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

Erinç Uludamar[1]*, Gökhan Tüccar[2], Kadir Aydın[1] and Mustafa Özcanlı[3]

[1]*Department of Mechanical Engineering, Çukurova University, 01330 Adana, Turkey*
[2]*Department of Mechanical Engineering, Adana Science and Technology University, 01180 Adana, Turkey*
[3]*Department of Automotive Engineering, Çukurova University, 01330 Adana, Turkey*

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 prominence 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-Alisaraei 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, C60 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.

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 HARMONIE™ 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

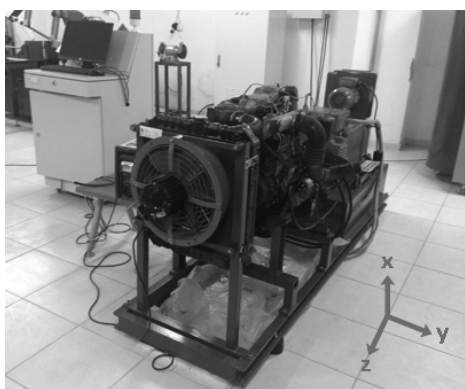The results mostly described as RMS value. The RMS value is the most relevant measure of vibration level since it gives an amplitude value by considering time history of the wave. Formulas, which were used to calculate RMS value, were presented in the following equations. In Equation 1 a_w (m/s²) represents the weighted acceleration and T represents measurement time

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

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.

$$Total\ a_{RMS} = \sqrt{a_{vertical}^2 + a_{lateral}^2 + a_{longitudinal}^2} \tag{2}$$

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,

Figure 1: Layout of experimental setup.

Brand	Mitsubishi Canter
Model	4D31
Configuration	In line 4
Type	Direct injection diesel with glow plug
Displacement	3298cc
Bore	100
Stroke	105
Power	91 HP @ 3500 rpm
Torque	223 Nm @ 2200 rpm
Oil Cooler	Water cooled

Table 1: Technical specifications of the test engine.

Test Fuels	Density (kg/l)	Cetane Number	Kinematic Viscosity at 40°C (mm²/s)	Gross Heating Value (kcal/kg)
D	0,837	59,3	2,7	45857
S20	0,844	53,8	4,2	44246
S40	0,854	53,0	4,5	43430
S60	0,865	50,9	4,6	42472
S80	0,876	47,6	5,1	41388
S100	0,886	44,5	5,5	39149
C20	0,846	54,3	4,5	43413
C40	0,857	53,4	4,8	42986
C60	0,867	51,7	5	41756
C80	0,877	49	5,2	40129
C100	0,883	46	5,4	38363

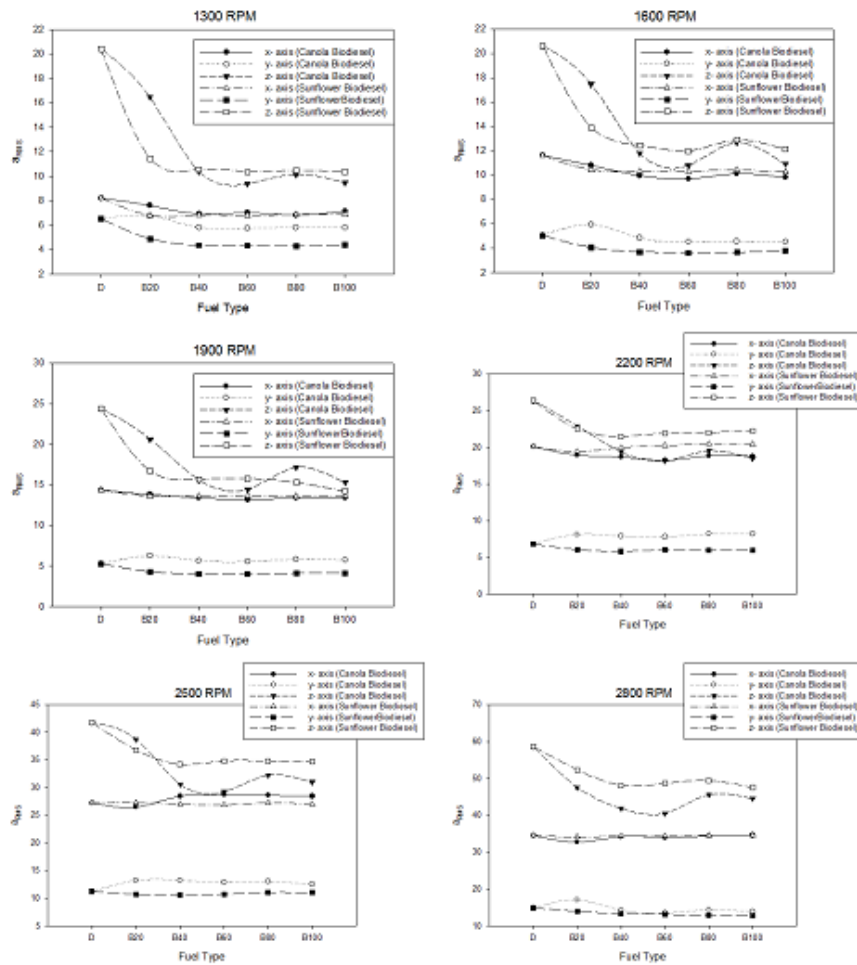**Table 2:** Fuel properties of the test fuels.

