공기액체질량비에 따른 이류체 선회형 분사의 분무거동 및 미립화 특성

이삼구*

Feature of Spray Transport and Atomization from Two-Phase Swirling Jet with Air-to-Liquid Mass Ratio

Lee Sam-Goo*

ABSTRACT

Experiments were performed in a two-phase swirling spray facility that has been described elsewhere. Measurements of spray transport and drop size distribution are analyzed over wide ranges of air to liquid mass flow ratios, utilizing four different internal mixing pneumatic nozzles. The spatial distributions of mean velocities, fluctuating velocities, and velocity-diameter correlation were quantitatively analyzed. Also, the exponential correlation curves were obtained with ALR along the spray centerline, which indicated an approximately identical formulation regardless of ALR. It indicated that the atomization characteristics were remarkably superior in the case of 30o of swirl angle with higher ALR. Among other things, nozzle configuration is one of the significant parameters affecting spray phenomena from an internal mixing nozzle. Turbulence intensities are increasingly degenerated with an increase of nozzle configuration, allowing a rapid increment of drop size distribution.

초 록

선회형 미립화기의 분무거동에 관한 논의는 현재 여러 연구자들에 의해 활발히 논의되고 있다. 본 연구에서는 이류체 내부혼합형 선회노즐의 특성을 파악하고자 공기와 액체의 질량비를 바꿔가며 최적의 미립화 조건을 알아보기 위하여 실시되었다. 이를 위하여 분무 유동장의 평균속도, 파동속도 및 액적크기에 관한 비교를 정량적으로 분석하였다. 각 유동조건에 따른 지수함수를 만족하는 상관관계 또한 도출하였는데, 이는 질량비에 관계없이 거의 동일함을 알 수 있었고, 질량비가 높을수록 선회각이 30o인 경우가 미립화 특성이 가장 우수하였다. 따라서, 본 연구에서 이루어진 결과에서는 노즐의 형상이 분무유동에 미치는 여러 인자중 가장 중요한 것이라 여겨진다.

Key Words: Drop Size Distribution(액적크기분포), Fluctuating Velocity(파동속도), ALR(공기액체질량비), Nozzle Configuration(노즐형상), SMD(Sauter 평균직경), PDPA(위상차 도플러 미립자 분석기)

1. Introduction

Pneumatic atomizers have been used in many industrial areas, because the sprays

---

† 2004년 5월 4일 접수 ~ 2004년 6월 1일 심사완료

* 정회원, 전북대학교 기계항공시스템공학부
연락저자, E-mail: comfy@naver.com

some inherent advantages such as spray uniformity and noticeable disintegration in the break up regime. Pneumatic atomization is based on the higher turbulent shear stresses that develop at the interface between the liquid and the air. Droplet disintegration in an atomizer is most effectively achieved by generating a high relative velocity with an increase of air to liquid mass flow ratio. The purpose of breaking up the liquid clouds into multitudinous small droplets is to increase the liquid surface area and achieve high relative velocity for atomization. Spray atomization is extensively applied in many industrial processes including furnaces and boilers, liquid rocket combustion, aircraft gas turbines, internal combustion, and other liquid-fuel fire systems.

A number of literatures have been discussed on the disintegration process, and some improved results were obtained. Mansour A. et al.[1] and S. G. Lee[2] et al. showed that the SMD is progressively reduced as the air to liquid mass ratio is increased. J. B. Kennedy[3] found that the SMD was to vary linearly with the liquid surface tension while the influence of the viscosity was minimized. Mullinger and Chigier[4] showed the advantage for the internal mixing atomizers that the atomizing fluid can generally be supplied to the mixing region at a higher pressure than the external mixing type. S. G. Lee[5-6] showed the results that the smaller droplets are inwardly entrained from the spray boundary.

The aim in this experimental investigation was intended to describe the turbulent fluctuating components and SMD variation issuing from internal mixing counterflowing two-phase jets. Some correlations of turbulent atomization characteristics were obtained by increasing the air mass flow ratio.

