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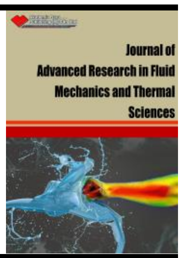

Characteristics of Spray Angle and Discharge Coefficient of Pressure-Swirl Atomizer

Zulkifli Abdul Ghaffar[1], Salmiah Kasolang[1,*], Ahmad Hussein Abdul Hamid[1]

[1] Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia

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ABSTRACT

A widely distributed spray is an important feature for an atomizer which is required in various applications such as gas cooling, gas turbine combustion, and fluidized bed granulator. Pressure-swirl atomizer is an example of atomizer which provides a wide spray angle through the swirling effect inside the atomizer. One of the important parameters affecting spray angle is atomizer geometrical constant, *K*. Another important parameter of pressure-swirl atomizer is discharge coefficient, C_d. Discharge coefficient describes the throughput of the liquid flow. An experimental test-rig was constructed to conduct the performance test of the atomizer. Acquired images were analysed using image-processing software. It was found that K has inverse relation with spray angle and direct relation with C_d. Prediction of spray angle and C_d using existing correlations also yields similar trends with the experimental results, but some parameters still need to be considered to perform an accurate prediction.

1. Introduction

Pressure-swirl atomizer is a widely applied atomizer for various industries. It is an example of atomizer which provides a wide spray angle induced by the swirling effect inside the atomizer. The schematic of pressure-swirl atomizer is shown in Figure 1. A wide spray angle is an important feature requires by various applications. For gas cooling applications, wider spray pattern of pressure-swirl atomizer combined with the slower velocity field will tend to allow for a more even mixing in the intake gases compared to the impinging jet atomizer [1]. In engine combustion [2-3], increase in spray angle increases the extent surrounding air exposure, leading to improved atomization, better fuel-air mixing, and better dispersion of the fuel drops throughout the combustion volume [4]. A wider spray angle also requires in fluidized bed granulator which affects the area of wetted bed [5]. Spray angle is defined as the angle of the spray profile. Schematic of spray angle is shown in Figure 2.

* *Corresponding author.*
E-mail address: salmiahk@uitm.edu.my

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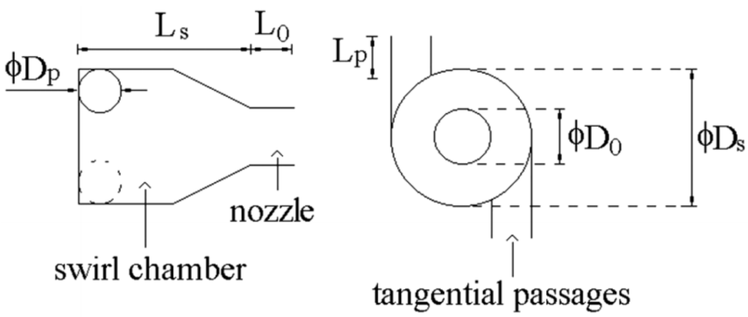


Fig. 1. Schematic of pressure-swirl atomizer [2]

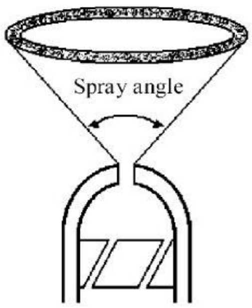


Fig. 2. Schematic of spray angle [6]

Research on pressure-swirl atomizer was conducted to study the effect of various parameters on the resultant spray angle. One of the important parameters affecting spray angle is called atomizer geometrical constant, *K* and defined as:

$$K = \frac{A_p}{D_o D_s} \tag{1}$$

where A_p is the tangential inlet port area, D_o is the orifice diameter, and D_s is the swirl chamber diameter.

Rizk and Lefebvre [7] investigated the influence of *K* on spray angle which covers the range of $0.1 \leq K \leq 0.4$ and observed the inverse relation of spray angle with *K*. Rizk and Lefebvre [7] also proposed empirical correlation which is in agreement with the findings of Dombrowski and Hasson [8]. Liao *et al.,* [9] has also observed the same trends with Rizk and Lefebvre [7] upon investigating the effect of *K* on spray angle. Rizk and Lefebvre [7] proposed correlation of spray angle, 2θ is:

$$2\theta = 6K^{-0.15}\left(\frac{\Delta P D_o^2 \rho_L}{\mu_L^2}\right)^{0.11} \tag{2}$$

where *K* is atomizer geometrical constant, ΔP is the pressure drop, D_o is the orifice diameter, ρ_L is the liquid density, and μ_L is the liquid dynamic viscosity.

