester was waited at separating funnel for 8 hours. And then, crude glycerine was separated from methyl ester. Finally, the crude methyl ester was washed by warm water until the washed water became clear and then it dried at 110°C for 1 hour. Finally washed and dried methyl ester was passed through a filter.

Test engines

A four-cylinder four-stroke diesel engine with 1500 ccm, 60 bhp and 1250 rpm maximum speed were used to conduct the engine experiments. The engine with in-cylinder pressure and two accelerometers were tested at different engine speeds (1300, 1600, 1900, 2200, 2500 and 2800 rpm).

Test procedure

A filter was used to filter the test fuels before the test engines. The test fuels were heated up to 60°C and kept at this temperature for 90 minutes by stirring. The test fuels were then passed through a filter.

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In this study, diesel engine vibration was measured using an accelerometer. The engine support was adhered on engine support to observe engine vibration just before transmitted to chassis. In literature, researchers gathered vibration data from engine block, which is far from the chassis connection of a vehicle. Therefore, in this study, accelerometer was adhered on engine support to observe engine vibration just before transmitted to chassis.


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Fuel properties were analysed by; Zeltex ZX 440 NIR petroleum analyzer with an accuracy of ±0.5 for determining cetane number; Tanaka AKV 202 auto kinematic viscosity test for determining the viscosity; Kyoto electronics DA-130 for density measurement and IKA-Werke C2000 Bomb Calorimeter for gross heating value determination.

**Experimental engine**

Experiments were performed on a Mitsubishi Canter 4D31, four stroke, four cylinder diesel engine and TT electric AMP 160-4B electrical dynamometer. Experimental layout was shown in Figure 1 and engine specifications were given in Table 1.

Before the experimental measurements were gathered, the engine had been warmed up to constant operating temperature (Figure 1). Then, fuels were tested at 1300, 1600, 1900, 2200, 2500 and 2800 rpm engine speeds (Table 1).

**Vibration meter and accelerometer**

Vibration data was recorded with the HARMONIETM measuring system, Samurai v2.6 from SINUS Messtechnik GmbH and the Tough book TM CF-18 portable PC. It is capable to double integration of the time signal as filtering according to ISO 10816, ISO 7919 and ISO 2954 standards and the measurement range of the vibration meter is 2 Hz to 20 kHz.

Triaxial ICP® accelerometer sensor from PCB electronics model 356A33 was adhered on engine support with quick bonding gels to measure the vibration even in high frequency range. Vibration data were gathered in three orthogonal axes of the engine (x- vertical axis; y- lateral axis, and z- longitudinal axis).

**Calculations**

The results mostly described as RMS value. The RMS value is the most relevant measure of vibration level since it gives an amplitude value by considering time history of the wave. Formulas, which were used to calculate RMS value, were presented in the following equations. In Equation 1 \( a_w (\text{m/s}^2) \) represents the weighted acceleration and \( T \) represents measurement time.

\[
T \int_0^T a_w(t) \, dt
\]

Total vibration acceleration (total \( a_{RMS} \)) is the value to show combined acceleration of three axes. It was calculated by the formula given in Equation 2.

\[
T a_{RMS} = \sqrt{a_{vertical}^2 + a_{lateral}^2 + a_{longitudinal}^2}
\]

**Result and Discussion**

Sunflower and canola methyl esters were used as biodiesel fuels and 100% low sulphur diesel fuel was used as reference fuel. Mixtures of the test fuels were prepared just before the experiments. Quality measurements of the fuels were performed according to TS EN 14214 biodiesel standard and EN 590 diesel standard. Fuel properties were given in Table 2.

RMS values of test engine at three orthogonal axes were illustrated in Figure 2. Previous studies were indicated that upward and downward movement of engine pistons primarily responsible of vertical motion whereas, longitudinal motion affected by torque variation and other auxiliary equipment cause the engine vibrate at lateral axis [12].

Total \( a_{RMS} \) values of the engine which fuelled with sunflower and canola biodiesels were presented in Figures 3 and 4, respectively. The results indicated as total \( a_{RMS} \) value according to different engine speeds. Engine speed was significantly affected the engine vibration severity at every fuel. Up to 60% canola and sunflower biodiesel addition, total \( a_{RMS} \) values were decreased and the least vibration acceleration observed with this blend ratio. For the blend of 80%, the total \( a_{RMS} \) values started to increase. However, pure biodiesel caused slight reduction compared to 80% blends. This trend was observed at all engine speeds for most of the test fuel. In addition, it should be pointed out that the descents of total \( a_{RMS} \) values were more significant until 40% biodiesel proportion. Addition of canola biodiesel decreased vibration severity more than sunflower biodiesel addition.

