Ballistic Imaging in the Near-Field of an Effervescent Spray

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Abstract

We have investigated liquid breakup mechanisms in the near nozzle region of a high pressure effervescent atomizer using ballistic imaging. This technique has revealed various breakup regimes depending upon total flow rate and the gas-to-liquid ratio (GLR). At low total speeds, the jet does not exhibit the wide spread angle and rapid breakup for which effervescent sprays are known, even at high GLR. Above a distinct threshold value for total flow rate, the jet passes through several recognizable flow regimes depending on GLR and it does achieve the expected wide spread angle and rapid breakup. Intermediate GLR's produce interesting flow patterns that seem to be generated by surging at the nozzle exit, and this surging can probably be attributed to the flow pattern just at the nozzle exit. Indeed, specific interior flows seem to generate the most rapid breakup and should be investigated further.

Introduction

Effervescent atomization offers the opportunity to mix liquid fuels very rapidly into a cross-flow of air, producing small droplets that can vaporize quickly, using relatively low injection pressure and fairly large-diameter nozzles [1, 2]. These last two points simplify the combustor design and improve reliability. Effervescent atomization is different from other twin-phase techniques such as air blast atomization because it is not necessary to provide high-speed air (at high pressure). Instead, the gas is mixed into the liquid before it exits the nozzle, so the gas pressure inside the injector is slightly higher than the fuel pressure (to ensure that gas bubbles mix into the liquid) and the velocity of the incoming gas can be low.

In most cases [2, 1, 3], the gas is introduced into the liquid through a number of holes passing through the wall separating the two flows, or through a sintered material. Often the gas chamber surrounds the liquid flow and the gas is injected through the walls of the passage into the liquid, or in some cases gas is on the inside with liquid on the outside. Past the point of mixing, the flow inside the nozzle passage is characterized by several regimes delineated primarily by the gas-to-liquid mass ratio (GLR). For low GLR (typically between 0.01 and 0.2) the gas produces dispersed bubbles in the confined liquid (called "bubble-flow"). At somewhat higher GLR (typically around 0.2 and above), the bubbles join to form long cylindrical shapes (called "slug-flow", see the simple representation in Figure 1). These formations occupy the center of the flow while the liquid flows primarily along the walls of the injector tube, aside from the disk-shaped liquid formations that bridge across and separate the various gas "slugs" from each other. As GLR increases, these slugs quickly merge to form a continuous column of gas which is surrounded by an annulus of liquid (called the "annular-flow regime"). The values for GLR provided here to delineate the various internal flow regimes are simply guidelines. The actual values for GLR at boundaries between regimes depend upon the specific nozzle design.

The effectiveness of this technique is attributed to the fact that the speed of sound in a twin-phase flow is orders of magnitude slower than the same speed in either of the pure substances [1]. The flow can thus choke at relatively low velocities, even with relatively large exit orifices (order of several hundred microns up to a millimeter). The change of pressure going from inside to outside of the injector body then causes the bubbles to expand rapidly just as they exit, exerting a force on the liquid structures and very rapidly shattering the liquid column. Especially in the bubble-flow regime this can be a complex, stochastic process that is not easily described in terms of correlations or numerical models. Even in the annular-flow regime it is difficult to estimate velocities, or the bulk properties of the flow (e.g. the speed of sound) with any accuracy.

Materials and Methods

In this paper we describe work aimed at the question: when does the near field transition to a process wherein the emerging field is shattered directly into droplets, without ligaments in evidence? We have applied a technique called ballistic imaging [4, 5] to image the liquid core under a variety of flow conditions. In paper we describe the technique, describe the specific experiments, and then present and discuss the experimental results.

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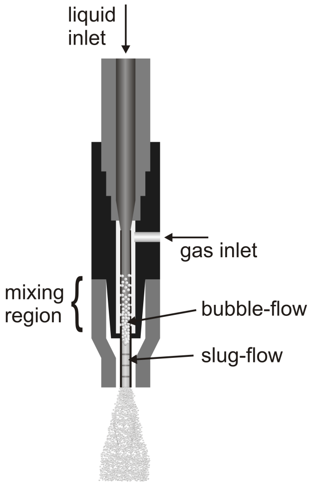

Figure 1. Example of a figure appearing at the end of the paper

Results and Discussion

The jet studied in thsi work is quite similar to that depicted in Figure 1 with two different nozzles (1 mm OD and 0.5 mm OD), and various values for the GLR. The application of ballistic imaging to these jets has revealed important mechanics in the near-nozzle region that have not been observed in prior work. The experimental evidence for two different nozzle sizes indicates that at relatively low flow rates, the jet does not exhibit the wide spread angle and rapid breakup for which effervescent sprays are known. They break up via fairly common mechanisms involving the formation of large ligaments which then break up further into drops, even at very high GLR.

At flow rates that exceed this flow rate threshold value, we observe a significant change in the breakup dynamics when the transition from GLR's typical of the bubble-flow regime to GLR's typical of the slug-flow regime occurs. This happens with both nozzle sizes at various total flow rates, and it depends upon the GLR of course. Flows that have just entered what appears to be the slug-flow regime produce distinct chevron shaped waves in the droplet field which are formed by coherent surging. The surging is most likely caused by the sudden destruction of large slugs of gas as each of the disks that separate them is burst. Whatever the source may be, it is a coherent process that produces wave-like behavior in the droplet field and hence the chevron structures. Instability also occurs at higher GLR, but it is less coherent. At very high GLR, the jet does seem to break up immediately upon exiting the nozzle.

These conclusions are based upon entirely new images of the near-nozzle flow, and they are somewhat speculative at this point. Further, simultaneous measurements are required to resolve the remaining questions.

Acknowledgement

The authors are grateful for technical assistance from Dr. Shukesh Roy (Spectral Energies, LLC), Mr. Kyle Frische (Innovative Scientific Solutions Inc.), Ms. Amy Lynch (Air Force Research Laboratories), and Dr. Stephen Lin (Taitech Inc.). Dr. Sedarsky was supported by the Swedish Research Council grant no. 621-2004-5504 and Air Force EOARD grant no. FA8655-06-1-3031. Equipment and funding was also provided in part by the Air Force Research Laboratory SBIR program (Barry Kiel, Program Manager) and the Air Force Office of Scientific Research (Dr.s Julian Tishkoff and Mitat Birkan, Program Managers).

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