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Comparison of mist generators between twin-fluid water suction type and single-fluid swirl type

Michio Sadatomi, Keiichi Tanaka and Akimaro Kawahara

***Abstract*—Sadatomi and Kawahara invented a multi-fluids mixer which is categorized as a twin-fluid type but have a merit of water suction type. The mixer is usable to generate micro-bubbles, etc. besides mists, fine droplets. In the mists generation, pressurized air alone is supplied because water can be sucked automatically by a negative pressure arisen downstream from the orifice in the mixer. The objective of the present study is to compare the performance between the above twin-fluid type atomizer and a common single-fluid swirl type atomizer studied in the present experiments. The comparison results showed that the twin-fluid type was superior to the singe-swirl type in the performance of CO_2 adsorption by the mists. The CO_2 adsorption rate by the twin-fluid type was about twice. Such results on the experiments and the comparisons are described in this paper.**

***Keywords*—atomizer, twin- and single-fluid types, hydraulic performance, CO_2 adsorption**

I. Introduction

Sadatomi and Kawahara invented a multi-fluids mixer shown in Fig. 1 [1] which is categorized as a twin-fluid type but have a merit of water suction type. The mixer is usable to generate mists [2–5], fine liquid droplets, as well as micro-bubbles [6, 7] when water is supplied and air is sucked. In the mists generation, pressurized air alone is supplied because water can be sucked automatically through a porous pipe by a negative pressure arisen downstream from an orifice in the mixer. Thus, the mixer is called as twin-fluid water suction type atomizer in the present paper. In our previous studies [2–5], better geometrical parameters was clarified, i.e., the diameter ratio of the orifice to the mixer pipe, the ratio of outlet length from the rear end of the porous pipe to the mixer pipe diameter, the geometry of the orifice, and the whole size.

The purpose of the present study is to compare the above twin-fluid type atomizer with a common single-swirl type one on the hydraulic and the CO_2 adsorption performances by the mists generated. At first, some findings in our previous study [4] have been introduced for the twin-fluid type mixer. Secondary, the present experimental results on the single-swirl type atomizer together with the comparison results between the twin-fluid type with the best size and the single-swirl type with the best performance have been introduced in the present paper.

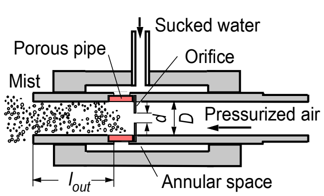

Figure 1. Twin-fluid atomizer patented by Sadatomi and Kawahara.

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II. Experiment

A. *Test Atomizers*

In our previous study [4], three twin-fluid type atomizers of L, M and S were tested in order to study size effects. As listed in TABLE I, the S type had 7 mm in the pipe diameter, 4.58 mm in the orifice diameter, and 20.5 mm in the outlet length, and fiber porous pipe of 25 μm in porosity and 1.5 mm in thickness. The M type and the L type were twice and three times larger than the S type besides the pore diameter and thickness of the porous pipe. In addition, the proportion of the mixer, such as the orifice to the pipe diameter ratio and the outlet length to the pipe diameter ratio, was determined so as to give best performance [2-5].

Fig. 2 shows the single-fluid swirl type atomizer tested. It is composed from a 7 mm I. D. pipe, a swirler, an orifice and a cap. The pipe diameter is the same as that of the twin-fluid S type atomizer. The swirler is the same as that used in a commercial atomizer (Maruhachi Co., Japan). As the orifice, eight types, each different in orifice diameter (0.5, 0.7, 0.9 and 1.1 mm) and thickness (1.0 and 3.0 mm), were tested to find the vest combination. For reference sake, the orifice originally used in the Maruhachi's atomizer was 0.7 mm in diameter and 3 mm in thickness, but having a conical dip face to the swirler.

TABLE I. SPECIFICATIONS OF TWIN-FLUID TYPE ATOMIZERS TESTED.

