High Pressure Spray Characterization of Vegetable Oils

Devendra Deshmukh*, A. Madan Mohan, T. N. C. Anand and R. V. Ravikrishna
Department of Mechanical Engineering
Indian Institute of Science Bangalore
India

Abstract

This paper reports data on high pressure spray characterization of Jatropha and Pongamia pure plant oils. Shadowgraphy technique is used to visualize the spray structure and measure cone angle and tip penetration, whereas Interferometric Laser Imaging for Droplet Sizing (ILIDS) technique is used to measure droplet sizes. A common rail injection system with a 180-μm single hole injector is used. Experiments show that both Jatropha and Pongamia pure plant oil sprays show poor atomization and presence of liquid core even at injection pressures as high as 1600 bar. A blend of 30% Pongamia oil with diesel was also studied. The spray structure of the blend appeared very similar to that of diesel, however SMD measured at a distance of 70 mm from nozzle tip at 3 ms after start of injection pulse showed 15% increase.

Introduction

This work is motivated by the need to utilize pure plant oil or Straight Vegetable Oil (SVO) as a diesel substitute in automotive engines. Jatropha and Pongamia oils are considered to be most suitable diesel substitutes in Asia and other parts of the world. However, there is no data in the literature on spray characteristics at high injection pressures typical of those found in common rail injection systems for these oils. SVOs and their derivatives are being used in diesel engines both as complete replacement and as blends with diesel. The advantages of SVO include renewability, heat content close to that of diesel fuel (about 80% of diesel fuel) and local availability [1].

Physical properties of SVO used as a fuel for diesel engine affect the spray atomization. Typical properties of diesel and different SVOs, used as fuel in diesel engine, are presented in Table 1. Dynamic viscosity for SVO is

Table 1: Physical properties of diesel and SVOs

Common name	Calorific value (kJ/kg) [2]	Density (kg/m^3)	Dynamic viscosity at 40°C (cP)	Surface tension at 30°C (mN/m)
Diesel	43,350	815	4	23
Jatropha oil	39,774	908	30	32
Pongamia oil	34,000	923	37	33

7-8 times higher than diesel, while surface tension is 30% higher. SVO viscosity can be reduced by heating [2] or blending with the diesel [3]. Viscosity of SVO can be reduced to level of diesel by preheating oil above 120°C. Blending up to 30% SVO with diesel can reduce viscosity of blend near that of diesel. To use SVO as fuel in diesel engine different strategies will be required so as to get maximum engine performance. Spray atomization is an important process governing diesel engine performance. High viscosity and surface tension of SVO have adverse effect on spray atomization, as they increases the SMD compared to that of diesel under similar conditions [4, 5]. To adapt the various SVOs and their blends in diesel engines, it is necessary to study their spray characteristics. This is the first reported study to the best of our knowledge on spray structure measurements of Jatropha and Pongamia SVOs.

*Corresponding author: deven@mecheng.iisc.ernet.in

Materials and Methods

A high pressure spray injection facility is developed, which utilizes a common rail diesel injection system. A high pressure pump is externally driven by an induction motor. Rail pressure is controlled using both a needle valve and the motor speed. Injection pressure can be varied from 200 bar to 1700 bar. The solenoid injector used is controlled using an injector driver (DRIVVEN Inc). Injection duration can be varied from 200 μs to 5000 μs. Spray structure is visualized using shadowgraphy technique. The optical setup consists of a pulsed Nd:YAG laser, diffuser, collecting lens and CCD camera with resolution 1600 X 1200 pixels. Pulse duration of the Nd:YAG laser used is around 7 ns. Spray structure at different injection pressure and at different time instants was visualized.

Droplet size measurement was done using the ILIDS technique [6, 7]. The technique measures individual droplet diameter in a visualization plane. The incident light scattered by transparent spherical particle produces two glare point in focused field. When defocused, these points give interference fringes whose number is proportional to the droplet diameter. Droplet diameter is given by the following equation:

$$D = \frac{\lambda}{\alpha}(cos(\Theta/2) + \frac{msin(\Theta/2)}{\sqrt{m^2+1-msin(\Theta/2)}})^{-1} \quad (1)$$

where λ is wavelength of the laser, α is collection angle, Θ is angle between laser sheet and camera and m is refractive index of the liquid. Optical setup for ILIDS technique is shown in Fig. 1. To get the maximum fringe contrast, camera was kept at 70° to laser sheet. Since the spray is dense, a rectangular aperture of 20 mm width and 5 mm hight was used to compress the interference image. Field of view for the given setup was 6.5 mm X 5 mm. SMD was calculated based on droplets measured from 300 images.

