

COMPARISON of SPRAY CHARACTERSTIC BETWEEN PRESSURE ATOMIZER AND AIR ASSIST ATOMIZER

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ABSTRACT

Pressure atomizer and twin fluid atomizer (of air assist type) are two common types of atomizers used in various industrial applications. In this work, the characteristics of spray issued from these two types of atomizers have been compared through experimental measurements. A swirl type pressure atomizer has been chosen. The pressure drop across the atomizer and the corresponding flow rate has been measured for water as the atomizing liquid. The spray cone angles have been evaluated at different liquid flow rates from Mie scattering images captured by passing a laser light sheet through the spray. The liquid dispersion in the spray has been measured using a mechanical patternator. It has been observed that for the pressure swirl atomizer, the flow number first reduces with the increase in liquid flow rate and then becomes invariant after a particular flow rate value. The cone angle of the spray from the pressure swirl atomizer increases with the increase in flow rate, while the air assist atomizer is found to produce an almost constant angle spray for all the liquid flow rates under study. However, the cone angle for the spray from air assist atomizer increases with the increase in air pressure. The liquid mass distribution in the spray shows that a hollow cone spray is generated from the pressure swirl atomizer, while for the air assist atomizer the spray is of solid cone type with maximum liquid mass flux near the central region of the spray.

Keywords: Pressure Swirl Atomizer, Air Assist Atomizer, Flow Number, Spray Cone Angle, Patterning.

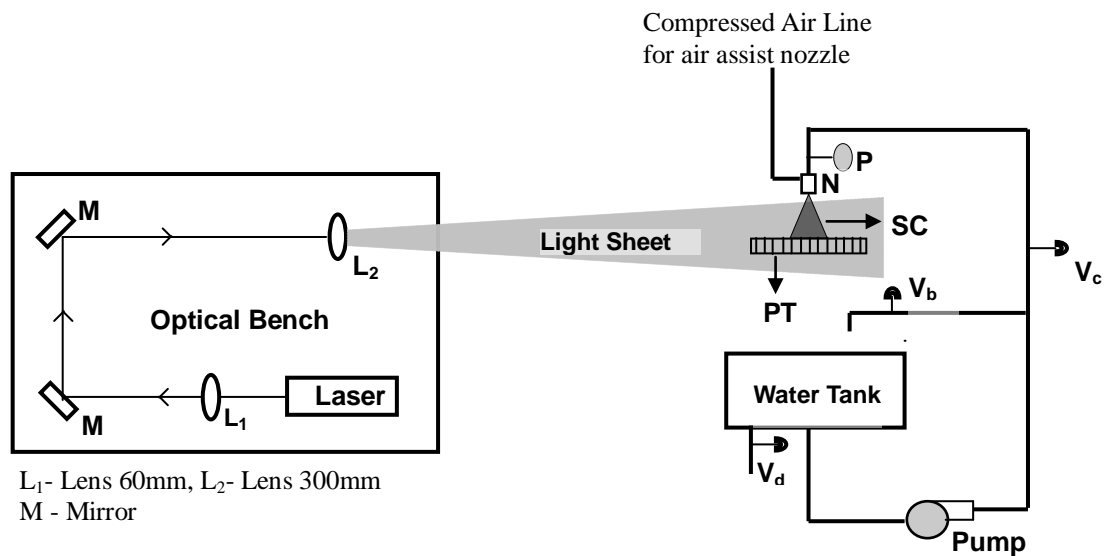
1. INTRODUCTION

The atomization of liquid into a multitude of droplets has many important industrial applications [1]. Atomization is caused by a disruption in the consolidating influence of surface tension by some external force. The increase in specific surface area achieved through atomization results in an increase in the rate of evaporation of liquid. Different types of atomizers are used in practice, out of which pressure atomizer and twin fluid atomizer are mostly employed in the atomization of liquid fuel. In pressure atomizers, liquid at high pressure enters the atomizer nozzle and a high velocity liquid jet or sheet issues from it into the surrounding environment. The high relative velocity between the liquid and the surrounding gaseous medium generates an aerodynamic force on the liquid surface resulting in its break up, first into ligaments and finally into tiny droplets. Pressure swirl atomizers are particularly useful for the combustors, like in gas turbine, because of their ability to spread the liquid over a wide angle. On the other hand, in twin fluid atomizer, the atomizing liquid need not have to be pressurized much as the atomization is achieved through the inertia of a second fluid which interacts with the liquid. Mostly air or steam is used as the second fluid, which is blasted with high momentum on the surface of the liquid.