Atomizer geometrical constant, *K* has also been an important parameter in investigating discharge coefficient, C_d [10]. Discharge coefficient allows prediction of the actual liquid flow rate for given operating conditions [11]. It is defined as the ratio of actual mass flowrate to the theoretical mass flowrate or mathematically,

$$C_d = \frac{Actual\ mass\ flowrate}{Theoretical\ mass\ flowrate} = \frac{\dot{m}_L}{A_o\sqrt{2\Delta P_L \rho_L}} \quad (3)$$

where $\dot{m}_L$ is the liquid mass flowrate, kg/s, A_o is the total discharge orifice area, ΔP is the pressure drop, and ρ_L is the liquid density.

Discharge coefficient was predicted by Rizk and Lefebvre [12] as a function of *K* in a correlation:

$$C_d = 0.35 \cdot \sqrt{K} \cdot \sqrt[4]{\frac{1}{N}} \quad (4)$$

where *K* is the atomizer geometrical constant and N is the orifice-to-swirl chamber diameter ratio (D_o/D_s).

The study on the effect of atomizer geometrical constant, *K* on spray angle and discharge coefficient was previously conducted and empirical correlation was proposed. However, the proposed empirical correlation still requires verification of its suitability of any system. Hence, this present study aims to conduct experimental investigation on the effect of atomizer geometrical constant, *K* on spray angle and discharge coefficient of pressure-swirl atomizers and compare the acquired results with the proposed empirical correlation to verify the empirical correlations.

2. Methodology

The investigated pressure-swirl atomizer has three tangential inlet slots and fabricated from acrylic rod. Post-machining was performed using abrasive paper and polishing liquid to ensure a smooth surface and good transparency. Transparency is crucial for accurate internal flow visualizations and characterizations. The dimensions of D_p, D_s, D_o, L_s, L_o, and α for the investigated atomizers are shown in Table 1.

Table 1
Dimensions of the tested atomizers

No.	D_p (mm)	D_s (mm)	D_o (mm)	L_s (mm)	L_o (mm)	α (°)
1	3.00	20	3.00	85	15	66
2	3.00	20	5.00	85	15	60
3	3.00	20	7.00	85	15	53

An experimental test-rig was manufactured as a platform for the atomizer performance test. Water was used as the working fluid considering its availability and ease of handling. A pulseless centrifugal pump was utilized for delivering water from the water supply tank to the atomizer through the waterline. The amount of water flowing out of the pump was controlled by a ball valve installed at the outlet. Measurement of water flow rates in the system was obtained from water flow transmitter. The flow of water was controlled by globe valve. Water strainer was installed prior to the water flow transmitter inlet to prevent unwanted debris passing through the meter and led to malfunctioned [13]. Water injection pressure was measured by digital pressure gauges. The injector was fixed in vertical downward position and produce water sprays into a water collection tank. A line diagram of the experimental test-rig is shown in Figure 3. High-speed shadowgraph technique was applied using high resolution camera for visualization of internal (air core) and external flow (spray angle) parameters. A flashlight was arranged with pointing towards the camera lens aperture.

Measurement of spray angle was adapted from our previous research [14]. It was performed by converting the spray images to binary form to facilitate the visualizations of the spray boundary as shown in Figure 4. Angle measurement tool was utilized in determining the spray angle as depicted in Figure 5.