Theoretically, at 1300 rpm, 1600 rpm, 1900 rpm, 2200 rpm, 2500 rpm, and 2800 rpm engine speeds, ignition frequency of four cylinder four stroke diesel engine are 43,33 Hz, 53,33 Hz, 63,33 Hz, 73,33 Hz, respectively.

<table>
<thead>
<tr>
<th>Test Fuels</th>
<th>Density (kg/l)</th>
<th>Cetane Number</th>
<th>Kinematic Viscosity at 40°C (mm²/s)</th>
<th>Gross Heating Value (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>0,837</td>
<td>59,3</td>
<td>2,7</td>
<td>45857</td>
</tr>
<tr>
<td>S20</td>
<td>0,844</td>
<td>53,8</td>
<td>4,2</td>
<td>44246</td>
</tr>
<tr>
<td>S40</td>
<td>0,854</td>
<td>53,0</td>
<td>4,5</td>
<td>43430</td>
</tr>
<tr>
<td>S60</td>
<td>0,865</td>
<td>50,9</td>
<td>4,6</td>
<td>42472</td>
</tr>
<tr>
<td>S80</td>
<td>0,876</td>
<td>47,6</td>
<td>5,1</td>
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<tr>
<td>S100</td>
<td>0,886</td>
<td>44,5</td>
<td>5,5</td>
<td>39149</td>
</tr>
<tr>
<td>C20</td>
<td>0,846</td>
<td>54,3</td>
<td>4,5</td>
<td>43413</td>
</tr>
<tr>
<td>C40</td>
<td>0,857</td>
<td>53,4</td>
<td>4,8</td>
<td>42986</td>
</tr>
<tr>
<td>C60</td>
<td>0,867</td>
<td>51,7</td>
<td>5</td>
<td>41756</td>
</tr>
<tr>
<td>C80</td>
<td>0,877</td>
<td>49</td>
<td>5,2</td>
<td>40129</td>
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<td>C100</td>
<td>0,883</td>
<td>46</td>
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</table>

**Table 1:** Technical specifications of the test engine.

**Table 2:** Fuel properties of the test fuels.
83.33 Hz, and 93.33 Hz, respectively. In Figure 5, a spectrum of the engine vibration was presented at 2200 rpm engine speed when it was fuelled with low sulphur diesel fuel. It can be seen from the figure that the dominant frequency was the piston stroke frequency (73.33 Hz) of the engine occurred at x- (vertical) axis due to the upward and downward movement of the pistons. Fluid impact or mechanical impact such as eroding of ball bearing may have caused vibration at high frequencies [14].

These reasons may have led to the highest vibration acceleration...
occurred in z- (longitudinal) axis. According to fuel type, at different engine speeds, vibration acceleration significantly changed along x- and z- axes whereas slight differences were observed at y- (lateral) axis. Due to vibration at x- axis depends on downward-upward piston movement, vibration at this axis increased with engine speed and the conversion of linear motion to rotational motion, a component of vertical force was directly transferred to the z- axes [12].

Conclusion
This study was carried out for investigation of diesel engine vibration characteristic which was fuelled with canola and sunflower biodiesels. Contrary to the literature, accelerometer was adhered on engine support, where it connected to the chassis. The test engine was run at six engine speeds with low sulphur diesel, biodiesel fuels and their proportions.

Following conclusions have been summarized:

- Vibration amplitude increased with engine speed.
- Canola and sunflower biodiesel addition into the low sulphur diesel fuel decreased the vibration acceleration of the diesel engine. Addition of canola biodiesel decreased vibration severity more than sunflower biodiesel addition.
- Up to 40% biodiesel blend of canola and sunflower biodiesels with low sulphur diesel fuel, vibration values significantly improved, and the least value observed with 60% biodiesel blend for most of the test fuel.
- The results also showed that, even though total $a_{max}$ of all frequencies were highest at longitude axis, at all engine speeds; the maximum vibration amplitude occurred in vertical axis due to upward and downward piston movement.

Acknowledgement
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References