The performance of an atomizer in producing a spray

is defined by several characteristic parameters [1]. The most crucial parameter is considered to be the droplet size distribution and mean drop diameter. However, there are other important parameters as well. One such parameter is the necessary pressure difference across the atomizer (Δp) required for a certain flow rate of the liquid (\dot{Q}). For the industrial atomizers, this is often represented by flow number ($FN = \dot{Q}/\sqrt{\Delta p}$). Alternately, coefficient of discharge ($C_d = \dot{Q}/(A_o \sqrt{2 \Delta p / \rho_l})$, where A_o = orifice area at discharge, ρ_l = liquid density) is used to correlate the pressure differential with the liquid flow rate. The dispersion of liquid mass across the spray has many important practical implications, particularly in case of liquid fuel combustors, where good mixing of the fuel and air is important. The cone angle of the spray (θ) generated by the atomizer shows the dispersion of the droplets as they are issued into the surrounding. However, it does not provide information on the actual distribution of the liquid mass flux within the spray volume. A patterning test in the spray provides the radial or circumferential distribution of the liquid mass flux across the spray.

There are works available in the literature to show the variation of flow number (or C_d), cone angle and



V_d - Drain Valve, V_b - Bypass Valve, V_c - Flow Control Valve, P - Pressure Gauge
N- Nozzle, SC- Spray Cone, PT- Patternator

Fig 1. Schematic diagram of the experimental set up showing the optical arrangement for the Mie scattering image

patternation for sprays from pressure swirl atomizers. Pressure swirl atomizers develop an air core inside the atomizer due to high tangential momentum of flow of liquid. Som and Mukherjee [2] performed a theoretical and experimental investigation on the formation of air core in simplex type pressure nozzle. Giffen and Muraszew [3] presented a fundamental analysis of the flow condition within a simplex nozzle, assuming inviscid liquid. They proposed a relation of coefficient of discharge to the ratio of air core area to discharge orifice area from their analysis. Jones [4] and Rizk and Lefebvre [5] expressed the coefficient of discharge for pressure swirl atomizer in terms of atomizer parameters and fluid properties. The inviscid analysis of Giffen and Muraszew [3] and Rizk and Lefebvre [5] and the viscous flow analysis of Rizk and Lefebvre [6] led to express the spray cone angle from swirl atomizers. Datta and Som [7] developed a numerical model for predicting the flow inside a pressure swirl atomizer and evaluated parameters like coefficient of discharge and spray cone angle from the output of the model. The model predictions agree well with the results from correlations given in [4], [5] and [6]. Guildenbacher et al. [8] studied the effects of nozzle pressure drop and ambient pressure on the cone angle produced from pressure swirl atomizer. They have found negligible influence of pressure differential on the spray cone angle at high ambient pressure. Dispersion of liquid in the spray is another important parameter that has been studied using either a mechanical or an optical patternator [9].

The studies on performance characterization of twin fluid atomizers have been mostly oriented towards the determination of drop size distribution in sprays generated from the atomizers [10]. Air blast atomizers have been introduced in the gas turbine applications to atomize the liquid fuel as they require lower fuel pressure and produce finer spray. Furthermore, these atomizers

ensure better mixing of fuel and air, decreasing the formation of soot in flame. Parameters like spray cone angle and liquid mass distribution in the spray received much less attention for this class of atomizers. However, these parameters are extremely important particularly where dispersion of the liquid in the spray is a vital requirement.

In the present work, we have considered one pressure swirl atomizer and one internal mixing type twin fluid atomizer, available commercially, to study the effects of flow number, spray cone angle and liquid dispersion in the spray at different liquid flow rates. The sprays are injected into the open atmosphere from the nozzles. The characterizing parameters for both the atomizers have been compared and the differences in their characteristics with the flow conditions have been reported.

