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CHARACTERIZATION OF STRAIGHT VEGETABLE OIL SPRAYS ISSUED FROM PRESSURE SWIRL AND TWIN FLUID ATOMIZERS

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ABSTRACT

In this study performances of sprays from a pressure atomizer (hollow cone) and a twin fluid atomizer are compared using sunflower straight vegetable oil (SVO). The study has been performed at different liquid temperature and pressure to estimate their effects on the spray characteristics. A Mie Scattering optical set-up, employing a laser light sheet and a charge coupled device (CCD) camera, is used to capture the spray images from which the spray cone angles have been evaluated. The liquid distribution from the spray is measured by a mechanical patternator placed at a definite distance below the atomizer. It is observed from the study that, flow number (FN) remains unchanged with the change in the flow rate for both the hollow cone and twin fluid atomizers. In case of hollow cone atomizer, FN increases slightly with the increase in oil temperature thereby consuming less power for delivering the fuel. This phenomenon has not been observed in case of twin fluid atomizer. For pressure atomizers the spray cone angle increases with the increase in the flow rate as well as with the increase in oil temperature. The cone angle of twin fluid atomizer exhibits almost a constant value for the entire operating range of liquid flow rate, but increases with the increase in both air pressure and oil temperature. Symmetrical patternations have been observed in the sprays with more spray areas at higher temperature and liquid pressure for hollow cone atomizer and at higher air pressure for twin fluid atomizer.

Keywords: Pressure Atomizer, Twin Fluid Atomizer, SVO, Spray Characteristics, Flow Number, Patternation.

1. INTRODUCTION

The current trend of energy research focuses on the sustainable development of alternative energy sources by conserving limited conventional fuels. The transportation and power sectors are consuming relatively more petro-fuel compared to other sectors, which can be replaced by biofuels extracted from biomass. India is an agro-based country which has a large supply of agro-based biomass. Straight vegetable oils (SVO) obtained from plant seeds, can be used as fuel in many applications like engine, gas turbine and furnaces. The basic components of Vegetable oil are triglycerides (90–98%) with a small amount of mono- and di-glycerides. Tri-glycerides consist of three fatty acid molecules and a glycerol molecule. These elements contain large amount of oxygen. They also contain free fatty acids (generally 1–5%), phospholipids, carotenes, tocopherols, sulfur compounds and traces of water. Commonly found fatty acids in vegetable oils are stearic, palmitic, oleic, and linolenic acid. The viscosity and density of straight vegetable oil is much higher than conventional petro-fuels due to the long fatty acid structures. Due to these properties the spray cone angle of SVO is small, whereas the liquid penetration is high when sprayed through the nozzles. In order to increase the spray cone angle of SVO, modifications, like increase in temperature of the liquid [1] or increase in liquid injection pressure, are to be employed. Though inedible oils are mainly used as an alternative resource, sunflower oil has been used in the present experiment. Table 1 shows the comparison of SVO with different oils used as fuels (like Jet-A, diesel) in several applications like gas turbines, engine, boilers etc.

Liquid fuel combustion requires atomization of the fuel in the form of a spray using spray atomizers. High quality of atomization is an important pre-requisite of good combustion and various injectors are used to achieve it. The atomizers inject the fuel in the form of a spray which undergoes breakup due to instabilities at the spray surface resulting in a multitude of droplets. The quality of atomization is characterized by the spray cone angle, liquid distribution in the spray (patternation), spray penetration and drop size

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distribution. At the same time, power consumed in achieving the atomization can be characterized by the atomizer flow number, which relates the liquid flow rate with the pressure drop. It is evident that by doing some modifications we can directly use the SVO in all energy generation fields and can help in finding alternative energy source which is our aim of this study.

