EXPERIMENTAL ANALYSIS OF THE SPRAY HALF CONE ANGLE OF AIRBLAST ATOMIZATION

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ABSTRACT

Airblast atomization is widely used in engineering practice from painting through metallurgy and healthcare to gas turbines. Besides its practical relevance, this kind of atomizer is an excellent model platform to investigate atomization phenomena since the atomizer geometry has a relatively low influence on spray formation. Although cone angle is a characteristic feature of a spray, there is no general definition for it, and estimation methods are not discussed by the public literature for airblast atomizers. The first problem is the clear definition of the spray boundary as droplets drift various distances over time from the nozzle axis via turbulence. A recommendation for gasoline fuel injectors can be found in ref. [1]. To characterize the steady-operating atomizers, typically the completion of primary atomization is considered. Since the edges of the spray may be curved, a well-defined distance from the nozzle should be set, e.g., as 60 times the orifice diameter [2]. However, the literature is not consistent in this sense [3, 4]. Therefore, the main goal of this paper to introduce a new methodology for describing the spray cone angle for airblast atomizers in the case of high-velocity atomization. The test rig is shown in Figure 1. The gauge pressure of the atomizing air, pg, was controlled by a regulator valve in the range of 0.3 and 2.4 bar in 6 steps. To ensure a wide parameter range, an electric heater was installed to the liquid line to set the preheating temperature, t_p, which varied between 25 and 85 °C in 5 steps. The liquid flow rate was fixed at 0.35 g/s, and investigated liquids were distilled water (W), standard diesel oil (D), light heating oil (LHO) and crude rapeseed oil (RO), following our previous work on atomization [5]. It resulted in 100 different conditions in total with a wide parameter range in surface tension, viscosity, and density, which are typical in combustion applications. The measured material properties along with their corresponding uncertainties are also discussed in [5]. A fan continuously removed the mist to provide good quality images to be analyzed.

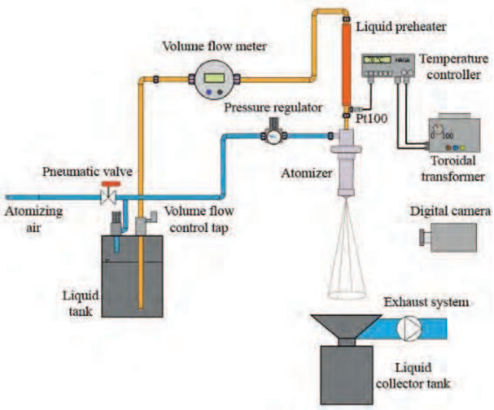

Figure 1: *Liquid and atomizing air piping and their instrumentation.*

The shutter speed has a significant effect on the spray cone angle as a longer exposure time allows more information to be collected in the peripheral regime where the droplet mass flux is low. Hence, 1/60 s, 1/80 s, and 1/100 s were used to get relatively sharp images while the spray was illuminated by a spotlight from the front. 5 pictures were recorded with all three settings, which means 1500 images in total to be processed. Therefore, an algorithm was developed for automatic evaluation in Matlab. The scheme is shown in Figure 2.

