Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 6 (2): 367-373, 2013
ISSN 1992-1454 / DOI: 10.3923/ajsr.2013.367.373

Comparative Study of Droplet Sizes of Water and Diesel Sprays

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ABSTRACT

The study of sprays of liquid fuels such as diesel can be hazardous and costly. However, by replacing the liquid fuel spray with non flammable liquids such as water can reduce these problems. In this study, the similarity between water and diesel in terms of spray characteristics is studied. The study focuses on the characteristic of droplet size of the sprays by using Phase Doppler Anemometer (PDA) using a spray nozzle with pressure of 50, 100 and 150 kPa. From the results, it is found that the droplet sizes of water and diesel are quite similar and thus water spray has the potential to replace diesel spray in non-combusting research studies.

Key words: Spray characteristics, droplet sizes, liquid fuel, atomization, diesel

INTRODUCTION

Atomization is defined as the disintegration of a liquid into small drop or droplets. The resultant suspension of fine droplets in a surrounding gas is termed spray. Atomization of a liquid into droplets can be achieved by various means: aerodynamically, mechanically and ultrasonically (Liu, 2000). The breakup of a liquid into droplets, for example, may be achieved by the impingement with a gas in a two fluid atomization and by centrifugal forces in rotary atomization. The processes of atomization could also be classified according to the energy used to produce instability in a liquid. Sprays can be defined as a dispersion of droplets produced by using a nozzle with sufficient momentum to penetrate the surrounding medium which is gaseous (Nasr *et al.*, 2002). Shape, pattern and some measure of droplet sizes are indication of spray characteristics. Atomization can be divided into two types. The first is primary atomization, which is near the nozzle and secondary atomization, which is the break-up of drops further downstream.

Practical atomization processes of liquid will generally include two fluid atomization, pressure atomization and rotary atomization. Atomization of normal liquids has been long studied in spray combustion (Djavareshkian and Ghasemi, 2009) and spray drying (Lolodi, 2011), with combustion being the widest spread application (Liu, 2000). In industrial production processes, sprays are widely used in food processing, pharmaceutical processes (Davidov-Pardo *et al.*, 2008), agriculture (Alam and Khan, 2002) and paper manufacturing (Nasr *et al.*, 2002). For processes involving vaporization, cooling or cleaning of gases, sprays used in fire suppression, air humidification and gas cleaning and conditioning. Processes in agriculture, surface cleaning and treatment, spray painting, coating and printing require sprays that have high momentum impact to achieve the desired results. Different industrial applications require different types of sprays in order to deliver their functions (Nolan, 2000). Full cone nozzles will result in complete spray coverage in a round, oval or square shaped area. In generating sprays, the liquid is usually swirled within the nozzle and mixed with non-spinning liquid that has bypassed an internal vane and then discharges through an orifice, forming a conical pattern. Full cone nozzles are most extensively used in industry (Bartell *et al.*, 1991).

The size of droplets is one of the properties normally used for the correlation of the combustion behaviour. Droplet sizes are generally different for different fluid properties and even for the same liquid droplets may differ in size due to influence of other conditions. Furthermore, sprays may be of monodisperse or polydisperse distributions and thus, there is a need for averaging in order to determine a the mean size that corresponds to necessary droplet properties (Lefebvre, 1989). Sauter Mean Diameter (SMD) or D_{32} is commonly used, which is given by:

$$D_{32}=\frac{\sum_{i=1}^{k}n_iD_i^3}{\sum_{i=1}^{k}n_iD_1^2} \tag{1}$$

where, n_i is the number of droplets within a range of is centered on diameter D_i and k is the number of ranges. Factors that affect the droplet sizes include nozzle type, spraying pressure, flow rate and spray angle (Lefebvre, 1989). An increase in the liquid flow rate or pressure through the nozzle will decrease the droplet size, while a decrease in flow rate will decrease the pressure drop and increase the drop size. As for spray angle, generally, an increase in spray angle will reduce the drop size and vice versa.

In studies of sprays involving liquid fuels such as diesel, the experiments can be hazardous and costly due to issues such as the need for repeated measurements, the need to properly discharge the fuel after the end of each experiment and the potential health hazards. It is suggested that replacing the diesel fuel spray with simple liquids such as water in non-combusting experiments may reduce these problems. Thus, in this study, the similarity between the characteristic droplet size of water and diesel sprays is studied using Phase Doppler Anemometer (PDA) system.

