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Microscopic Spray Characteristics in the Effervescent Atomizer with Two Aerator Tubes

Hyung Gon Kim*
Graduate School, Department of Mechanical Engineering, Kagoshima University, 1-21-40, Korimoto, Kagoshimasi, 890-0065, Japan
Toshiaki Yano
Department of Mechanical Engineering, Kagoshima University, Japan
Kyu Keun Song
RCIT, Chonbuk National University, Korea
Torii Shuichi
Department of Mechanical Engineering and Materials Science, Kumamoto University, Japan

An experimental study is performed on atomization characteristics and stable operating conditions for the injection of high viscous waste vegetable oil using an effervescent atomizer with 2 aerator tubes. Consideration is given to the effects of ALR and liquid viscosity on the velocity and mean diameter of the injected droplet. It is found that (i) as ALR increases, the axial velocity of the droplet is increased, while half-velocity width and SMD are decreased regardless of the change in liquid viscosities, (ii) the rate of fine drop distribution occupied in the total spray field is increased with an increase in ALR, and (iii) the effect of viscosity on the atomization characteristics is minor. Consequently, it is expected that the effervescent atomizer will exhibit an excellent atomization performance at the high ALR condition, regardless of liquid viscosities.

Key Words : SMD, PDPA, Effervescent Atomizer, ALR

Nomenclature

ALR : Air-to-Liquid Ratio ($\dot{m}_a/\dot{m}_l$) : ratio of mass flow rate of air through the atomizer to that of liquid, -
b : Half-velocity width, mm
d : Exit orifice diameter, mm
D_{30} : Volume diameter, μm
$\dot{m}_a$: Mass flow rate of air, g/s
$\dot{m}_l$: Mass flow rate of liquid, g/s
r : Radial coordinate, mm
SMD : Sauter Mean Diameter, μm
u : Drop axial velocity, m/s
V_c : Volume of mixing chamber, m^3
z : Axial distance downstream of atomizer, mm
θ : Diffusion angle of nozzle exit orifice, degrees

* Corresponding Author,
E-mail : kimhygojp@yahoo.co.jp
TEL : +81-99-285-8247; **FAX** : +81-99-285-8246
Graduate School, Department of Mechanical Engineering, Kagoshima University, 1-21-40, Korimoto, Kagoshimasi, 890-0065, Japan. (Manuscript **Received** November 20, 2002; **Revised** May 28, 2004)

1. Introduction

The effervescent atomization technique was originally developed by Lefebvre et al.(1988). The researchers reported that the effervescent atomizers exhibit significant advantages in comparison with the atomizers of conventional pressure, rotary, and twin-fluid types. For the example, good atomization can be achieved with injection pressures that are several times lower than those required by other types of atomizers.

Droplet velocity and mean drop size of the spray are the important parameters in most applications. Among the parameters, the effect of ALR (Air-to-Liquid Ratio) on the droplet velocity and mean droplet size of the spray has been investigated by several researchers.

Panchagnula and Sojka (1999) measured the radial and axial velocities of the droplet in the spray reproduced by the effervescent atomizer and disclosed that the droplet velocity decreases with increasing axial distance from the atomizer tip. From the similar study, Kim (2002) reported that the growth rate of half-velocity width of the spray increases with an increase in ALR. Roesler and Lefebvre (1989), Lefebvre et al. (1988), and Li et al. (1994) investigated the effect of ALR on the drop size of the spray. Throughout these different experimental conditions, SMD of the spray is a non-linear function of ALR. In other words, mean droplet size decreases rapidly in the low ALR range, while a somewhat slow attenuation yields with a further increase in ALR. Buckner and Sojka (1991) and Lund et al. (1983) investigated the variation of mean drop size with a change in liquid viscosity.

