An Experimental Study on a Multiple-Orifice Twin-Fluid Atomizing Nozzle for NO_x Reduction

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A multiple-orifice twin-fluid atomizing nozzle was developed and manufactured to investigate spray characteristics and determine the optimum nozzle. Four nozzles were designed with variances in the orifice diameter and the angle between the facing mixing orifices. In experiment, the flow rate decrease as air pressure increases. The spray angles keep steady in spite of the air-water pressure changes. In the constant flow rate, the SMD is inverse proportion to air pressure increase. The four nozzles showed the best spatial distribution due to the concentric structure of the mixing orifice

1. Introduction

A twin-fluid atomizer is one of the most widely used fuel spray methods used in utility boilers, industrial furnaces, and agriculture sprays. The twin-fluid mechanism can easily control the atomization characteristics by either increasing or decreasing the amount of air. The mechanism yields the adequate mixing of the fuel and air and excellent atomization. Flame stabilization, reduction of NOx, and high efficiencies are obtained due to the advantages of the twin-fluid nozzle.

A multiple-orifice twin-fluid atomizing nozzle is one of the typical twin-fluid nozzles. It is usually used in a large size combustor that requires large changes in the load and high output. Many studies have been performed on the twin-fluid atomizing nozzle since there are various applications. Nikiyama and Tanazawa [1] suggested empirical equations to predict the average droplet diameter of the liquid column breakup and the distributions of the droplets. Clare and Radcliffe [2] measured the B-C oil spray performance of the twin-fluid atomizer. Mullinger and Chigier [3] designed and manufactured a twin-fluid type atomizer. Additionally, the relation between a weight ratio of liquid and gas and a nozzle configuration was investigated in their work. Song [4] performed to find out the effect of the mixing port length of twin-fluid atomizers on the spray performance, using air and water as the test fluids. Water and air flow rates and drop sizes were measured at each injection pressure condition for different mixing port lengths. However, further work is needed to examine the factors that influence the spray characteristics. In an internal mixing twin-fluid atomizer, there are many ways in collision and mixing of gas with fuel ; therefore, many design parameters must be considered. Mass flow rates of the liquid and gas, methods of introducing them, and various nozzle configurations are included in the parameters. Especially, the relation between breakup and spray characteristics according to nozzle configurations are important in the design of the atomizer. In the present study, four multiple orifice nozzles were designed and manufactured. The angle and dispersion, SMD, velocity of spray were investigated to determine the optimum nozzle configuration, which can be utilized in reducing the NOx in real combustion.

2. Experimental apparatus

Fig. 1 shows a schematic diagram of our experimental apparatus. The apparatus is composed of a nozzle system, the fluid supply system, a gas supply system, and a measurement system. In the fluid supply system, a pump and an air compressor are utilized in obtaining the appropriate pressure of fuel and air, respectively. An Argon-Ion Laser, a MEGAPLUS camera [Model ES 1.0] & digital camera, and a patternator, PDPA are used to measure the angle and dispersion of the spray.