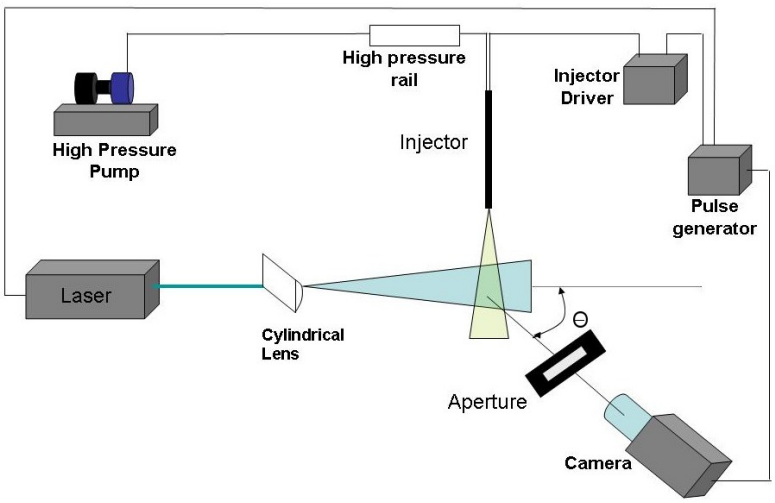


Figure 1: ILIDS Setup for droplet size measurement

Results and Discussion

Spray characterization is done for Pongamia, Jatropha SVOs, diesel and SVO blend - P30 (30% Pongamia oil + 70% diesel by volume) at different injection pressures and injection duration. SVOs are very viscous compared to diesel. Due to this high viscosity, injection characteristics are found to be different compared to those of diesel. SVO is difficult to inject at low injection pressure and small injection duration. It was observed that both Jatropha and Pongamia SVO could not be injected below 500 bar injection pressure and injection duration below 700 μs even at oil temperature of 60^oC. For spray characterization of SVO, injection duration of 1000 μs was used with oil temperature of 60^oC. Injection delay for these oils is shown in Fig. 2. Injection delay for Pongamia SVO is 0.9 ms even at 700 bar injection pressure while diesel has maximum injection delay of 0.55 ms at 300 bar. Injection delay decreases with increasing injection pressure. High viscosity of SVO gives high resistance to injector needle movement at the start of injection causing higher injection delay.

Spray tip penetration as function of time is shown in Fig. 3 for injection pressure of 650 bar. Diesel spray tip penetration is shown for injection duration of 500 μs whereas for SVOs and blend duration is 1000 μs. SVO tip

penetration is lower compared to that of diesel and P30 blend. This may be due to energy lost during injection due to high viscosity. Spray cone angle was measured for P30 blend and diesel spray. Cone angle was measured based on spray spread at a distance 100 times the nozzle diameter from the nozzle tip. For diesel, spray cone angle was measured to be 9 deg, whereas for P30 blend spray cone angle was observed to be 10 deg.

Instantaneous images of the spray structure for diesel and P30 blend are show in Fig. 4. Spray structure and

