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Factors Affecting Spray Cone Angle of Pressure Swirl Atomizer for Gas Turbine Combustion Chamber: Theoretical and Experimental Analysis

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Abstract

Objectives: The droplet distribution after atomization depends on spray cone angle; hence it affects the performance of combustor. The previous studies and their results are conflicting as atomizer geometry or operating a parameters change which needs to be generalized. **Methods/Statistical Analysis:** In the present work the effect of discharge orifice diameter, nozzle angle and injection conditions on spray cone angle are studied experimentally. A pressure swirl atomizer with different geometry has been investigated at different injection pressure. The photographs are captured to measure the spray cone angle of the liquid coming out of the atomizer. **Findings:** It has been found that spray cone angle is directly proportional to injection pressure and inversely proportional to geometry constant and nozzle angle. The published correlations are compared with experimental results and it is found that the spray cone angle is not only the function of geometric parameters but also the function of injection pressure and liquid properties. **Applications/Improvement:** The results can be helpful in deciding preliminary dimension of the gas turbine combustion chamber.

Keywords: Discharge Orifice Diameter, Empirical Correlations, Experimental Analysis, Nozzle Angle, Pressure Swirl Atomizer, Spray Cone Angle

1. Introduction

Because of simple geometric construction and good atomization characteristics, the wide range of applications of pressure swirl atomizer in combustion, agriculture and medical science had been suggested in[1]. Figure 1 shows the schematic diagram of pressure swirl atomizer. The liquid enters the atomizer from tangential inlet ports and passes through swirl chamber. Because of tangential inlet liquid start swirling in swirl chamber and it comes out of the discharge orifice in the form of swirling liquid sheet. As sheet get propagate in to atmosphere it get disintegrated in to small droplets because of aerodynamic resistance. As liquid get converted into droplets, it reduces vaporization time, increase time available for complete combustion and provides better mixing. The detailed studies of effects of spray characteristics are explained in literature[2-5].

The studies of different types of atomizers commonly used for combustion applications are found in[1,6-8]. Large number of researchers studied the breakup of liquid sheet theoretically and experimentally. The analysis had been carried out to measure atomizer performance in terms of droplet diameter only. The spray cone angle also plays an important role in the formation of spray structure. The dif-

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ferent effect of injection pressure on spray cone angle has been documented in different literature[9-12]. It can be concluded from their results that the injection pressure is not the only controlling parameter of the spray cone angle. It might depend on other parameters also, like liquid properties, discharge orifice diameter and atomizer dimensions.

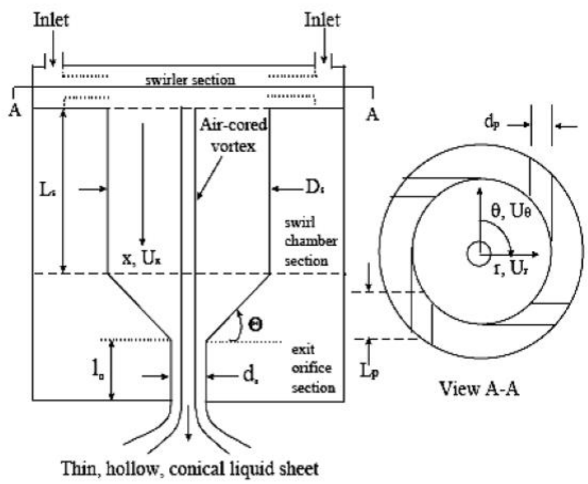

Figure 1. Schematic diagram of pressure swirl atomizer.

In the present work the experiments are carried out to find spray cone angle of liquid coming out of pressure swirl atomizer of different discharge orifice diameter and nozzle angle at different injection pressure. The results are compared with calculated spray cone angle using existing empirical equations.

2. Experimental Analysis

The developed experimental setup for the measurement of spray cone angle is shown in Figure 2. Cylindrical Test Chamber (TC) is made of diameter 500 mm and length of 800 mm from Quartz having 6 mm thick wall. The Fuel Tank (FT) contains fuel of 50 litters. The gear pump (M&P) is used to supply fuel to the test chamber. Its maximum discharge pressure is 25 bars. The pressure swirl atomizer is attached with nozzle assembly (N) which hold the nozzle in its position.

The fuel injected at pressure of 6,9,12,15 and 18 bar to the different atomizers shown in Table 1. The photographs of spray are captured using camera Nikon D60. Figure 3 shows the spray from nozzle having an angle 45° and discharge orifice diameter as 0.4 mm for different injection pressure. The photographs are analyzed using Adobe Photoshop to measure spray cone angle.

