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# Vibration and acoustic characteristics of a city-car engine fueled with biodiesel blends

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## HIGHLIGHTS

- Investigation on the impact of UCO bends on the engine vibro-acoustic behavior.
- The engine is mainly used in micro-cars in urban areas.
- Data analysis to select the vibration/acoustic components related to the combustion.
- Indicators used to evaluate the effect of blends on vibration and noise radiation.

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## ABSTRACT

A number of studies have demonstrated that biodiesel is a more environmentally sustainable fuel than petroleum-derived fuels since it is a renewable source of energy and it allows to reduce undesired exhaust emissions (e.g. unburned HC, CO and particulate matter).

However, specialized literature highlights there is still the need to further investigate performance, emissions and NVH characteristics of engines equipped with up-to-date technologies fueled with biodiesel blend.

The aim of the present paper is to investigate the vibro-acoustic behavior of a small displacement engine, mainly employed in micro-cars, fueled with blends of distilled biodiesel (obtained from used cooking oil) and ultra low sulfur diesel fuel up to 40% by volume. Demands for reducing chemical and noise pollutions, traffic congestion and parking difficulties in urban areas make the micro-cars one of the possible solutions for the future urban environment, especially if the engine is fueled with biodiesel blends for their potential of reducing the pollutant emissions.

An original methodology developed by the authors for in-cylinder pressure characterization via non-intrusive measurements is here applied to evaluate the impact of biodiesel content on the combustion process and therefore on engine vibration and noise emissions. The data processing in frequency domain allowed to extract the components mainly related to the combustion events. Concerning vibration signals: for all blends, the vibration amplitudes increases with the increase of engine speed values; B40 is characterized by highest values of RMS of accelerometer signal almost in the complete engine operative field. RMS values obtained for B10 are the lowest ones in most of the investigated engine operative conditions.

Concerning noise radiation: the Noise Index was used to evaluate the components of the emission where the combustion energy demonstrated to be concentrated. The results show an increase of Noise Index for all blends with the increase of engine speed. B10 is characterized by the highest values in most of the testes conditions. B40 values demonstrated the opposite behavior.



## 1. Introduction

In the past years, many types of fuels have been proposed for internal combustion engines, among which those made from agricultural products have been demonstrated to be suitable for Diesel engines.

*Abbreviations:* deg CA, crank angle degree; NI, noise index; NVH, noise vibration harshness; RMS, root mean square; STFT, short time Fourier transform; UCO, used cooking oil; ULSD, ultra-low sulfur diesel.

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Biodiesel is a type of biofuel made from different kinds of fats and vegetable oils [1]. Many studies have been performed with the aim to analyze the effects of biodiesel on the injection process, spray formation, combustion, engine performance, vibration, noise and pollutants emissions [2–4]. Most of researchers agree that the use of biodiesel is responsible for an increase of brake specific fuel consumption, a reduction of particulate matter emission as a consequence of the oxygen content in the fuel and also of the chemical structure of the fuel molecule. The reduction of such an emission mostly comes along with increase of $NO_x$ emission. The main issues are related to the biodiesel higher viscosity than conventional fuels, and deposit formation and material degradation at long-term.

Although the researches on biodiesel combustion in engines and pollutant emissions are in a great number, few studies can be found on engines equipped with up-to-date technologies (e.g. common-rail, EGR, DPF). Moreover, only some researches are devoted to the employment in diesel engine of advanced biofuel obtained starting from a mixture of used cooking oil (UCO), a source not suitable for human consumption [5,6]. UCO offers many benefits when it is used as a fuel source since it can be prepared at relatively cheap price in comparison with fresh vegetable oil costs and its disposal problem is eliminated. An et al. [7] evaluated the performance and pollutant emissions of an EURO IV diesel engine fueled with biodiesel derived from UCO in different blend ratios. In the study conducted by Can [8], UCO in blends with diesel fuel was tested in a single cylinder diesel engine at fixed value of engine speed. Chang et al. investigated the effects of using waste cooking oil in biodiesel blends on the toxic organic pollutant emissions from a diesel engine [9].

