Air Purification Using Mists Generated by an Efficient Multi-fluid Mixer

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Abstract: Sadatomi and Kawahara developed a special twin-fluid atomizer called a multi-fluid mixer, which can spray mists by supplying air alone because water is automatically sucked by a vacuum pressure arisen inside the mixer. In the present paper, firstly, some applications of the mists sprayed by the atomizer are described. Secondly, the performance of the twin-fluid atomizer with best performance was compared with those of the commercial twin-fluid MMA100 type together with the single-fluid swirl type. In the CO₂ adsorption tests, mists were sprayed five minutes by the respective types in turn in a test room, and time variations of CO₂ concentration in air after the introduction of CO₂ in the room were measured at the bottom of the room to compare the CO₂ adsorption rates by the mists for the respective cases. In addition, diameters of droplets for the respective types were measured with a microscope. As a result, superiority of our twin-fluid atomizer was confirmed, because 40% droplets were 20 to 40 μm in diameter, and the CO₂ adsorption rate by the mists with our twin-fluid atomizer was 25% higher than that with the commercial ones.

Key words: Air purification, mist, atomizers, CO₂ adsorption, power.

1. Introduction

Atomizing nozzles or atomizers are categorized as single-fluid type, twin-fluid type and special types with rotating disc, vibrating plate, etc. [1]. Of these, the twin-fluid type is usually employed if one must spray a great deal of fine liquid droplets smaller than 100 μm [1]. However, the twin-fluid type has a demerit because two pressurizers respectively for water and air must be prepared, and the total cost of equipment and electricity is higher than that for the single-fluid type.

Sadatomi and Kawahara [2] invented a special twin-fluid atomizer called multi-fluid mixer in Fig. 1 which is the twin-fluid type but has a merit because water is automatically sucked through a porous pipe by a negative pressure arisen downstream from the orifice in the mixer. Thus, the mixer can be operated with a lower electric power than the usual twin-fluid type, i.e.,

operable with a solar power [3-8]. The mixer is also usable as a micro bubble generator [9, 10] when water is supplied and air is sucked.

In our previous studies, a mathematical model to predict its hydraulic performance was proposed and validated [4], and better geometrical parameters were experimentally clarified [5-8], i.e., the diameter ratio of the orifice to the mixer pipe, the ratio of the outlet length from the porous pipe to the mixer pipe diameter, the geometry of the orifice, the whole size, and the CO₂ adsorption performance by the mists.

The purpose of the present study is to compare the above twin-fluid type with commercial single-swirl and twin-fluid types on the spray performance and the CO₂ adsorption performance with the mists. In the present paper, firstly, applications of the mists by our twin-fluid atomizer have been described. Secondly, the present experimental results on the hydraulic performance and the CO₂ adsorption performance by the mist with the three atomizers have been described.

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

2. Experiment

2.1 Test Atomizers

Three atomizers of L, M and S in our twin-fluid type were tested in order to study the size effects [7]. The pipe and the orifice diameters of S type were 7 and 4.58 mm respectively as listed in Table 1, and the outlet length was 20.5 mm, and the fiber porous pipe was 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 porosity and the thickness of the porous pipe. Of these, the S type showed the best performance, i.e., the highest in the spray rate to the pneumatic power required [7].

Figs. 2a and 2b show the commercial atomizers tested, i.e., a twin-fluid MMA100 (Kyoritsu Gokin Co., Japan) for atomizing fine mists, and a single-fluid swirl type (Maruhachi Industrials Type Co., Japan) for gardening use. The twin-fluid MMA100 can spray without water power because the air pressure near the atomizer outlet becomes negative. The single-fluid swirl type is composed from a 7 mm I. D. water inlet, a swirler, and a cap with 0.7 mm orifice. The inlet diameter is the same as that of the twin-fluid S type.