The present study will investigate the possibility of applying of effervescent atomization to incineration, because effervescent atomizers have many excellent characteristics in waste incineration applications. As shown in the research of Kim et al. (2003), the effervescent atomizer is insensitive to the changes of nozzle orifice diameter, and so a larger nozzle orifice diameter can be used to reduce clogging substantially. The liquid flow velocity in the discharge orifice is much lower than that of a conventional atomizer. Therefore, erosion problems created by solids suspended in the waste can be greatly reduced. Furthermore its lower velocities in the orifice lead to lower drop velocities. As a result, the burnout lengths are shorter and the incinerator can be made more compact (Sovani et al., 2001).

Authors have studied the difficulty of low-caloric wastes incinerating. Actually, this study was carried out for a preliminary examination to inject vegetable oil waste into incinerator as a main or auxiliary fuel. To prevent clogging by solids suspended in the waste, a large nozzle exit orifice diameter was designed. As shown in Fig. 1, to inject liquid (i.e., low-caloric liquid phase wastes and waste vegetable oil) into the incinerator, simultaneously with fixed quantity, an effervescent atomizer with two aerator tubes is specially designed. The detailed manuscript of the designed nozzle will be shown in the following.

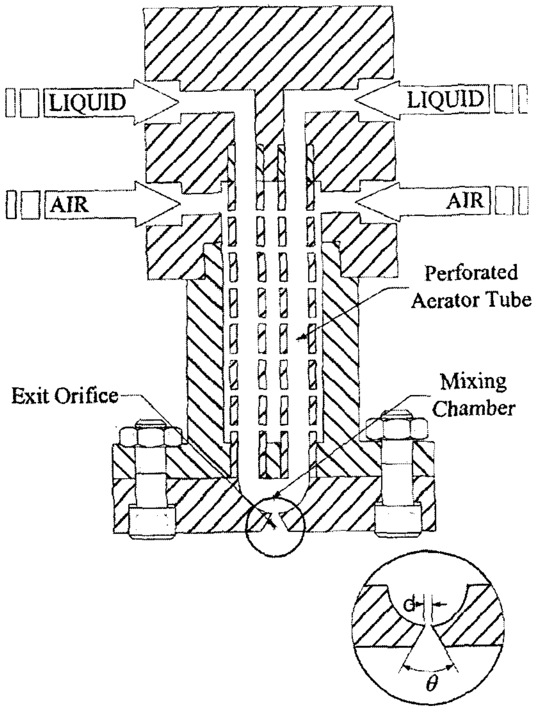


Fig. 1 Schematic diagram of effervescent atomizer

In order to investigate the atomization characteristics and the stable operating condition of the nozzle designed here, an emphasis is placed on the measurement of drop velocity, mean diameter of the drop and size distribution using 2-D PDPA (Phase Doppler Particle Analyzer) with the variation of ALR.

2. Experimental Apparatus and Conditions

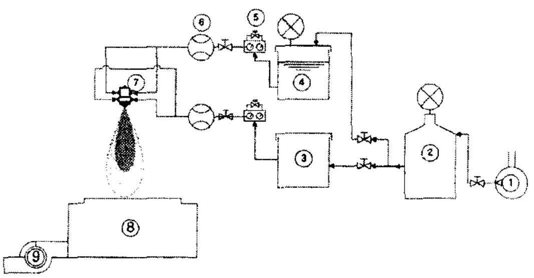
The effervescent atomizer used in the present study is schematically shown in Fig. 1. It consists of five main components: (1) two liquid (water or vegetable oil) supply port, (2) four air (atomizing gas) supply port, (3) two aerator tubes where the air is bubbled into the liquid stream, (4) a mixing chamber in which two phases are mixed, and (5) an exit orifice. Here, to inject low-caloric liquid phase wastes and waste vegetable oil into the incinerator, an effervescent atomizer with 2 aerator tubes is specially designed. Liquid is supplied through two ports at the side of the effervescent atomizer, flows down inside twin perforated tubes, moves the mixing chamber and is injected in the vertical direction from the exit orifice. Correspondingly, the air is supplied to a chamber with the perforated concentric annulus through four ports, which are located around the atomizer. Since the air supply pressure is slightly higher than that of the liquid supplied in the atomizer, the air flows through the perforated concentric annulus and simultaneously mixes with the liquid, resulting in the formation of bubbles. The two-phase mixture that contains bubbles flows toward the mixing chamber and is ejected through the exit orifice. Table 1 shows the geometry of the effervescent atomizer used in this study.