Table 1: Comparison between Diesel, Jet-A and SVO

Properties	Diesel	Jet-A	SVO
Density(kg/m3)	827.4	807	900-940
Kinetic viscosity (cSt at 40^{0}C)	1.72	0.88	30-40
Flash point (^{0}C)	44	38	230-280
Cloud point (^{0}C)	-6	-	-4 to 12
Lower calorific value (MJ/kg)	43	43.2	38-39
Ignition temperature	250	220	325-370

Many works have been reported in the literature on the characterization of vegetable oil sprays. **Prussi et al.** [2] investigated the use of straight vegetable sunflower oil and its blend with diesel in a micro-gas turbine (MGT). They confirmed that MGT can be operated using SVO with a little modification and by adjusting the controlling parameters. Also the observed CO emissions at nominal condition were almost same for both the fuels. **Lu et al.** [3] focused on spray combustion of pure fast pyrolysis bio-oil from rice husk using an internal mixing air-blast atomizer. They concluded that bio-oil has the potential to replace diesel and can be used as a fuel source for large-scale combustion systems such as furnace, boiler and gas turbine. Some other researchers have done experiments on engines by using SVO as fuel. **Daho et al.** [4] created a model for predicting the evaporation characteristics of cottonseed oil and diesel fuel in the temperature range of 684–917 K under atmospheric pressure. **Alton et al. [**5**]** studied the effects of using vegetable oil fuels and their methyl esters on diesel engine. They concluded that compared to diesel fuel, a little amount of power loss happened whereas a higher amount of particulate emissions is observed for vegetable oil fuels. **Altun et al.** [6] also observed the same result using a blend of 50% sesame oil and diesel fuel in a direct injection diesel engine. **Hazar and Aydin** [7] used raw rapeseed oil blended with diesel fuel by 50% and 20% in volume in a compression ignition engine. Results showed that heating is necessary for smooth flow and to avoid fuel filter clogging. It also reduces the fuel mass consumptions. **Deshmukh et al.** [8] presented some results of high pressure spray characterization of SVOs under atmospheric conditions. They observed that the injection delays of these oils are much higher than diesel fuel due to their high viscosity. The presence of an intact liquid core is observed at atmospheric pressure. **Wander et al.** [9] investigated a compression ignition engine fueled with soy straight vegetable oil, blended with diesel at volume percentages of 10, 30, 50, 70 and 100%. The results show an increase in the specific consumption with slightly lower engine efficiency due to the lower heating value of oil. **Abdullah** [10] studied the effect of kinematic viscosity of SVO on fuel injection spray characteristic using constant volume high pressure spray chamber and concluded that high injection pressure can produce relatively small-size droplets and improve the atomization. **Malkawi et al.** [11] studied breakup mechanisms for high-viscosity corn oil and compared to those for diesel fuel in conjunction with electrostatic atomization.

Apart from the above applications, SVO can be used in some other areas like in the furnace for domestic heating, boiler for power generation, food industry for preservation and also as lubrications and insecticides. **Khan et al.** [12] investigated thin film deposition for sunflower oil electro-sprayed by single electro-spraying on a highly conductive (aluminum) and insulating target surface (Parafilm). For both aluminium foil and Parafilm the droplet deposition was found to be random. **Vaitilingom et al.** [13] carried out important experiments on the use of rape seed oil as a substitution for domestic fuel in burners. Tests were conducted on a fully-monitored 260 kW boiler test-bench. It is found that the crude industrial rape seed oils led to filter clogging in few minutes. The performance data and combustion efficiency was equal to that of domestic fuel and the emission values obtained with the optimal adjustments are far below the limits defined by the European norm in force. The reuse of waste vegetable oil is also a growing concern and some of work has been reported. **Arslan** [14] studied the use of waste cooking oil (WCO) methyl ester as an alternative fuel in a four-stroke turbo diesel engine. The engine was fueled with diesel and three different blends of diesel/biodiesel. The biodiesel fuels produced slightly less smoke than the conventional diesel fuel, which could be attributed to better combustion efficiency. The use of biodiesel resulted in lower emissions of total hydrocarbon (THC) and CO, and increased emissions of NOx. This study showed that the exhaust emissions of diesel/biodiesel blends were lower than those of the diesel fuels, which indicates that biodiesel has more favorable effects on air quality. Thus these studies can give a deeper insight to understand and calculate different parameters involved in the application of the spray.

Various types of atomizers are in use for the atomization of liquid fuels. Among them, gas turbines mainly use hollow cone pressure atomizers and twin fluid atomizers. A comparison of performance of these atomizers with straight vegetable oils can give useful insight regarding the use of atomizer for spraying SVO in gas turbine applications. The present work focuses in this direction and uses a hollow cone pressure atomizer and an air assist twin fluid atomizer for spraying sunflower oil. Atomizer and spray parameters like spray cone angle, flow number and liquid patternation have been compared at different operating conditions.