Name	Pipe dia. D mm	Orifice dia. d mm	Orifice opening area ratio, $(d/D)^2$
L type	21	13.8	0.429
M type	14	9.16	0.429
S type	7	4.58	0.429

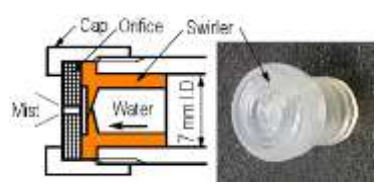

Figure 2. Single-fluid atomizer tested.

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B. *Hydraulic Performance Test*

Fig. 3 shows the test apparatus for the single-fluid type atomizer. Water was supplied with a high pressure pump after controlling the volume flow rate, Q_L, by monitoring the gauge pressure at the atomizer inlet, $P_{L(in)}$. The pressure was measured with a calibrated sensor and a data acquisition system. A calibration curve between Q_L and $P_{L(in)}$, obtained in our preliminary test, permitted us the accuracy of within 1 % for the Q_L measurement. The hydraulic power required for the mist generation, L_L, was obtained by substituting the data into

$$L_L = \left(P_{L(in)} + \rho_L v_{L(in)}^2/2\right)Q_L \, . \tag{1}$$

Here, $v_{L(in)}$ is the mean water velocities at the atomizer inlet.

In the twin-fluid type [2-5], air was supplied from a gas compressor, and the volume flow rate, Q_G, and the gauge pressure, $P_{G(in)}$, at the atomizer inlet were measured with calibrated sensors and a data acquisition system. Water, on the other side, was sucked from a water tank whose water level was the same as the water inlet of the atomizer. The water flow rate, Q_L, could be controlled with a valve before measuring flow rate. The pneumatic power required for the mist generation, L_G, were obtained by substituting the above measured data into

$$L_G = \left(P_{G(in)} + \rho_G v_G^2/2\right)Q_G \, . \tag{2}$$

Here, ρ_G and v_G are the air density and the mean air velocity at the atomizer inlet.

Furthermore, mist droplet diameter was measured with an oil pond method. In the method, the droplets were captured momentarily by opening a shutter covering the inlet of a small oil pond, and the diameters of the droplets in the pond was measured with a digital micro-scope and an image processing system. Spray angle was measured with a picture and the radial distribution of mist flow rate below 0.50 m below from the atomizer exit. The distribution was determined by collecting the droplets with a lot of test tubes square arrayed.

C. *CO_2 Adsorption Test*

Fig. 4 shows the test room for CO_2 adsorption by the mist. The room was divided into the CO_2 room and the mist room by a perforated plate. The atomizer was placed at the center of the plate 1.8 m above from the bottom of the room, 1.2 m in width and depth and 2.0 m in height. CO_2 concentration in the mist room was detected by two sensors placed at the bottom. The procedure of the CO_2 adsorption test was as follows: Firstly, 1.5 l CO_2 at standard condition was filled in a balloon placed outside the CO_2 room. Secondly, three minutes after the mist spray in the mist room, the CO_2 in the balloon was released into the CO_2 room for two minutes for full diffusion while the mist was sprayed continuously in the mist room. Thirdly, after the stop of spray, CO_2 began to flow down through a lot of 50 mm I.D. holes in the perforated plate by

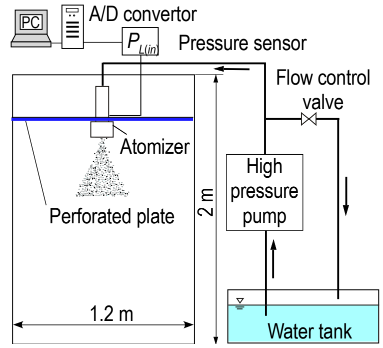

Figure 3. Test apparatus for the single-fluid type atomizer.

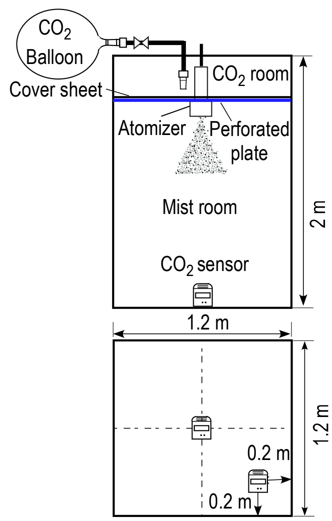

Figure 4. Test room for CO_2 adsorption by mist.

removing a sheet covering the plate. At the same time, CO_2 concentrations at the bottom of the mist room were measured every 5 seconds for 10 minutes. In order to know the effects of the mist spray, a similar measurement with no mist spray was also conducted.

