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Design and Development of a Control Volume Spray Chamber (CVSC) for Fuel Spray Visualization †

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Abstract: Biofuels have attracted significant attention in recent years as a potential replacement of fossil fuels. In order to test a new fuel, it is necessary to know its physiochemical properties. Fuel spray atomization of any fuel is the most critical process that has a direct effect on the fuel–air mixing ratio, combustion and emissions. This research presents the design and development of a control volume spray chamber (CVSC) for analyzing macroscopic fuel spray characteristics under varying operating conditions. The spray results reveal that the fuel penetration length (FPL) and spray cone angle (SCA) both decreased with the increase in ambient pressure, but when the injection pressure was increased, a longer FPL and wider SCA were observed. The light intensity levels revealed broader and higher drop densities at the axial distance of 40 mm from the nozzle.

Keywords: control volume spray chamber; spray characteristics; fuel penetration length; spray cone angle

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1. Introduction

Nowadays, biofuels attract many engine manufacturers as an alternative fuel to diesel due to their biodegradable nature. They are clean and renewable source of energy. Biodiesel comprises an excess of oxygen that enhances combustion and reduces the particulate matter and soot emissions [1]. Biofuels usually have a higher fuel viscosity and surface tension which affects the fuel injection process and spray quality when used in a diesel engine.

Spray characteristics have a major effect on the combustion process which defines the thermal efficiency of an engine. In order to use biofuels or their blends in a diesel engine, it is necessary to study the fuel spray characteristics that will provide a better insight into their performance and emission properties. Wang et al. [2] developed a control volume vessel (CVV) to study the spray behavior of palm oil and cooked oil and found that a greater cone angle and a larger drop size are observed for biodiesels when compared to diesel. Agarwal et al. [3] studied the spray behavior of Karanja biodiesel in a constant volume spray visualization chamber comprising four optical windows and using a multi-hole injection nozzle. Lee et al. [4] investigated the macroscopic spray properties of biodiesel and its blends obtained from soybean and canola oil in a pressurized spray chamber with five optical windows. FPL is the distance covered from the tip of the nozzle to 95% of the farthest distance the fuel has reached, while SCA is the angle between the two lines starting from the nozzle tip and passing through the periphery of the spray until the half point of the penetration length.

The effect of viscosity and surface tension on the fuel spray properties of castor oil, neem oil and sunflower oil was revealed by Das et al. [5]. Bohl et al. [6] used a control volume vessel with four optical windows of 100 mm diameter to study the spray behavior of palm oil, used cooking oil and soyabean. Biofuels that are being produced from edible sources are less likely to be used on a commercial scale; that is why biofuels derived from nonedible sources are more popular and beneficial. In this study, a control volume spray vessel (CVSV) with three optical windows was developed to analyze the macroscopic spray properties of diesel.

2. Materials and Methods

First, a CAD model of the CVSC was made using SolidWorks (2021, Dassault Systèmes, Vélizy-Villacoublay, France). An exploded view of CVSC assembly can be observed in Figure 1.

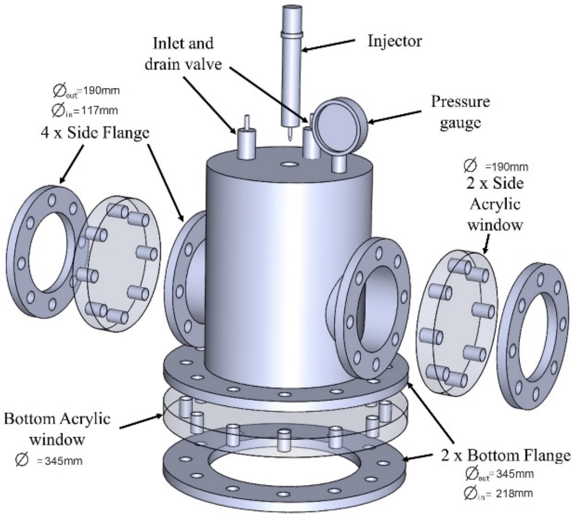

Figure 1. Schematic diagram of CVSC with fabrication details.

