ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 24 (2011) 866 – 872
Procedia Engineering
www.elsevier.com/locate/procedia

2011 International Conference On Advances In Engineering

Experimental Investigations on Spray Characteristics in Twin-Fluid Atomizer

Pipatpong Watanawanyoo[a*], Hiroyuki Hirahara[b]
Hirofumi Mochida[c], Teruyuki Furukawa[d], Masanori Nakamura[e]
and Sumpun Chaitep[f]

[a,c,d]*Graduate School of Science and Engineering, Saitama University, Saitama, Japan, 338-8570*
[b,e]*Department of Mechanical Engineering, Saitama University, Saitama, Japan, 338-8570*
[f]*Department of Mechanical Engineering, Chiang Mai University, Chiang Mai, Thailand, 50200*

Abstract

A twin-fluid atomizer was designed and developed for fuel atomization. The droplet characteristic in the spray which was produced with the atomizer was investigated experimentally. Air flow induced in the atomizer causes a pressure reduction, hence the fuel is sucked into the atomizer. The mixture flow of air and liquid caused the atomization downstream due to the turbulence. In the twin-fluid atomizer, atomization is attained by injecting an air stream at tip of the liquid inlet port. In this research, the test liquid supply pressure was kept constant and the air flow rate through the atomizer was varied over a range of air supply pressure to obtain the variation in air liquid mass flow ratio (ALR) from 0.2 to 2.7. The results revealed that the air assisted atomizer had a capability to inject the test liquid in the range of the rates of 0.0019-0.00426 kg/s, with the use of air pressure supplied from 68.9 to 689 kPa. The images of the spray were obtained with a shadowgraph technique and analyzed to obtain the particle size and its distribution. Droplet size from twin-fluid atomizer had various sizes in the range of about 17-200 μm. The atomizer can be applied for aerosol and combustion purposes.

Selection and/or peer-review of ICAE 11

Keywords: Air liquid mass flow ratio (ALR), Air assisted atomizer, Twin fluid atomizer, shadowgraph technique, Droplet size

* *Corresponding author. Tel.:+81-048-858-3488; fax:+81-048-858-3711.*
E-mail address:s09dh052@mail.saitama-u.ac.jp.

doi:10.1016/j.proeng.2011.12.416

1. Introduction

1.1. Classical atomization

Atomization is an essential process in which a bulk fuel is converted into small droplets. It represents a disruption of the consolidating influence of surface tension by the action of internal and external forces. In the absence of such disruptive forces, liquid surface tension tends to pull the liquid into the form of a sphere, which has the minimum surface energy [1]. Liquid viscosity has an adverse effect on atomization because it opposes any change in liquid geometry. On the other hand, aerodynamic forces acting on the liquid surface promote the disruption process by applying and external distorting force to the bulk liquid. Therefore, a breakup occurs when the magnitude of the disruptive force just exceeds the consolidating surface tension force. When a bulk liquid is exposed to another continuous phase, for example, a liquid column, jet or sheet emerging from a atomizer into a moving gaseous environment, or free surface in a blowing gas flow, the competition between the cohesive and disruptive forces will dominates the liquid surface behaviour, leading to oscillations and perturbations in the liquid. Under constructive conditions, the oscillations may be amplified to such an extent that the bulk liquid disintegrates into droplets.

This initial breakup process is often referred to as primary breakup or primary atomization. The population of larger droplets produced in the primary atomization may be unstable if they exceed a critical droplet size and thus may undergo further disruption into smaller droplets. This process is usually termed secondary breakup or secondary atomization. Therefore, the final droplet size distribution produced in an atomization process is determined by the liquid properties in both the primary and secondary disintegration.

1.2. Twin-fluid atomizer

The twin-fluid atomizer, i.e. the air assisted atomizer provides the finest degree of atomization for a given flow capacity and supplied pressures. There is a desirable choice; i.e. wide angle of solid, full and hollow cone or flat spray. The spray pattern remains in such defined shape only as long as the velocity of the atomizing air is maintained. The droplets in spray may evaporate completely, depending on their size, exposure time, the relative humidity, and other ambient conditions. Atomizers are classified depend upon various techniques; i.e. pressure atomizer, twin fluid atomizer, rotary atomizer, electrostatic and ultrasonic atomizer [2]. All of these are widely used in the combustion applications**.** In contrast to single fluid atomizers requiring high pressures to produce fine sprays, twin fluid atomizers can provide a fine spray at relative lower supply pressures [2]. Internally mixed atomizers are gaining popularity because of the controllability over the atomization process.