III. Experimental Results

A. *Hydraulic Performance of Twin-fluid Type Atomizer* [4]

Fig. 5 shows mist flow rate data, Q_L, when the water suction valve was full opened, against the mean air velocity at the atomizer inlet, v_{G1}. The data for L, M, S type atomizers are simultaneously plotted. Q_L increased with v_{G1} because a negative pressure downstream from the orifice was stronger with v_{G1}. Q_L is highest in L type because the porous pipe area for sucking water becomes wider with the atomizer size.

Fig. 6 compares mist flow rate data, Q_L, for the three sized atomizers against the power, L_G. Q_L data when two S type atomizers were used are also shown. This figure teaches us that if Q_L demand is over 0.0125 l/s, multiple use of S type atomizer is better than the use of L type because L_G becomes low. Thus, S type is the best in the hydraulic performance.

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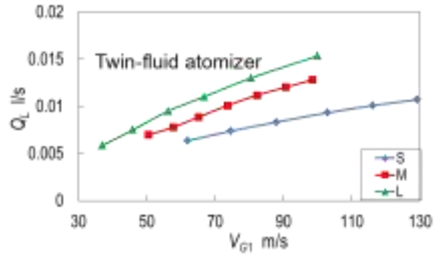

Figure 5. Mist flow rate against mean air velocity at twin-fluid atomizer inlet.

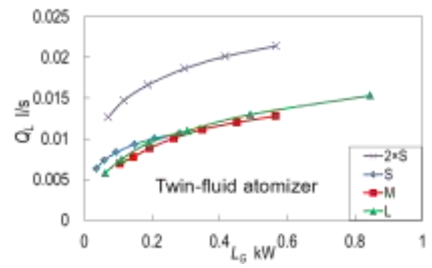

Figure 6. Comparison of mist flow rates among three atomizers S, M, L.

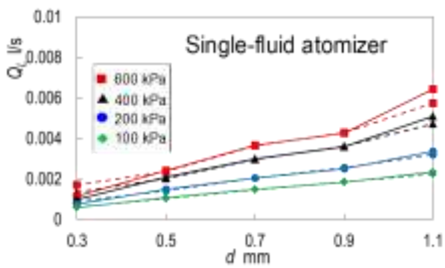

Figure 7. Mist flow rate against orifice diameter for single-fluid atomizer.

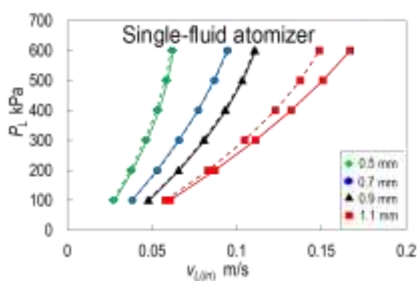

Figure 8. Inlet pressure against mean water velocity for single-fluid atomizer.

B. *Hydraulic Performance of Single-fluid Type Atomizer*

Fig. 7 shows the mist flow rate data, Q_L, against the orifice diameter, d, as the water inlet pressure, $P_{L(in)}$, a parameter. The data for t = 1.0 and 3.0 mm thick orifices were connected with solid and broken lines, respectively, and the effects of t are small. Q_L is roughly proportional to d, but not to $P_{L(in)}$. The trends of data depend on the characteristics of the pressure drop through both the swirler and the orifice of the atomizer.

Fig. 8 shows the inlet pressure data, $P_{L(in)}$, against the mean water velocity at the atomizer inlet, $v_{L(in)}$. The effects of the orifice thickness, t, are small. $P_{L(in)}$ increases non-linearly with $v_{L(in)}$ at a fixed d because it is the same as the pressure drop through the atomizer. In addition, the gradient of $P_{L(in)}$ to $v_{L(in)}$ is steeper with decreasing of the orifice diameter, d.