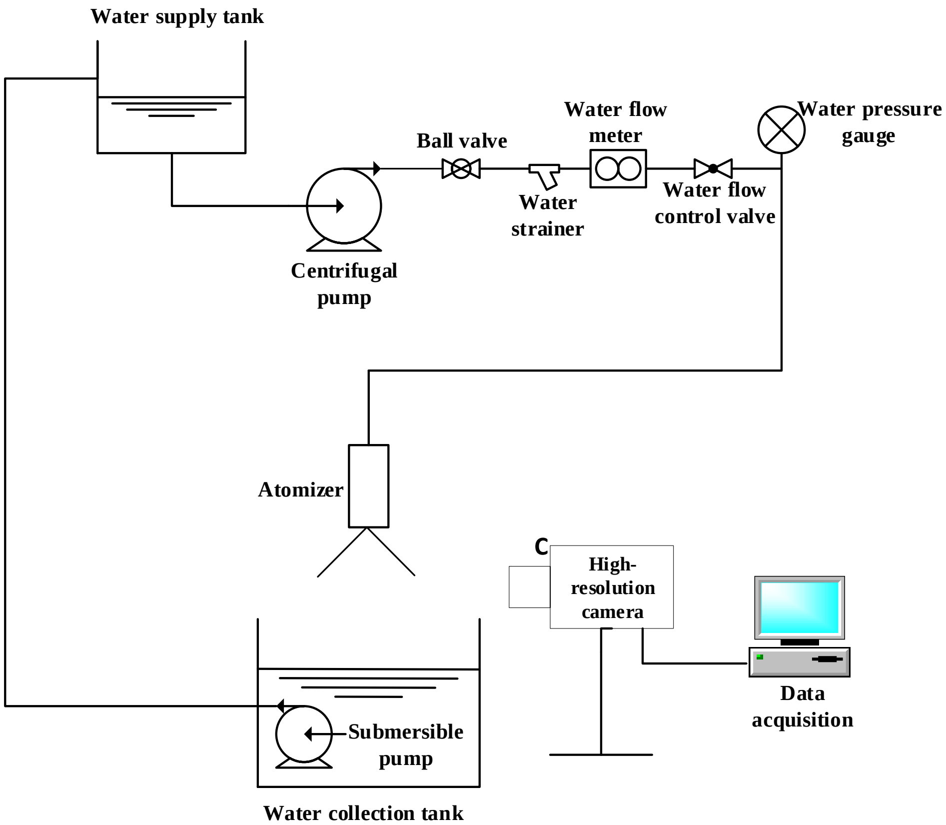
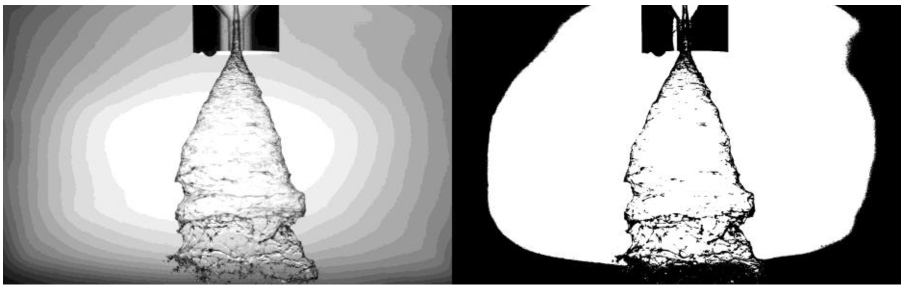


Fig. 3. Line diagram of the experimental test-rig



(a) (b)

Fig. 4. (a) Original and (b) binary converted spray image

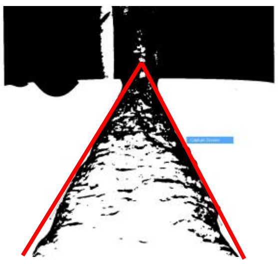


Fig. 5. Angle measurement tool (highlighted in red)

3. Results

The results are presented in three sub-sections, which are: 3.1 Spray angle, 3.2 Discharge coefficient, and 3.3 Prediction of spray angle and discharge coefficient using existing correlations.

3.1 Spray Angle

The effect of *K* on spray angle is presented in Figure 6. It is clearly observed that the spray angle is inversely proportional to the atomizer geometrical constant, *K*. The experimental finding has almost similar trend to the research findings by Rizk and Lefebvre [7] and Liao *et al.,* [9]. However, the present experiment observed narrower sprays than the previous research findings for the same atomizer geometrical constant. This could be attributed to the value of ΔP in Rizk and Lefebvre [7] and Liao *et al.,* [9] experiments were higher than the present research. Higher ΔP promotes higher tendency for turbulence to occur with growth in the liquid sheet momentum and components of velocity [15]. Effect of ΔP on spray angle has also been investigated by various researchers [6-15-16] which concluded that increase in ΔP enlarge the spray angle.