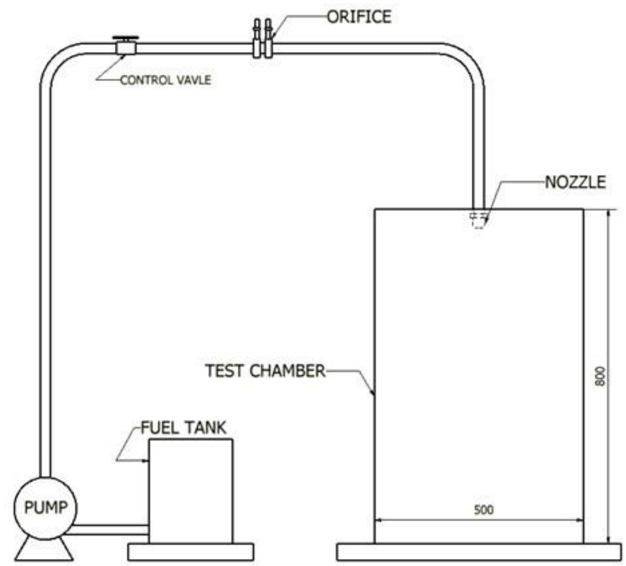

Figure 2(a). Schematic diagram of experimental setup.

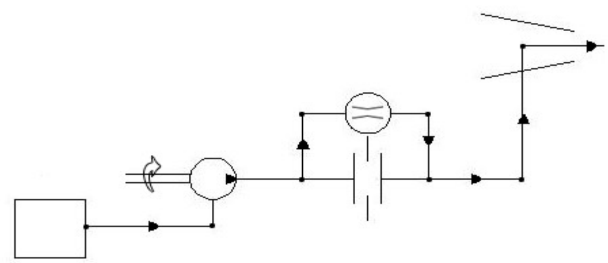

Figure 2(b). Hydraulic circuit diagram.

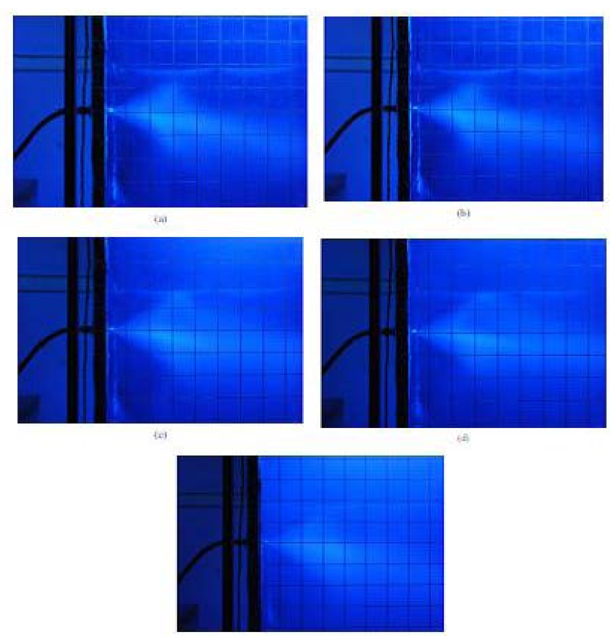

Figure 3. Spray from nozzle angle 45°, discharge orifice diameter 0.4 mm and injection pressure (a) 6 bar, (b) 9 bar, (c) 12 bar, (d) 15 bar, and (e) 18 bar.

3. Theoretical Analysis

According to viscidtheory[9] spray cone angle is a function of ratio of area of tangential inlet port (A_p) to the diameter of swirl chamber (D_s) and discharge orifice diameter (d_o)[6] analyse the flow in pressure swirl atomizer considering non-viscous liquid and the spray cone angle is expressed as a function of atomizer constant ($K = A_p/D_s d_o$) and ratio of area of air core (A_a) to area of discharge orifice (A_o). It led to the following expression of the spray cone half angle[6]:

Where θ is spray cone angle and X is A_a/A_o

In[10] had also given the following equation for spray cone angle in terms of *X:*

X is ratio of area of air core to area of discharge orifice so:

Empirical[11] correlation, the film thickness (t) is expressed as:

Where m_L is liquid mass flow rate, μ_L is viscosity of liquid, ρ_L is density of liquid, ΔP_L is liquid injection pressure differential and l_o is length of discharge orifice.

Eq. 5 derived[12] for spray cone angle which includes effect of geometrical parameters, operating parameter and fluid properties.

4. Results and Discussion

Figure 4 shows the effect of injection pressure on spray cone angle for nozzle angle of 45°. It is clear from the figure that the spray cone angle increase with increase in injection pressure but the effect of discharge orifice diameter cannot be summarized. Therefore the results are plotted against the atomizer constant K.