MATERIALS AND METHODS

A schematic of the spray rig is shown in Fig. 1. The system comprised of a tank, which was used to supply the liquids to the nozzle. A stainless steel centrifugal pump, which maximum capacity was rated at 4 bars, was used to supply pressure to the nozzle. A pressure gauge was mounted at the discharge side of the pump to indicate the liquid pressure. A back pressure valve was used to return the flow back to the tank. An F-75s full-cone spray nozzle manufactured by Akoka was used to produce the spray. The nozzle can be operated at pressures of up to 5 bars. The air inlet diameter was 6.35 mm and the nozzle outlet diameter was 1.3 mm.

Phase Doppler Anemometry (PDA) was used to measure droplets sizes of both liquids. The system consists of a transmitter, a receiver, a signal processor and a computer. Laser was split by utilization of a beam splitter and frequency shift module. With a lens mounted on the transmitter, the two lasers would intersect at a point referred as probe volume or measurement volume. When a drop passes through the probe volume, the scattered light forms an interference fringe pattern. The phase shift between the scattered light and incident light enabled quantification of the droplet diameter through the use of data processing in the computer using the BSA Flow Software. The PDA system measures droplet sizes individually instead of globally such as that featured by systems like Malvern Particle Sizer or Digital Image Analysis Technique (Lad *et al.*, 2011) and thus it is also known as a point measurement system. Detailed description of this setting was reported by elsewhere (Sulaiman and Mohd-Nor, 2003).

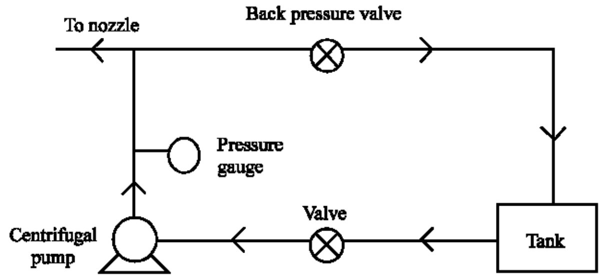

Fig. 1: Schematic of the spray rig and liquid flow loop

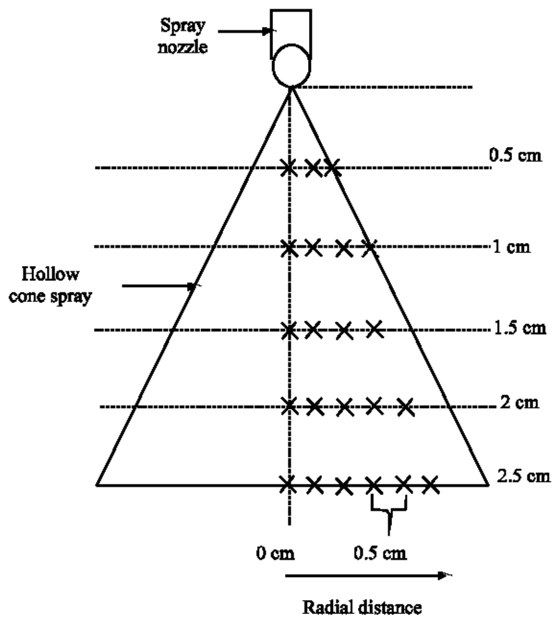

Fig. 2: Measurement points relative to nozzle tip

The experiments were conducted at the different distances from the nozzle tip, as shown in Fig. 2, for different spray pressures and liquid. The readings were taken only on the middle plane of the sprays when they were fully developed. The horizontal and vertical intervals between the measurement points were 0.5 cm. Assuming that the sprays were almost symmetrical, measurements were conducted for only half portion of the sprays.

RESULTS AND DISCUSSION

The experiments on the sprays were conducted to determine the characteristics of water and diesel spray by using the PDA systems. The primary data provided information on the data counts and the individual droplets' diameters. The SMD values were calculated by using Eq. 1.

Shown in the Fig. 3a is a typical distribution of water droplet diameters at a vertical distance of 0.5 cm below the nozzle tip at a pressure of 50 kPa. The data are in the range of between 200 µm and 1000 µm. The SMD at this set of data is 736 µm with a standard deviation of 218 µm. Clearly the spray droplets are polydisperse since due to the wide range of diameters as verified by the large standard deviation. The same trend in Fig. 3a is also displayed by the typical diesel sprays