Figure 2 depicts a schematic of the experimental apparatus. The steady liquid-air mixture is continuously supplied to the effervescent atomizer from the pressurized storage tank. Compressed air and liquid are properly filtered and regulated. A few valves, pressure gauges, pressure regulators and flow meters are located in the feed line to provide the desired operating conditions. The mists generated by small drops, are collected in a liquid receiver to prevent splashing and then are discharged by a suction blower attached to the bottom-side of the liquid receiver. Two-dimensional PDPA, which consists of an optical system, a signal processing system and a two-dimensional traversing system, is used to investigate the atomization characteristics of the spray produced by the effervescent atomizer. The optical system is composed of transmitting optics, receiving optics, and a 750 mV air-cooled Ar-ion laser. The PDPA provides the information on the individual drop size and its velocity.

In this study, water and vegetable oil are used as a working fluid, respectively. During the experiment, the mass flow rate of liquid, $\dot{m}_l$, is kept at 2.8 g/s and the mass flow rate of air, $\dot{m}_a$, is changed from 0.2 g/s to 0.6 g/s. Thus ALR (Air-to-Liquid Ratio) is changed from 0.071 to 0.214. Tables 2 and 3 show the experimental conditions and properties of working fluids used in this study, respectively. Drop velocity and drop mean diameters are measured at the distances of 30, 50, 100, 150, and 200 mm downstream of the nozzle tip. And each axial measurement station has 41 measurement points along $\pm r$ direc-

Table 1 Atomizer geometry

Exit orifice diameter, d	2.5 mm
Diffusion angle, θ	60°
Volume of mixing chamber, V_c	1.89×10^{-5} m^3



① Air compressor ⑥ Flow meter
② Air storage tank ⑦ Effervescent atomizer
③ Air surge tank ⑧ Liquid receiver
④ Liquid storage tank ⑨ Suction blower
⑤ Pressure regulator

Fig. 2 Schematic diagram of the experimental apparatus

Table 2 Experimental conditions

Liquid	Water or Vegetable oil
Atomizing	Air
Liquid mass flow rate	2.8 g/s
Air mass flow rate	0.2, 0.3, 0.4, 0.5, 0.6 g/s
ALR	0.071~0.214

Table 3 Properties of working fluids

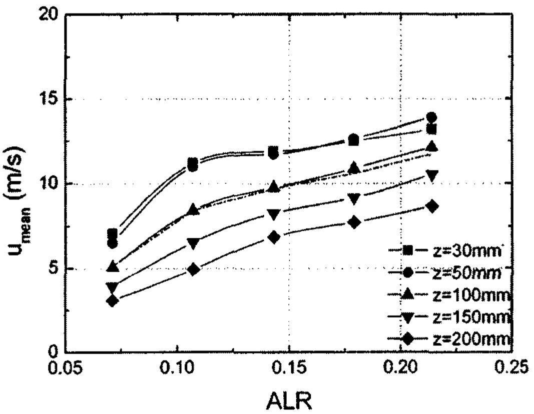
Liquid	Density kg/m^3	Viscosity kg/m·s	Reflective index
Water	998.2	0.001	1.334
Vegetable oil	907.6	0.066	1.473

tion. The measurement volume can be positioned easily at various locations without moving the diagnostic systems. The atomizer is positioned at the calculated location by using a computer controlled traversing system, which permits positioning within 0.005 mm. The data quantities are determined by collecting 10,000 pieces of data or within 10 seconds of the sampling time at each measurement station.