2. Experimental Methodology

Four nozzles conforming to the internal mixing swirl jet is specially designed as shown in Fig. 1. The discharge orifice diameter do is 2mm, swirl chamber diameter Ds is 9mm, and the length to diameter ratio of the final discharge orifice(l. =1.3) is 0.65. Four swirl angles such as the actual values being 15°, 30°, 45°, and 60° to the central axis have been utilized with different mass ratio. Two working fluids with four inlet passages were swirled through the tangential ports that give the liquid and air high angular velocities, interacting in the mixing chamber, and then sprayed into the stagnant air.

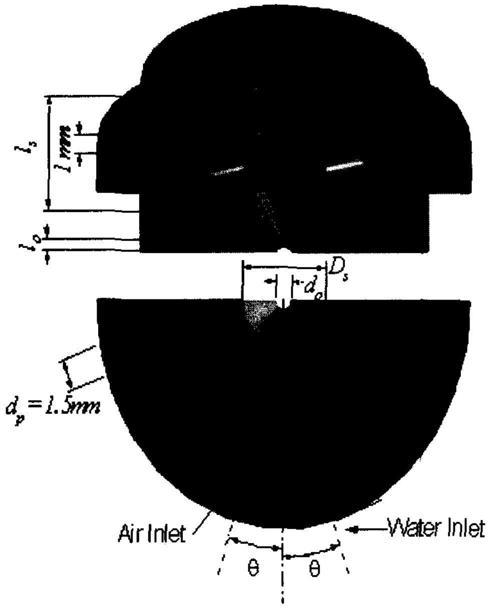

Fig. 1 Specification of nozzle for the experiment

Continuous and steady water and pulsation-free air are supplied to the mixing chamber from the pressurized storage tank as shown schematically in Fig. 2. Experiments were conducted for the liquid flow rate was kept constant at 7.95 g/s and the air pressures were meticulously increased; varying the mass ratios between two mediums from 0.085 through 0.122. PDPA as diagnostics was equipped on a three-axis automatic traversing system that permits positioning to within 0.02 mm. The calculated fringe spaces for the wavelength of 476 nm, 488 nm, and 514.5 nm are 5.02 ㎛, 5.11 ㎛, and 5.39 ㎛, respectively. It provides information on individual particle sizes ranging from 1 ㎛ to 250 ㎛ passing through the measurement volume in this investigation. Also, the focal lengths of the transmitting and receiving optics were 400 and 500mm, respectively.

The radial profiles of a geometric sequence space at each measurement locations were obtained at axial stations of Z/d, from 10 to 20 downstream from the nozzle exit. Droplet quantities were statistically calculated by collecting approximately 10,000 sample data. The sampling time depended on the local number density of drops, and the 10 seconds was set as the upper limit to collect meaningful number of scattering signals.

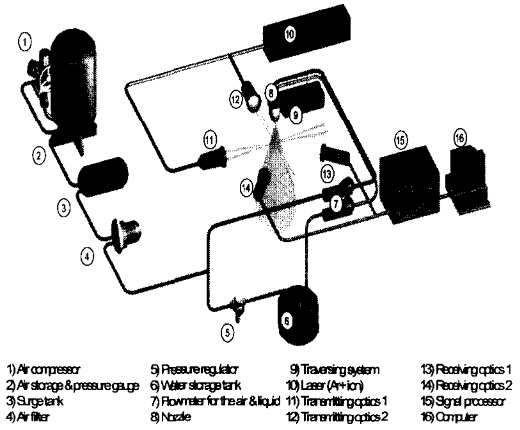

Fig. 2 Experimental set-up and diagnostics

3. Results and Discussion

Figures 3a-3b show the radial profiles of 3-D mean velocity distributions with swirl angles at axial locations. It showed that the droplets emanating from the nozzle exhibit an approximate flow similarity regardless of swirl angles. It also reveals the droplet in the central parts propagate farther downstream due to easy access of atomizing air, whereas the accelerations at the spray boundary are discernibly less by the loss of axial momentum and the surrounding drag.

