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Spray characteristics of biodiesel/blends in a high pressure constant volume spray chamber

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ABSTRACT

The spray characteristics of the fuel greatly influence emissions from diesel engines. Spray development plays an important role in improving the combustion and emission characteristics of a fuel because it directly affects the air–fuel mixture formation. Spray characteristics of the fuel mainly depend on fuel injection pressure, fuel density, fuel viscosity, ambient pressure and temperature. Among these, the effect of ambient pressure is very important parameter directly affecting spray pattern. This study investigates the effect of ambient pressure on spray characteristics such as spray tip penetration, cone angle and spray area in a constant volume spray chamber by employing spray visualization and image processing techniques. The fuels used for the investigation are Karanja biodiesel (KB100), diesel (KB0) and blends (KB5 and KB20). The results of macro-analysis show that with increasing ambient pressure, spray tip penetration decreases, and cone angle and spray area increase. Comparing Karanja biodiesel and blends with diesel, B100 gives highest spray tip penetration, cone angle and spray area followed by KB20, KB5 and diesel respectively because of fuel density differences.

1. Introduction

Increasing industrialization and motorization has led to greater use of petroleum products. Because of increasing fuel cost and stringent emissions, diesel has become an increasing attractive, efficient and less expensive fuel compared to gasoline [1]. However, diesel engines are at a disadvantage because they produce higher level of nitrogen oxides (NOx), which is classified as a toxic emission by most environmental regulatory bodies throughout the world [2,3]. The exhaust emissions largely depend on the combustion characteristics in the engine combustion chamber. Incomplete combustion in the cylinder caused by low temperature and pressure conditions because of exhaust gas recirculation (EGR) lead to reduction in NOx formation however increase in particulate matter (PM) emissions. Both situations are directly related to the air–fuel mixture formation followed by combustion. For complete combustion, adequate mixing of air–fuel mixture is essential and mixing of fuel with air depends on the amount of fuel injected, spray characteristics and atomization characteristics of the fuel [4,5].

Biodiesel is an oxygenated fuel containing mono-alkyl ester derived from bio-origin. It is degradable, non-toxic and environment friendly fuel, produced from vegetable oils, waste cooking oil, and animal fats by employing process of transesterification [6,7]. In India, most engine trials have been carried out using biodiesel derived from feed-stocks such as *Jatropha curcas* and Karanja oils. Fuel spray characteristics are a consequence of complex two phase flow processes occurring during fuel injection. A clear understanding of the processes involved is important to achieve improved engine performance with lower emissions [8]. Although such importance has long been recognized, the knowledge of spray characteristics of biodiesel and blends so far is limited. This is due to experimental difficulties in characterization of biodiesel spray, which are rapidly evolving, and highly dynamic phenomenon under high pressure and temperature conditions. In present study, spray images have been captured for the fuel sprays inside the high pressure constant volume chamber. Further macroscopic analysis of spray images has been done for investigation of spray characteristics like spray tip penetration, spray cone angle and spray area using optical technique.

Spray tip penetration is defined as the length of the spray between the nozzle hole and the farthest spray tip. Knowing the position of the nozzle hole, one needs to find the extreme point of the spray [9,10]. Several definitions of the spray cone angle exist. The spray cone angle is defined as the angle between two lines connecting the nozzle tip and two half penetration points on the spray boundary [10]. Spray area is defined as an area covered by the spray of fuel in the combustion chamber at chamber (high pressure–temperature) conditions.

The effect of ambient temperature and pressure on spray tip penetration and spray volume of DME and LPG at constant volume were investigated by Lee et al. [11]. They found that spray tip

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penetration becomes longer and the width becomes larger as the ambient temperature increases because the gas density becomes lower. A similar study was conducted by Sidu et al. [12]. The penetration and volume of DME and LPG spray was investigated for the influence of temperature largely in high ambient density conditions [11,13]. Ying et al. [14] suggested that addition of DME in diesel decreases spray penetration however spray cone angle increases. As expected, the spray penetration of DM20 is lower than diesel with an increase in injection time. It can be attributed to the fact that density of DM20 is lower than diesel and the volatility of DM20 is higher than diesel. Park et al. [15] investigated the effect of injection pressure on spray tip penetration, which increases with increasing fuel injection pressure. Suh and Lee [16] investigated the effect of in-cylinder pressure on the spray tip penetration and spray cone angle. They reported that development of DME and diesel spray with high ambient pressure was lower and the spray angle was wider than those at atmospheric pressure. The fuel sprays at atmospheric conditions (P_{amb} = 0.1 MPa) diffuses significantly due to lower ambient density in the chamber compared to other ambient conditions. They found that spray tip penetration decreases with increase in ambient pressure because of high ambient density. It also decreases spray momentum and induces slower spray development. Therefore, a droplet cannot spread in the axial direction and instead stagnates and spreads in the radial direction.