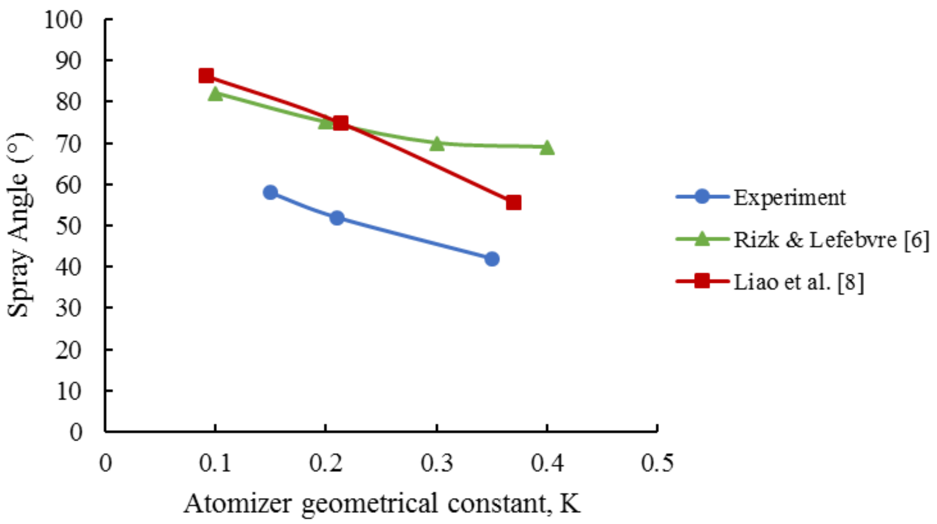


Fig. 6. Effect of *K* on spray angle

3.2 Discharge Coefficient

The effect of *K* on C_d is presented in Figure 7. It is obviously spotted that C_d is directly proportional to the atomizer constant *K* with an upward trend. C_d is a measure of atomizer efficiency at discharging liquid. It is also indicating the amount of friction exists within the system that has hindered an efficient liquid discharge. Value of C_d equals to 1 characterize a perfect frictionless flow.

Comparison with previous research by Rizk and Lefebvre [12] and Liao *et al.,* [9] showed that C_d has a similar trend with present research by a direct proportional relation to *K*. The C_d of Rizk and Lefebvre [12] and Liao *et al.,* [9] has almost similar value along the increase of *K* but the present research only depicted a similar value with Liao *et al.,* [9] at *K* = 0.15. Present research portrayed an abrupt increase in C_d with *K* as *K* approaching 0.4. The value of C_d is 0.5 which is larger than both observed by Rizk and Lefebvre [12] and Liao *et al.,* [9]. This indicates a more efficient liquid discharge from the present pressure-swirl atomizer. The probable reasoning of the phenomenon is the ratio of effective flow area, A_{eff} to the discharge orifice, D_o of the present research is larger. This allows more fluid discharging the orifice. The effective flow area, A_{eff} can be defined as:

$$A_{\text{eff}} = \frac{\pi}{4}(D_o^2 - D_a^2) \quad (5)$$

where D_o is the discharge orifice diameter and D_a is the air core diameter.

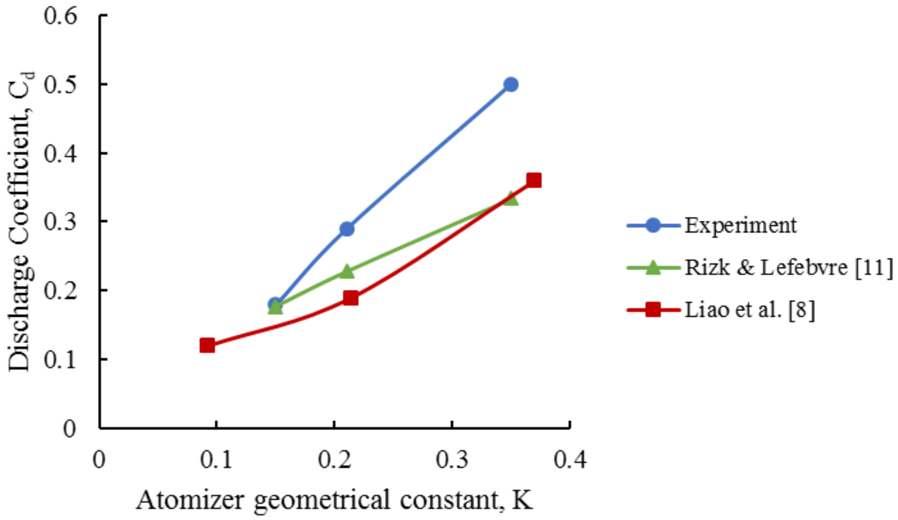


Fig. 7. Effect of *K* on C_d

3.3 Prediction of Spray Angle and Discharge Coefficient Using Existing Correlations

Comparison of spray angle between the experimental results and calculated using existing empirical correlations proposed by Rizk and Lefebvre [7] is shown in Figure 8. It is observed that both has a similar trend; spray angle is inversely related to atomizer geometrical constant, *K*. However, the correlation does not accurately predict the spray angle. The empirical correlation seems to predict a larger spray angle value at every atomizer geometrical constant, *K*. This may suggest that the proposed empirical correlation is not universal and only suitable for a specific range of parameters, i.e., ΔP and D_o.