Since t effects on the atomizer performance are small as described above, the data for t = 1.0 mm orifice case alone are used hereafter to compare data for the twin-fluid type.

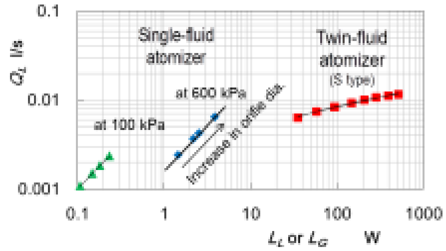

Figure 9. Comparison of mist generation rate between single-fluid type and twin-fluid type.

TABLE II. Mean and Sauter Mean Droplets Diameters for Single-Fluid 1 mm Thick Orifice Type with Different Orifice Diameter.

Orifice dia. mm	0.5	0.7	0.9	1.1
Mean droplet dia. μm	32	26	48	60
Sauter mean droplet dia. μm	56	67	79	120

Fig. 9 compares Q_L data between the single-fluid 1.0 mm thick orifice type at $P_{L(in)}$ = 100 kPa and 600 kPa and the twin-fluid S type. The abscissa is the power needed for the mist generation, L_L for the single-fluid type and L_G for the twin-fluid type. Q_L in the single-fluid type is roughly proportional to L_L while that in the twin-fluid type is roughly proportional to $L_G^{0.25}$. The ratio of the mist generation rate to the power needed for the mist generation, Q_L/L_L or Q_L/L_G, was about ten times higher in the single-fluid type than the twin-fluid type. Thus, for saving energy, the single-fluid type is superior to the twin-fluid type.

C. *Droplet Diameter and Atomization Angle*

For the twin-fluid type atomizer, the Sauter mean droplet diameter of the mist, defined as $d_{32} = \Sigma d_i^3 / \Sigma d_i^2$, was reported in our previous papers [4, 5]. Here, d_i is the diameter of each droplet. For the S type, most of the droplet diameter was 5 to 50 μm, and d_{32} was 82 μm at v_{G1} = 78 m/s (Q_G = 180 l/min) and Q_L = 0.1 l/min [4]. In addition, d_{32} became smaller with increasing of v_{G1}, and with decreasing of Q_L.

For the single-fluid type atomizer, droplets diameter data were obtained at $P_{L(in)}$ = 600 kPa in the present experiment for the four atomizers with 1 mm thick orifices. TABLE II lists the mean and the Sauter mean diameters of droplets captured at 0.3 m below the atomizer exit. The droplets becomes bigger with increasing of d. The composition of the droplets is shown in Fig. 10. It depends on the orifice diameter, d, i.e., the smaller droplets become dominant with decreasing of d.

Fig. 11 compares the radial distributions of droplets at 0.5 m below the atomizer exit. The data for the twin-fluid S type,

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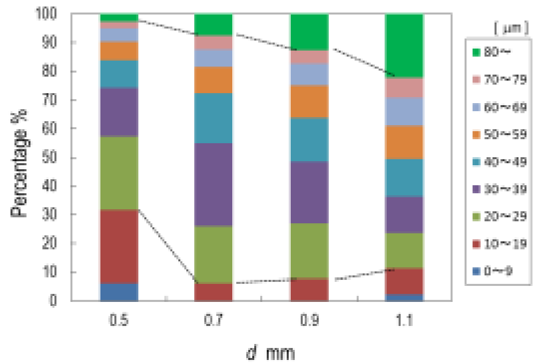

Figure 10. Effects of orifice diameter on droplet diameter composition for single-fluid 1 mm thick orifice type atomizers.

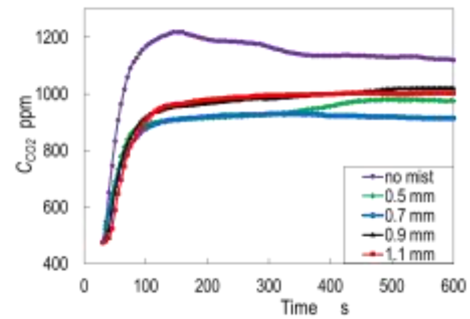

Figure12. Time variation in CO_2 concentration in air at the bottom of mist room – Effects of orifice diameter in single-fluid 1 mm thick type atomizers.