Higher viscosity of biodiesel results in loss of flow efficiency and reduction in injection velocity. Spray penetration was found to be marginally higher for biodiesel, while cone angle was lower, which was attributed to its poor atomization characteristics. Liquid lengths were higher for biodiesel due to its higher boiling temperature and heat of vaporization as compared to diesel [17]. Lee et al. [18] reported that spray tip penetration of biodiesel and blends showed a similar pattern, regardless of the mixing ratio of biodiesel. The atomization performance of biodiesel blends was inferior to diesel due to relatively higher surface tension of biodiesel. However there are various differences in physical parameters of biodiesel and diesel, and it is therefore necessary to study the spray characteristics of biodiesel with respect to its application in internal combustion engines [6].

2. Experimental setup

The experimental setup for investigating the biodiesel sprays is shown in Fig. 1. The fuel is supplied from the fuel tank to the injector using a simple mechanical (jerk type) fuel pump, with a fuel delivery pressure set at 200 bars. All experiments were carried out at constant fuel injection pressure of 200 bars. The fuel injector used in the experimental setup is a mechanical injector with three nozzle holes (0.29 mm diameter) located 120° apart from each other. The injector injects the fuel in a customized constant volume spray visualization chamber. There are four optical windows bolted on to the constant volume spray chamber with the help of flanges, which are used for optical measurements and capturing the images under various experimental conditions.

A halogen white light source (Thorlabs, USA; OSL1) is used as illumination source for spray visualization. An optical fiber (6 mm diameter, 91 cm long) guides the white light onto the region of interest (Fig. 2).

The white light source was placed in front of one of the windows and fiber optics of the white light source is placed right in front of a small aperture covering the window, so that an intense light beam can be directed towards the region of interest in the constant volume spray chamber. The camera was placed at an angle of 30° from the centre line of the optical window, which is exactly 90° from the window with white light source. The high speed camera (Basler; A601fc) used in the experiment records images at 60 fps (maximum) (with 8 bit, 640 × 480 pixel image). The constant volume spray chamber is made of brass and is designed to withstand pressure upto 10 bars. The camera is connected to a data acquisition system with the help of a IEEE1394 cable. Images are captured using 'Streampix v.3' software, which has the ability to acquire the images in a single shot mode or video mode. The captured images were further processed using 'NI Vision Assistance 2009' software, which has graphical tools to analyze these captured images. The best images of one complete injection event were selected from amongst all recorded images of a particular combination of injection pressure (200 bars) and chamber pressure (1 bar, 4 bars, 7 bars and 9 bars) for a particular fuel. Among these

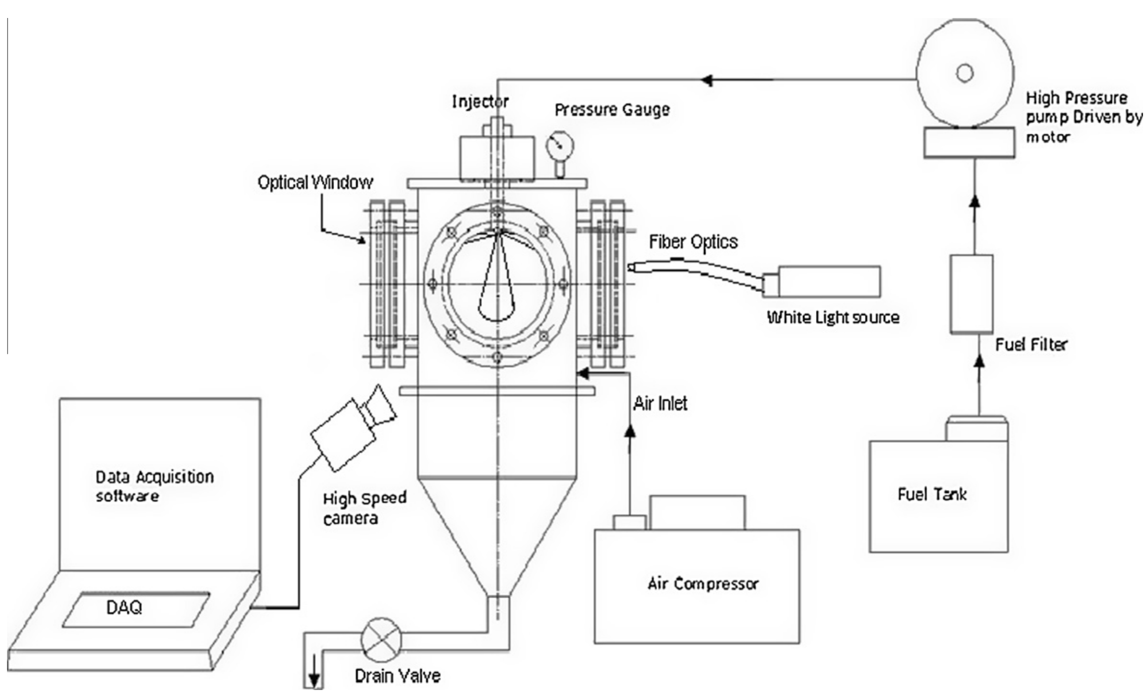

Fig. 1. Schematic of experimental setup.