2. EXPERIMENTAL

The schematic of the experimental set up is shown in figure 1. It has a fuel tank, from which the liquid fuel (SVO) is forced by a gear pump through the atomizer into the surrounding air. The flow rate is controlled with a needle valve (V_n) and a ball valve (V_b). A pressure transducer placed just before the nozzle reads the pressure differential across the nozzle. The liquid contained in the tank is indirectly heated to achieve a better control on its temperature. A double walled cylindrical tank is used for this purpose. The outer cylinder is filled with transformer oil, which is heated with the electric heaters that in turn makes the liquid fuel hot and the temperature is sensed by a RTD type temperature sensor (Pt-100). During operation, oil temperature may drop in the line due to heat loss from the pipe. A thermocouple placed just before the nozzle measures the oil temperature before the atomizer. The thermocouple also feeds to a feedback loop controller that alters the reservoir heating so that the oil temperature just upstream of the nozzle is maintained close to a specific preset temperature. The flow rate is measured with a graduated volume measuring flask and a stopwatch.

Mie scattering technique is used to measure the spray cone angle. A light sheet is formed using a 10 mW He-Ne red laser of wavelength 632 nm, using suitable lenses and mirrors. The light sheet is placed at the central plane of the spray and scattered images are captured by placing a CCD camera normal to the light sheet. The images are analyzed with software to measure the included cone angle of the sprays.

A mechanical patternator (PT) has been used to measure the liquid mass flux distribution within the spray. The patternator is built with 1 cm× 1 cm × 4.5 cm rectangular collection tubes having 1 mm thin walls. The tubes are placed in closely packed linear arrays along eight radial directions, which are 45 degree apart from each other. The mass of the liquid collected per unit time per unit area has been calculated. After getting data from each collection tube, contours have been plotted from which circumferential liquid distribution of the spray can be obtained.

3. METHODOLOGY

In our experiment we have investigated the atomizer performance and spray characteristics of sunflower oil SVO using a hollow cone pressure swirl atomizer and a twin fluid atomizer. In the hollow cone atomizer, liquid is injected directly to the atomizer through a swirler. It imparts a swirling motion to the liquid in the atomizer, which finally comes out through an orifice placed at the tip of the nozzle in the form of a hollow cone spray. On the other hand, in the twin fluid atomizer, moisture free compressed air flows with the