Figure 2: RMS values of the test engine at three orthogonal axes with various engines operating speed.
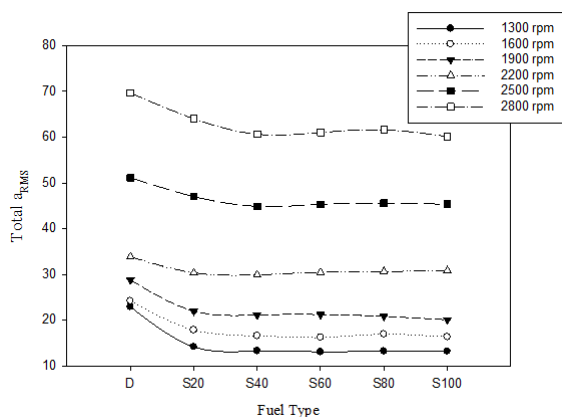

Figure 3: Total a_{RMS} values of sunflower biodiesel.
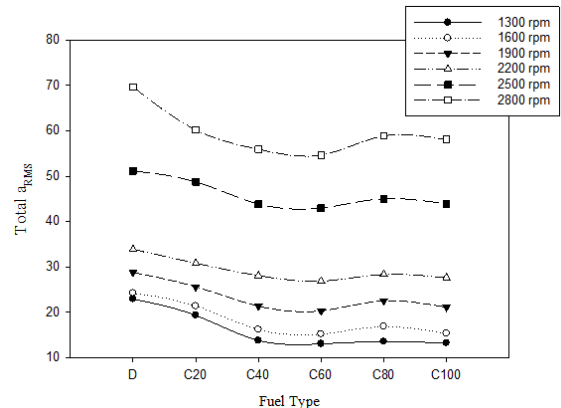

Figure 4: Total a_{RMS} values of canola biodiesel.

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].

