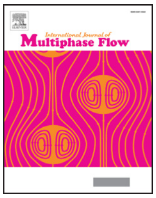
International Journal of Multiphase Flow 82 (2016) 35–48

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

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



Acoustic performance of effervescent sprays by time–frequency method with different atomizer structures under different operating conditions

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ARTICLE INFO

Article history:
Received 20 June 2015
Revised 25 November 2015
Accepted 15 December 2015
Available online 8 March 2016

Keywords:
Effervescent spray
Internal flow
Acoustic performance
Atomizer structure

ABSTRACT

The acoustic performance of effervescent sprays was experimentally investigated at various liquid flow rates and gas to liquid ratios (GLRs) by mass under pressure < 0.5 MPa. A transparent effervescent atomizer with different mixing chambers and exit orifices was used in the study. An unconventional description of spray characteristics under various internal flow regimes was obtained using the adaptive optimal kernel (AOK) spectrogram of the spray acoustic in the time–frequency domain. Acoustic energy was calculated using the Hilbert Huang transform (HHT) method, which provides a quantitative comparison of vibration intensity under different structures and operating conditions. A new evaluation of spray unsteadiness was established based on acoustic energy analysis. Results showed that gas flowing out of the orifice leads to an increase in the amplitude of high frequency components. The spray characteristics under different internal flow regimes could be reflected from the AOK spectrograms, through which a new perspective on effervescent sprays in the time domain is presented. Acoustic energy was mostly influenced by both the air flow rate and geometry of the exit orifice and showed reduced sensitivity to the structure of the mixing chamber. The structure of the atomizer affected the internal gas–liquid two-phase flow structures and further influenced spray steadiness. A study of the present condition revealed that a structure with a farther location of aerator holes and a small exit orifice diameter strengthens the stability of pray performance.

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Introduction

Effervescent atomization is a two-phase technique developed in the late 1980 s by Lefevbvre and colleagues (Lefebvre et al., 1988; Roesler and Lefebvre, 1988; Lefebvre, 1989). This technique exhibits satisfactory performance only by consuming a small quantity of atomizing gas under low injection pressure. This method has been widely used in recent years in various industrial applications, including gas turbine combustors, internal combustion engine industrial painting, and agricultural sprays (Sovani et al., 2001; Sovani et al., 2005; Panchagnula and Sojka; 1999).

The approach has drawn considerable interest from researchers. Such an atomization technique provides several advantages over conventional atomizers and has been described in Sovani et al. (2001). It is characterized by low sonic velocity for a two-phase mixture and a pressure jump at the atomizer exit. The atomizing gas consequently undergoes sudden pressure relaxation and rapid expansion at the atomizer exit, thereby shattering the liquid into ligaments and drops (Ramamurthi et al., 2009). The gas–liquid two-phase interaction reportedly has an important function in aiding liquid atomization.

Effervescent atomization involves a complex mechanism and numerous processes that are difficult to understand. Since the first investigation into effervescent atomization by Roesler and Lefebvre in 1987 (Roesler and Lefebvre, 1988), many studies using both experimental and theoretical methods have been conducted to deepen our understanding of effervescent sprays. Gadgil and Raghunandan (Gadgil and Raghunandan, 2011) captured some salient features of near-orifice jet breakup by flow visualization typically at low GLRs. They classified the near-orifice spray structures into three modes: discrete bubble explosions, continuous bubble explosions, and annular conical spray. They also observed the unsteady behavior of the spray breakup, which was strongly influenced by bursting bubbles. Edwards and Marx (Edwards and Marx, 1995) developed an unsteadiness evaluation method based on interparticle time distribution using the PDPA. This method is considered classic in the field and has been employed by various researchers in studying effervescent spray unsteadiness (Luong and Sojka, 1999; Heinlein and Fritsching, 2004). Jedelsky and Jicha

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http://dx.doi.org/10.1016/j.ijmultiphaseflow.2015.12.012
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(Jedelsky and Jicha, 2008) also developed a method of evaluating spray unsteadiness by measuring the pressure fluctuations in the mixing chamber of the atomizer, and results revealed the relationship between atomizer internal two-phase flow patterns and spray unsteadiness. Gomez (Gomez, 2009) and Shepard (Shepard, 2011) investigated the effects of bubble size on the properties of effervescent spray. They applied shadowgraph image visualization to characterize the shape, velocity, size, and size distribution of droplets. The results of both studies demonstrated that bubble and droplet size have a non-linear relationship. Shepard (Shepard, 2011) also indicated that an optimal bubble size that produces the finest spray exists. Sovani et al. (Sovani et al., 2001), Konstantinov et al. (Konstantinov et al., 2010), and Qian et al. (Qian and Lin, 2011) comprehensively summarized effervescent atomization from different perspectives. In these reviews, the factors that benefit achieving good atomization effects were concluded and discussed on basis of the research on both internal mixing and spray processes.