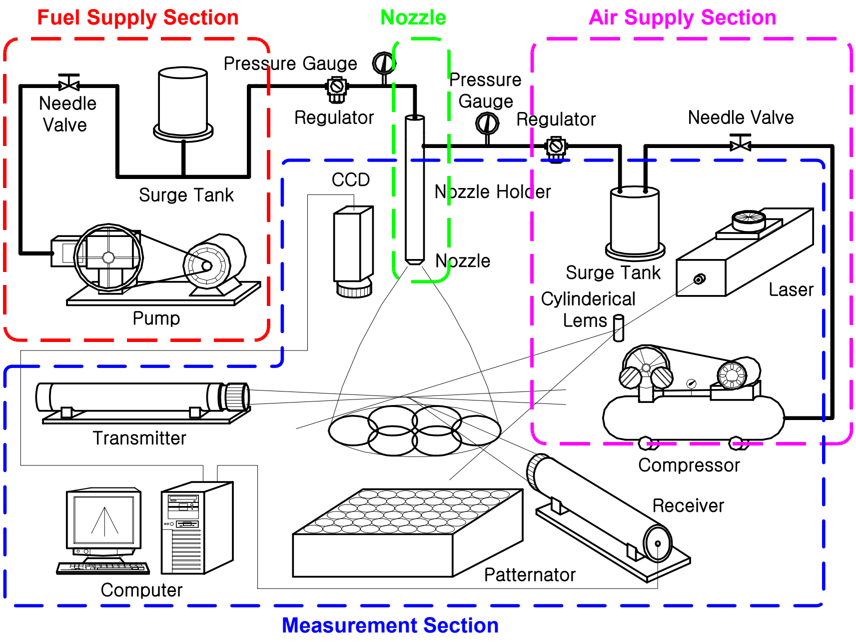


Fig. 1 Schematic Diagram of Experimental Apparatus

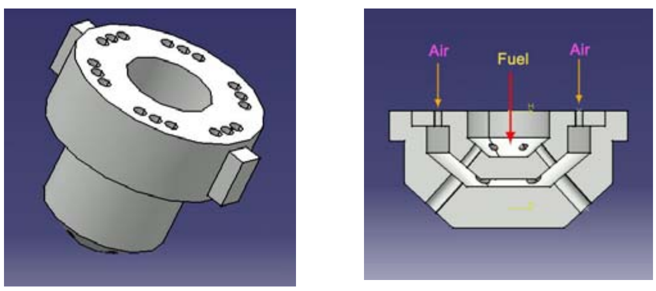


Fig. 2-1 **Schematic of Nozzle**

Fig. 2-2 The Photograph of Nozzle

Fig. 2-1, Fig. 2-2 shows a schematic diagram and photograph of the nozzle. An angle of 80, 74 degrees between the mixing orifice is an optimum angle which is obtained according our experience. Table. 1 indicates specifications of the nozzles. Four pieces of nozzles are designed and manufactured with a variance in diameters of mixing orifices, and angles between the mixing orifices.

Table. 1 **Dimensions of Nozzle (Unit : mm)**

	D_M	D_A	D_F	No.holes	θ
1	1.50	1.50	1.00	6	80
2	1.60	1.50	1.00	6	74
3	1.70	1.50	1.00	6	74
4	1.80	1.50	1.00	6	74

3. Results and discussion

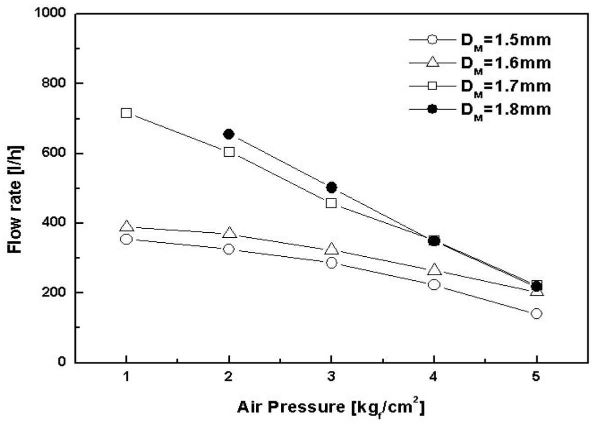
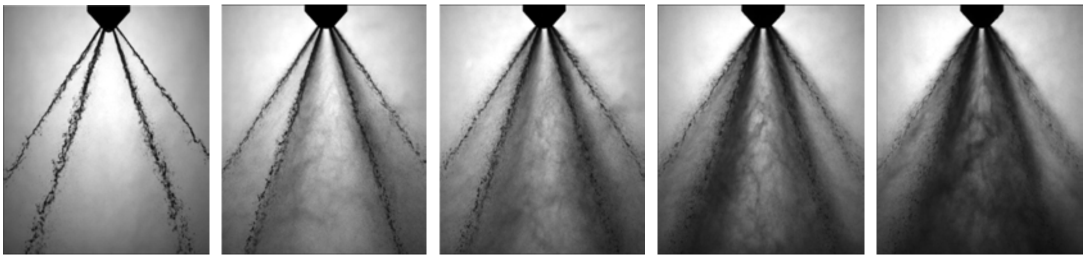