Furthermore, despite of the high number of publications concerning the effects of biodiesel on diesel engine combustion and pollutant emissions, only few papers are related to vibration and noise aspects. Fattah et al. [10] reviewed the impact of various biodiesel fuels on noise emission and highlighted the influence of chemical and physical properties of biodiesel on combustion development. Sanjid et al. [11,12] experimentally investigated a diesel engine and compared the sound levels of different biodiesel blends. Results show that noise emission was significantly reduced using blends in comparison with diesel fuel. Yildirim et al. [13] tested a six cylinder diesel engine at a constant engine speed and measured vibration and noise related to four different fuels. They highlighted that mean noise of diesel fuel is often higher than biodiesel; the highest vibration was obtained with B50 fuel. Redel-Macías et al. [14] showed that the use of biodiesel/diesel fuel blends improves the sound quality of the noise emission. Shaikh and Umale [15] compared the vibro-acoustic behavior of a single cylinder diesel engine fueled with biodiesel blends at a fixed value of engine speed. Results show that as the percentage of biodiesel blends increases, noise and vibration are reduced. Zhen et al. [16] examined the effects of biodiesel on produced noise of a four cylinder turbocharged diesel engine. The sound energy level of combustion noise obtained fueling the engine with biodiesel and its blends was higher than that one obtained when the engine was fueled with diesel fuel. Alisarei et al. [17] evaluated the vibration of a tractor engine; the results show that the vibration levels significantly are affected by the percentage of biodiesel in the blend. Ahmed et al. [18] investigated the noise emission of biodiesel blends in a four cylinder diesel engine. The sound levels with all the blends were found to be lower than diesel fuel. In [19], Heidary et al. examined the vibration of a tiller engine. The results indicate that fuel blends have significant effect on the vibration: B5, B20 and B100 have the lowest vibration, B10 and B15 have the highest vibration.

In summary, literature reports somehow contradictory conclusions about both performance and pollutant emissions and noise and vibration characteristics. The differences in the obtained results are to be ascribed to the origin and quality of biodiesel, to the engine type and engine testing in terms of speed, load conditions, fuel injection strategy and ambient conditions. This suggests the importance of further investigating combustion, pollutant emissions, NVH characteristics of engines at the current state of art fueled with a second generation of biodiesel.

This work is framed within a wide research activity devoted to investigate the engine used in micro-city car when it is fueled with an advanced biofuel from a mixture of used cooking oil (UCO). The first phase of the research aimed at analyzing the engine performance and pollutant emissions. The main results of such activity are reported in [20].

The present paper shows the results of the second phase of the research program, that was devoted to investigate the noise and vibration characteristics of the city car engine fueled with blends of different percentage of biodiesel from UCO and diesel fuel. The new contribution of this work is related both to the type of fuel and engine that was investigated. Furthermore, the methodology used to process the acquired data is original; it was developed by the authors with the aim of characterizing the crank-angle evolution of in-cylinder pressure by means of non-intrusive measurements, such as microphones, accelerometers. The same methodology was here used to evaluate the impact of fuel properties on the combustion events in terms of RMS of the accelerometer data and of Noise Index [21]. The approach retains a general validity and could be used in a real-time control algorithm in which the settings of the injection parameters could be accomplished to achieve a target by comparing the estimated and desiderated values. The desiderated values could be set in regards to not only the engine performance and emissions factors, but also to the NVH aspects.

## 2. Experimental equipment and engine specifications

A 2-cylinder, water-cooled, common rail diesel engine was used in steady-state testing (the engine specifications are reported in Table 1). The engine was installed in a non-anechoic chamber in the Engineering Dept. Laboratory of ROMA TRE University, without special acoustic monitoring precaution.

It was connected to SIEMENS 1PH7 asynchronous motor and was instrumented for pressure and temperature measurements to fully characterize the engine operative conditions. Instantaneous pressure were measured in one of the cylinders (the preheating plug was substituted by the piezoelectric pressure probe AVL GU13P) and in different positions along the intake (piezoresistive transducers Kistler 4007BS5F) and exhaust systems (piezoelectric water cooled transducers AVL QC43D).

Vibrations and sound radiation measurements were performed by means of Endevco 7240C mono-axial piezoelectric accelerometer and microphone (Bruel and Kjaer Free-field ¼-in. type 4939, with associated preamplifier type 2670). Tables 2 and 3 report

**Table 1**
Engine specifications.

| | |
|---|---|
| Engine type | Four stroke, direct injection, naturally aspirated, water cooled |
| Cylinders | 2 |
| Displacement | 440 $cm^3$ |
| Bore | 68 mm |
| Stroke | 60.6 mm |
| Compression ratio | 20:1 |
| Maximum power | 8.5 kW @ 4400 rpm |
| Maximum torque | 25 Nm @ 2000 rpm |