2. EXPERIMENTAL

An experimental set up (Fig. 1) has been built for testing the atomizers with water as the working liquid. The set up has a water tank from which water is forced by a centrifugal pump through the atomizer nozzle (N) into the surrounding stagnant air. The flow rate of water is controlled using a needle valve (V_c) in the line and also with a by pass valve (V_b). The nozzles are carefully mounted to keep their axes vertical. A pressure gauge (P), which is fitted in the line just before the nozzle, reads the pressure differential across the nozzle. A graduated measuring flask is used to collect the water coming from the nozzle over a certain time to measure the liquid flow rate.

The cone angle of the spray is measured by taking Mie images of the spray. The necessary optical set up is also shown in Fig. 1. A He-Ne laser is used for the purpose and two optical lenses (L₁ and L₂) are used to produce a light sheet. The sheet is focused at the center to

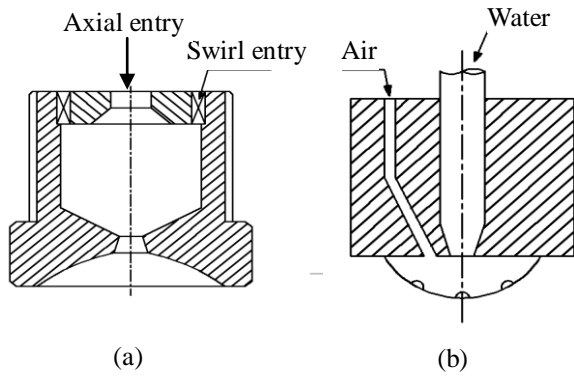


Fig 2. Constructions of the (a) pressure swirl atomizer and (b) air assist atomizer, used in the experiments

the spray. A CCD camera (not shown in the figure) is placed at right angle to the light sheet to collect the scattered image of the spray. The image is then analyzed to determine the spray cone angle.

A mechanical patternator has been built to measure the distribution of the liquid mass flux in the spray. In the patternator a number of small collection tubes with thin walls are placed radially from the center of the spray. The tubes are placed in four radial directions, which are 90° apart. The sampling tubes are allowed to fill with liquid for 10 s. The mass of liquid collected per unit area per unit time at a particular radial location is computed by averaging the collection data of four sampling tubes at different azimuthal directions at that radius.

Two different nozzles are used in the experiments. One of them is a pressure swirl nozzle (Fig. 2a), while the other is an air assist nozzle (Fig. 2b). In the pressure swirl nozzle, the liquid entering the nozzle is split into two parts. One part of the liquid enters axially through a central port, while the other part takes the swirl port to enter the swirl chamber. The liquid finally comes out through small orifice at the tip of the nozzle. For the air assist nozzle, moisture-free compressed air from an air compressor is used to atomize the liquid. The liquid enters the nozzle body through a central port and air through three ports around the liquid port. The air jet at high velocity impinges on the liquid stream inside the atomizer to issue a spray through four small orifices at the tip of the nozzle.

3. RESULTS AND DISCUSSIONS

A number of tests have been performed using both the atomizers and the performance parameters, like flow number, spray cone angle and spray patterning, have been evaluated from the tests. A lot of work is available in the literature regarding the variation of these spray parameters at different operating conditions for the pressure swirl atomizer. However, similar data on air assist atomizer is relatively sparse. In this circumstance, it would be interesting to compare the characteristics of sprays from pressure swirl and air assist atomizers in terms of flow number, spray cone angle and liquid dispersion. We have used one atomizer of each type and varied the liquid flow rate to observe its effect on the

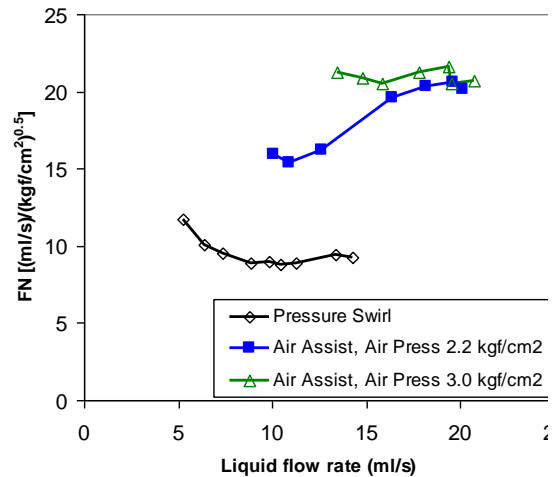


Fig 3. Variation of flow number (FN) with liquid flow rate for two atomizers

performance parameters. In case of the air assist atomizer, the air pressure into the atomizer has also been varied to observe its effect.

