Applied Energy 124 (2014) 35–43

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Performance, combustion and emission tests of a metro-bus running on biodiesel-ULSD blended (B20) fuel

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HIGHLIGHTS

- Power and torque characteristics of B20 fuelled bus were similar to ULSD.
- Combustion characteristics of B20 and ULSD were also similar.
- Emissions of CO and HC were lower for B20 than ULSD.
- NO_X emission of B20 was higher than ULSD.
- PM_{10} and opacity were lower for B20 than ULSD.

ARTICLE INFO

Article history:
Received 6 September 2013
Received in revised form 17 February 2014
Accepted 2 March 2014
Available online 20 March 2014

Keywords:
Biodiesel
Performance
Combustion
Emission
Particulates
Diesel engine

ABSTRACT

A diesel engine driven metro bus was tested in a chassis dynamometer with 20% biodiesel mixed with 80% ultra-low sulfur diesel (ULSD), termed B20, to find out its performance, combustion characteristics and emissions. In this study, B20 was chosen instead of 100% biodiesel (B100) due to the fact that, with lower calorific value of B100, the engine could potentially lose power and torque which would make the bus unsuitable to climb hills with full load during peak hours. The performance of the bus such as torque and power with B20 were found to be very similar to ULSD. Therefore, there was no drivability issue with B20. The combustion characteristics of B20 and ULSD were also found to be very similar with B20 having 4.8° more combustion duration than ULSD due to low volatility and presence of heavier molecules in biodiesel. In terms of emissions, CO and HC were reduced but NO_X was increased by an average of 4.4% mainly due to inherent presence of oxygen in biodiesel. It was also found that with B20 the emission of PM_{10} particulates were 19% and 47% lower at lower and higher speeds, respectively. Based on the findings, it can be concluded that B20 is a suitable choice of alternative renewable fuel for existing diesel engine that needs little or no modifications to improve the sustainability of fuel and reduce environmental emissions.

1. Introduction

Depletion of fossil fuel and serious concern of pollutions from burning of fossil fuels in internal combustion (IC) particularly petrol and diesel engines have led many researchers around the world to find suitable alternative fuels for IC engines to replace the fossil fuels fully or partially. Among many alternative fuels, biodiesel is renewable and because their properties are similar to diesel means that the fuel can be used in diesel engines with no or minor modifications specially with biodiesel–diesel blended fuels [1]. Though 100% biodiesel can be used in diesel engines but the issues of loss of power and torque due to lower calorific value of biodiesel need to be considered. Being renewable, their use in diesel engines can reduce the emission of greenhouse gas CO_2. Biodiesel can also reduce other harmful emissions such as carbon monoxide (CO), hydrocarbon (HC) and particulate matters [2–6]. Furthermore, by using biodiesel as an alternate source of fuel, oil importing countries can reduce their dependency on crude oil. Because of these advantages many countries promote the use of biodiesel and a few countries have passed legislation to contain a minimum amount of biodiesel in diesel. The European Community (EC) attracts a 90% tax reduction for the use of all biofuels including biodiesel [7]. However, due to higher viscosity and lower calorific value biodiesel cannot be used in diesel engines as a sole fuel when full power of the engine is required without major modifications to the engine. In most cases, biodiesel is mixed with diesel and mixing proportions vary from country to country. In Europe, biodiesel

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http://dx.doi.org/10.1016/j.apenergy.2014.03.007
0306-2619/

blend of up to 7% (B7) shows compatible with any diesel engines though the use of 30% biodiesel blend (B30) is also reported [8]. In the United States, the most popular blends are B20 and B35 [9]. Most literatures have reported to have calorific values lower with biodiesel compared to diesel specially those which are produced from soybean and canola. However, biodiesels produced from sources such as Jatropha Curcas has calorific values close to diesel. In such cases, use of 100% biodiesel in diesel engines is reported to use in transportation in countries like Czech Republic [7] without any problem of loss of power or torque.

Many researches have been carried out to investigate the effects of use of biodiesel on engine performance, emissions and combustion characteristics. The oxygen content of biodiesel fuel is expected to promote more complete combustion and thus effectively reduce emissions of particulate matter (PM), carbon monoxide and hydrocarbons. However, due to lower calorific value and higher viscosity a blend of 30% biodiesel in 70% diesel was tested in laboratory under different driving cycles on 2 Euro 3 commercial trucks [8]. The fuel consumption of B30 increased proportionally to the deficit of the fuel heating value and the average efficiency showed a small increase of 1%. The emissions of CO and HC showed a slight increase and NO_X did not vary which are in partial disagreement with other researchers' data. However, PM, soot fraction and particles showed a significant reduction. In cold start cycle when the catalytic converter's efficiency was not fully reached, a clear toxicity reduction of polycyclic aromatic hydrocarbon (PAH) showed lower risk of carcinogenic. In another tests, regulated (CO, NO_X, HC and PM) and unregulated emissions of PAHs and nitro-polycyclic aromatic hydrocarbons (N-PAHs) from a B20 fuelled diesel engine showed slight reductions [6,10–12]. When 35% biodiesel was blended with 65% petroleum diesel, tests with in-use heavy-duty trucks showed similar fuel economy but B35 emitted significantly much lower CO, HC and particulates emissions than diesel [9].