2.2 Spray Performance

Fig. 3 shows the test apparatus for the twin-fluid type atomizer [4-7]. Air was supplied with a compressor

Fig. 2 Commercial atomizers tested.

after controlling the air volume flow rate, Q_G . The air flow rate, Q_G , and the gauge pressure at the atomizer inlet, P_{G1} . The volume flow rate and the pressure were measured with calibrated sensors and a data acquisition system. The accuracies of Q_G and P_{G1} measurements were within 2% and 1% from our preliminary tests. The pneumatic power required for the mist spray, L_G , was obtained by substituting the above measured data into Eq. (1):

$$L_G = (P_{G1} + \rho_G v_{G1}^2 / 2) Q_{G1}. \quad (1)$$

Here, ρ_G and v_{G1} are the air density and the mean air velocity respectively at the atomizer inlet. However, no power was required to supply water, because water was automatically sucked from a water tank whose level was the same as the water inlet of the atomizer. The water supply rate, Q_L , was measured with a calibrated turbine flow meter within 1%, and could be adjusted by partially closing the flow control valve in the water supply line.

In the single-fluid swirl type test, air supply line and water supply line in Fig. 3 were replaced by a water supply line from a high pressure pump to the atomizer top. The valve in the water line was used to control the volume flow rate, Q_L , and the gauge pressure at the atomizer inlet, P_{L1} . The hydraulic power needed for the mist spray, L_L , was obtained by substituting the data into Eq. (2):

$$L_L = (P_{L1} + \rho_L v_{L1}^2 / 2) Q_L. \quad (2)$$

Here, v_{L1} is the mean water velocities 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

Table 1 Specifications of twin-fluid type atomizers tested.

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

Fig. 3 Test apparatus of spray performance for the twin-fluid type atomizer.

covering the inlet of the oil pond 0.2 m below the atomizer exit, and the diameters of more than 500 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 the mist 0.50 m below the atomizer exit. The distribution was determined by collecting the droplets with a lot of test tubes square arrayed.

2.3 CO₂ Adsorption Performance with Mist

Figs. 4a and 4b show the test room of CO₂ adsorption by the mist, having 2.0 m in height and 1.2 m in width and depth. A perforated plate with a cover sheet was placed 1.8 m above from the bottom, and divided the room into the CO₂ room and the mist room. The atomizer was placed at the center of the plate. CO₂ concentration in air in the mist room was detected by two sensors placed at the bottom. The procedure of the CO₂ adsorption test was as follows: Firstly, 1.5 L of CO₂ at standard condition was filled in a balloon placed outside of the CO₂ room. Secondly, the mist was sprayed five minutes in the mist room, three minutes after the spray start the CO₂ in the balloon was released to the CO₂ room for two minutes for full diffusion. Thirdly, the spray was stopped, and CO₂ began to flow down through the perforated plate by removing the cover sheet. At the same time, CO₂ concentrations at the bottom of the mist room were measured every 5 seconds for 10 minutes. In order to know the effects of

(a) Picture of test room

(b) Sketch of apparatus

Fig. 4 Test room for the CO₂ adsorption by mists.

the mist spray, a similar measurement with no mist spray was also conducted.

3. Practical Applications

Our concern is the development of ecological spray systems which can spray a great deal of finer droplets around 20 μm in diameter with a low power such as solar cells. As the practical applications of such a system, an evaporative cooling of fine droplets in greenhouses [3], and baby pig house in summer, and

adsorptions of smoke and fuel gas emitted from combustors, etc. have already been conducted.

Figs. 5 and 6 show the evaporative cooling of a baby pig house and a solar cell on the roof, which was broadcasted by the Tokyo Broadcasting System Television. In the cooling system, a high pressure type blower was driven with the electricity from the 450 W solar cells, and pressurized air together with water at atmospheric pressure was supplied to the multi-fluid mixers in order to supply fine droplets in the house. Since high temperature in the house causes the loss of appetite and the poor growth of the baby pigs, the cooling in summer without commercial electricity is quite ecological.

