Fuel 139 (2015) 537–545

Contents lists available at ScienceDirect

Fuel

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

Effect of different percentages of biodiesel–diesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine

Subhash Lahane, K.A. Subramanian *

Engines and Unconventional Fuels Laboratory, Centre for Energy Studies, Indian Institute of Technology Delhi, New Delhi 110 016, India

HIGHLIGHTS

- In-line fuel injection pressure and spray penetration is higher with all biodiesel blends.
- Chance of wall impingement is to be critical with B20 but more with B25, B50, and B100.
- Ignition delay and rate of pressure rise decreased with all biodiesel blends.
- NOx emission increases with all biodiesel blends (B20: 15.6% and B100: 22.8%).
- B15 is the optimum blend based on change in NOx emission and no wall impingement.

ARTICLE INFO

Article history:
Received 9 February 2014
Received in revised form 2 June 2014
Accepted 11 September 2014

Keywords:
In-line fuel pressure
Spray penetration
Wall impingement
NOx emission
Diesel engine

ABSTRACT

A comparative study of effect of different biodiesel–diesel blends (B5, B10, B15, B20, B25, B50 and B100) on injection, spray, combustion, performance, and emissions of a direct injection diesel engine at constant speed (1500 rpm) was carried out. The penetration distance increased with increase in percentage of biodiesel in diesel due to enhanced in-line fuel pressure. The simulation results indicate the spray penetration with biodiesel–diesel blend up to B15 does not lead to wall impingement but B20 is to be a critical limit of wall impingement (within uncertainty ±1.3%). However, it is observed clearly from the simulation results that probability of wall impingement is more with higher blends (B25, B50 and B100). The ignition delay period decreased with all biodiesel blends due to higher cetane number resulting in less rate of pressure rise and the smooth engine running operation. The engine torque does not change significantly with biodiesel–diesel blends up to 20% (B20). However, the torque reduction is about 2.7% with B100 at the rated load. Carbon monoxide (CO), hydrocarbon (HC) and smoke emissions decreased with all biodiesel–diesel blends. However, oxides of nitrogen (NOx) emission increased in the range of 1.4–22.8% with all biodiesel–diesel blends at rated load due to oxygenated fuel, automatic advance in dynamic injection timing (DIT), higher penetration and higher in-cylinder temperature. A notable conclusion emerged from this study is the optimum biodiesel–diesel blend based on no wall impingement (B15: 0% and B20 ±1.3% uncertainty limit) and increase in NOx emission (B15: 4.1% and B20: 15.6%) in a conventional (unmodified) diesel engine is up to B15.

1. Introduction

The main driving force behind the implementation of biodiesel in diesel engines is due to enhancement of fuel quality, self reliance of energy need, and boosting of rural economy. The higher cetane number of Karanja biodiesel (CN:58) could provide the easy starting of the engine, lesser white smoke, shorter ignition delay, less probability of knocking and smooth running of diesel engine as compared to base diesel [1]. The sulfur and aromatics in biodiesel are lower as these properties would affect on formation of particulate matter in diesel engines. However, the bulk modulus is higher with biodiesel (1500 MPa) than base diesel (1350 MPa) as this property indicates the compressibility of the fuel that would effect on injection characteristics of diesel engines. In a diesel engine, the fuel spray characteristics which deal the interaction of the injected fuel with the surrounding hot air during ignition delay period and combustion, is mainly dependent on injection characteristics such as injection delay, in-line fuel injection pressure, dynamic injection timing (DIT), in-cylinder injection duration and injector nozzle con-

* Corresponding author. Tel.: +91 11 26591247; fax: +91 11 26581121.
E-mail address: subra@ces.iitd.ac.in (K.A. Subramanian).

http://dx.doi.org/10.1016/j.fuel.2014.09.036
0016-2361/

figuration. The fuel spray characteristics play an important role in the improvement of combustion and engine performance, because it influences the mixture formation process of fuel with air in the engine cylinder [2]. Some information on diesel fuel spray characteristics is available in literature. However, information on biodiesel spray is scanty.

1.1. Injection and spray characteristics of a diesel engine using biodiesel–diesel blends

Diesel engine process including injection, spray, mixing, ignition and combustion influences its performance and emission characteristics. Among these processes, injection and spray process are important as they are affected by the quality of fuel, resulting in alteration of combustion characteristics of diesel engines. As biodiesel has a different physico-chemical property (density, viscosity, distillation properties, bulk modulus, surface tension, etc.) as compared to base diesel, its effect on the injection [3] and spray characteristics of the engine need to be studied in order to find scopes for solving these problems.

Fuel injection system plays a vital role on enhancing engine efficiency and emission reduction of the modern diesel engine [4]. The injection characteristics of a diesel engine include injection delay, static injection timing, DIT and injection duration. The duration of injection delay is defined as the duration between DIT and static injection timing. DIT is defined as the actual injection timing where the fuel is started to inject into the cylinder. The fuel-injection process is important as it influences fuel spray characteristics (break-up length, spray cone angle, sauter mean diameter (SMD), penetration and air entrainment) and mixture formation process [2].