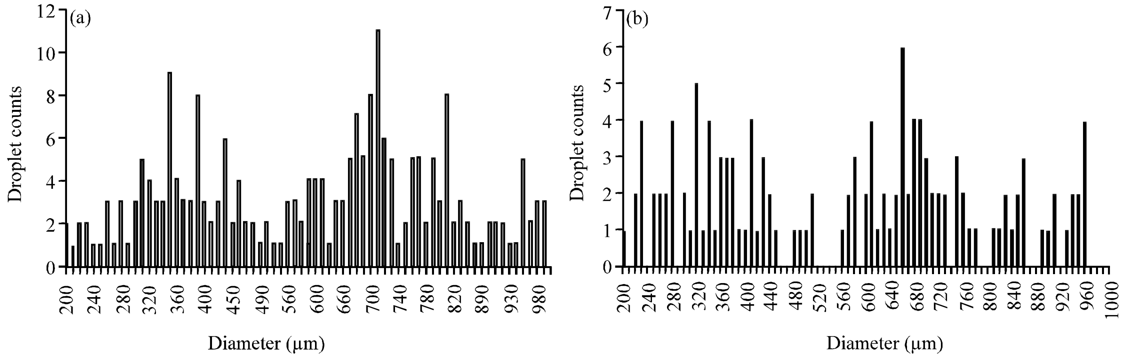

Fig. 3(a-b): Typical frequency of droplet diameters for (a) Water and (b) Diesel recorded using the PDA system

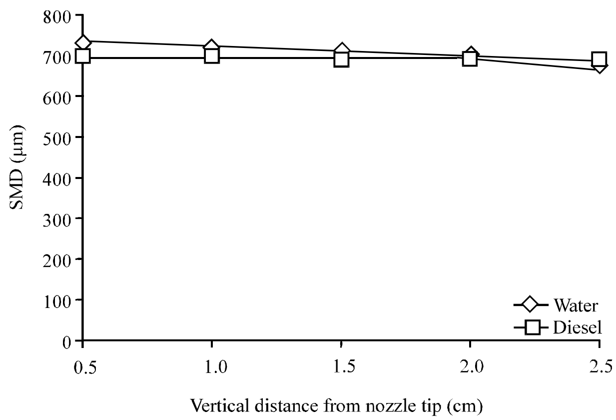

Fig. 4: SMD of water and diesel sprays at 50 kPa

shown in Fig. 3b which was obtained at the same pressure and same location relative to the nozzle tip. Also a polydisperse spray, the SMD for the diesel spray is 715 μm with a standard deviation of 224 μm.

The comparison of Sauter Mean Diameter (SMD) between water and diesel at 50 kPa at different vertical distances from the nozzle tip is shown in Fig. 4. Water is shown to have slightly larger SMD's than that of diesel although the difference becomes smaller at farther vertical distance from the nozzle tip. The largest SMD value is at 0.5 cm distance from nozzle tip which is around 740 μm and the smallest value is around 670 μm. The SMD of water decreases slightly with the distance from the nozzle tip. For diesel, the SMDs are almost constant around 700 μm at each distance. Both liquids display nearly the same pattern i.e., decrease in SMD with the vertical distance.

Figure 5a shows the comparison of Sauter Mean Diameter (SMD) between water and diesel sprays at 100 kPa at different vertical distances from the nozzle tip. It displays the same pattern as in Fig. 4, in which water has the larger SMD than that of diesel sprays at any vertical distance from nozzle tip except at 2.5 cm. The largest SMD value (740 μm) is measured at 0.5 cm below the nozzle tip and the smallest value is around 650 μm. The SMD of water decreases with the distance from the nozzle tip. There is a sudden drop by about 70 μm at the point of 2.5 cm below the nozzle tip. For diesel, the SMD are almost constant around 700 μm at each distance. The trends of SMD variation with distance for both liquids in Fig. 5a are shown to be of similar patterns to that displayed in Fig. 4 i.e., SMD decreases with the vertical distance.

Shown in Fig. 5b is the comparison of Sauter Mean Diameter (SMD) between water and diesel sprays at 150 kPa at different vertical distances from the nozzle tip. The SMD for water is shown to be larger than that of diesel at any location. The largest SMD value (750 μm) is at 0.5 cm below the nozzle tip and the smallest value being around 710 μm. The SMD of water decreases with the vertical distance from the nozzle tip. There is a sudden drop by about 60 μm at the distance of 2.5 cm below the nozzle tip. For diesel, the SMD are displayed to be almost constant at about 700 μm. The SMDs for both liquids show similar patterns as those in Fig. 4 and 5.