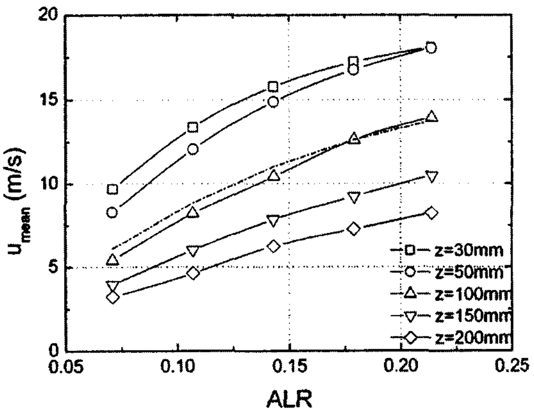
3. Results and Discussion

3.1 Axial velocity of droplet

Figure 3 shows the effect of ALR on the axial velocity of the droplet for water and vegetable oil, respectively. It is observed that (i) the averaged axial velocity of the droplet is increased with an increase in ALR, and (ii) as the axial distance from the nozzle tip is increased, the velocity is diminished over the range of ALR considered in this study. Average velocity value of the axial mean velocity is shown in Fig. 3(a) and (b), as a dash-dot line. It practically coincides with a trajectory of z=100 mm, regardless of liquid viscosity. Therefore, total spray field can be classified to upstream (z=30−50 mm), midstream (z=100 mm), and downstream (z=150−200 mm), by an averaged velocity value of axial mean velocity. The effect of ALR on the axial velocity of the droplet is in good agreement with the results of Panchagnula and Sojka (1999) and Kim (2002). One observes that the axial velocity of the vegetable oil is higher than that of the water at the axial locations of z=30 and 50 mm, while the axial velocities of the vegetable oil and water are almost the same at the axial locations of z=100, 150, and 200 mm. This discrepancy of the axial velocity is attributed to the inertial force of a working fluid. That is, an attenuation of the droplet velocity along the flow is attributed to the fact that the inertial force of the droplet is suppressed by the drag force caused by the mass of the atomizing gas. Thus the change in the liquid viscosity hardly affects the drop axial velocity in the downstream of the spray.



(a) Water, 2.8 g/s

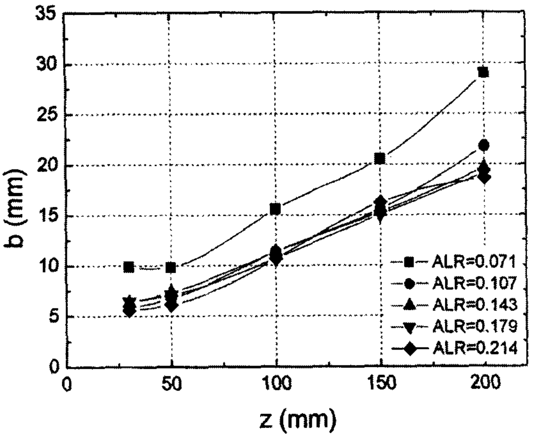


(b) Vegetable oil, 2.8 g/s

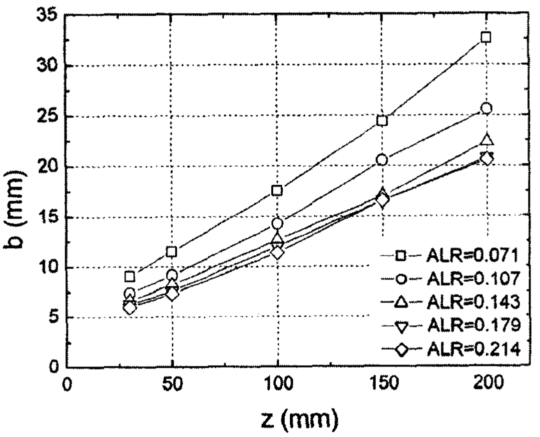
Fig. 3 Variation of axial mean velocity with ALR