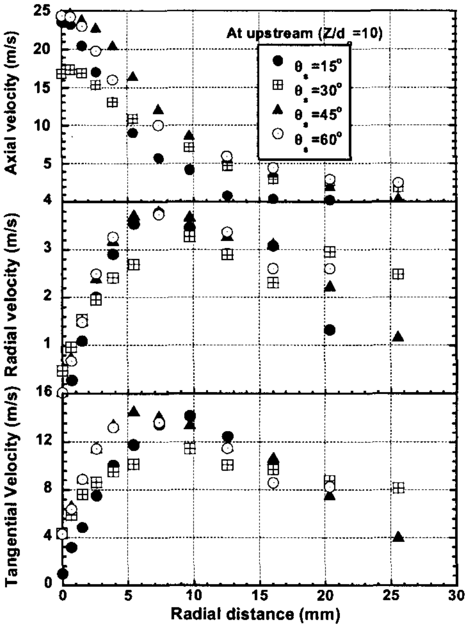

Fig. 3a Mean velocity distributions withdifferent swirl angles measured at upstream location

This is attributed to the fact that the spray behavior near the axis seems to have higher momentum and is subject to higher acceleration even though its geometric conditions are dissimilar. Distributions in Figs. 3a-3b are seen to be geometrically symmetric along the axis, showing nearly qualitatively consistent value. But, the distributions for the case of q_s=30° are quite smaller even in the central parts. This difference in axial velocity variation can be a possible prediction for the optimal swirl nozzle. However, the growth rate, or the spray dispersion did not indicate bigger differences among those swirl angles. Radial and tangential velocities in the center show a minimum value, which comprise the maximum in axial velocity.

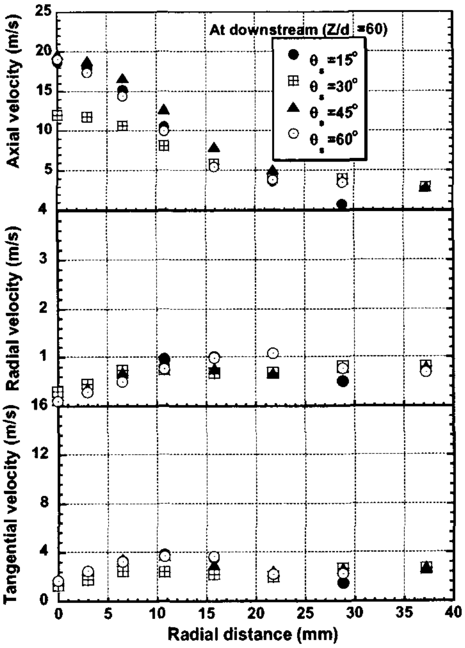

Fig. 3b Mean velocity distributions with different swirl angles measured at downstream location

This is mainly because the effects of downward axial penetration tend to subside the growth rate. But the spray trajectory in radial and tangential components exhibit a progressive dispersion to the outer, shifting the location of maximum velocity at all conditions. After reaching a maximum value, the velocities are sluggishly decreased. Even though the spray patterns are similar, big differences in magnitudes of velocity are apparent between two components

Spray transport is quite comparable as indicated by the turbulence intensities and SMD variations as shown in Figs 4a-4b. The droplets located in the center and the downstream regions have the maximum axial turbulence intensity for both cases, while having comparatively smaller values toward the spray boundary and the upstream location. This explains that the spray acquires larger velocity fluctuations for all the cases in the center as an acceleration stage. But, an interesting result can be drawn from this. Even with a higher axial momentum close to the nozzle exit, the downstream turbulence intensities are much higher than the upstream. This is presumably caused by the non-spherical particles or less disintegrated droplets at upstream.

