Experimental Thermal and Fluid Science 75 (2016) 66–76

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Combined effervescent and airblast atomization of a liquid jet

A. Kourmatzis [a,*], A. Lowe [b], A.R. Masri [b]

[a] Department of Engineering, Macquarie University, Sydney, NSW 2109, Australia
[b] Clean Combustion Research Group, Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney, Sydney, NSW 2006, Australia

ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form 1 February 2016
Accepted 4 February 2016
Available online 10 February 2016

Keywords:
Effervescent atomization
Airblast atomization
Primary atomization

ABSTRACT

Effervescent atomization shows great promise towards the production of small droplet sizes, but it can suffer from substantial instabilities. Adding a coaxial shear flow to a central two-phase bubbly flow is a simple extension of effervescent atomization, however, the characteristics of a combined air-blasting shear flow and effervescent mode of fragmentation have not been well described in the literature. By making use of LDA/PDA measurements, high speed microscopic imaging of the atomization zone, and advanced image processing techniques, quantities such as the axial velocity fluctuations, pulsation frequencies, ligament sizes and liquid area fractions are measured and analysed with respect to the relative mass of effervescent air and air-blast air. The work shows that the coaxial air blast flow does not change the frequency of the effervescent core pulsations but can act to dampen fluctuations whilst simultaneously improving dispersion characteristics. For this hybrid atomization mechanism, the measured axial velocity fluctuations are now a combined result of the instability of the effervescent spray core as well as mixing from the surrounding air flow. Analysis suggests that frequencies associated with the effervescent atomization process can occur on similar scales as the surrounding mixing frequencies. Furthermore, sinusoidal instabilities from the coaxial air flow are seen as superimposed onto the effervescent core indicating that a complex coupling can occur between the two modes of atomization.

1. Introduction

Pressure as well as air assisted atomization techniques are relevant to a wide variety of industrial problems, perhaps the most common one being in the combustion of liquid fuels. Airblast atomization, where a coaxially flowing air stream atomizes a central liquid jet, is widely investigated, with a large volume of literature having examined the influence of key dimensionless groups on the atomization process [1–8]. It is now widely accepted that the overall Weber number of the flow, the mass flux of liquid with respect to the air flow as well as the liquid jet Reynolds and Ohnesorge numbers are relevant to the classification of the fragmentation mechanisms [2]. In general, the atomization regimes can be delineated in a similar way as with air assisted droplet atomization [5] given that similar phenomena have been observed. More recent work has concentrated on the influence of gas phase turbulence on atomization [9] re-confirming the influence of the Rayleigh–Taylor instability in these types of flows, whilst also extending previous work to account for a dimensionless measure of turbulent fluctuations. For more details on air-blast atomization the reader is directed to the extensive literature on the subject as reviewed by Lasheras and Hopfinger [2].

Effervescent atomization, a technique developed by Lefebvre and Wang [10] has not yet reached the level of maturity as its air-blast counterpart even though the mechanisms which lead to fragmentation in this type of atomizer are now broadly understood as reviewed in Sovani et al. [11]. The ratio of effervescent air to liquid mass flow-rate (the gas to liquid ratio or GLR) is a critical parameter that dictates the nature of the bubbly flow inside the nozzle. The atomization mechanism is largely controlled by the size of bubbles as well as the void fraction in the nozzle (creating bubbly, slug or annular flow) [11]. The geometry of the atomizer, such as the size and number of aeration holes, orifice diameter and GLR all dictate the nature of the two phase flow and the subsequent droplet size [12–17]. Bubble nucleation is also an important issue in effervescent atomization and this has been studied in a two dimensional configuration by Lhuissier and Villermaux [18]. Effervescent atomization has also been utilized in combustion, where rather than aeration using air, a flammable gas is injected into the liquid serving both as the atomizing gas as well as part of the combustible mixture [19]. Gadgil and Raghunandan [20] examined instability characteristics in greater detail including quantifying the bursting distance which leads to atomization, while other work by Schroder et al. [21] has analysed instabilities in very viscous liquids. Computations of effervescent atomization, while scarce, are gradually evolving, and Qian et al. [22] have reproduced some

* Corresponding author.

http://dx.doi.org/10.1016/j.expthermflusci.2016.02.002
0894-1777/

aspects of the experimental data, but more development is still needed.

It is clear from the literature that effervescent atomization occurs only at some liquid jet diameters downstream of the nozzle [11], and this has generally been attributed to the expansion of air as the two phase mixture leaves the orifice channel encountering a sudden pressure drop. However, more recent work by Shepard [23] suggests that longitudinal instabilities in the flow direction dictate the atomization process. He argued that atomizing packets resemble colliding portions of liquid as opposed to bursting bubbles. This conclusion was a result of observing radially expelled as opposed to spherically expelled liquid. The latter is more representative of a bubble explosion while a longitudinal collision dominates the former, as in Meier et al. [24].