Measurements were also conducted to determine the Sauter Mean Diameter (SMD) at different radial distances for both water and diesel sprays. The distance between points to point was 0.5 cm. In general, it was found that the trends of SMD in radial direction were of mixed values. Table 1 and 2 display the SMD values at different radial distances for water and diesel sprays. It was

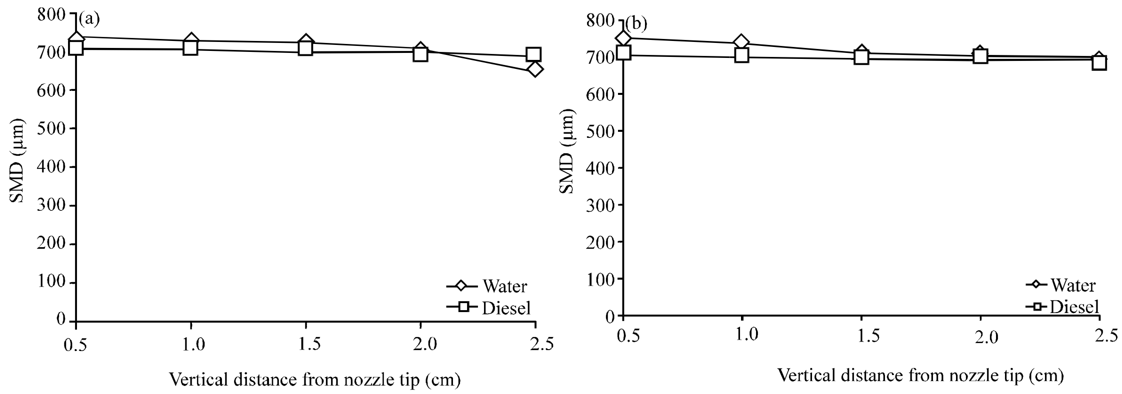

Fig. 5: Droplet sizes for water and diesel sprays at (a) 100 kPa and (b) 150 kPa

Table 1: Sauter mean diameter (SMD) of water droplets at different spray pressure and radial distance from nozzle

	SMD (μm)			
	Radial distance (cm)			
Pressure (kPa)	0.5	1.0	1.5	2.0
	403	370	0	0
	433	412	429	0
50	486	454	493	0
	500	474	489	515
	544	512	503	525
	398	410	0	0
	401	424	435	0
100	401	401	425	0
	433	412	412	429
	450	433	399	421
	368	404	0	0
	387	413	415	0
150	393	368	406	0
	414	414	430	490
	403	370	383	456

Table 2: Sauter mean diameter (SMD) of diesel droplets at different spray pressure and radial distance from nozzle

	SMD (µm)			
	Radial distance (cm)			
Pressure (kPa)	0.5	1.0	1.5	2.0
	398	323	0	0
	404	380	390	0
50	413	401	411	0
	420	419	429	431
	431	424	411	436
	363	387	0	0
	379	354	365	0
100	381	360	378	0
	394	379	361	380
	401	383	390	413
	313	368	0	0
	329	303	318	0
150	335	320	330	0
	356	339	350	350
	378	319	360	389

assumed that the sprays were symmetrical and thus measurements were performed only on one side of the spray as shown earlier in Fig. 2. There is a large difference in SMD values between the middle point measurement and radial distance of both liquids. The SMD at middle region of the spray are generally larger in size than that at locations away from the spray axis. For the SMD of radial distance, the values are approximately constant with distance. The SMD of water are larger than that of diesel at any point. There is a sudden decrease in SMD at 0.5 cm away from the axis but the SMD values start to increase back until the border of the spray. As the pressure increases, the SMD is shown to decrease.

CONCLUSIONS

A study on the similarity between water and diesel sprays was attempted by comparing the temporal distributions of Sauter Mean Diameter (SMD). The pressures were varied at 50, 100 and 150 kPa. From this work, the following conclusions can be drawn:

- The sprays of water and diesel are polydisperse as the droplets has a wide range of diameters
- Both water and diesel sprays have the largest droplet sizes close to the nozzle tip (0.5 cm below) at any pressure. At 2.5 cm away from the nozzle, the droplet sizes for both liquids were found to be the smallest
- Generally water has the larger droplet sizes that of diesel at each pressure
- As the pressure increases, the SMD for both liquids at the center increases and as the vertical distance from nozzle tip increases, the SMD decreases
- As the pressure increases, the SMD for both liquids decreases in radial distance away from the axis

There is only a small difference between the values of SMD for water and diesel sprays. On average, their trends of SMD distributions are almost the same. Therefore, it can be concluded that the SMD of water and diesel are identically same and it is probable that water sprays can be used to represent diesel sprays in non-combusting experiments pertaining to droplet diameters.

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