Fig. 3 Water Flow Rate for Injection Pressure ($P_W = 3kg_f/cm^2$)

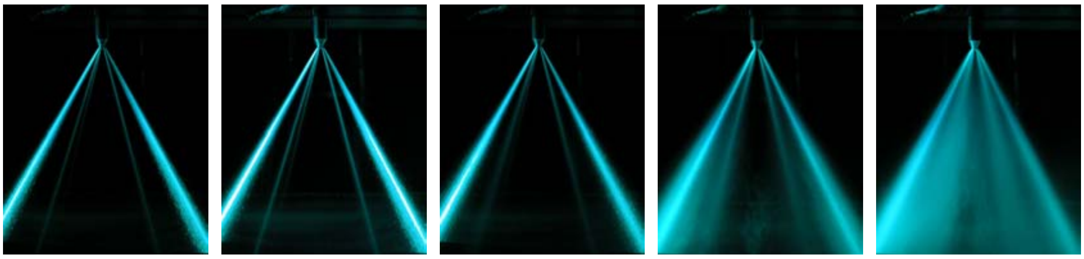
In the external mixing twin-fluid nozzle, the pressures of fuel and air do not affect their flow rates. However, there are changes of flow rates according to pressures of the fuel and air in the internal mixing twin-fluid nozzle. The flow rates of the fuel and air decreased and increased respectively as the pressure of the air increased in the internal mixing twin-fluid nozzle. Fig. 3 shows the flow rates of each nozzle with a variance in the pressure of air, maintaining the water pressure of $3kg_f/cm^2$. The fuel flow rate of all the nozzles decrease as the air pressure increase. This can be explained by the fact that the increasing air pressure affects the water pressure and blocks the introduction of the fuel into the mixing zone. This is

attributed to the fact that due to the small diameter of mixing orifice, the increase of the air pressure significantly blocks the introduction of the fuel.
Fig. 4 & Fig. 5 shows how to measure the spray angle of the nozzle with multi-orifices. Generally, the spray angle indicates the angle from the position from which the spray begins to eject from the nozzle. It is demonstrated based on the total spray formation due to the multiple orifices of the nozzle since the total spray formation is closely associated with the size of the combustor. Fig. 6 is a comparison of each nozzle with an increase in the air pressure, maintaining the fuel pressure of 3 kgf/cm^2. As shown in the Fig. 6, much changes of spray angle cannot be found.



P_A=1 kgf/cm^2 P_A=2 kgf/cm^2 P_A=3 kgf/cm^2 P_A=4 kgf/cm^2 P_A=5 kgf/cm^2

Fig. 4 Spray angle for air pressure with CCD [Fuel=5 kg$_f$/cm^2 ,D_M=1.5]



P_A=1 kgf/cm^2 P_A=2 kgf/cm^2 P_A=3 kgf/cm^2 P_A=4 kgf/cm^2 P_A=5 kgf/cm^2

Fig. 5 Spray angle for air pressure with Argon-Ion Laser & digital camera [Fuel=5 kg$_f$/cm^2 ,D_M=1.5]