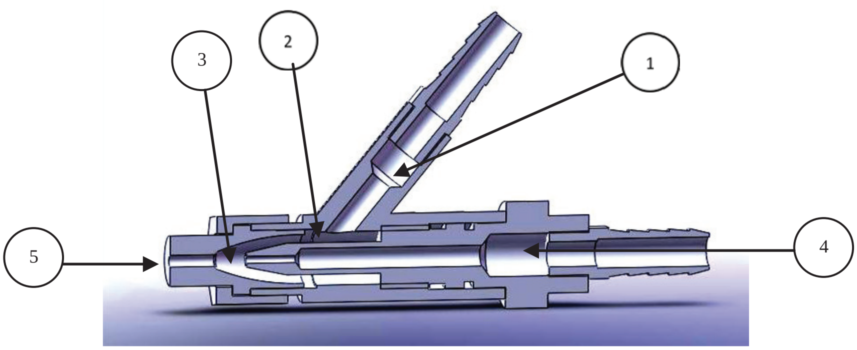

Fig. 1. Schematics of the internal mixing atomizer

The structure of the atomizer used in the present study is shown in Fig. 1. Liquid enters the water chamber (2) through water inlet port (1). The liquid is sucked through the tip of taper needle (3) because of the pressure difference created at the needle tip by air pressure. The air is supplied through air inlet port (4) and injected through small hole at the upstream of water entry point. Two streams, air and water, interact at the internal mixing chamber of the atomizer and droplets are discharged through outer chamber (5). This two-phase flow finally comes out of the injection orifice of the atomizer (2.5 mm in diameter).

2. Experimental Setup

2.1. Shadowgraph Technique

Flow visualization was conducted by using the shadowgraph technique. The spray is placed in-line with the laser, speckle killer and CMOS camera. The laser beam generates a homogeneous background illumination, while the water droplets is focused on CMOS sensor as a shadowgraph image. Depending on the situation of the droplet with respect to the focus plane and depth-of-focus of the camera arrangement, the droplets show up as either sharply focused or blurred images. A continuous wave Nd: YAG laser was used to illuminate the spray at nozzle exit and the camera was engaged with the focal length 200 mm, whose resolution was 1280 x 1024 pixels. This setup is shown in Fig. 2. The external spray characteristic was studied by taking flow images of the spray at different air supply pressures using a shadowgraph technique [3]. The liquid flow rate, corresponding to a particular air flow rate was measured using a calibrated digital flow meter. The location of the measurement planes in the spray were defined by the axial distance from the nozzle (y) and radius (x). The origin was set on the exit of the nozzle. By traversing the measurement section, the spray images were acquired at an axial location of 100 mm downstream from the nozzle.

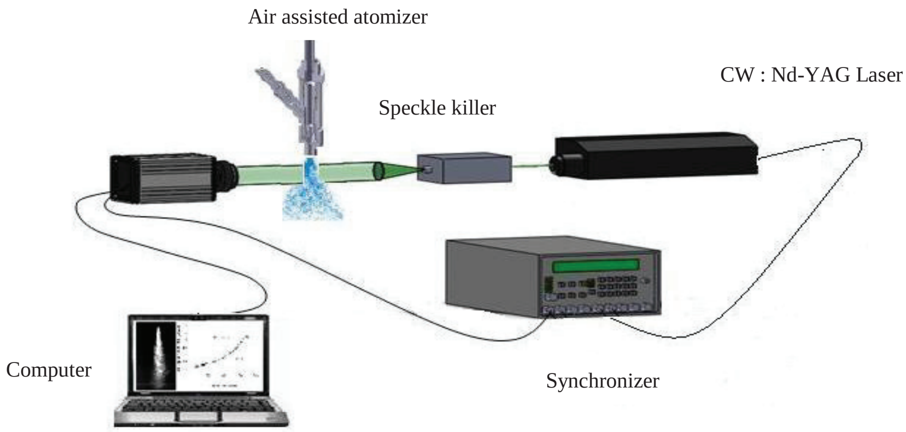

Fig. 2. Optical setup for shadowgraph observation

Fig. 3 shows a schematic diagram of the experimental system used in the present experiment. Water was supplied from a water tank which is sucked by pressure difference. Both air and water mass flow rates were controlled and measured using mass flow controllers. These controllers also gave line pressures history and those data were sent to a computer for monitoring and recording.