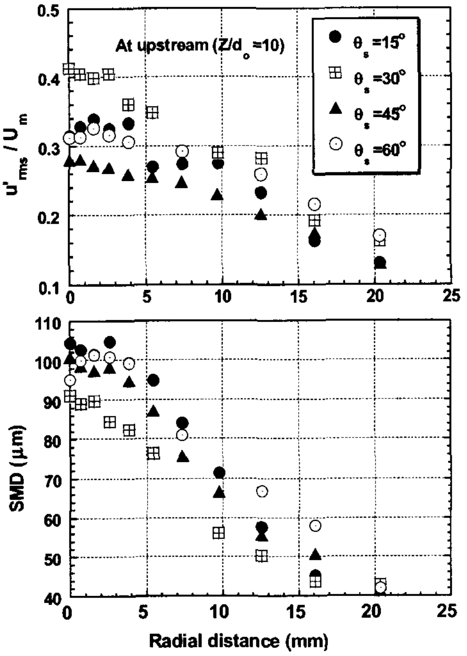

Fig. 4a Variation of turbulence intensities and SMD with swirl angles at upstream location

As the sprays are in the process of disintegration, it is considered that the better atomization of the droplets could be possibly observed at downstream region, which is one of the characteristics in counter-swirling internal mixing nozzle.

The 3-D velocity fluctuations are plotted at upstream along the radial distances as shown in Fig. 5 Since the axial fluctuating velocities before fully developed region do not show an immediate respond to the surrounding air-stream, they propagated with straight trajectories due to the strong axial momentum. Thus, the axial fluctuating components are relatively highest around the central axis even with an increase of ALR. For example, the maximum axial fluctuating velocity for the highest ALR is about 8.3 m/s, where the magnitude for the lower case is approximately 7.2 m/s.

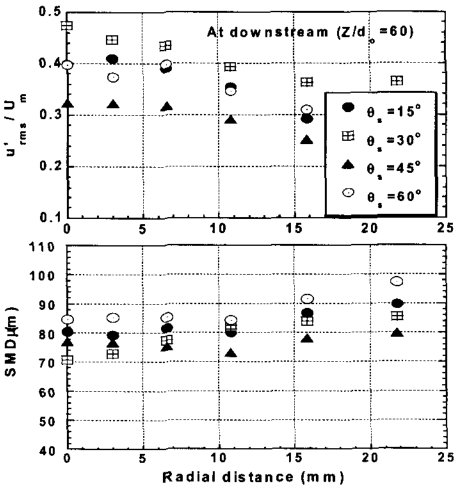

Fig. 4 4b Variation of turbulence intensities and SMD with swirl angles at downstream location

The spray behavior of radial fluctuation velocity is evidently different from the axial component as shown. In accordance with the jet results, two peaks are evidently observed. The radial fluctuations are gradually increased from the center to a maximum and then decreased to a local minimum at the outer boundary, substantiating the wider spray width. Increasing the atomizing air causes the spray droplets to fluctuate briskly. Fluctuation levels for the ALR of 0.122 are also higher at whole radial profiles. However, the magnitude for the lower ALR is gradually decreased, which is reasonably coincident with that of the mean velocity distribution. The radial fluctuations obtain their maximum values in regions where the axial fluctuating velocity gradients are comparatively low. In contrast to their negligible response to the mean radial velocity in the center, the fluctuations at spray boundary are comparatively higher due to the enhanced disintegration and swirling inclination in this nozzle.

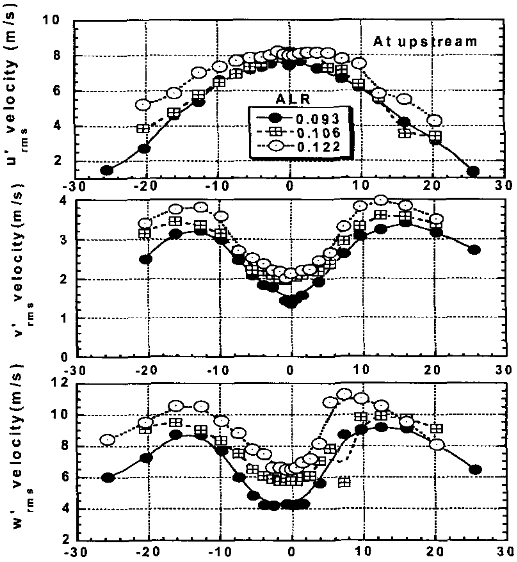

Fig. 5 Radial variations of 3-D fluctuating velocity with increment of ait to liquid mass ratio

The development of tangential fluctuating velocity is apparently important for turbulent dispersion of the spray. There is some qualitative similarity with the radial fluctuating velocities having two peaks caused by the strong swirling component. But, the quantitative magnitudes are definitely disparate, which can be explained by the higher spreading effect. Near the center region (-5 〈 Radial 〈 5), the levels of the tangential fluctuating velocities are small, illustrating an opposite phenomenon with those for the axial fluctuating velocities. Meanwhile, the location of the maxima is shifted outward from the center at all the cases of ALR. Consequently, it is shown that straight trajectory in axial fluctuating velocities leads to a reduction of the turbulence in radial and tangential directions around the center.