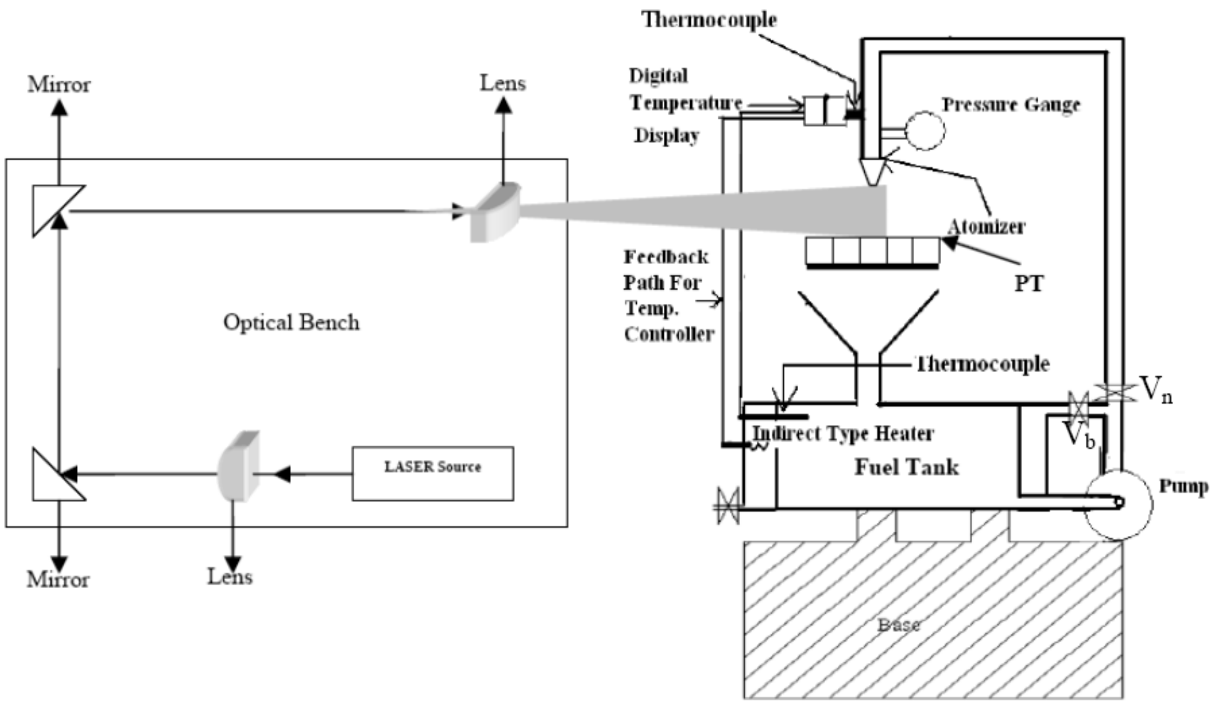

Fig.1. Schematic of the experimental set up. (PT = mechanical patternator, V_n = needle valve, V_b = ball valve)

liquid to atomize the liquid. Figure 2(a) shows the images and (b) shows the schematics of the nozzles used in the experiments. The nozzle tip plane is kept horizontal and the LASER light sheet is passed through the central plane of the spray. The experiments have been conducted at three different temperatures of the liquid (45^{0}C, 60^{0}C and 75^{0}C). The flow rate is measured and the corresponding value of pressure drop has been recorded from the pressure transducer. The flow number (FN) of atomizer, defined as the ratio of volume flow rate (Q) times square root of density (ρ) by pressure drop across the atomizer (ΔP) as in Eq. (1) is evaluated.

$$\mathrm{FN} = Q\sqrt{\frac{\rho}{\Delta P}} \qquad (1)$$

To determine the spray characteristics, the spray cone angle has been measured for each flow rate. The spray cone angles are measured by drawing tangents through the outermost periphery of the spray images just at the nozzle exit. For the twin fluid atomizer the experiments have been conducted at two different air pressures (0.5 and 1.5 bar). Figure 3 shows a typical Mie scattered image of a spray. The patternation test has been done for SVO at different temperature and pressure. The patternator has been placed 10 cm below

Hollow cone atomizer Twin fluid atomizer

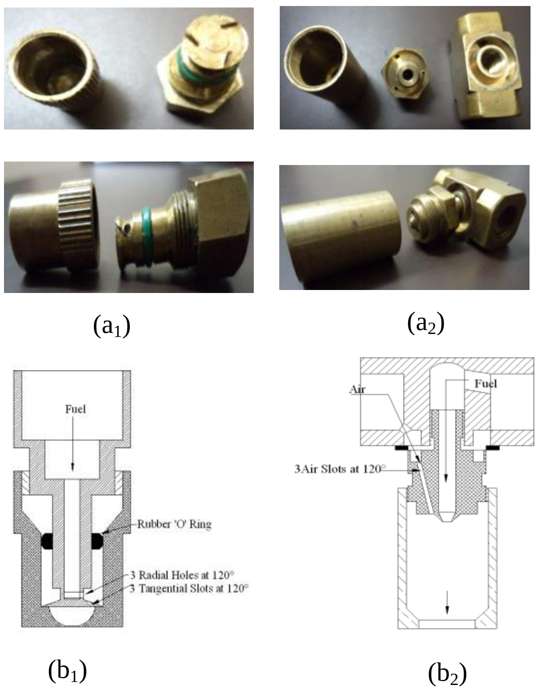

Fig.2. (a) Images and (b) schematic diagrams of nozzles used in the experiment.

the nozzle tip. The liquid is taken out from the patternator block with the help of a calibrated syringe of 5 ml and the volume of the liquid collected is measured from it.

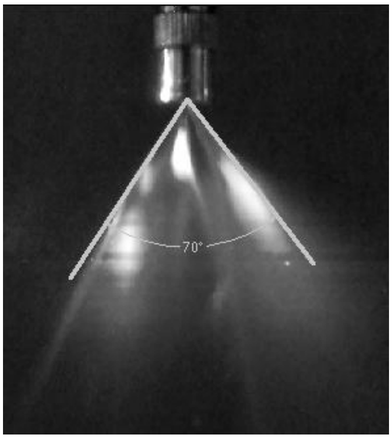

Fig.3. Picture showing cone angle of sunflower oil issued from hollow cone nozzle at 75^{0}C and 3 bar pressure.