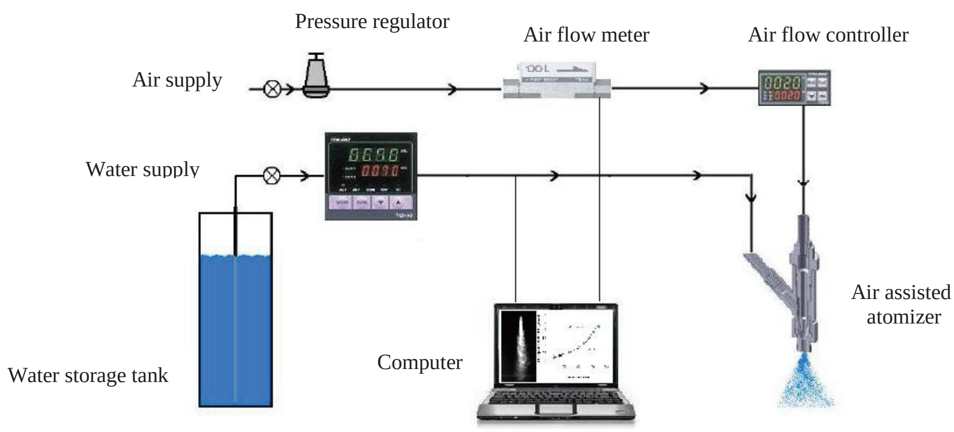

Fig. 3. Schematic diagram of the spray generation and experimental system

3. Results and Discussion

3.1. Atomizer Performance Test

The performance of the air assisted atomizer was operated for test with respect to the water flow rate. The atomizing air pressure was supplied between 68.9-689 kPa (10-100 psi), correspondingly consumed 1.9×10^{-3}-4.3×10^{-3} kg/s of water. The measured values of water and air mass low rate in terms of the feed pressure are shown in Fig. 4.

The air mass flow rate increased from 0.0004 kg/s to 0.0086 kg/s with supplied air pressure increasing. The water and the air flow rate through the atomizer were varied according to the air supply pressure, so *ALR* was determined as a function of supplied air pressure. For example, when air assisted pressure was 689 kPa, air mass flow rate was 0.0086 kg/s and water mass flow rate was 0.00378 kg/s, hence *ALR* = 0.0086/0.00378 = 2.27 was obtained.

Next, the spray solidity was studied by taking pictures of the spray at different air supply pressures. The water flow rate corresponding to a particular air mass flow rate, *ALR* was measured by using a calibrated flow meter. The water supply pressure was then varied and the entire procedure was repeated for different values of air supply pressure and an air density was obtained. The calculated values of *ALR* and air pressure are shown in Fig. 4.

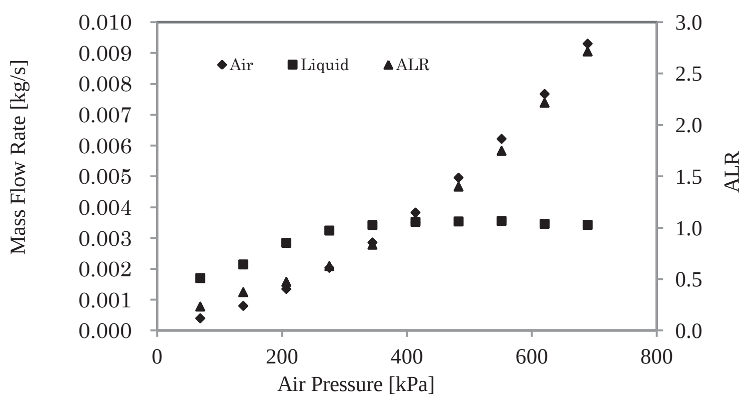

Fig. 4. The measured value of mass flow rate and air pressure with ALR

3.2. Characteristics of Near Nozzle Flow

In the most basic sense, a spray corresponds simply to the introduction of liquid into a gaseous environment through a nozzle with which the liquid, through its interaction with the surrounding gas and by its own instability, breaks up into droplets. The formation of a spray begins with the detaching of droplets from the outer surface of a continuous liquid core extending from the orifice of the injection nozzle, as shown in Fig. 5. The disintegration of the liquid core into the ligaments or large droplets is called primary breakup. In the present case, the instability of the liquid was induced in the internal mixing chamber due to the interaction between the liquid and high speed air. Therefore the primary stage is more unstable rather than that in single-fluid atomizer. The liquid ligaments and large droplets will break up further into small droplets due to the interactions between the liquid ambient gas or droplet collisions. The process of this further break-up is called secondary breakup. The near nozzle region, where the volume fraction of the liquid is usually larger than that of the ambient gas is called the dense spray region. Correspondingly, the downstream region where the volume fraction of the liquid is relatively low is called the dilute spray region.