The numerical analysis of injection characteristics using biodiesel–diesel blends (B25, B50, B75 and B100) was carried out by Kegl and Hribernik [5] and Kegl [6]. They reported that the DIT advanced whereas injection duration and in-line pressure increased with all biodiesel–diesel blends. The process of atomization and fuel–air mixing rate could be enhanced by increasing the in-line fuel injection pressure [7]. However, it may increase penetration distance which results in more probability of wall impingement. National Renewable Energy Lab (NREL), USA reported that the automatic advance in injection timing is due to higher bulk modulus of biodiesel (1500 MPa) than diesel (1350 MPa) as it implies the compressibility of the fuel [8]. The bulk modulus of biodiesel is higher than base diesel resulting in significant increase in in-line fuel pressure. The fuel spray penetration distance increases with increase in the in-line fuel pressure resulting in increase of probability of wall impingement [9]. It may be noted that wall impingement is one of the main durable issues of a diesel engine that needs to be reduced. It could be reduced mainly by reducing the penetration distance.

Fuel quality parameters including viscosity, density, and surface tension influence the spray characteristics of diesel engines. High viscosity and surface tension of biodiesel increase SMD, which affects fuel atomization [7]. Gao et al. [10] studied the spray characteristics of three biodiesel fuels (Jatropha, palm and used fried oil). SMD and spray penetration increased with increasing percentage of biodiesel in diesel but the spray cone angle decreased resulting in poor atomization. It may be noted that the injection characteristics alter fuel spray and combustion which influence performance and emission characteristics of diesel engines for biodiesel–diesel blends. Hence, injection characteristics are a central theme of design of a diesel engine for biodiesel utilization.

1.2. Combustion characteristics of a diesel engine using biodiesel–diesel blends

The combustion characteristics are one of the important tools to optimize performance and emission characteristics of diesel engines. Due to different properties of diesel and biodiesel, both fuels exhibit different combustion characteristics with respect to change in engine load. The main aim of optimization of fuel spray characteristics is improvement of mixture formation process which influences auto ignition and combustion process of diesel engines [11,12]. Biodiesel fuel comprises of 10–11% oxygen (by weight) which would enhance the heat release rate during combustion and reduces emissions (CO, HC, and Smoke/PM) significantly except NOx [13–15]. Combustion with biodiesel fueled diesel engine starts earlier at advanced dynamic injection timing due to higher bulk modulus. The peak rate of pressure rise is lower for biodiesel due to shorter ignition delay [16]. As high ignition delay leads to high rate of pressure rise, some extend to knocking, noise and NOx emission, it is necessary to lower the ignition delay. So, the combustion characteristics such as ignition delay, start of combustion, rate of pressure rise, etc. of a diesel engine for Karanja biodiesel–diesel blend need to be studied in detail in order to find the scopes for further improvement of the performance and emission reduction.

1.3. Performance and emission characteristics of a diesel engine using biodiesel–diesel blends

Biodiesel has low carbon content than diesel fuel (Diesel: 87 and Biodiesel: 77.2 wt.%). Hence, biodiesel fueled diesel engines will emit lower carbon based emissions than base diesel. Graboski and McCormick [17] studied the performance and emission characteristics of a diesel engine fueled with biodiesel–diesel blends (B10, B20, B30, B50 and B100) as compared to base diesel. The results indicated that CO, HC, PM, smoke and Poly-Aromatic Hydrocarbon (PAH) emissions decreased with the biodiesel–diesel blends whereas brake specific fuel consumption (BSFC) and NOx increased significantly [18,19]. Rakopoulos et al. [20] reported that the BSFC increases with the oxygen enrichment in the fuel but it does not affect with oxygen enrichment in the intake air. The percentage of torque reduction was reported as 0.85%, 1.25%, 2.33% and 5.90% with B20, B35, B65 and B100 respectively.

Experimental investigation was carried out to study the performance and emission characteristics of a diesel engine fueled with different percentages of karanja biodiesel–diesel blends (B5, B10, and B15) [21]. They concluded that B10 (karanja biodiesel–diesel blend) is the optimum blend for diesel engines. However, Mahanta et al. [22] concluded that B15 and B20 could be the optimum in terms of fuel efficiency and power developed. However, the optimum biodiesel–diesel blend would depend on particular feedstock [23,24]. It was reported that the appropriate biodiesel–diesel blend required for ensuring the optimum performance and low emission. As biodiesel is produced from different feed stocks, the physico-chemical properties of biodiesel will vary with the feed stock [25]. Lin et al. [23] reported the effect of biodiesel's feedstock on a diesel engine performance. They studied engine performance characteristics with biodiesel derived from different feed stocks including soybean oil methyl ester (SOME), peanut oil methyl ester (PNOME), corn oil methyl ester (COME), sunflower oil methyl ester (SFOME), rapeseed oil methyl ester (ROME), palm oil methyl ester (POME), palm kernel oil methyl ester (PKOME), and waste fried oil methyl ester (WFOME), and these results were compared with base diesel as given in Table 1. In general, they reported that carbon, hydrogen, oxygen, and sulfur content will influence the calorific value of a fuel and hence, it would also influence the engine performance and emission characteristics. Similarly, the combustion, performance and emission characteristics of a diesel engine fueled with biodiesel derived from wasting cooking oil were compared with base diesel [26,27]. The chance of wall impingement will be more for biodiesel fueled diesel engine due to higher injection pressure. Hence, the optimum biodiesel–diesel blend has to be