4. RESULT AND DISCUSSION

After conducting the experiments with both hollow cone and twin fluid atomizers, the following results are obtained. The variations of spray cone angle with different flow rates have been plotted for three different liquid temperatures in Figure 4. It is seen that the cone angle increases with the increase in the flow rate for the pressure swirl hollow cone atomizer. It has also been observed that the increment in spray cone angle with the increase in flow rate remains low at low liquid flow rate, but it increases with the increase in flow rate. Moreover, an increase in liquid temperature increases the spray cone angle for a particular flow rate of the liquid. This can be attributed to the reduction in viscosity of the liquid with the increase in temperature. In case of the twin fluid atomizer the spray cone angle behaves differently with the liquid flow rate. Here the cone angle remains almost constant for a given air pressure with varying liquid flow rate. However, with the increase in the air pressure, cone angle increases. Similar effect of liquid temperature on spray cone angle is observed in twin fluid atomizer as in pressure atomizer, though the variation in the cone angle is much less in the former.

The variation of flow number at different liquid flow rates and for different temperatures for SVO has been shown in Figure 5 for the two atomizers under study. In this result it is seen that for a particular nozzle the flow number remains almost the same for a particular liquid temperature. But as the liquid temperature increases, the liquid viscosity decreases

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and therefore the pressure drop across the nozzle orifice decreases. Hence, the flow number increases slightly with temperature.

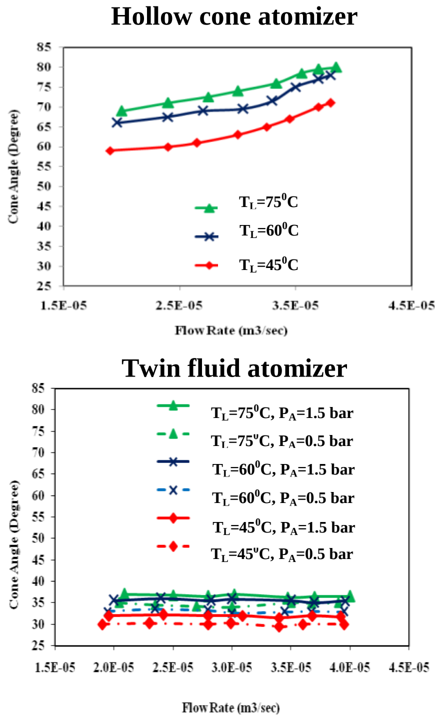

Fig.4. Variation of cone angle with liquid flow rate for a hollow cone and twin fluid nozzle with SVO at different temperatures and pressure.

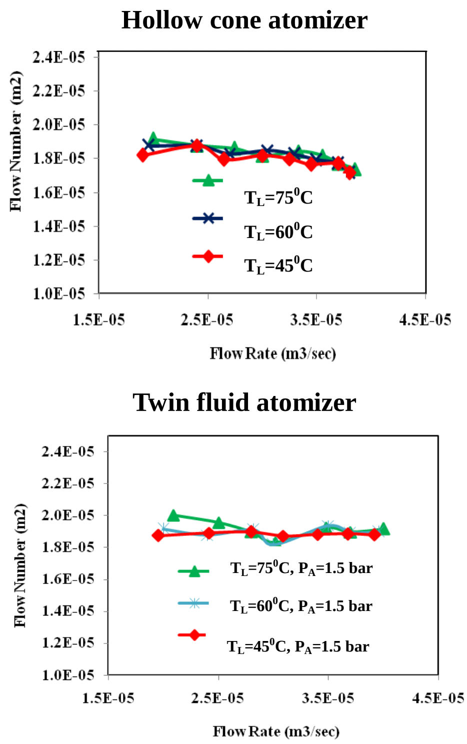

Fig.5. Variation of flow number with liquid flow rate for a hollow cone and twin fluid nozzle with SVO at different temperatures and pressure.