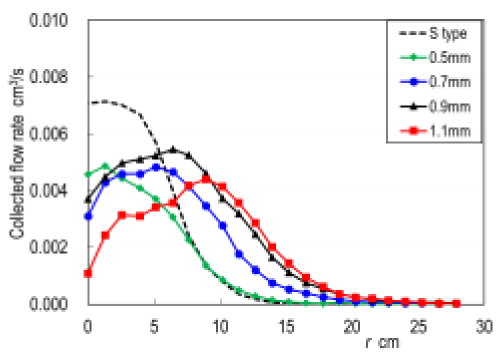

Figure 11. Comparison of radial distribution of droplets captured at 0.5 m below atomizer exit.

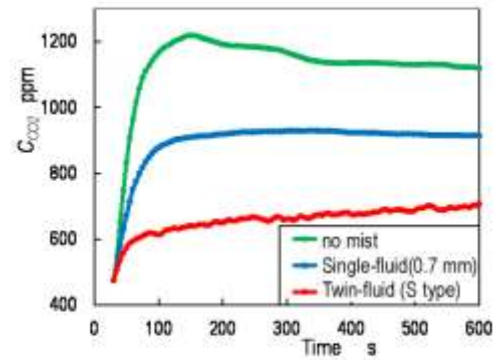

Figure 13. Time variation in CO_2 concentration in air at the bottom of mist room – Effects of mists generated by a single-fluid type atomizer (1 mm thick orifice with 0.7 mm orifice diameter) and a twin-fluid S type atomizer.

taken at Q_G = 180 l/min and Q_L = 0.1 l/min [5], concentrates in the central part of r = 13 cm, corresponding to 30 ° in the atomization angle. The data for the single-fluid type with t = 1 mm thick orifice are lower in the central part than the surroundings, and the distance to the peak increases with d. Since the swirl flow becomes stronger with increasing of d, the droplets especially heavier ones go outside due to the centrifugal force on the droplets. Thus, the droplets data taken in the central part, shown in TABLE II and Fig. 10, must be smaller than those in the outside.

D. CO_2 Adsorption Performance

In Fig. 12, time variation in the CO_2 concentration in air at the bottom of the mist room are compared among five cases: four mist filled cases by the atomizers with different orifice diameters at t = 1.0 mm, and no mist spray case. Shortly after the release of CO_2 from the CO_2 room, the detection of CO_2 concentration at the bottom of the mist room was started. The CO_2 concentration in about 30 second from the start, showed the same value as that outside of the mist room, i.e., about 480 ppm, because CO_2 could not reach to the detectors. The concentration after 30 seconds rapidly increased with time, and took a maximum value at about 150 to 600 seconds. The arrival time to the detector depended on the existence of the mist, and the fastest case was the no mist spray case. In no mist spray case, the concentration after the peak decreased gradually because of some leakage of CO_2 to the outside.

The mass of CO_2 adsorbed by the mist is known from the concentration difference between the mist filled case and the no mist spray case. Thus, the atomizer with 0.7 mm orifice diameter is the best among the atomizers tested. Since it gave the highest percentage in a droplet diameter range from 20 μm to 80 μm (or 70 and 60 μm) in Fig. 10, the droplets in this diameter range must be effective to the CO_2 adsorption.

The mist whose droplet diameter is smaller than 20 μm is called “dry-mist” in Japan, and is reported to be effective to the mitigation of heat island phenomena in megalopolis [8]. This means that the droplets smaller than 20 μm cannot adsorb CO_2 because of evaporation. In addition, the droplets larger than say 80 μm seems ineffective to the CO_2 adsorption, because of too short adsorption time due to the faster falling velocity. Furthermore, the interfacial area concentration (= the sum of interfacial area divided by the volume occupied by droplets and air) is lower for the larger droplets than the smaller droplets at a fixed total liquid volume.

