Effect of flow conditions on spray cone angle of a two-fluid atomizer

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Abstract

A visual study is conducted to determine the effect of operating condition on the spray cone angle of a two-fluid atomizer. The liquid jets exit from peripheral inclined orifices and are introduced to a high speed gas stream in the gravitational direction. Using a high speed imaging system, the spray cone angle has been determined for Reynolds numbers ranging from 4×10^4 to 9×10^4 and different Weber numbers up to 140. The results show that the spray cone angle depends on the operating conditions especially in lower values of Reynolds and Weber numbers. Also, a correlation has been derived to predict the spray cone angle in terms of these two parameters.

Introduction

Two-fluid atomizers are widely used in various industrial systems such as gas turbine combustors. Spray angle is one of the important parameters for evaluating the atomizers performance. Most of the sprays have a conical shape wherein the cone angle is usually defined as the angle between the tangents to the spray envelope at the atomizer exit. In combustion systems, the value to be selected for the cone angle will depend on the shape of the combustion chamber prior to the air and fuel mixing conditions.

Many practical systems require atomizers that distribute the fuel in the form of a less concentrated and lower penetrated spray. Also, the spray angle of a two-fluid atomizer should be such that it could provide a good mixing between the two fluids. Therefore, it will be very important to develop an accurate method for predicting the spray cone angle in such atomizers.

Varde [1] made a liquid fuel spray injected into a gaseous environment in order to investigate the effects of nozzle orifice size and operating conditions on the spray cone angle. The results showed the spray cone angle to depend on the orifice dimensions as well as on the operating conditions. Also, he derived a correlation to predict spray cone angle in terms of Reynolds and Weber numbers.

Laryea and No [2] investigated the cone half-angle of the spray produced by an effervescent diesel injector as a function of atomizing gas-to-liquid ratio (GLR) and injection and ambient pressures. Their results show that increasing the ambient pressure causes a nonlinear decrease in spray angle followed by an increase that ultimately approaches to an asymptotic value when the pressure reaches 5 MPa. They also suggested an empirical equation to predict the cone angle produced by the tested diesel injector.

In the present paper, the spray angle of a two-fluid atomizer is investigated at different Reynolds and Weber numbers. The tested atomizer consists of six liquid inclined ports positioned peripherally at 55° angle with respect to the gas stream with gravitational direction. The spray angle measurement is based on a visual method using a high speed video camera and image processing technique. In each flow condition, the spray angle is measured using a frame by frame image analysis. Also, a correlation has been derived to estimate the spray cone angle in terms of both the Reynolds and Weber numbers.

Materials and Methods

The experimental setup used in this study consists of three main parts, i.e. the liquid feed line, the compressed gas line and the atomizer. The two-fluid atomizer is connected to the liquid and compressed air lines using an interface fixture. A schematic of the atomizer and its photographic view are shown in Figure 1.

The visualization system used in this study consists of a high speed digital camera that was set at a recording rate of 2500 fps with an exposure time of 100 ns capable of recording image files with a resolution of 640×480 pixels. The spray angle has been calculated using image processing techniques applied for each flow condition.

Results and Discussion

Figure 2 shows the spray cone angle produced by the two-fluid atomizer as a function of its operating conditions. In each Weber number, an increase in Reynolds number causes a decrease in spray angle followed by approaching to an asymptotic value for higher Reynolds numbers. Also, increase in Weber number in a constant

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value of Reynolds causes the spray cone angle to decrease with a descending slope. Therefore, in higher values of Weber, the spray angle becomes less dependent to Weber number.

The following correlation has been developed based on experimental data to predict the spray cone angle as a function of its operating conditions, i.e. Reynolds and Weber numbers:

$$\theta = -12.56\ln\left(\frac{\mathrm{Re}}{10^4}\right) - 1.55\ln\left(\frac{We}{10}\right) + 97.72 \qquad 4\times10^4 \le \mathrm{Re} \le 9\times10^4 \quad , \quad We \le 140 \,. \tag{1}$$

An error analysis indicates that this correlation is applicable over the entire range defined for Reynolds and Weber numbers with a maximum error of 6.4%.

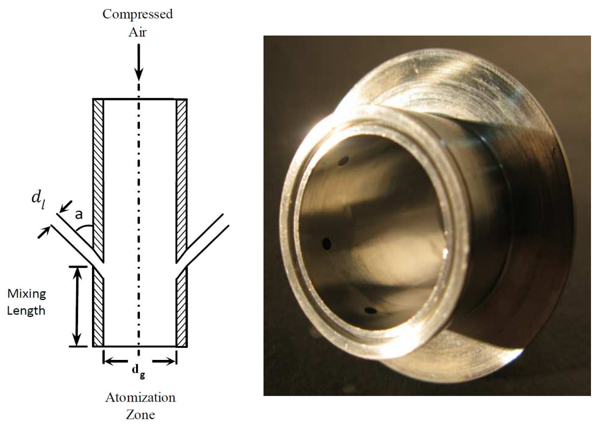
Nomenclature

a	liquid jet angle, degree
d_l	liquid hole diameter, mm
Re	liquid Reynolds number, $\rho_l U_l d_l / \mu_l$
U_g	gas jet velocity, m/s
U_l	liquid jet velocity, m/s
We	gas Weber number, $\rho_g \left(U_g - U_l \sin a\right)^2 d_l / \sigma_l$
μ_l	liquid viscosity, kg/(m s)
ρ_g	gas density, kg/m^3
ρ_l	liquid density, kg/m^3
σ_l	liquid surface tension, N/m

References

[1] Varde, K.S., *The Canadian Journal of Chemical Engineering* 63(2):183-187 (2009).

[2] Laryea, G.N., and No, S.Y., *Journal of Electrostatics* 60:37-47 (2004).



(a) (b)

Figure 1. The two-fluid atomizer used in this study, (a) a schematic, (b) a photographic view.

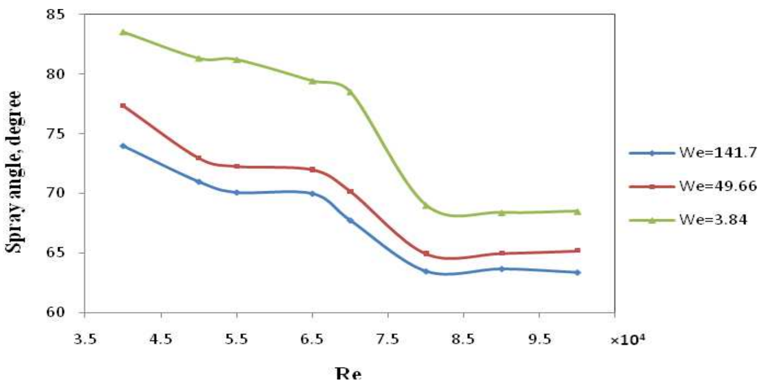


Figure 2. Spray angle variations against Reynolds in different Weber numbers.