3.2 Half-velocity width

Figures 4(a) and (b) show the streamwise variations of the half-velocity width for the atomizers of water and vegetable oil, respectively. Here, the half-velocity width is defined as the radial distance from each axial location where the mean streamwise velocity is half of the maximum one. In other words, the half-velocity is dependent on the axial velocity of the droplet. One observes that the half-velocity width is increased with an increase in the axial distance from the atomizer tip under the same ALR condition and similar characteristics appear for two different working fluids. On the other hand, at the fixed axial location, the widest half-velocity width is yielded at ALR=0.071 and after that its value decreases with an increase of ALR in this study. Finally, the half-velocity width is converged to



(a) Water, 2.8 g/s



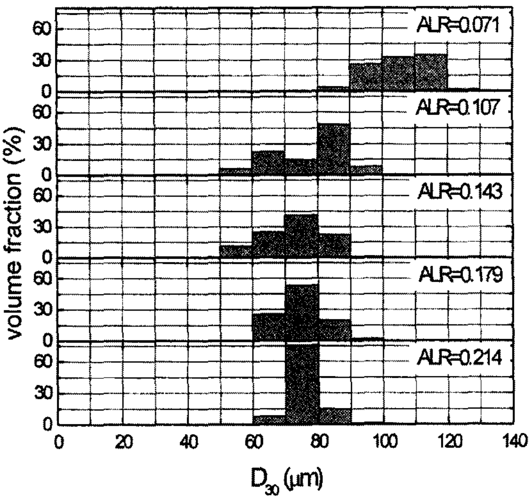
(b) Vegetable oil, 2.8 g/s

Fig. 4 Variation of half-velocity width with axial distance

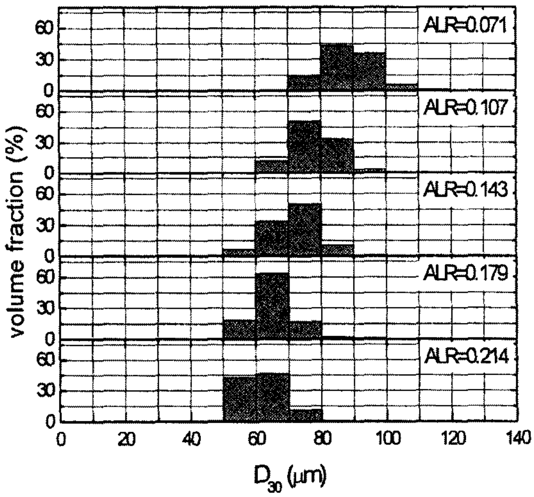
that of ALR=0.214, regardless of the change in the liquid viscosity. From Fig. 4(a) and (b), it is found that the half-velocity widths for the experimental conditions considered here are significantly decreased in comparison with that of ALR=0.071. This trend is also seen in the experimental results of Kim (2002). Compared with the case of water, at the fixed axial location, the half-velocity width of vegetable oil is shown slightly wider than that of water and the half-velocity of the vegetable oil steadily decreases with an increase in ALR.

3.3 Drop size distribution

Figures 5(a) and (b) show the drop size distributions of water and vegetable oil, respectively.