Figure 3 shows the variation of atomizer flow number with flow rate of the liquid. Flow number (FN) is evaluated from the flow rate of liquid and the corresponding liquid pressure differential across the atomizer. Flow number is a characteristic of the hydrodynamics within the atomizer. Higher flow number ensures more liquid flow rate while consuming less pumping power in pressurizing the liquid. It is observed from the figure that the flow number for the pressure swirl nozzle first decreases with the increase in liquid flow rate till a particular flow rate is reached. Beyond this flow rate, the flow number remains almost unchanged with further increase in the flow rate. This trend in flow number is typical for a pressure swirl nozzle as also reported by the earlier researchers. However, for the air assist nozzle, the variation of flow number with liquid flow rate does not present any consistent trend. This shows that flow number cannot be a representative parameter in describing the performance of the air assist atomizer. In air assist atomizer the atomization process is achieved through the impact of the air jet on the stream of liquid. As a result, the role of liquid pressure is less significant in these atomizers.

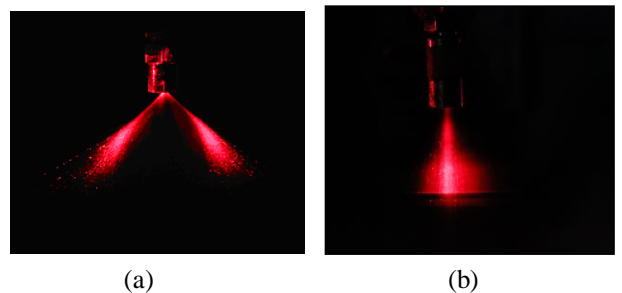


Fig 4. Mie scattering images of spray from (a) pressure swirl atomizer ($\dot{Q} = 10.42$ ml/s, $\Delta p = 1.4$ kgf/cm²) and (b) air assist atomizer ($\dot{Q} = 13.41$ ml/s, $\Delta p = 0.4$ kgf/cm², air pressure = 3.0 kgf/cm²)

Figure 4a and 4b show the Mie images of sprays from the two atomizers under test. A hollow cone spray (Fig. 4a) is clearly observed for the pressure swirl atomizer. This is due to the formation of air core in the atomizer as a result of the swirling flow inside the nozzle. The overall spray from the air assist nozzle (Fig. 4b), coming out from three orifices at the nozzle tip, generates a single solid spray in the surrounding. The cone angles of the sprays are measured by drawing tangents through the outermost periphery of the spray in the Mie images.

Figure 5a and 5b show the variation of spray cone angle (θ) with the liquid flow rate the pressure swirl and air assist atomizers, respectively. The cone angle of the spray from the pressure swirl atomizer increases with the increase in flow rate (Fig. 5a). Rizk and Lefebvre [4] used a theoretical approach to derive an expression of spray cone angle for pressure swirl atomizer and for viscous liquids. The expression shows that for a particular atomizer and a particular liquid, the spray cone angle gets widened with the pressure differential across the atomizer such that $(\theta/\Delta p^{0.11})$ remains a constant. We have plotted the parameter $(\theta/\Delta p^{0.11})$ for the different conditions of test and the result corroborates the above (Fig. 5a). This can be taken as a validation of the measurement technique employed in the test. In case of the air assist atomizer, the spray angle (θ) is found to remain nearly constant with the variation in the liquid flow rate (Fig. 5b). It means that an air assist atomizer produces a constant angle spray for all the liquid flow