In many practical applications where effervescent atomization is likely to be used, it is possible that it is employed in tandem with a coaxially flowing air stream. This hybrid mode would be intuitively expected to affect the mixing characteristics, droplet size as well as general atomization phenomena. To the authors' knowledge, there has been no systematic investigation which considers the combined impact of an effervescent component driving atomization due to aeration in the liquid, and a coaxially flowing air component which drives atomization due to interfacial instabilities. The literature has investigated situations where an air flow exists both within and external to a liquid annulus [25], however this is different from effervescent atomization where the air is injected directly into the liquid. Additionally, effervescent atomization is known to be unstable, and though the mechanism of the instability formation requires further investigation, it is known that the instabilities are related to the void fraction in the nozzle [15,21,20,26,27]. Given the pulsations that occur in effervescent atomization, which are nevertheless accompanied by greatly reduced droplet sizes, it is possible that with the addition of an atomizing air-blast component, the pulsating characteristics can be modified.

In this contribution we present a system which allows for a hybrid atomization mechanism to take place near to the liquid injection nozzle. Making use of laser/phase Doppler anemometry, microscopic high speed backlight imaging as well as advanced image processing techniques, we present and analyse mean flow and mixing characteristics for the case of effervescent and combined effervescent–airblast atomization. Spectral analysis is performed both on the LDA data as well as on the high speed image sequences in order to examine the influence of the airblast component on the effervescently induced instabilities as a function of blasting air, as well as spatial location in the spray.

The paper will first present the atomizer, and subsequently outlines the experimental techniques used with associated errors. Secondly, we will present key results characterizing this hybrid fragmentation process in terms of morphology. Then, we present and discuss the flow-field and mixing characteristics before analyzing the dominant instabilities and other quantitative features of the near-field atomization zone.

2. Experimental methods

The atomizer used for these experiments is shown in Fig. 1. It has an overall length of approximately 130 mm and consists of an 'outside-in' effervescent component as originally presented by these authors in Kourmatzis et al. [28], but now with a high speed air stream which flows coaxially to the central two phase liquid core, consisting of standard tap water and air. The effervescent design consists of 16 aeration holes each of a diameter of 0.75 mm, equally spaced apart by 1 mm and perpendicular to the direction of liquid flow. For these experiments, the inner diameter of the effervescent nozzle steps down from 2 mm to a final orifice of diameter D_l = 500 μm. The nozzle, shown in zone A of Fig. 1 is kept flush with the blasting air which flows through a tube of diameter, D = 12 mm. The spray is ejected downwards into atmospheric conditions where a variety of cases were investigated as specified in Table 1. The exit Weber number, defined for air blast cases only is given by $We_{exit} = \rho U^2 D_l/\sigma$ where U is the air blast mean velocity, σ is the surface tension of water and ρ the density of air. The GLR values presented suggest that all of the conditions tested here are either in a homogeneous bubbly flow or slug flow break-up regime with no case exhibiting an annular break-up flow, which would typically require a GLR > 5% [11]. Observations of multiple small bubbles within the liquid jet would agree with this assessment. Given the very low air-flow rates necessary for effervescent atomization, a narrow range Bronkhorst (EL-FLOW MFC PN64) gas mass flow controller was used providing a maximum output of 10 ln/min with 'ln' denoting normal litres per minute, with a standard accuracy of 0.5%. The liquid was supplied at room temperature through a *FP*1/8-20-G-5/81 Tri-flat rotameter with an accuracy of at least 5% over the measurement range. The injected pressure of the air was measured just upstream of the ejection nozzle and ranged from 15 to 180 kPa, as measured using a Wika Swiss movement analogue pressure gauge with a maximum range of 250 kPa.

2.1. LDA system

A commercial laser Doppler anemometry system (TSI Model FSA 3500/4000) has been used for characterization of particle velocity where full details on errors and uncertainties have been provided in Gounder et al. [29]. In these experiments, the receiver is positioned in a 45° forward scattering configuration where the assembly transmits two pairs of beams with wavelengths 514.5 nm and 488 nm to measure the axial and radial components of velocity respectively, with typically 10,000 samples in each channel being collected per run. A Bragg cell is utilized to shift one beam from each pair by 40 MHz to allow measurement of velocity in the negative direction. Built-in probe volume correction (PVC) has been implemented to correct for lower detectability of small particles towards the measurement volume edge due to the Gaussian light intensity profile. Throughout this contribution, we sub-range velocity statistics and present data which has been sampled from droplet sizes in the range $0 < d < 10$ μm. As the PDA instrument cannot measure non-spherical droplets of which a substantial number are present in effervescent atomization, we sub-range over a narrow range of spherical droplets in order to remove bias amongst different spray cases. Additionally, this acts as a close representation of the gas phase velocity so that the mean and rms flow velocity mentioned throughout the paper is obtained from these LDA measurements, sub-ranged from the droplets in the range $0 < d < 10$ μm. Furthermore, given the large velocity gradients which can be present in a hybrid effervescent–airblast atomizer, all LDA data is normalized for velocity bias in real-time.

Where an FFT is conducted on the LDA data, there is a restriction on the maximum frequency measurable which is dictated by the frequency of particle detection through the LDA probe volume. Therefore, at outer radial locations, where generally lower particle concentrations are present, maximum frequencies measurable in some instances could not exceed 600 Hz without introducing aliasing.

2.2. Imaging system

A high speed diode laser operated at 532 nm and 10 kHz was employed as the high speed light source (Edgewave INNOSLAB