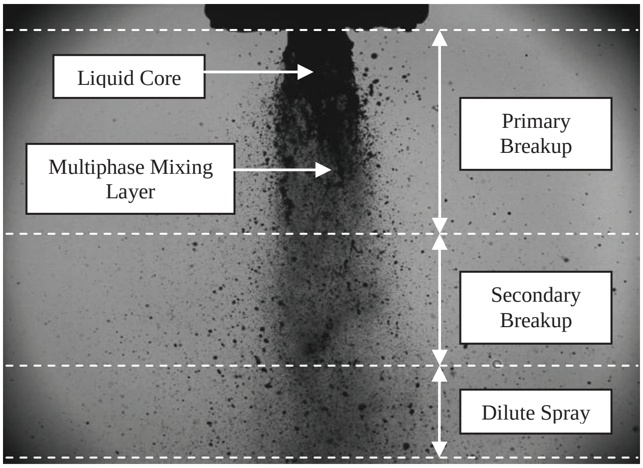

Fig. 5. Observations of a spray generated by twin-fluid atomizer

Fig. 6 shows the spray structure 100 mm downstream from the discharge orifice. At this location where ligaments and non-spherical droplets were still present, the secondary atomization process takes place. In this process, the relatively large initial droplets which were resulted from the primary breakup process disintegrated into smaller droplets that may finally evaporate. The mechanism of deformation and disintegration of liquid droplets has been studied experimentally by, Zama et al. [4], and Bundhurat. et al. [5]. Hirahara et al [6] have reported the deformation and disintegration of water and silicone oil droplets were investigated experimentally in a shock tube. Optical visualization was performed by means of the shadowgraph method. Droplets with diameters in the range of 200 to 500 μm were generated by an oscillating capillary. The smallest Weber number in the present experiments is close to the critical value of the breakup. The droplets disintegrated in the stamen or bag mode for moderate values of the Weber number.

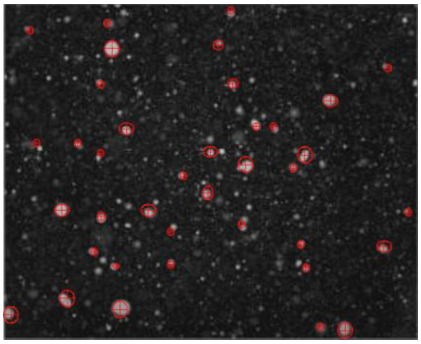

Fig. 6. Droplets image acquired 100 mm downstream from discharge orifice

Since this region is relatively dense, the existence of a large number of droplets increases and the probability of droplet collision increases. The algorithm for calculating the droplet size with binary image processing method and edge detection program with MATLAB were applied in the experiment. The shadowgraph droplet analyzer system measures droplet diameter from the size of droplet shadow captured only in focus with sharp boundaries data images. In the particle size algorithm, the appropriate values are set for detection thresholds base on light intensity. The final droplet image pattern is obtained as the image formed by the pixels having an intensity level higher than the threshold. An instructive image of drop size distribution may be obtained by plotting a histogram of drop size, each ordinate representing the number of drops whose dimensions fall. A typical histogram of this type is shown in Fig. 7. Droplet size from air blast atomizer had various sizes in the range of about 17-200 μm,.