Structure is important and may be the only factor to consider when effervescent atomization is introduced to a certain industry process. A number of researchers have focused on the designs of atomizer structures with satisfactory atomization performance. Sovani et al. (Sovani et al., 2005) investigated the effects of the atomizer structure—including the exit orifice diameter, needle lift, and aerator pore size—on the injector performance. Camera and Malvern particle analyzer were used to measure the spray cone half-angle, mean drop size, and drop size distribution. Their results recommended several ways to improve the spray performance of effervescent atomizers in diesel engines. Chin and Lefevbvre (Chin and Lefebvre, 1995) emphasized the ratio of the area of aerator holes to the area of the discharge orifice as an important parameter affecting spray SMD and provided a method to determine the optimal size of the aerator hole for a small SMD under a certain discharge orifice size and GLR. Wade (Wade, 1994) and Wade et al. (Wade et al., 1999) investigated the influence of the location of the aerator holes relative to the final discharge orifice on the mean drop size. The results showed that a larger distance between the aerator and the final discharge orifice would benefit a small drop size. Wang et al. (Wang et al., 1989) measured the mean drop sizes and drop-size distributions under different gas-injector geometries and discharge orifice diameters and reported that atomization quality is less sensitive to gas-injector geometry and injector orifice diameter. Another indication of their experiments is as follows: the smallest exit orifice diameters produce sprays with the lowest SMDs at the lowest injection pressure; the largest orifice diameter nozzles produce the smallest droplet sizes at the largest injection pressure. A large number of successful experiments determined the relationship between spray performance and structure parameters. However, studies on the cause of the phenomenon are scarcely reported. Several studies considered the internal flow (flow regimes) when analyzing the influence of structure on spray performance (Ramamurthi et al., 2009; Shepard, 2011; Wade et al., 1999; Wang et al., 1989).

Both internal flow and external flow play important roles in effervescent atomization. The process of gas flowing out of the exit orifice should be the bridge between internal flow and external flow. However, this process is characterized by complex physics and highly nonlinear phenomena, impeding theoretical analysis. Experimental methods such as high-speed images constitute a feasible, reliable, and valid approach to studying this issue. Lin and Kennedy (Lin et al., 2001) investigated bubble formation and coalescence phenomena inside the aerated liquid injector by using backlit photography. The acoustic signature inside the mixing chamber was measured using a pressure transducer. The structures of the internal two-phase flow inside the aerated liquid injector and the near-field structures of the corresponding sprays were examined. Their results showed a strong relationship between internal flow and aerated liquid spray. Catlin and Swithenband (Catlin and Swithenbank, 2001) used a high-speed video to investigate both the internal two-phase flow and external atomization. Their experiments demonstrated the process of gas flowing out of the exit orifice and bursting along the liquid jet. Lorcher et al. (Lorcher et al., 2005) combined an electrical measurement technique and high-speed camera to demonstrate how internal flow parameters (pressure and volumetric flow rates of liquid and gas) and flow regime affect the mean diameter of the spray droplet. The results showed that internal flow parameters vary under a certain condition and cause the mean diameter of the spray droplet to be time-dependent. The experimental images obtained from the experiment revealed that bubbles undergo deformation when approaching and flowing out of the nozzle exit. These investigations have provided useful insights into the evolution of bubbles (gas) both inside and outside the atomizer. However, techniques such as the use of a high-speed camera remains limited when used to analyze the air ejected from the exit orifice. A method must be developed for an in-depth analysis and a detailed description of effervescent atomization, particularly the process of bubbles (gas) flowing out of the exit orifice.

Acoustics comes from the vibration of an object and commonly occurs in engineering technology and the natural world. Acoustic analysis has been widely applied in various fields because acoustic waves contain abundant information about the characteristics of objects under study. Acoustic waves are also generated during the effervescent spray process; however, few studies have attempted to elaborate on the acoustic characteristics of effervescent spray. Acoustic analysis aims to obtain detailed information on the gas–liquid two-phase flow structure coming out of the orifice. This study also intends to obtain a deep understanding of the two-phase atomization technique, with a new insight into the relationship between the geometry of the atomizer, operating conditions, and spray features.

This study investigates the acoustic performance of effervescent spray by time–frequency analysis. This paper is organized as follows: Section 2 describes the facilities, instruments, and procedures used in the experiment. Section 3 explains the basic concepts of the time–frequency method. Section 4 presents the experimental tests, analysis, and results. Section 5 concludes the study.

Experimental facility

Atomizer

A designed transparent outside-in type effervescent atomizer was used in the experiments. The atomizer was made of Plexiglass to allow visualization of the flow of the air–liquid mixture, the contour, and one characteristic structure shown in Fig. 1. The entry ports of the liquid and gas were located at the top of the atomizer body. The pressured liquid flows directly into the mixing chamber, and the aerating gas flows into the mixing chamber through small aerating orifices in various arrangements. The configurations of the mixing chamber are tabulated in Table 1. For each configuration, the aerating orifices are located in four columns at 90° intervals from one another on an 8 mm diameter mixing chamber. The distance between the last-row aerator holes and the final discharge orifice is 65 mm. A circular cross-section with a diameter of 1.0, 1.2, 2, or 3.2 mm was used for the final discharge passage. The lengths of the discharge passages are 0.6, 1.2, 3.6, or 7.2 mm under the 1.2 mm orifice diameter and 3.6 mm under other orifice sizes.

Experimental setup

The experimental setup is schematically shown in Fig. 2. Water and air were used as the test liquid and the atomizing gas,

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