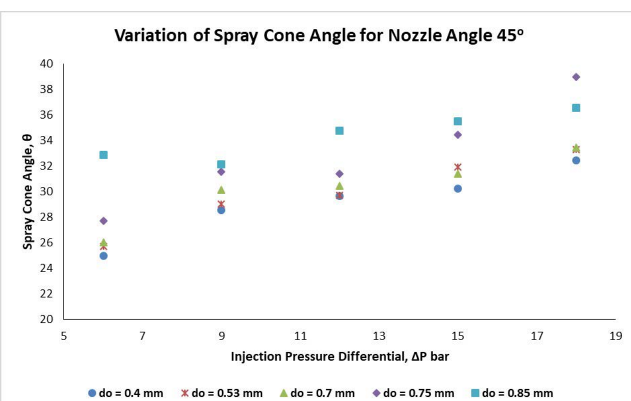

Figure 4. Variation of spray cone angle with injection pressure for different exit orifice diameter.

The result shown in Figure 5 is of effect of atomizer constant on spray cone angle. From figure it can be conclude that the spray cone angle is inversely proportional to the atomizer constant. For the present case other parameters are constant in K, the spray cone angle is only dependent of discharge orifice diameter. The increase in discharge orifice diameter, do not allow spreading the spray and it decreases the spray cone angle. It is clear from Figure 6 that as the nozzle angle increase, the spray cone angle increases. The tangential velocity of the liquid increases as the nozzle angle increases and that increase the spray cone angle.

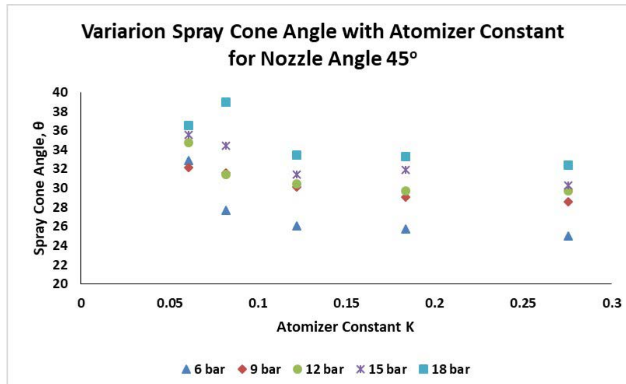

Figure 5. Variation of spray cone angle with atomizer constant at different injection pressure.

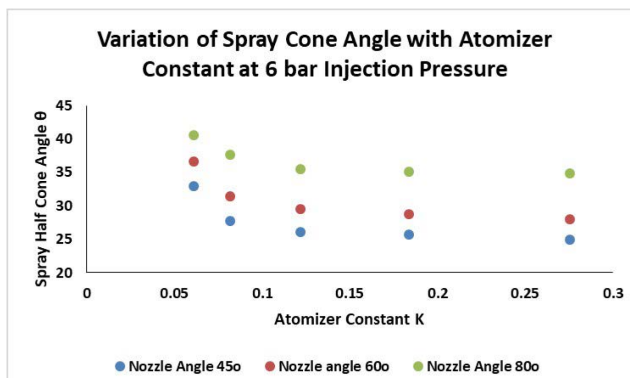

Figure 6. Variation of spray cone angle with atomizer constant at different nozzle angle.

Figure 7 shows the comparison of experimental spray cone angle with derived from empirical equations available. The results are compared with eq. 2 and 5. The spray cone angle derived from eq. 2 shows very high value compared to experimental results because it includes the effect of geometrical parameter only. The eq. 5 for the spray cone angle includes the operating parameter, geometric parameter and liquid properties and therefore it is in good agreement with the experimental results.

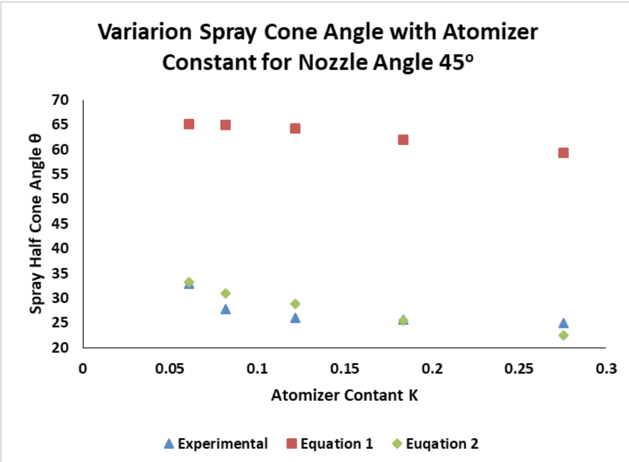

Figure 7. Comparison of experimental and empirical equation for spray cone angle.

5. Conclusions

The experimental analysis has been carried out on pressure swirl atomizer to study the effect of geometrical parameter and operating conditions on spray cone angle. The experimental results are compared with Rizk and Lefebvre's empirical equations. From the results it can be concluded that the spray cone angle is directly proportional to injection pressure and inversely proportional to atomizer constant. The nozzle angle has also inverse effect on the spray cone angle. The equation 2 shows very high value of the spray cone angle compared to eq. 5 and experimental results. The equation 5 is in well agreement with experimental results therefore it can be said that the spray cone angle is not only the function of geometrical parameter but also the operating parameters and liquid properties.

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