(a) Water, 2.8 g/s, z=100 mm



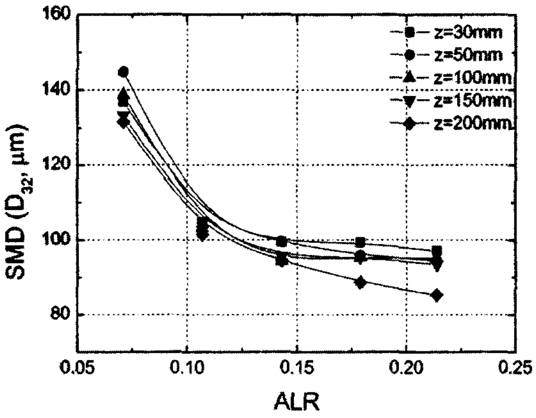
(b) Vegetable oil, 2.8 g/s, z=100 mm

Fig. 5 Influence of ALR on drop size distribution

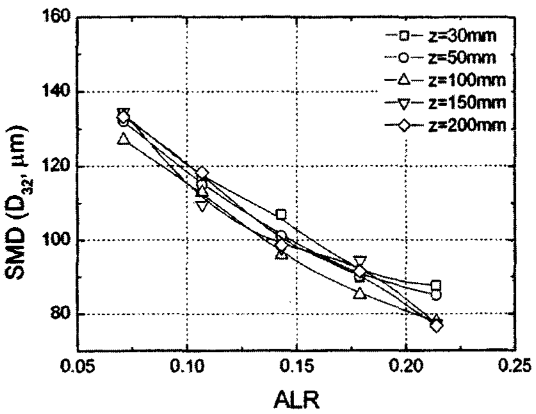
It is observed in Fig. 5(a) that at ALR=0.071 the coarse drop (over 100 μm) exist, and as ALR is increased, they diminish gradually. A similar trend appears in the drop size distribution of the vegetable oil, as seen in Fig. 5(b), though the maximum size is less than 100 μm over the range of ALR considered in this study. As mentioned above, it is concluded that as ALR is increased, the rate of the fine drop occupied in the drop distribution of total spray field is amplified, regardless of the different liquid viscosity. This tendency can be explained by the relative velocity between a liquid and an air, which are injected from the atomizer. That is, an increase in ALR will provide the higher relative velocity at the interface between the liquid and gas phases. Consequently, the atomization is enhanced, resulting in the finer drop.

3.4 SMD

SMD is the most common mean diameter of the droplet for combustion and spray flow. Figures 6(a) and (b) depict the influence of ALR on SMD of water and vegetable oil, respectively. One observes that SMD decreases with an increase in ALR, regardless of the change in liquid viscosity. In Fig. 6(a), SMD of water rapidly decreased in the low ALR region, and gradually approaches a certain value as ALR is increased. This behavior is in accordance with the experimental results of Roesler and Lefebvre (1989), Lefebvre et al.(1988), and Li et al.(1995). This substantial attenuation of SMD corresponds to the rapid decay of the axial drop velocity in the low ALR region, as shown in Fig. 3(a). In contrast, the corresponding SMD distribution of vegetable oil steadily decreased over the whole range of ALR, as seen in Fig. 6(b).



(a) Water, 2.8 g/s



(b) Vegetable oil, 2.8 g/s

Fig. 6 Influence of ALR on SMD

In this study, to compare SMD between water and vegetable oil, the difference of SMD shows a maximum difference of just 17 at only the condition of z=200 mm, ALR=0.107, but a very small difference within 10 at the any other conditions. When you consider the fact that the viscosity of vegetable oil is 66 times that of water, it is regarded that even these small differences can be ignored.

4. Conclusion

Axial drop velocity, half-velocity width, drop size distribution, and SMD have been examined to investigate microscopic characteristics of effervescent atomizer with two aerator tubes and find stable operating condition for the injection of vegetable oil waste having high viscosity.

Axial drop velocity is increased with an increasing ALR. But a half-velocity width decreases more as ALR increases, and converges to half-velocity width of a high ALR condition. With an increasing of ALR, the rate of fine drop occupied in the drop distribution of the total spray field is amplified with an increase in the relative velocity between the liquid and gas phases. SMD is decreased with an increase of ALR. High viscosity of vegetable oil has a slight effect on atomization characteristics including drop axial velocity, half-velocity width, drop size distribution, and SMD.

Consequently, when an effervescent atomizer is used as an injection method to inject highly viscous vegetable oil waste into an incinerator, it is expected that effervescent atomizer will exhibit excellent atomization performance, specially, at ALR=0.179 and 0.214 where narrow and fine drops were narrowly distributed and a small SMD was shown.

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