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Experimental assessment of performance and emissions maps for biodiesel fueled compression ignition engine

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HIGHLIGHTS

- Study of combustion characteristics for biodiesel, diesel and theirs blends in CI engine.
- Effects of engine speed and load on performance and emissions maps are investigated.
- The BSFC for biodiesel shows an inverse behavior to petrol diesel and its blends.
- UHC emissions increase with engine speed. The effect of load is noticeable for blends.
- CO and PM emissions are correlated with load. They are less sensitive to engine speed.

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ABSTRACT

Attempts to use many types of biofuel have been tried throughout the past. Waste cooking oils (WCO) represent attractive alternatives to edible fat and oils for the production of biodiesel fuel from different points of view: they are inexpensive feedstock for biodiesel production. At the same time, using this kind of feedstock eliminates food versus fuel competition. Finally, Their use supposes an environmentally friendly approach.

Internal combustion engines operate correctly on a wide range of speeds and loads. However, only few studies on biodiesel fueled engines are undertaken for performance mapping. In the present study, the effects of entire operational range of speed/load on engine performance and emission levels of an engine are investigated when neat WCO biodiesel (B100) and its blends (B25) and (B50) are used. The obtained results are compared to those of conventional diesel (B0).

The suitability of WCO biodiesel has been established by many researchers. However their results report a wide disparity on emission levels. Combustion characteristics, performance and emission maps will be performed to give appropriate indications explaining the divergence reported in literature. The map indicates that B50 and B25 exhibit similar trends of BSFC to diesel fuel, across the speed variation albeit with difference in response levels. Contrariwise B100 shows an inverse behavior with speed increase. Results show also that Unburned Hydro-Carbons (UHC) emissions are highly correlated with engine speed. However, CO and PM emissions are extremely correlated with load and they are less sensitive to engine speed. NOx emissions are generally higher with biodiesel except some extreme zones of the map.

1. Introduction

The rising worldwide demand for fossil energies i and its related pollution problems require urgent development of renewable and environmentally friendly energy sources. Therefore, biomass derived fuels like biodiesel are required to substitute diesel fuel. Biodiesel is technically suitable for use in compression ignition engines. It is comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats. It is designated as B100 and it meets the requirements of European Standard EN-14214 and/or the American Society for Testing and Materials D-675 [1].

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Bio-fuels might contribute to meet the future energy supply demands as well as helping to the reduction of green house gas emissions (GHG). However, extensive adoption of biofuel required more land to cultivate energy feedstock. Natural forests are snatched in some countries for plantation purposes of biodiesel industry. In addition, this can increase the conversion of cultivable land usages from food to biofuel production [2,3], causing food shortage [4]. Many investigations are currently led on the numerous sustainable energy options in agriculture including the use of more energy efficient technologies and the replacement of fossil fuels using renewable energy powered technologies [5].

Ester of fatty acids (biodiesel) differs from diesel fuel in its composition and properties which could lead to differences in engine performance, combustion characteristics and exhaust emissions. Literature sources present exhaustive lists of biodiesel advantages: it helps decreasing GHG emissions to the atmosphere, it does not contain sulfur or aromatic compounds, it is renewable in nature and safer to handle, in addition, its oxygen content reduces emissions related to poor combustion conditions [6,7]. Biodiesel use results in some drawbacks comparing to diesel fuel including: high specific fuel consumption, substantial emissions of oxygenated-hydrocarbons, poor flow properties at low-temperature conditions, drop in brake thermal efficiency and high costs of production [8].

The use of waste fats or vegetable oils as feedstock for transesterification process can partially solve the problem of biofuel production costs. Talebian-Kiakalaieh et al. [9], claimed that using WCO as feed stock can reduce biodiesel production costs up to 60–90%.

Frying oil leads to various chemical and physical changes resulting in the formation of some polymerized tri-glycerides and free fatty acid. These undesirable compounds increase the molecular weight of the oil and reduce its volatility. Thus, fatty acid esters of fried oils influence fuel properties such as viscosity and burning characteristics resulting in greater amount of carbon residue [10,11]. Nevertheless, the suitability of WCO methyl ester as a biodiesel has been ascertained by many researchers, even the obtained results are mixed, mainly about emissions.