Fig. 13 compares the CO_2 adsorption performance between the mists filled with the single-fluid 0.7 mm orifice diameter type at $P_{L(in)}$ = 600 kPa and the twin-fluid S type at v_{G1} = 78 m/s and Q_L = 0.1 l/min. The CO_2 concentration difference from the no mist spray case is about twice larger in the twin-fluid type than the single-fluid type. This suggests that the droplets from 20 μm to 80 μm (or 70 and 60 μm) are twice more in the twin-fluid type case than the single-fluid type case.

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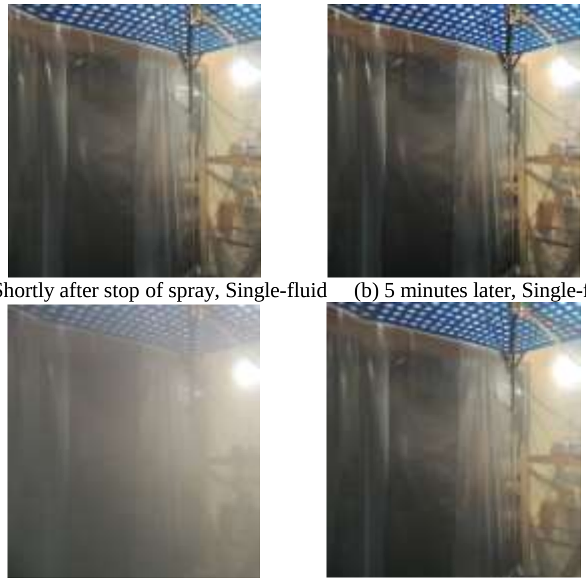

(a) Shortly after stop of spray, Single-fluid (b) 5 minutes later, Single-fluid

(c) Shortly after stop of spray, Twin-fluid (d) 5 minutes later, Twin-fluid

Figure 14. Pictures of mist room for the single-fluid atomizer and the twin-fluid atomizer: (a), (c) shortly after the stop of spray and (b), (d) 5 min later.

By considering the CO_2 concentration difference between the value at 600 s and the value at 30 s for three cases, we can confirm that about 70 % of CO_2 in the mist room was adsorbed in the twin-fluid type case while about 35 % in the single-fluid type one. Thus, the twin-fluid atomizer is superior to the single-fluid atomizer in the CO_2 adsorption by the mist under the above operation conditions.

Figs. 14 (a) – (d) shows the pictures of mist room after the stop of spray by the single-fluid atomizer and the twin-fluid atomizer. Figs. 14 (a) and (d) are those shortly after the stop of spray while (b) and (d) 5 minutes later. In the single-fluid atomizer case, the inside of the room is lightly foggy because the lager droplets fell down within 5 minutes after the stop of spray. In the twin-fluid case, on the other side, the inside of the room is densely foggy because almost of the droplets are smaller than 50 μm, and some of them suspended even after 5 minutes. This is why the CO_2 adsorbed is more in the mist by the twin-fluid atomizer.

IV. Conclusions

The performance of the twin-fluid water suction type atomizer invented by Sadatomi and Kawahara was compared with those of the single-fluid swirl type atomizer with the same inlet pipe diameter. For the twin-fluid type, the size effects on the hydraulic performance [4] and the air and water flowrates effects on the droplets size [5] are briefly introduced, and the best one, i.e., S type was selected. For the single-fluid type, the effects of orifice thickness and orifice diameter were clarified in the present study, and the best one, the atomizer of 1 mm thick orifice with 0.7 mm orifice diameter, was selected. From the comparison of the above two best atomizers, the followings were found:

1. The ratio of the mist generation rate to the power required, Q_L/L_L or Q_L/L_G, was about ten times higher in the single-fluid type than the twin-fluid type.
2. The droplet size of the mist in the central part was similar between the two types, but that in the outer part was larger in the single-fluid type than the twin-fluid type.
3. The CO_2 adsorption performance by the mist was about twice higher in the twin-fluid type than the single-fluid type.

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