Comparison for three fluctuating velocities and SMD along the centerline is plotted depending on the ALR in Fig. 6. Fluctuating velocity quantities are comparatively small at lower ALR but rapidly increase with an increase of ALR. The enhanced fluctuating levels are evidently propagated as the ALR is increased, resulting in a more pronounced improvement in atomization. Thus, it can be concluded that the fluctuating components are inversely proportional to the SMD variation.

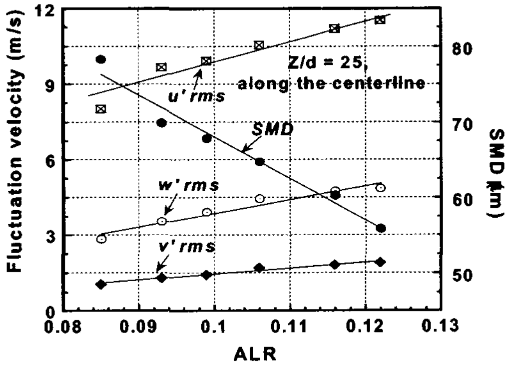

Fig. 6 Comparison of fluctuating components and SMD with ALR along the center

4. Conclusions

Although the magnitude of axial velocity distributions for the case of swirl angle in 30 degree are quite smaller in the central parts, it can explain the positive effects for droplet breakup and disintegration. Especially, the turbulence intensities for this case are higher than the other cases at all axial locations, explaining higher propensity for brisk fluctuations to be shattered with finer droplets. It also showed positive effects of increasing the ALR. Increasing the atomizing air causes the spray droplets to fluctuate briskly. The axial fluctuating components are relatively highest around the central axis with an increase of ALR. The radial fluctuations obtain their maximum values in regions where the axial fluctuating gradients are comparatively low. Fluctuating quantities are small at lower ALR but rapidly increase with an increase of ALR. Accordingly, it can be concluded that the fluctuating quality with an increment of ALR is inversely proportional to the SMD variation.

Nomenclature

do: Final discharge orifice diameter
dp: Diameter of passages for the fluids
Ds: Swirl chamber diameter
lo: Length of final discharge orifice
ls: Length of swirl chamber
lap: Length of air-inlet passages
lwp: Length of liquid-inlet passages
SMD: Sauter mean diameter
Um: Maximum axial velocity at the centerline
u'rms: Root mean square of the axial fluctuating

Z: Axial distances from the nozzle tip

References

1. Mansour A. and Norman Chigier (1990): "Disintegration of Liquid sheets," Physics. Fluids A., 706-719
2. Lee, S.G., Rho, B.J. and Song, K.K. (2001): "Spray transport and atomization in two phase swirl atomizer," Proceedings of ILASS-Asia
3. Kennedy, J.B., (1986); "High number SMD correlations for pressure atomizers," Journal of Engrg., for gas turbines and power, 191-195
4. Mullinger, P.J and Chigier, (1974): "The design and performance of internal mixing multijet twin fluid atomizers," Journal of the Institute of fuel, 251-261
5. Lee, S.G. and Rho, B.J. (2000): "Analysis of turbulent flow and disintegration characteristics featuring the counter-swirl pneumatic nozzle," 4th JSME-KSME Thermal Engineering Conference, Oct. 1-6, Kobe, Japan
6. Lee, S.G., Rho, B.J. and Song, K.K (2001): "Turbulent disintegration characteristics in twin fluid counter flowing atomizer," 39th AIAA Aerospace and Sciences Meeting and Exhibit, AIAA 2001-1047, Reno, Nevada, U.S.A