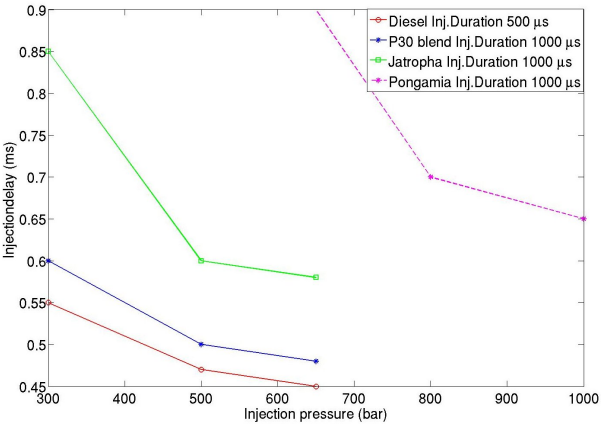


Figure 2: Start of Injection Delay

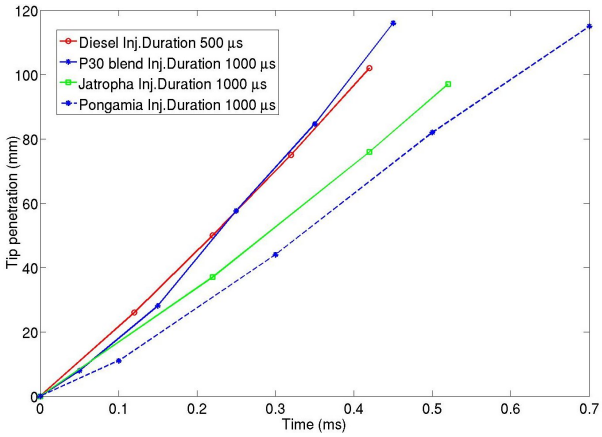


Figure 3: Spray Tip Penetration

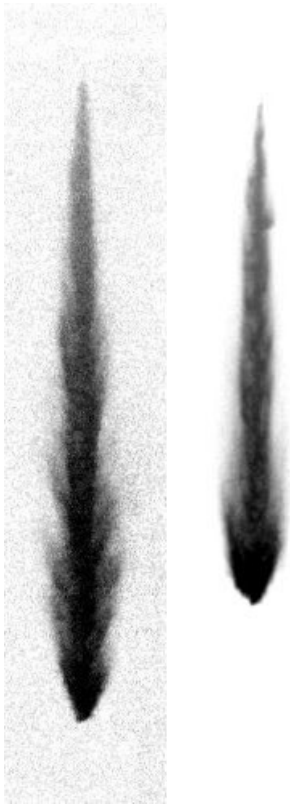
penetration is similar for both fuels. Figure 5 shows instantaneous spray structure images for Jatropha SVO, Pongamia SVO and P30 blend at injection pressure of 650 bar and 0.2 ms after start of injection. It is interesting to observe presence of liquid core for both the SVOs(Fig. 5b, 5c). Spray structure of the P30 blend Fig. 5a), however show improved atomization. A magnified view of the near nozzle structure of the SVO spray revealed that there is an intact liquid core present, which remains unbroken even at high injection pressures up to 1600 bar. Figure 6 shows the liquid core for different injection pressure at 20 mm from the nozzle tip after 2 ms from start of injection pulse. Increasing injection pressure increases the diameter of the liquid core. This is due to increase in the mass flow. Liquid core diameter at 1200 bar pressure was observed to be around 120 μm. Presence of intact liquid core indicates that viscous and surface tension forces in SVO spray are high enough to suppress disintegration of the liquid core.

Droplet size measurement

Droplet size measurement is done for diesel spray and P30 blend at 650 bar injection pressure and 3 ms from start of injection pulse. Droplet sizing was done at 70 mm from nozzle tip, radially at 2 mm from the spray axis. For SVO spray, as there was no disintegration of the liquid core, droplet size measurement was not attempted. Figure 7 shows the droplet size distribution for diesel and P30 blend. SMD is calculated from 300 images. The variation in SMD between diesel and P30 blend is small (15%). This may be due to the fact that droplet measurements are conducted at 3 ms , by which time a large portion of the spray has passed the 70 mm location. Thus, droplets measured are typically associated with smaller size and lower velocity. Droplet measurements at earlier time instants were not possible with the ILIDS technique due to the very large droplet density. A large droplet density is associated with overlapped images and fringes in arbitrary direction due to multiple scattering. Such interference images can not be processed to yield droplet diameters. From spray structure of diesel and P30 blend, it is observed that the spray is highly dense in the core region, especially during the initial phase of injection. Future work will focus on establishing the feasibility of the ILIDS technique for such conditions.

Conclusion

Spray characterization of Jatropha and Pongamia SVO in a common rail injection system at high injection pressure is conducted using shadowgraphy technique. Results show presence of an intact liquid core even at injection pressures as high as 1600 bar. Due to high viscosity of SVO, injection delay is observed to be much higher compared to that of diesel fuel. Spray tip penetration for SVO is observed to be less than that of diesel. It appears that viscous and surface tension forces in the SVO spray are high enough to suppress disintegration of the liquid core. A blend of 30% Pongamia oil with diesel was also studied. Result show that spray structure in terms of spread and penetration are almost identical to that of diesel, however droplet size measurements using the ILIDS



(a) Diesel (b) P30 Blend

Figure 4: Diesel and P30 blend spray structure. P_{inj}=650 bar, Injection duration 500 μs

technique at a later instant showed a slight increase in the SMD.