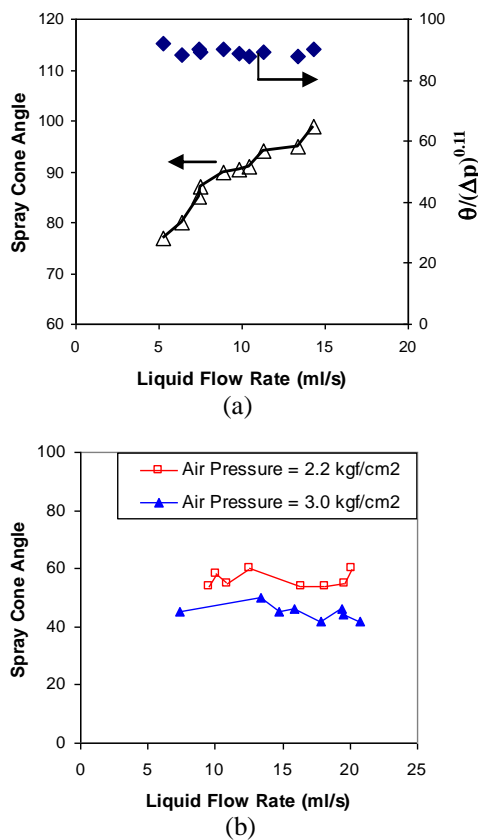


Fig 5. Variation of spray cone angle with liquid mass flow rate for (a) pressure swirl and (b) air assist atomizers

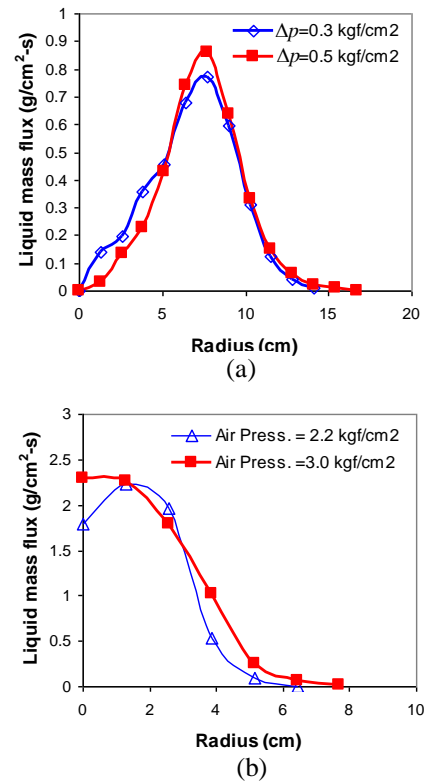


Fig 6. Variation of liquid mass flux with radius at a distance of 15.6 cm from the nozzle outlet for (a) pressure swirl and (b) air assist atomizers

rates when the air pressure remains unchanged. Fig. 5b further shows that the cone angle increases as the air pressure into the nozzle is increased.

Figure 6a and 6b show the distribution of liquid mass flux across a plane in the radial direction from the centerline of the spray. The distribution has been measured by placing the patternator at a vertical distance of 15.6 cm from the exit of the nozzles. The liquid distribution for the pressure swirl atomizer shows a hollow cone spray characteristics, with only a very little mass flux close to the axis. The maximum liquid mass flux is collected at a radial distance of 7.7 cm from the central axis. A variation of pressure differential from 0.3 bar to 0.5 bar across the atomizer does not make any major change in the dispersion pattern of the liquid. The peak flux is reached nearly at the same radial location for both the cases. However, the spray shows dispersion up to a higher radial location at higher injection pressure. This corroborates to the observation of Fig. 5a, where a higher cone angle of the spray at higher pressure is observed. The liquid mass flux distribution for the air assist atomizer shows a completely different trend. In this case, the maximum liquid mass flux is observed either on the centerline or remains close to it (Fig. 6b). The patternation tests for the air assist atomizer were conducted by keeping the liquid pressure constant, while changing the air pressure. It is seen that for the higher air pressure, the peak liquid flux is reached right on the spray centerline and the spray is also dispersed up to a greater radial location. This corroborates the observation regarding the effect of air pressure on the spray angle.

4. CONCLUSIONS

A comparison of the performance parameters for pressure swirl and air assist atomizer has been drawn through experimental measurements. The flow number is found to be an indicative parameter for pressure swirl atomizer, while for air assist atomizer the flow number does not seem to produce any consistent trend in its variation. The spray cone angle for pressure swirl atomizer increases with the increase in liquid flow rate, while the air assist atomizer gives a nearly constant angle spray at all flow rates. The spray angle for the air assist atomizer increases with the increase in air pressure. The liquid dispersion in the spray from a pressure swirl atomizer results in the formation of a hollow cone spray with the peak liquid flux occurring at a radial location away from the center. The air assist atomizer on the other hand results in a solid cone spray with the liquid mass flux being maximum at or near the central region of the spray. The results would be important in choosing the atomizers for a particular application in practice.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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