International Journal of Multiphase Flow 79 (2016) 214–224

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

journal homepage: www.elsevier.com/locate/ijmultiphaseflow

Experimental study on the influence of liquid and air boundary conditions on a planar air-blasted liquid sheet, Part II: prefilming zone length

Baptiste Déjean*, Pierre Berthoumieu, Pierre Gajan

DMAE, Onera, Toulouse, France

ARTICLE INFO

Article history:
Received 6 March 2015
Revised 2 July 2015
Accepted 1 September 2015
Available online 24 September 2015

Keywords:
Atomization
Airblast
Liquid sheet
Prefilming
Experimental study

ABSTRACT

In this work, experiments were performed on a prefilming atomizer. For this purpose, an injector used for liquid sheet pulverization was adapted to highlight the influence of the prefilming zone. Breakup length, oscillation frequency and drop size were studied for various prefilming zone lengths and airflow configurations (convergent or divergent and different air thicknesses). Various influences were observed depending on the air configuration, with an improvement of the atomization process for convergent configuration when an optimum prefilming zone length is chosen. At the same time, visualizations of liquid dynamics and liquid thickness measurements on the prefilming zone have enabled the classification of liquid evolution in three regimes: “smooth”, “waves” and “accumulation”. The use of primary atomization parameters enables a cartography gathering all of the experimental conditions studied during this work to be proposed. Finally, a comparison of these results with previous correlations highlights the necessity to take into account the geometrical aspect of injection systems to predict the atomization characteristics.

Introduction

In order to improve combustion in aeronautical engines, numerical simulations are required to reduce costs linked to the development of new combustion chambers. Due to the multi-scale physics coexisting during the atomization and combustion process, computing all of the phenomena from the liquid injection to the combustion process entails too important cost and time efforts to be applied on realistic configurations. In order to reduce these costs, the approach generally used consists of injecting the liquid phase as small droplets from numerical injectors. The resulting spray behavior is then computed using a well-known dispersed two-phase flow method. The inlet conditions for this droplet injection (size and velocity) are currently defined using empirical relationships obtained from experimental data. Nevertheless, they are in general limited to a specific injection system and given flight conditions. Another approach will be to define these inlet conditions from a first unsteady simulation of the atomization process up to the formation of the first independent liquid structures. This more general approach, which takes into account the unsteady phenomena resulting from the preliminary interaction between the airflow and the liquid phase, also necessitates physical models to couple the two computing methods.

In order to improve these simulations, more accurate and universal models are needed. To do so, a better understanding of the various steps of the atomization process, as well as the influent parameters, is necessary. Currently, predominant parameters, such as flow velocity, have been well identified, but the influences of other parameters linked to the injector geometry or fluid properties are not clearly understood. Therefore, the available correlations used to predict the main atomization characteristics (instability frequencies, breakup length or drop size) could not give accurate results. The aim of current studies is thus to improve our knowledge about the influence of various parameters, such as fluid properties, pressure and geometrical characteristics, in order to propose more robust correlations for the atomization prediction.

In some aeronautical injector, the liquid fuel is injected as an annular liquid sheet sheared on both sides by airflows. In these systems, a prefilming zone appears before the formation of the liquid sheet. In this zone, the liquid fuel flows as a sheared film on a wall. The influence of this prefilming zone on the atomization process needs to be analyzed.

The first studies relating to this kind of injector date back to the work of Lefebvre and Miller, (1966) and their team (Rizk and Lefebvre, 1980; Rizk and Lefebvre, 1982; Rizkalla and Lefebvre, 1975); they were performed in order to characterize the specific spray droplet size distribution for different injectors. In parallel, other authors worked on the same issues (Bryan et al., 1971; Jasuja, 1979). A few years later, Sattelmayer and Wittig studied the influence of the air

* Corresponding author: Tel.: +33 562252571.
E-mail address: baptistedej@hotmail.com, Baptiste.Dejean@onera.fr (B. Déjean).

http://dx.doi.org/10.1016/j.ijmultiphaseflow.2015.09.001

Table 1
Atomization characteristic correlations.

Bhayaraju and Hassa (2006)	$D_{32} = 215.07\, We_{g,t_l}^{-0.31}$ with $We_{g,t_l} = \frac{\rho_g (u_g - u_l)^2 t_l}{\gamma}$
Gepperth et al. (2010 and 2012)	$f \approx 0.331 \frac{u_g}{x_{inlet}} \sqrt{Re_{inlet}} \frac{\rho_g}{\rho_l}$ avec $Re_{inlet} = \frac{x_{inlet} \rho_g u_g}{\mu_g}$ with x_{inlet} the distance between injector leading edge and liquid injection from (Wert, 1995) $D_{32} = 0.324 \frac{\gamma}{\rho_g u_g^2} (We_{g,D_d} (T_{tot} - T_{ini}))^{\frac{2}{3}}$ with T_{tot} et T_{ini} the non-dimensional initiation and total breakup times defined in Wert *with* $We_{g,D_d} = \frac{\rho_g u_g^2 D_d}{\gamma}$ *and* $D_d =$ $3.130 \sqrt{\frac{(V/b) x_{inlet}}{u_g}} (\frac{\rho_l}{\rho_g})^{1/2} Re_{inlet}^{-1/4}$ where D_d is the diameter droplet produced from ligaments and V/b the surface liquid flow rate
Chaussonnet (2014)	$\frac{D_{32}}{h_a} = \frac{C_1}{\sqrt{We_{g,h_a}}}$ with $We_{g,h_a} = \frac{\rho_g (u_g - u_l)^2 h_a}{\gamma}$ with h_a the prefilming thickness and C_1 *a* constant equal to 2.01

where D_{32} is the Sauter mean diameter, f the oscillation frequency, t_l the liquid thickness, u_g and u_l respectively the air and liquid velocities, ρ_g and ρ_l the air and liquid densities, γ the surface tension, μ_g and μ_l the air and liquid dynamic viscosities.