In spite of the high consensus in trends of performance and emissions recognized in the literature when using biodiesel, there is still a lack of correspondence in the conclusions made by some authors. This may be due to various factors like biodiesel feedstock, blending ratio and engine operating conditions which affect the combustion characteristics and pollutant formation processes [12].

Lapuerta et al. [13] reported that ethyl esters obtained from WCO emit lower UHC at medium load conditions. Nevertheless no clear tendency was established at low load conditions. Such trends are in agreement with An et al. [14] observations. The UHC emissions are found to be lower at all engine operation conditions, except under partial load at very low speed. It has been proved that load conditions have a significant effect on carbon monoxide (CO) emissions. Although Lin et al. [15], Durbin et al. [16] reported an augmentation of particulate matter (PM) emissions when fueling with WCO biodiesel, an evident decrease in particulate matter emissions with the biodiesel is the noticeable trend in literature. Most of the published studies revealed a slight increase in nitrogen oxides (NOx) emissions when using WCO biodiesel. However, a number of authors claimed that NOx increased only under some conditions such as alcohol-base of tested ester and certain conditions of load.

Usually, compression ignition engines are designed to operate well within useful operational speed–load condition, however, performing accurately transient load/speed tests are extremely complicated and quite expensive (these require an entirely automated test-bench with electronically control of motoring and dissipating dynamometer, fast responses exhaust gas emissions analyzers, etc.). Individual load or speed accelerations tests are of wide acceptance rather than examination of the engine performance during the entire transient Cycle [17].

To characterize the responses of diesel-engined vehicles, during a transient/driving cycle, many relatively straightforward approaches are presented in literature [18–22]. These approaches use as a basis the steady-state engine tests, rectification coefficients are applied to account for transient discrepancies based on individual transient data.

Therefore, in spite of the steady applications like generators or the marine sector, utilization of a steady-state test cycle gives an alternative to transient test when engine performance and emissions are of special interest instead of the investigation on the overall driving cycle [7].

Only few studies of biodiesel fueled engine cover the full speed–load spectrum. Thus, the objective of this work is to investigate the effects of engine speed and load, over the entire operational range of a direct injection compression ignition engine, when fueled with biodiesel. Construction of combustion characteristics, performance and emissions maps gives a closer look contributing to explain some divergences reported in literature.

2. Materials and methods

For the present investigation, a naturally aspirated, direct injection (DI) diesel engine developing 7.5 kW at 2500 rpm was used. Table 1 gives the engine specifications. An eddy current dynamometer is coupled to the engine for converting the generated power to electricity that will be directly injected to the network. Acquisition and control of measured signals were performed by two systems. The first one commands the engine dynamometer and measures engine speed, torque, exhaust emissions, temperature and pressure in the collectors at a low-frequency. A second system allows the acquisition of high-frequency measurements (pressure in the cylinder, angular position of the crankshaft and fuel injection). Cylinder pressure was measured each 0.2 °CA using a water cooled piezoelectric pressure sensor, type AVL-QH32D. The pressure of injection measurement was performed by a piezoelectric transducer, type AVL-QH33D, placed between the fuel injector and the injection pump. An encoder, type AVL-364C, located in the flywheel measured the crankshaft angular position. The intake air flow was measured by a differential pressure transmitter, type LPX-5481. The test setup was equipped with a number of thermocouples type K for temperature measurements of engine parts. An active transmitter for humidity and temperature, type HD-2012-TC/150 allows measure of ambient temperature. The measure of fuel flow was performed using a Coriolis mass-flow meter.

Regarding emissions, a Crystal COSMA 500 gas analyzer placed on the line of the engine exhaust gas was used to analyze the main pollutants. Emissions of UHC were measured by FID (flame ionization detector) using a heated hydrocarbon analyzer (model GRAPHITE 52 M) while those of nitrogen oxides (NOx) were measured via a chemiluminescence nitrogen oxide analyzer

Table 1
Specifications of test engine.

Maximum power	7.5 kW @ 2500 rpm
Cooling system	Air cooled
Number of cylinders	01
Volumetric ratio	18–1
Bore	95.30 mm
Stroke	85.50 mm
Connecting rod length	165.30 mm
Swept volume	630 cc
Injection pressure	250 bar
Injection timing	13 °CA before TDC