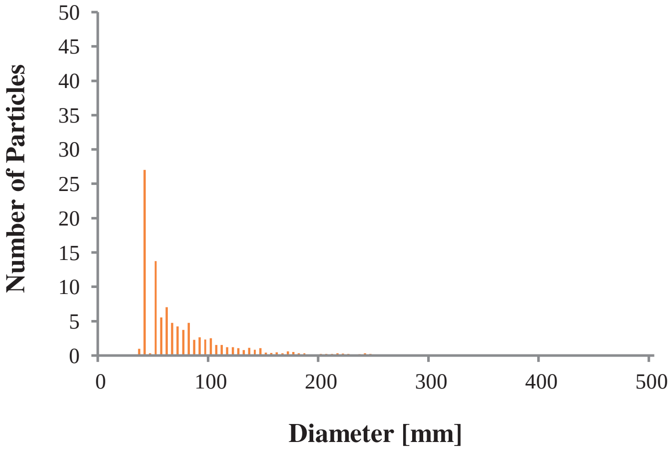

Fig. 7. Typical histogram of droplet size

At the lower air flow rates, water jet maintains its mostly coalition for a longer distance from the nozzle before breaking up, as shown in Fig. 8 (a). As the air flow rate is increased the initial filaments become shorter and breakup of the filament into droplets happens closer to the nozzle, as shown in Fig. 8 (b). Thus as the air flow rate is decreased, the point of initial breakup is moved away from the nozzle exit. Fig. 8 (c) shows the prompt breakup mode in twin fluid atomizer. This effect can be observed in the series of shadowgraphs at nozzle exit, as shown in Fig. 8 In general, for low air flow rates, an experiment becomes less repeatable, since the droplets are not breaking up as quickly and larger droplets are produced. This means that there are a smaller number of larger droplets, some of which appear not to be following the airflow as accurately as the smaller particles.

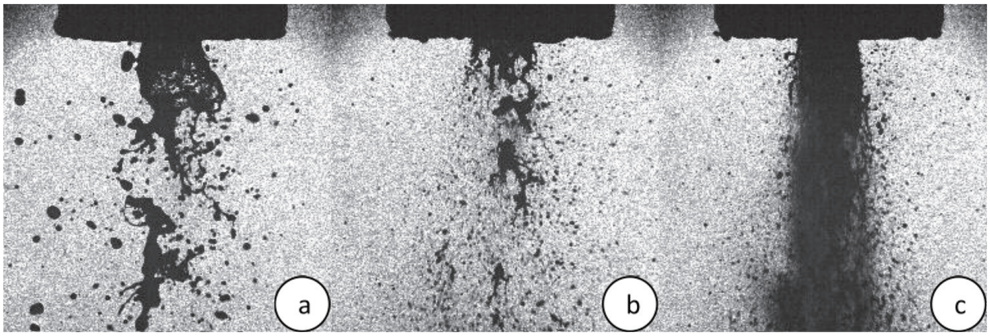

Fig. 8. Shadowgraphs at nozzle exit for air flow rates of a) 0.000405 kg/s, b) 0.0037 kg/s, c) 0.0086 kg/s

4. Concluding Remarks

Air assisted atomizer system was designed and developed for fuel injection. The purpose was to utilize a low pressure in supplying of atomized fuel. The results revealed air assisted atomizer had a capability to inject the test liquid in the range of the rates of 1.9×10^{-3}-4.3×10^{-3} kg/s, with the use of air pressure supplied from 68.9 to 689 kPa. In this research, the test liquid pressure was kept constant at atmospheric pressure and the air flow rate through the atomizer was varied over a range of air supply pressure to obtain the variation in air liquid mass flow ratio, *ALR* from 0.2 to 2.7. Droplet size from air blast atomizer had various sizes in the range of about 17-200 μm. As the air flow rate is increased the initial filaments become shorter and breakup of the filament into droplets happens closer to the nozzle. Thus as the air flow rate is decreased, the point of initial breakup is moved away from the nozzle exit. The nozzle can be applied for aerosol and combustion purposes.

References

[1] Lefebvre, A. Henry, Atomization and spray, *Hemisphere Publishing Corporation*, Chapter 4, 1989, pp. 105-106.

[2] May, Y. Leong, Vincent, G. Mcdonell and Scott, G. Samuelsen, Mixing of an airblast-atomized fuel spray injected into a crossflow of air, *Paper No. NASA/CR-2000-210467,* NASA Center for Aerospace Information, 2000.

[3] Watanawanyoo P., H. Mochida, H. Hirahara and C. Sumpun, Flow characteristics of fluid droplet obtained from air assisted atomizer, *Proceedings of ASME-JSME-KSME Joint Fluids Engineering Conference 2011, Paper No. AJK 2011-31013*.

[4] Y. Zama, M. Kawahashi and H. Hirahara, Simultaneous measurement method of size and 3d velocity components of droplets in a spray field illuminated with a thin laser- light sheet, *Measurement Science and Technology*, 2005, Vol. 16, pp. 1977-1986.

[5] Bundhurat D., Chaitep S., Checkel D., Watanawanyoo P. and H. Hirahara, Numerical and experimental investigation on laminar hot-gas flow with injected water spray, *Australian Journal of Basic and Applied Sciences,* (2010), Vol. 4(6), pp. 1240-1250.

[6] H. Hirahara and M. Kawahashi, Experimental investigation of viscous effects upon a breakup of droplets in high-speed air flow, *Experiments in Fluids*, 1992, Vol. 13, pp. 423-428.