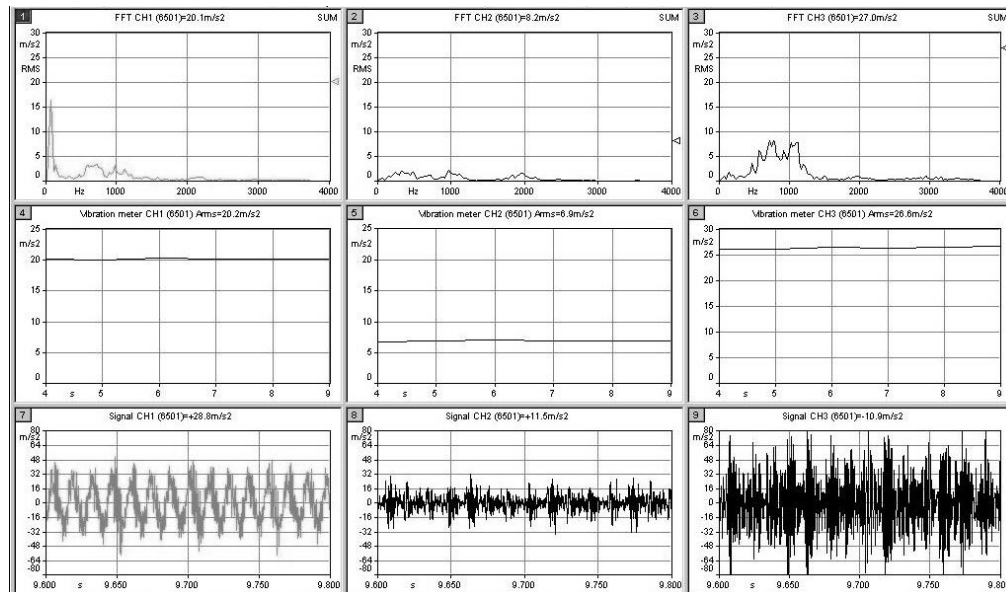These reasons may have led to the highest vibration acceleration

Figure 5: Spectrums of the engine vibration in three axes at 2200 rpm engine speed signal recorded fuelled with low sulphur diesel fuel.

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_{rms} 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

References

1. Roy MM, Wang W, Bujold J (2013) Biodiesel production and comparison of emissions of a DI diesel engine fueled by biodiesel–diesel and canola oil–diesel blends at high idling operations. Applied Energy 106: 198-208.

2. Bergthorson JM, Thomson MJ (2015) A review of the combustion and emissions properties of advanced transportation biofuels and their impact on existing and future engines. Renewable and Sustainable Energy Reviews 42: 1393-1417.

3. Talebian-Kiakalaieh A, Amin NAS, Mazaheri H (2013) A review on novel processes of biodiesel production from waste cooking oil. Applied Energy 104: 683-710.

4. Arbab MI, Masjuki HH, Varman M, Kalam MA, Imtenan S, et al. (2013) Fuel properties, engine performance and emission characteristic of common biodiesels as a renewable and sustainable source of fuel. Renewable and Sustainable Energy Reviews 22: 133-147.

5. Lee KT, Lim S, Pang YL, Ong HC, Chong WT (2014) Integration of reactive extraction with supercritical fluids for process intensification of biodiesel production: Prospects and recent advances. Progress in Energy and Combustion Science 45: 54-78.

6. Farobie O, Yanagida T, Matsumura Y (2014) New approach of catalyst-free biodiesel production from canola oil in supercritical tert-butyl methyl ether (MTBE). Fuel 135: 172-181.

7. Özener O, Yüksel L, Ergenç AT, Özkan M (2014) Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel 115: 875-883.

8. Yu Y, Naganathan NG, Dukkipati RV (2001) A literature review of automotive vehicle engine mounting systems. Mechanism and Machine Theory 36: 123-142.

9. Czech P, Lazarz B, Madej H, Wojnar G (2010) Vibration diagnosis of car motor engines. Acta Technica Corviniensis: Bulletin of Engineering 3: 37-42.

10. Tomaszewski F, Szymanski GM (2012) Frequency analysis of vibrations of the internal combustion engine components in the diagnosis of engine processes. The Archives of Transport 14: 117-125.

11. How HG, Masjuki HH, Kalam MA, Teoh YH (2014) An investigation of the engine performance, emissions and combustion characteristics of coconut biodiesel in a high-pressure common-rail diesel engine. Energy 69: 749-759.

12. Gravalos I, Loutridis S, Moshou D, Gialamas T, Kateris D, et al. (2013) Detection of fuel type on a spark ignition engine from engine vibration behaviour. Applied Thermal Engineering 54: 171-175.

13. Taghizadeh-Alisaraei A, Ghobadian B, Tavakoli-Hashjin T (2012) Vibration analysis of a diesel engine using biodiesel and petrodiesel fuel blends. Fuel 102: 414-422.

14. Chen J, Randall RB, Peeters B (2016) Advanced diagnostic system for piston slap faults in IC engines, based on the non-stationary characteristics of the vibration signals. Mechanical Systems and Signal Processing 75: 1–21.