2.1. Fabrication of Experimental Setup

CVSC was fabricated at our workshop in GIK Institute. Several processes involved during fabrication can be observed in a Figure 2. The process started with a hollow cylinder made of cast iron shown in Figure 2b. Two holes were made in the cylinder using gas welding for the optical windows, after which 2 small cylinders were welded to these windows as shown in Figure 2d. Then, the side flanges and the bottom flange were welded, which can be observed in Figure 2e,f. Figure 2g,h shows the cutting of the acrylic window on the lathe and drill machine. Finally, the top plate of the chamber was cut with a hole in the center for the injector, as shown in Figure 2i,j.

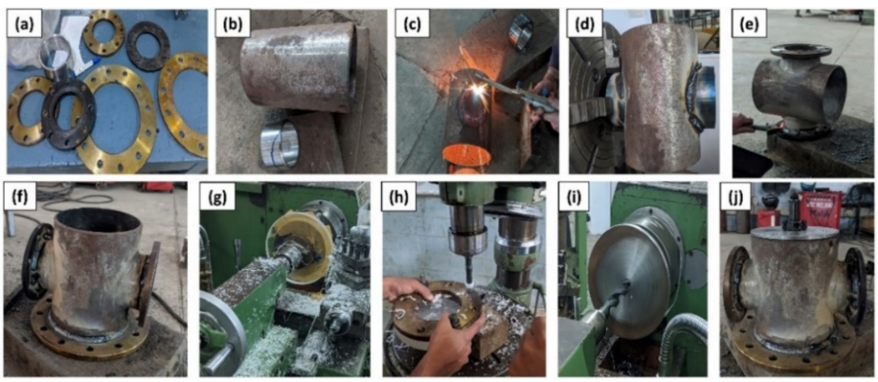

Figure 2. Design materials and processes involved during fabrication of CVSC. (**a**) 4 small and 2 large flanges of CVSC windows, (**b**) Cylindrical body of CVSC, (**c**) Holes being made on cylindrical body for side windows, (**d**) Grinding from the inner side of CVSC after welding, (**e**) Removal of slag after welding of 2 side flange, (**f**) 3 flanges welded to the CVSC, (**g**,**h**) Cutting of acrylic sheet for the CVSC windows, (**i**) Drilling of hole on the top plate for injector mounting, (**j**) Injector mounted on the top of CVSC.

Figure 3a,b shows the front view and side view of the CVSC, respectively. The inside and the outside views of CVSC from the bottom are shown in Figure 3c,d, respectively.

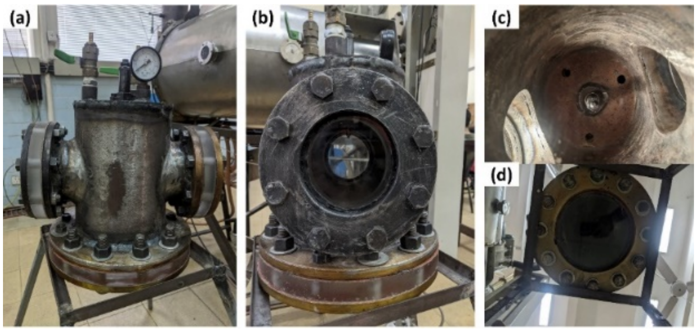

Figure 3. Various orientations of CVSC. (**a**) Sealed CVSC rested on a stand, with pressure gauge, injector and drain valves on the top, (**b**) Side view of CVSC, (**c**) Inside view of CVSC from the bottom window and (**d**) Bottom view of CVSC.

2.2. Experimental Setup

The CVSC was mounted on the stand, as shown in Figure 3a. Two 100 W LED lights were used for illuminating the chamber through side windows. An injector with 0.29 mm hole diameter was used. Video recording of the spray process was captured at 960 frames per second through the bottom side of CVSC. Images were extracted from the slow-motion videos using DaVinci Resolve software (Blackmagic Design, 18.0.1v, Victoria, Australia). Spray images were then processed using Image J software (National Institutes of Health and LOCI, 1.48 v, Bethesda, MD, USA, and Madison, WI, USA) to quantify the macroscopic spray properties of the jet.