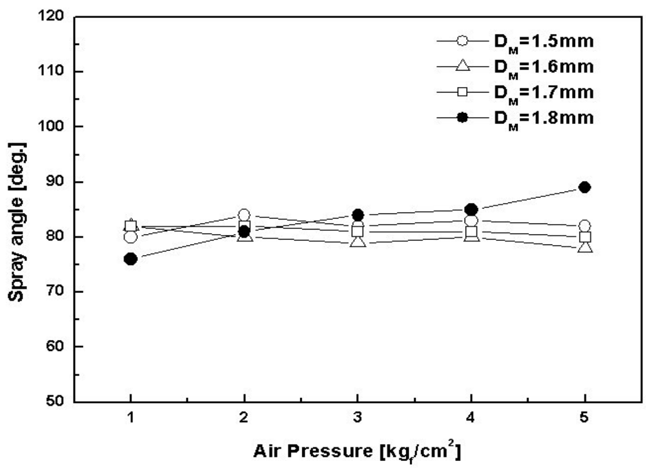


Fig. 6 **Spray Angle for Injection Pressure [P_W = 3kgf/cm^2]**

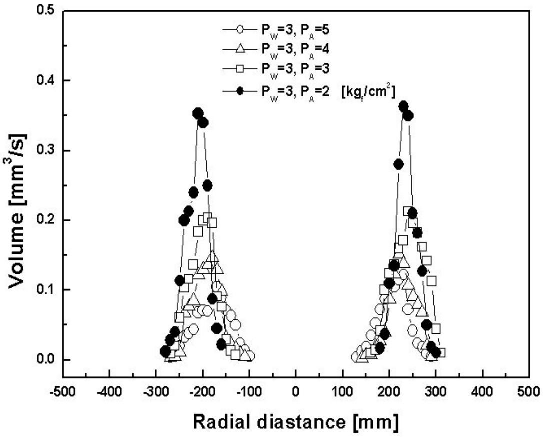
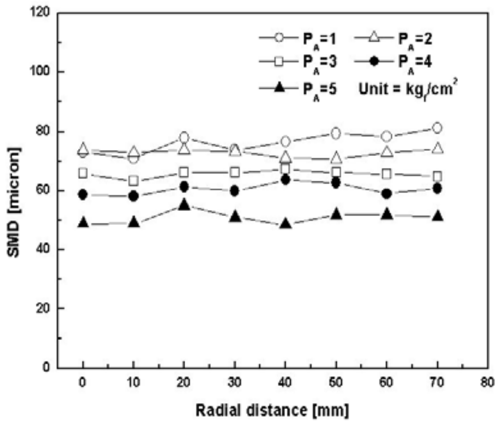
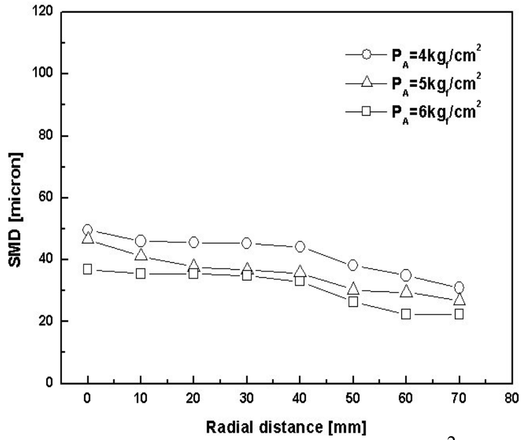


Fig. 7 Measurement of the Spray Dispersion using a Patternator [D_M=1.5, D_A=1.5, D_F=1.0]

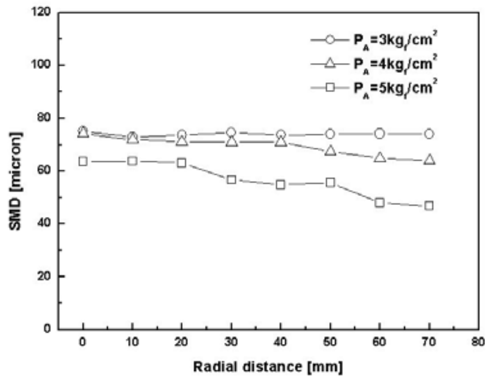
Fig. 7 shows the fuel volume collected in the patternator with a variance in the air pressure and the constant water pressure of 3kgf/cm^2. The patternator has 100 holes of 10 mm by 10 mm, and is installed at the 300 mm from the nozzle tip. The peak volume becomes smaller and the spray dispersion larger as the air pressure increases. Atomization performance increases as the air pressure increases.