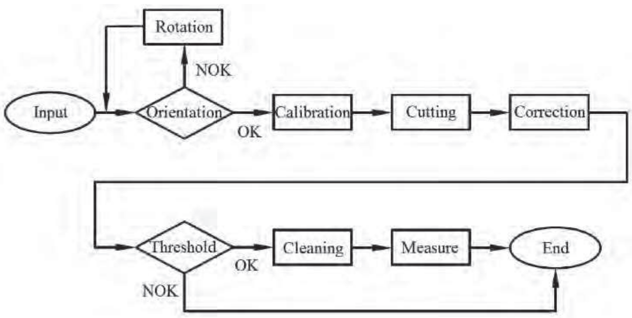

Figure 2: *Liquid and atomizing air piping and their instrumentation.*

The first step is scanning the image to be processed. Then the important part of the image has to be cut to an uniform shape. Pre-calibration is required for cropping, which in this case determines the relationship between the number of pixels in the image and the physical dimensions. The outlet diameter of the liquid jet is 400 µm, which was considered as a reference for image calibration. This is followed by corrections, where the gamma correction was used principally. This procedure involves grayscale conversion, which preceded the binary conversion. This intermediate step was necessary to set the appropriate threshold value through numerical derivation to find the boundaries of the spray. The appropriate threshold value was the beginning of the constant slope section which varied from image to image. Therefore, standard deviation for the derivative values is applied, which is normalized to make the images comparable. The resulting binary image has a background pixel value of 0 (black) and a spray value of 1 (white). In this case, the boundaries of the spray are still very disordered, so the borders need to be refined and smoothed. Meanwhile, the gaps inside the spray are filled. By searching for the first and last white pixels in a row, the spray boundaries can be determined. Then two lines were fitted from which the spray cone angle was calculated. If the suction of the mist is too strong, the spray cone angle is distorted. However, the small droplets resulted by high pg are less prone to leave the test section, shown in Figure 3.

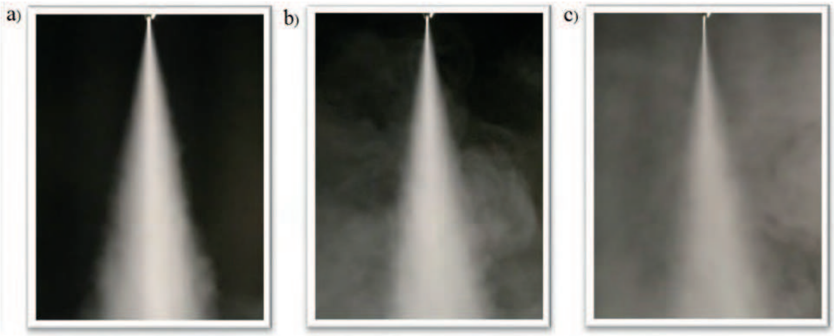

Figure 3: *Different quality raw images of D at* t_p *= 25 °C and* p_g *= a) 0.3 bar, b) 0.9 bar, c) 2.4 bar.*

The image corrections eliminated the differences caused by the varying shutter speed, hence the averaging was performed together, without considering this parameter. The specified cone angles as a function of p_g and *tp* for D and RO is shown in Figure 4. The results show that the spray cone angle decreases with increasing pg for all cases. This can be explained by the effect of continuously increasing axial impulse force from the atomizing air. The results show that the spray cone angle decreases with increasing p_g as the axial momentum of the atomizing air increases and convection intensifies. Turbulence is counteracting with this phenomenon, however, the former effect is stronger. Increased *tp* features slightly increased cone angle overall, however, this trend is far from universal. In case of D, the opposite trend was observed. For a better visual representation, Figure 5 is shown where the t_p was put on the abscissa while the data sets are sorted by p_g.

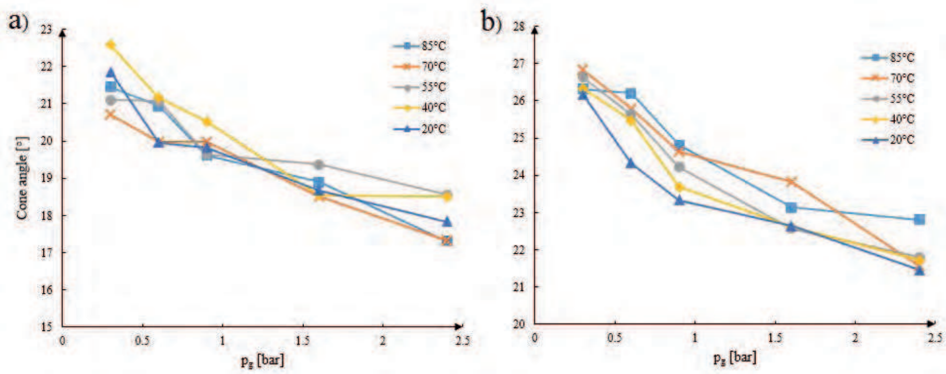

Figure 4: *Spray cone angle as a function of* p_g *at various* t_p *in the case of a) D, b) RO.*