thickness and prefilming zone length. Their liquid flow rate ranged from 0.1 to 2.9 cm²/s. They concluded that both parameters have a negligible effect on drop size, but affect other characteristics, such as the spray angle (Sattelmayer and Wittig, 1986). They also highlighted viscosity and surface tension influences. Further studies on these types of injector are more recent. Working with various pressure conditions, with a liquid flow rate ranging from 0.6 to 5.4 cm²/s and two prefilming length of 2 and 4 mm, Bhayaraju et al. (Bhayaraju, 2007; Bhayaraju and Hassa, 2006, 2009) highlighted various atomization regimes, depending on the Weber number. From their regime classification, they proposed a correlation to predict drop size. Finally, the most recent works on prefilming atomizers are those of Gepperth et al. During their first study (Gepperth et al., 2010), they measured the main characteristics of the atomization process: oscillation frequency, wavelength and drop size. Correlations were then proposed to predict them. Their liquid flow rates ranged from 0.25 to 0.75 cm²/s. During a second study, they worked on the influence of the geometrical aspect and reached conclusions regarding the low influence of the prefilming zone length (20.6 and 47.6 mm) and the importance of prefilming zone thickness (1 and 2.5 mm) (Gepperth et al., 2012, 2013). From this work, Chaussonnet, (2014) proposed another correlation based on the same measurements in order to predict primary droplet size. He used it, coupled with a model of secondary atomization, to simulate spray creation at prefilming injector outlet. The various correlations obtained during these studies are summarized in Table 1. This state of the art shows the influence of some geometrical aspects on liquid atomization. Nevertheless, no study worked on the influence of the airflow configuration and few of them considered the influence of the prefilming length.

Thus, the aim of this study is to complete the previous results by comparing the main features of the atomization process obtained with or without the prefilming zone (Dejean et al., 2015).

Experimental test-rig

The "SHAPE" test bench, described in the previous paper dealing with the liquid sheet atomization (Dejean et al., 2015), is also used for this experiment. A horizontal airflow from 20 to 100 m/s can be obtained (this value, which is used to characterize airflow velocity, corresponds to the maximum velocity of the air flow profile). This wind tunnel enables the introduction of edges, in order to modify air thickness and configuration. The various air cases are named using a letter (*C* or *D* for convergent or divergent, respectively) and a number corresponding to the air thickness (Fig. 1). The injector used (with an external shape of a NACA 63-010) is derived from the previous study, by adding a prefilming zone with various lengths (0, 2, 4, 6; 8, 10, 20 and 40 mm) at the outlet (Fig. 1). Water is used at ambient temperature. The surface liquid flow rates varies between 1.5 cm^2/s (corresponding to a liquid velocity (u_l) of 0.5 m/s) and 13.2 cm^2/s ($u_l = 4.4$ m/s). Note that, due to geometrical constraints, there is a 0.85 mm step in the upper airflow before its interaction with the liquid film formed in the prefilming zone.

Measurement systems

Various experimental techniques were adapted, developed and applied to measure the various characteristics of the atomization process. For this purpose, image processing based on PLIF measurement by high-speed camera was undertaken. For droplet size measurements, a laser diffraction technique used by a Malvern analyzer system was chosen. In this case, the droplet population is analyzed over a measurement volume corresponding to the laser path through the spray. The probe volume location is placed sufficiently far from the downstream edge of the prefilming zone to ensure that only spherical droplets are considered. In order to characterize the airflows, a hot wire measurement was performed at the wind tunnel exit. All of these techniques are described in the previous paper (Dejean et al., 2015).

Flow visualization

Flow visualizations of the liquid behavior in and downstream of the prefilming zone are performed. A back lighting method is used. Two spots, one for the prefilming zone and the other for the liquid sheet and atomization zone, illuminate the liquid. The camera is placed on the top of the injector in order to obtain a good image contrast and to highlight the unsteady wave formation. A Phantom v.341 high-speed camera is used. The acquisition rate is fixed at 3200 frames per second, in order to clearly observe the liquid dynamics.

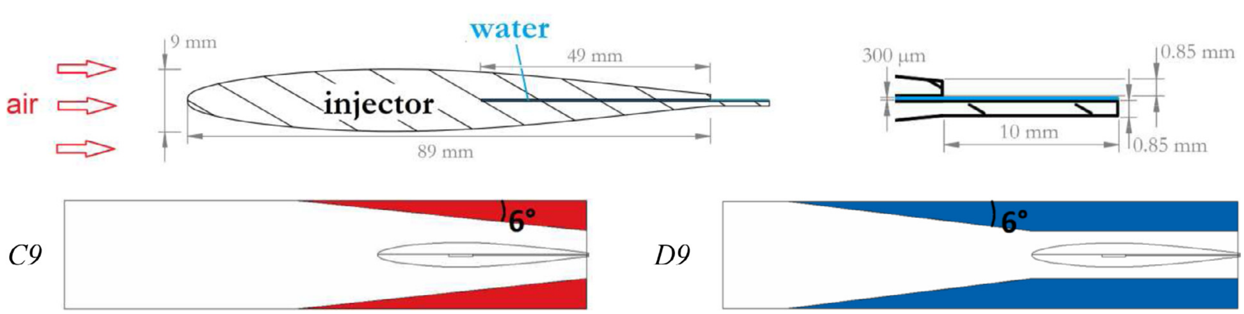

Fig. 1. Geometry of the prefilming injector used for experiemental study and the different restriction types used in order to have two air flow configuration: C for convergent (in the left part of the diagram) and D for divergent (in the right part).