TRANSPORT PHENOMENON OF DROPLETS IN THE DEVELOPING REGION OF THE ATOMIZER WITH INTERNAL IMPINGING MECHANISM

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ABSTRACT

This paper investigates the droplet transport phenomenon in the developing region of the spray injected by the atomizer with internal impinging mechanisms. The characteristics of the spray are measured by a two-component phase Doppler particle analyzer (PDPA) and the images are taken by a high speed camera. Instantaneous flow image shows the intermittence of the spray jet as injected with internal impingement. On the other hand, a large-scaled sinusoidal flow structure along the axial direction is observed when the spray jet is injected without internal impingement. Hence flow impingement inside the atomizer has strong effects on the structure of the spray jet because of the enhanced mixing processes between the liquid and gas phases. It turns out that the spray jet with internal impingement has a wider and more uniform distribution. Measurements of the distribution of the spray droplets and volume flux justify the above observation.

Keywords: Droplet Transport, Turbulence, Atomization, Internal Impingement, PDPA

1. INTRODUCTION

Atomization involves the disintegration processes of liquid matter to increase its specific surface area for engineering applications. Atomization of liquids is widely used in energy production system such as spray combustion in furnaces, gas turbines, diesel engines, and rockets. It is also employed in process engineering applications such as spray drying, evaporative cooling, powder metallurgy, and spray painting. Recent development of medical applications such as the delivery of drugs to the lungs also relates to the atomization technology [1]. The atomization of most liquids can be achieved simply by creating a sufficiently high relative velocity between the liquid to be atomized and the surrounding gas. This process is called “twin-fluid” or “air-assisted” atomization.

Air-assisted atomizers can be divided into two types: internal and external mixings, depending on where the first contact between the liquid and gas phase takes place. However, atomization with the internal-mixing mechanisms normally elicits a finer spray. For example, ultra-fine droplets (i.e., SMD $\leq 10 \mu m$) are produced by internal mixing atomizers at GLR as low as 0.14 [2]. Therefore, if abrasion and fouling are not serious, internal-mixing atomizers are preferred due to their high efficiency of energy transfer from atomization gas to liquid.

Performance of the internal-mixing atomizers with coaxial liquid feeding has been widely investigated for more than three decades. The effects of nozzle design, loading, as well as liquid and gas properties on spray characteristics have been reported in the literature [3-5]. Many researchers also investigate the performance of the effervescent atomizer to produce the fine water droplets [6, 7]. However, the fabrication of the device is relatively complicated as comparing to other types of twin-fluid atomizer.

Most of the researchers had characterized the performance of the atomizers in terms of various design configurations of the orifice. For example, Tamaki et al. [8] investigated the performance of the atomizer with multiple openings. They found that its atomization performance was enhanced with the arrangement of a wire net or a gap at the inlet of the nozzle. Kufferath et al. [9] further investigated the outlet port length of a twin-fluid atomizer and found that uniform profile of SMD distribution was achieved with the longer outlet ports. Wang et al. [10, 11] further investigated the effects of the aspect ratios and the cross sectional areas of a slit nozzle on the atomization performance of melt using an internal mixing atomizer. Their results showed that better atomization performance can be achieved under the lower aspect ratios and larger cross sectional areas of the atomizers. Furthermore, the slit orifice with round corner produced the spray with finer particles.

The internal structure of the atomizer is also an important design parameter since the internal structure determines the upstream conditions of the mixing and energy transfer mechanism between the liquid and gas phases. As a comparison, the effects of the internal structure on spray characteristics have not been widely explored in the literature. Hence this paper attempts to investigate the effects of internal structure on the atomization performance. The twin-fluid atomizer is designed with and without the internal impinging mechanism as shown in Figure 1. Comparison of the flow structure and the transport processes of the spray jet under different design configurations will be described in this paper.
2. EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows the schematic of the atomizers used in this paper. The atomizers (a) and (b) illustrate the design of the atomizer with and without internal impinging mechanism, respectively. The liquid stream of the atomizer (a) is first injected at the distributor. It results in two streams of the spray flows. They are further introduced to the mixing chamber of the atomizer with flow impingement. The secondary atomization processes take place when the above two streams come together. Finally, the two phase flow is injected through the orifice for further atomization. On the other hand, the liquid stream of atomizer (b) is directly introduced to the mixing chamber and mixed with the gas flow. It is in turn injected through the orifice for atomization.

The pressurized air is supplied through two 1/4-inch tubes from two sides of the atomizers. The pressurized liquid is fed through a 1mm opening on the top. The diameter of the orifice is 2mm.

The experimental setup is shown in Figure 2. The test stand is designed for a down-sprayed type atomization experiment. It consists of a spray chamber, an optical table, a collection tank, and an exhaust fan. Liquid was delivered from a pressurized water tank and gas supplied from a compressed air tank. The Sauter mean diameter of the spray flow fields were measured by a two-component phase Doppler particle analyzer (PDPA) by Aerometrics Inc. The PDPA system has the following major components: a 3-watt Argon ion laser source, mirrors, a transmitter, a receiver, a Doppler signal analyzer and a processing computer. The schematic diagram is illustrated in Figure 2 to show the optical arrangement of the PDPA system. The droplet size, two orthogonal velocity components can be obtained in real-time measurement. The data presented in this paper were collected by taking 10000 samples at each measuring point. Measurements were performed at 100 to 400 mm from the nozzle. The measuring domain is shown in Figure 3. The coordinate system was defined that R is in the horizontal direction parallel to the laser light and Z is in the vertical direction parallel to the axial direction of the spray jet. The origin of the coordinate system is located at the center of the nozzle exit.

3. RESULTS AND DISCUSSION

This section describes the characteristics of the spray issued from the atomizers with and without internal impinging mechanism. Experiments are performed under the operating conditions of the gas pressure of 2.3 bar and liquid pressure of 1.5 bar. The gas-to-liquid mass ratios are 1.2.

3.1 Flow Visualization of the Spray Jet

Figure 4 illustrated the spray flow field of the atomization processes with and without internal impinging mechanism. The images were taken by the high speed camera lightening with a laser sheet. The duration of the laser light sheet was 29 μs/pulse. Photos at down stream positions of 100mm and 200mm from the nozzle are presented. Each image covers 40mm height in the actual scale with the resolution of 512×208 pixels.

As can be seen from this figure, the vortices in the shear layer region of the spray jets are observed in both cases. It is resulted from the higher shear stress between the high speed spray and the ambient air. The vortex motion involved in the spray flow enhances the entrainment of the ambient air into the spray. This will in turns attribute to the transport process of the spray droplets and enhance the mixing processes between the continuous phase and the dispersed phase. These processes are important in the spray combustion systems to achieve the higher efficiencies.

One can also observe the flow intermittence in the spray jet injected under internal impingement. On the other hand, a large scaled sinusoidal flow structure in the axial direction can be observed for the spray jet injected without internal impingement. It turns out that the spray jet with internal impingement has a wider distribution of the spray in