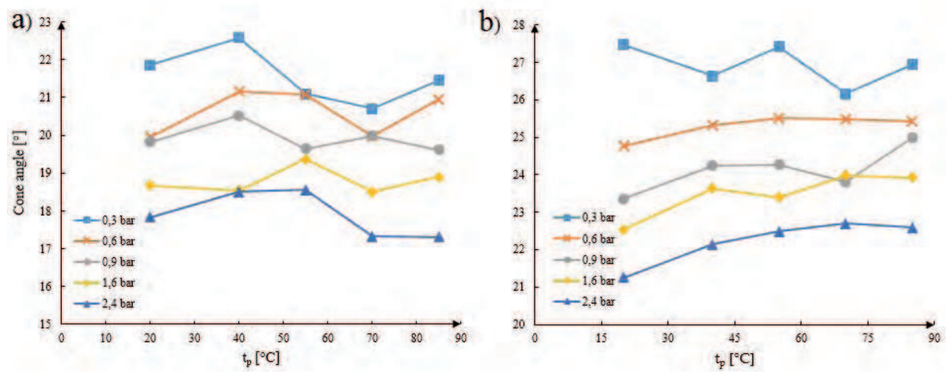

Figure 5: *Spray cone angle as a function of* t_p *at various* p_g *in the case of a) D, b) RO.*

The final goal was to determine an empirical correlation that adequately describes the characteristics of the cone angle for airblast atomization in a wide range of conditions. Therefore, various dimensionless numbers have been investigated, using two of them with two constants, AL and BL, forming a power law relation. Using the least squares method, the density ratio and air-to-liquid mass flow ratio, ALR, provided the best fit, shown by:

$$\theta = A_L \cdot \frac{\rho_{L,20°C}}{\rho_L} \cdot ALR^{B_L},$$

Here, ALR is primarily responsible for describing the changes in pg. The density ratio describes the effect of liquid preheating, where pressure dependency can be neglected. Figure 6 shows the empirical correlation and measurement results for LHO which performed the best with maximum deviation of 3.59 %. It was followed by RO by 4.51 %, W by 4.77 %, and D by 5.76% which is 1.2° in numbers. This is an acceptable deviation, since the formula which developed by Giffen and Muraszew for pressure-swirl atomizer showed a 5% deviation from the measured values [6]. The liquid dependent constant in Eq. 1. is summarized in Table 1.

***Table 1**. Constant of Eq. 1 for the investigated liquids.*

Atomized liquid	A_L	B_L
W	24,58	-0,09
D	20,60	-0,19
LHO	24,97	-0,20
RO	25,05	-0,19

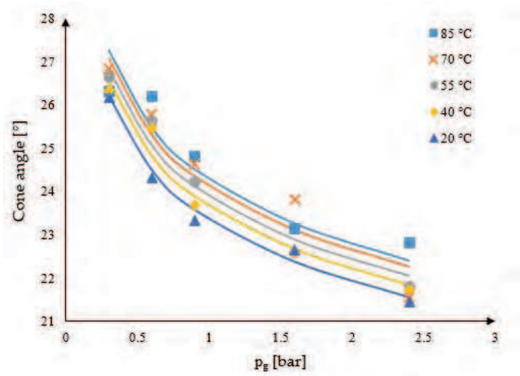

***Figure 6:** Measured and calculated spray cone angle values for LHO.*

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Keywords
Spray cone angle, rapeseed oil, threshold, image processing, airblast atomizer