The power of diesel engine decreases with increasing proportion of biodiesel due to lower calorific value of biodiesel. The loss of power can be compensated by increasing the fuel flow by moving the fuel rack position to higher level resulting higher brake specific fuel consumptions (bsfc) [13,14]. However, when the fuel rack reaches its maximum position the fuel flow cannot be increased further means that the engine will produce lower power than diesel at higher power regions. The reduction of performance by running 100% biodiesel was compensated by advancing injection timing [8,15]. Advancing injection timing means more time for evaporation of the fuel for the premixed combustion phase which is needed due to higher viscosity and lower volatility of biodiesel. The resulted performance showed reductions in bsfc, CO, HC and smoke levels and increases in efficiency, maximum in-cylinder pressure and NO_X emission [2,13,16–18]. Compression ratio as well as injection pressure along with injection timing were also varied by many researchers to improve the performance of diesel engine running with biodiesel [2,14]. Increasing compression ratio to 18, 19 and 20 from original setting of 17 showed reduction of bsfc with increases of brake thermal efficiency and exhaust gas temperature. The emissions of CO and HC also decreased with increased compression ratio. Increasing the injection pressure from 18 to 20 and 22 MPa at 20 N-m engine load and 2200 rpm of a DI diesel engine using biodiesel showed reduction in HC, CO and opacity due to better combustion which also resulted in higher NO_X emission [2].

Combustion characteristics of biodiesel showed that the premixed and diffusion-controlled phases are very similar to diesel. Depending on the source and the process of producing biodiesel, the cetane number (CN) of biodiesel can be higher or lower than diesel fuel. Biodiesel produced from Soy and WCO showed shorter ignition delay of 7.9° and 7.8°, respectively compared to 8.2° of ULSD due to higher cetane number [1,13,19]. As a result of shorter ignition delay biodiesel ignited earlier and consequently, the energy released during premixed phase was lower resulting lower heat release rate than diesel [1,19]. The angle of occurrence of peak pressure advanced towards the top dead center (TDC) due to lower ignition delay, and due to lower corresponding combustion volume the peak pressure also increased. The peak pressures and the corresponding angle of occurrences of biodiesel derived from Jatropha, Karanja and Polanga were found to be 84.7 bar occurring at 4.8° after TDC, 84.2 bar occurring at 4.9° after TDC and 85.3 bar occurring at 5° after TDC whereas with diesel the peak pressure was 78.7 bar occurring at 5.8° after TDC [19]. The angle of occurrence of peak pressure needs to be monitored carefully as peak pressure occurring too close to TDC will affect the engine performance and may cause severe knock and as a consequence the durability of the engine may hamper. However, biodiesel derived from Palm oil and Canola showed longer ignition delay. When operating with B20 of such fuel, due to longer ignition delay more fuel was injected and consequently, the peak pressure was slightly higher than diesel [20].

It is also interesting to note that to improve the performance of the engine and to compensate the power loss due to lower calorific value of biodiesel, the injection timing is usually advanced to allow more time for the fuel to evaporate and thus the peak pressure is further increased occurring even closer to TDC. However, this advancement is limited to the point where the peak pressure occurs safely after TDC. Advanced injection timing was found to improve power and reduce bsfc, CO, HC and smoke [7,21]. The diffusion-controlled phase is usually longer for biodiesel due to higher viscosity, low volatility and heavier molecules present in biodiesel [13,22–24].

For performance, emission and combustion analysis, most of the researches on engine with diesel and other alternative fuels were carried out on engines connected to dynamometers in the laboratory. Chassis-dynamometer is usually used to run vehicles following a particular drive cycle to measure the performance, emissions and drivability [8,12,18,25–27]. For such engine which resides inside the vehicle, combustion analysis is difficult to perform due to complex nature of the experiment which needs instruments such as pressure transducer which needs to be cooled, TDC encoder and rpm sensor to be fitted into the engine and then synchronize the data received from these sensors. However, in this research a metro-bus was tested on a chassis-dynamometer, and performance, emissions as well as combustion analyses were performed. The performance and emissions of the whole vehicle with the engine may vary from those of the engines alone connected to dynamometers due to associate losses from the engine output-shaft to the wheel of the vehicle. Therefore, one of the objectives of this research was to correlate the in-cylinder combustion data with the performance and emissions of the engine with the bus. Results are discussed with the perspective to add new information of the diesel bus performance on chassis-dynamometer with the blended fuel and also, to compare to other researches work on engine tested on engine-dynamometer. The bus was tested with both ULSD for base line operation and 20% biodiesel blended with 80% ULSD in a chassis-dynamometer.

2. Experimental apparatus and procedure

In this research a four stroke MAN diesel engine powered metro-bus having 6-cylinders was tested in a chassis-dynamometer. The specifications of the engine are listed in Table 1. Fig. 1 shows the schematic diagram of various instruments attached to the bus and the engine. The power, torque and speed of the bus were measured at the wheels by the chassis-dynamometer. To facilitate the measurement of fuel flow, the fuel delivery and overflow lines