Acknowledgment

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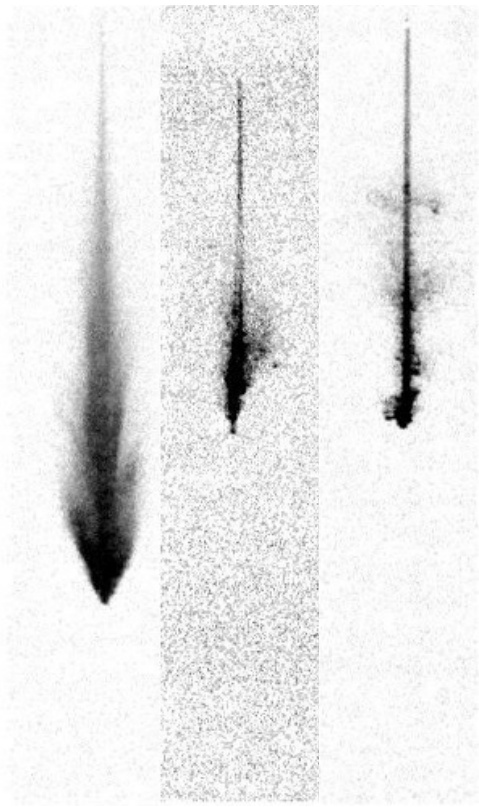
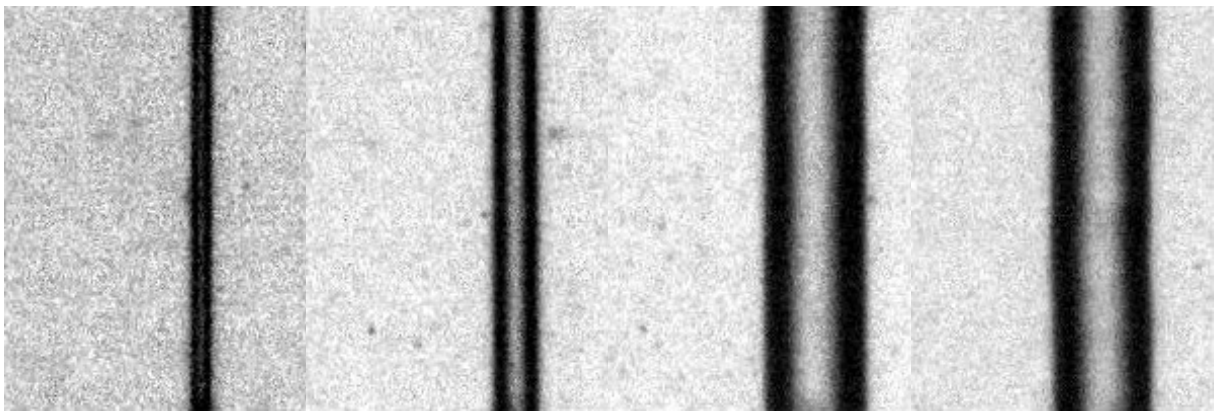


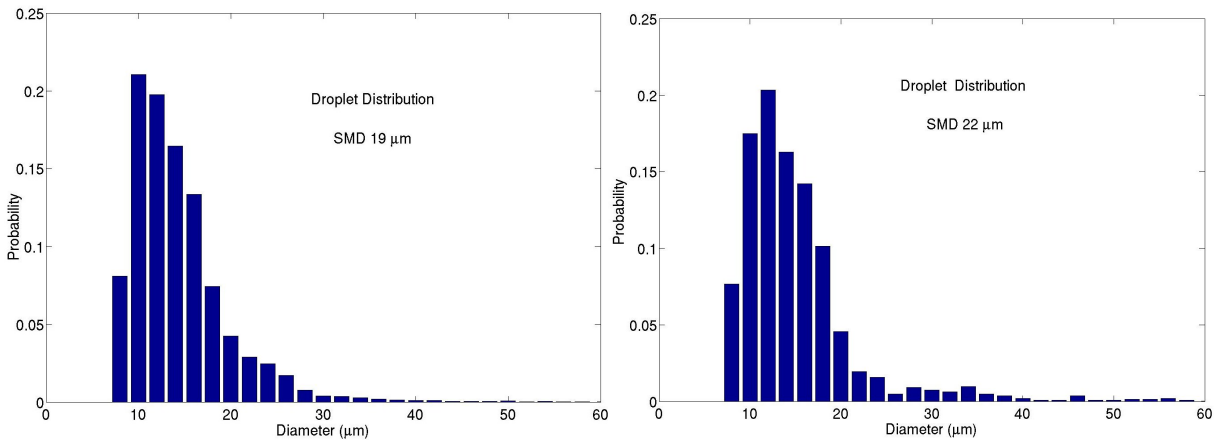
(a) P30 Blend (b) Jatropha (c) Pongamia

Figure 5: Spray Structure for different fuel at P_{inj}=650 bar, Injection duration 1 ms



(a) P_{inj}=900 bar (b) P_{inj}=1200 bar (c) P_{inj}=1400 bar (d) P_{inj}=1600 bar

Figure 6: Liquid Core at 20 mm below injector tip for Pongamia spray after 2ms from start of injection pulse



(a) Diesel (b) P30 Blend

Figure 7: Droplet size distribution (P_{inj}= 650bar, injection duration = 0.5 ms, time = 3 ms from start of injection pulse)