3. Results

Fuel Spray Analysis of Diesel

Diesel is tested in the CVSC to study the macroscopic spray behavior, the injection and ambient conditions along with the fuel properties, which are given in Table 1. It can be seen from Figure 4a,c that a higher injection pressure increases the FPL because, at higher pressures, the fuel is injected with a greater force and possesses a higher momentum, allowing it to penetrate further. When the ambient pressure is increased, incoming fuel jet faces more drag, due to which the jet expands radially and the FPL decreases. The injection pressure also increases the SCA; however, the ambient pressure has a dominant effect. Figure 4b shows the spray density in radial direction in terms of light intensity levels at axial locations of 10 mm and 40 mm. The light intensity closer to the nozzle is narrow because it did not have enough time to expand, while at 40 mm, a broader light intensity can be seen for both the ambient pressures. A maximum intensity was observed at an ambient pressure of 8 bar and at the axial location of 40 mm, while the lowest was recorded for a 2-bar ambient pressure at the axial location of 10 mm.

Table 1. The injection and ambient conditions along with the fuel properties for analyzing the fuel spray in a CVSC.

Parameter	Quantity	Parameter	Quantity
Injection pressure	500, 1000 bar	Injection duration	2 ms
Injection temperature	300 K	Chamber diameter	218 mm
Ambient pressure	2 & 8 bar	Nozzle diameter	0.290 mm
Chamber temperature	300 K	Diesel density	837.9 kg/cm^3

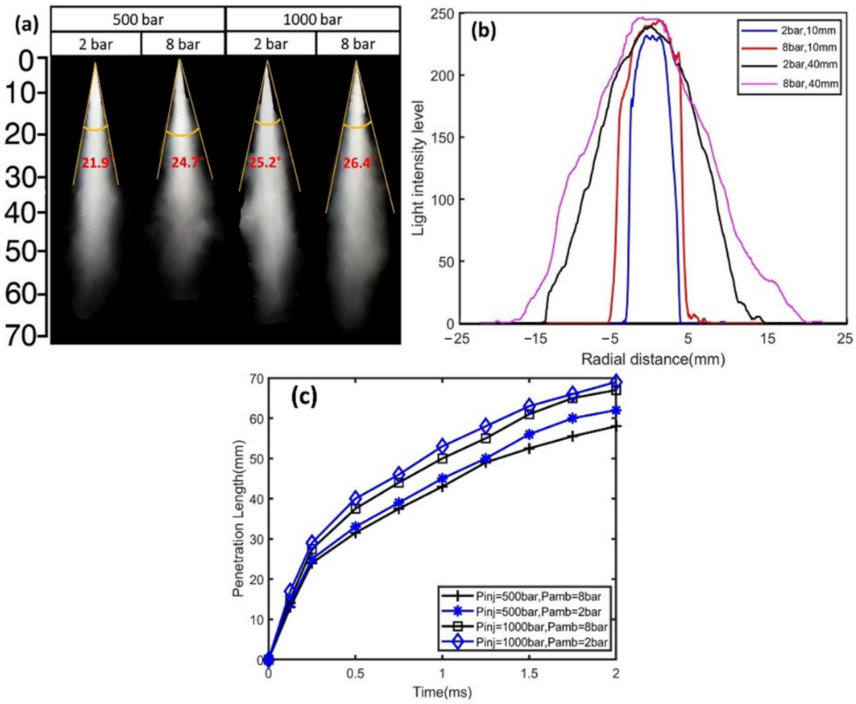

Figure 4. (**a**) Experimental images of diesel spray showing PL and SCA for two different injection and ambient pressures. (**b**) Light intensity levels with regard to radial distance for 2 axial locations and ambient pressures for 1000 bar injection pressure. (**c**) PL for diesel spray against varying injection and ambient pressures.

4. Conclusions

The three-window design of the CVSC was effective for fuel spray visualization for both single and multi-hole injectors. An increase in injection pressure enhanced the FPL and SCA while an increase in ambient pressure caused a reduction in the FPL and SCA. The light intensity, which depicts the spray density, was narrow when closer to the nozzle and expanded in the axial direction. The maximum intensity is at the core of the spray and decreases in the radial direction, as the spray is less dense at the outer periphery.

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