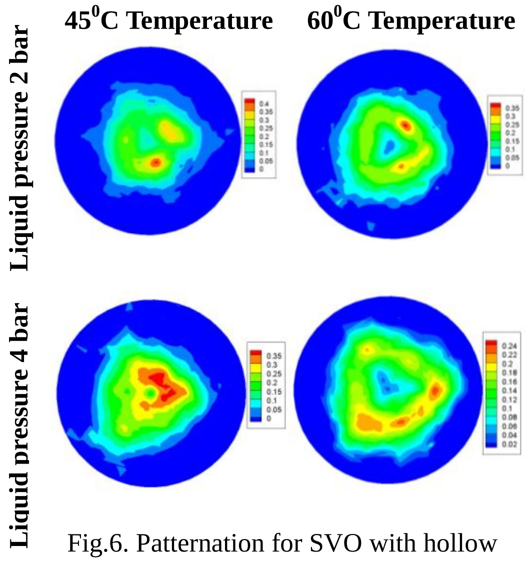

Fig.6. Patternation for SVO with hollow cone atomizer.

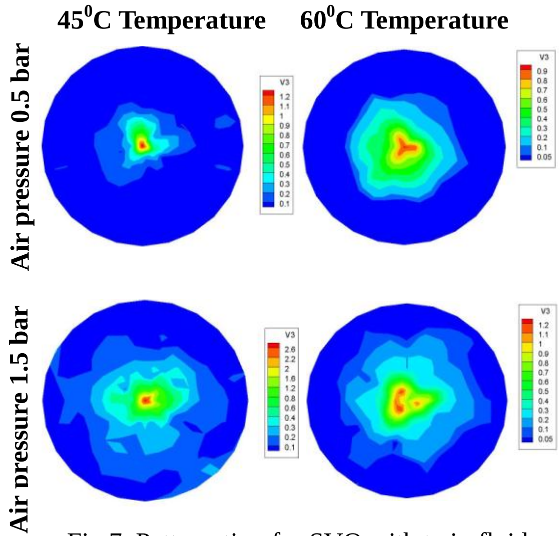

Fig.7. Patternation for SVO with twin fluid atomizer.

Figure 6 and 7 shows the spray patternations of SVO with pressure swirl hollow cone atomizer and twin fluid atomizer, respectively. For hollow cone atomizer the patternation (Fig. 6) has been done at two different temperatures of the liquid and with two liquid pressures. For twin fluid atomizer the results have been plotted at two different liquid temperatures and with two different air pressures maintaining the liquid pressure constant (Fig. 7). It is evident from Fig. 6 that in case of the hollow cone pressure atomizer the liquid concentration is low near the center. This is the obvious characteristics of the typical hollow cone spray. However, as the patternation measurement is done at some distance down the atomizer, transport of some mass of liquid towards the centre is evident. The larger radial spread of liquid mass at higher temperature and higher pressure are indicators of increased spray cone angle under those operating conditions. The liquid mass distribution in

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case of the twin fluid atomizer is different. Firstly, the radial spread of the liquid is much less here because of the lower spray cone angle of the spray. Secondly, the liquid is more concentrated near the center. However, similar to pressure atomizer, twin fluid atomizer shows radial increase in the liquid mass distribution at higher liquid temperature and air pressure respectively.

5. CONCLUSION

Characteristics of sunflower straight vegetable oil (SVO) sprays from a pressure atomizer and a twin fluid atomizer are studied. The parameters which mainly characterize the atomization are flow number or coefficient of discharge, spray cone angle, drop size distribution and mean drop diameter, and spray patternation. From the experiments we observed that as the liquid temperature increase, the FN increases while maintaining its trend with flow rate. In the measurement of spray cone angle, the twin fluid atomizer exhibits almost a constant cone angle over the entire operating range of liquid flow. It is observed that the spray cone angle increases as flow rate increases for the pressure atomizers. Hollow cone atomizer requires more pumping power for SVO at a constant flow rate whereas the twin fluid shows the opposite result. Cone angle produced by the hollow cone atomizer is more than that from twin fluid atomizer for SVO. With the increase in liquid pressure and temperature for hollow cone and twin fluid atomizer more symmetrical patternation has been observed. These results can throw useful insight in choosing SVO in various fields of applications as alternative fuel.

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NOMENCLATURE

Symbol

Q	Liquid flow rate	(m^3/sec)
ΔP	Pressure drop	(Pa)
C_d	Coefficient of discharge	-
θ	Half cone angle of the spray	(Degree)
X	Area ratio	-
A_O	Exit area of the orifice	(m2)
ρ	Density of the liquid	(Kg/m^3)
T_L	Temperature of liquid	(^{0}C)
P_A	Air pressure	(Pa)

Subscripts

A	Air
L	Liquid
O	Orifice

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