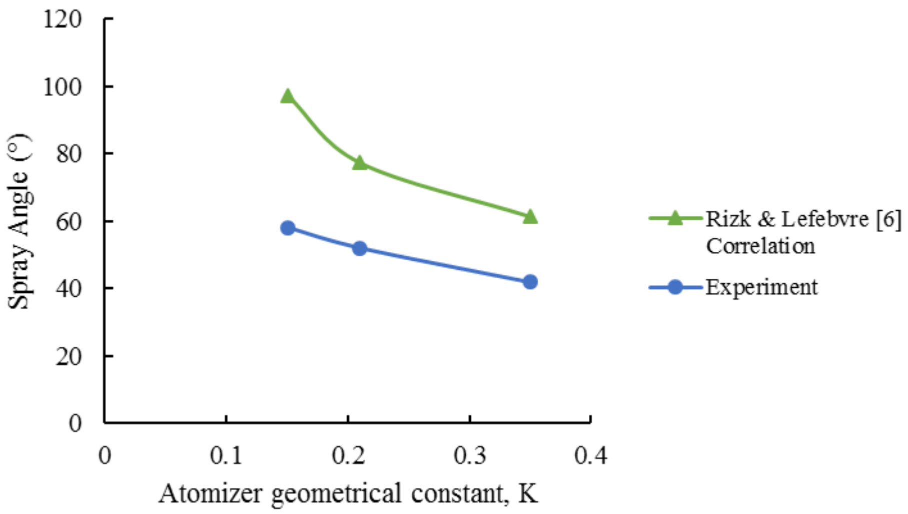


Fig. 8. Comparison of experiment and existing correlations on spray angle

The experimental results and Rizk and Lefebvre [7] correlation of discharge coefficient, C_d were compared as shown in Figure 9. It is observed that both results show a direct proportional trend but with different slope. Initially, both experimental and correlation show a similar result of C_d but as atomizer geometrical constant increase, the experimental result depicted a higher C_d. This might indicate that the empirical correlation is lacking an important parameter known as effective flow area, A_{eff} as discussed in previous sub-section.

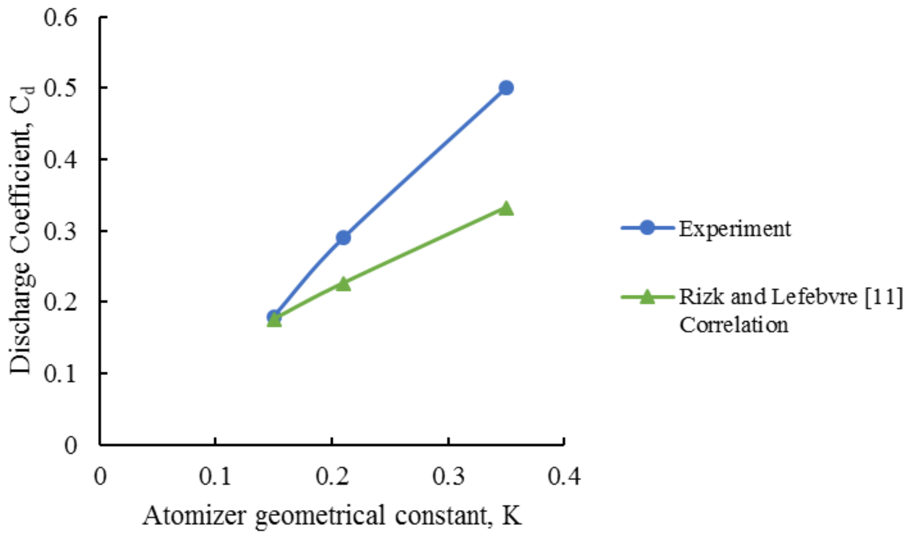


Fig. 9. Comparison of experiment and existing correlations on discharge coefficient

4. Conclusions

An experimental investigation was conducted to study the effect of atomizer geometrical constant on spray angle and discharge coefficient. The acquired results were compared with existing data from literature. The existing proposed empirical correlation was used to predict the spray angle and the obtained results were compared with experiments. It was found that the influence of atomizer geometrical constant, *K* to the spray angle may also depends on pressure drop, ΔP. Although the value of *K* in present research is the same with existing data from literature, the obtained spray angle is differs considering different value of pressure drop, ΔP. The investigation on effect of *K* on C_d revealed that a parameter also needs to be considered in predicting the C_d. This parameter known as effective flow area, A_{eff}.

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