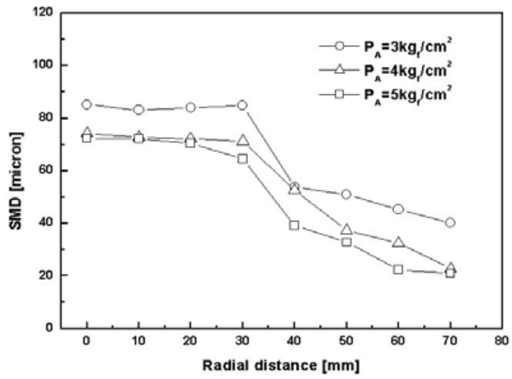
(a) D_M =1.5mm , P_W = 3kgf/cm^2



(b) D_M =1.6mm , P_W = 3kgf/cm^2



(c) D_M =1.7mm , P_W = 3kgf/cm^2



(d) D_M =1.8mm , P_W = 3kgf/cm^2

Fig. 8 **The SMD for Nozzles**

Fig. 8 and Fig. 9 are the SMD for nozzles. It is measured at the 300 mm from the nozzle tip and each 10mm in radial direction as the whole radial distance is 70mm.

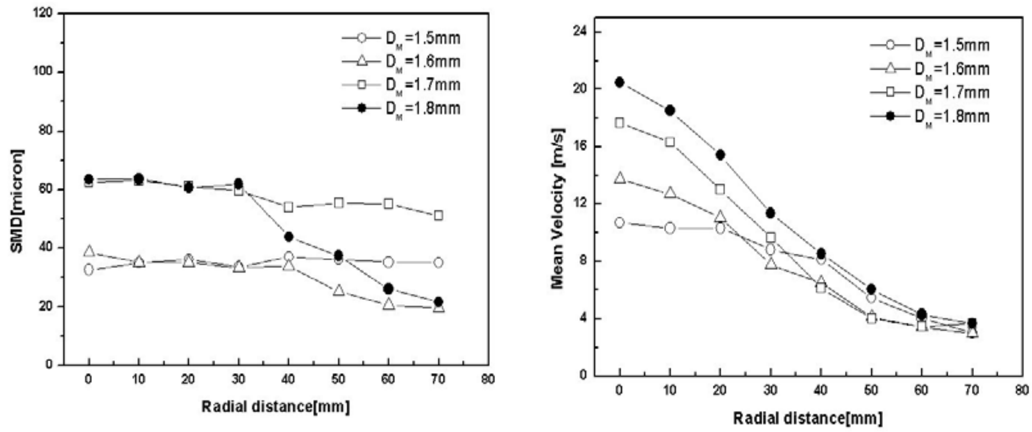


Fig. 9 The SMD & Velocity for Nozzles [P_W = 2kgf/cm^2 ,P_A= 5kgf/cm^2]

Fig. 8 shows that the SMD decreases as air pressure increases, with water pressure fixed. It is demonstrates that atomization is much finer when air pressure increases than water pressure. As shown in Fig. 9, the larger the diameter of the mixing orifice, the larger the SMD investigated. Additionally, complete jet breakup can hardly be obtained in the region near the center as the mixing orifice diameter increases. The mean velocity reaches maximum in the center of the nozzle and reduces as the radial distance increases.
At the point 300mm away from the nozzle tip, the variances of the SMD can be shown unchangeable regardless of the variances of radial distance. This means that atomization can be improved due to collisions caused by large momentum in the center of spray stream and the breakup and recombination of droplets stripped from the core axis of spray according to the flow and friction of ambient air.

4. Conclusions

An internal mixing twin-fluid type atomizer with multi-orifices was developed and manufactured for the spray nozzle of a heavy-oil boiler. Four nozzles were designed with variances in the orifice diameter and the angle between the orifices. The following conclusions are drawn:

(1) The spray angle showed unchangeable and unaffected spray shape in spite of the variance of air and water pressure.

(2) An atomization increases as the air pressure increase and the diameters of the mixing orifice decreases.

(3) The SMD shown decreases with increasing air pressure while fix the value of water pressure. It's better to increase air pressure than to increase water pressure to obtain finer atomization.

Nomenclatures

P_w : Pressure of Water [kg_f/cm^2]
P_a : Pressure of Air [kg_f/cm^2]
D_F: Diameter of Fuel Orifice[mm]
D_A : Diameter of Air Orifice [mm]
D_M : Diameter of Mixing Orifice [mm]
θ : Angle between the Mixing Orifice [°]

Subscripts
w : Water
a : Air
F : Fuel Orifice
A : Air Orifice
M : Mixing Orifice

5. References

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