The adsorptions of black smoke in the chimney from a furnace burning RPF (refuse paper & plastic fuel) were tested by use of our spray system in a local boiler maker. Figs. 7a-7c show the pictures of the original boiler system with a RPF stock in front, RPF and a blower for air supply to the furnace. Originally, four cyclone separators were inserted in series between the furnace and the chimney outlet, but black smoke was still emitted as shown in Fig. 8a due to the incomplete combustion and to the poor cyclone separators performance.

Fig. 5 Evaporative cooling of a baby pig in Kumamoto Prefecture broadcasted by TBS TV, Japan.

Fig. 6 450 W solar cell on the roof of the pig house.

(a) Boiler system with RPF stock

(b) RPF

(c) Blower for air supply

Fig. 7 Original boiler systems in Oita Prefecture.

(a) Before revision

(b) After revision

Fig. 8 Black smoke removal by atomized droplets, etc.

The boiler maker asked us to find an economical method to remove the black smoke. According to our advice, the maker took off three from the four separators in order to reduce the pressure drop from the furnace to the chimney outlet, and add one more blower in series at the inlet of the original blower in order to supply more air to the furnace for better combustion, and inserted our spray system into the smoke pass in order to adsorb finer smoke dust. As a result, the smoke could be cleaned up as shown in Fig. 8b.

4. Comparison of Performance between Twin-fluid Type and Single-fluid Type

4.1 Spray Performance

Fig. 9 compares the maximum mist flowrate, Q_L , among the twin-fluid S type, the twin-fluid MMA100 type and the single-fluid swirl type. The maximum means that the splay was conducted under the fully opened flow control valve in the water supply line. The abscissa is the power required to operate the atomizer, the pneumatic power, L_G , for the two kinds of twin-fluid types and the hydraulic power, L_L , for the single-fluid type. In the two twin-fluid types, Q_L increases with L_G because Q_L increases with the air supply rate, Q_G . In the single-fluid type, Q_L is proportional to $L_L^{1/3}$. This is because L_L is given as $Q_L P_{L1}$, and P_{L1} , being the same as the pressure loss through the atomizer, is proportional to Q_L^2 .

If ten atomizers of the single-fluid type are used at the same time, Q_L exceeds that for the twin-fluid S type, but the total of L_L is one-hundredth lower than that for the twin-fluid S type. Thus, the single-fluid type has a merit in saving energy, but has a demerit of large liquid droplet as described in Fig. 10.

Fig. 10 compares droplet size distributions among the three atomizers, and Table 2 lists the operation conditions of Q_L and Q_G , the mean and the Sauter mean droplet diameters. The operation condition for the single-fluid type corresponds to that shown in the maker's manual and that for the MMA100 to the

maximum Q_L , and that the S type to nearly the same Q_L as that in the single-fluid type. In the MMA100 type, 75% droplets are smaller than 20 μm , called "dry mist" and reported to be effective to the mitigation of heat island phenomena in megalopolis [11]. In the single-fluid type, 40% droplets are larger than 80 μm , which cannot suspend in air. In the twin-fluid S type, smaller droplets than 20 μm are 45%, and 20 to 40 μm droplets are 40%, while 20% for the MMA100 type. Since the fall velocity of droplet increases with its size, the smaller and the denser droplets seem effective to adsorb harmful gases. However, too small droplets like dry mist cannot adsorb them because they disappear due to evaporation.

Fig. 9 Comparison of the maximum mist flow rate among twin-fluid S and MMA100 types and the single-fluid type.

Fig. 10 Comparison of droplet size distribution among twin-fluid S and MMA100 types and the single-fluid type.

Table 2 Operation conditions and drop sizes for three atomizers.

Atomizers	Q_L (l/min)	Q_G (l/min)	d_m (μm)	d_{32} (μm)
Single-fluid swirl type	0.09	0	77	132
Twin-fluid MMA100	0.38	27	17	35
Twin-fluid S type	0.10	170	27	86

4.2 CO₂ Adsorption Performance with Mist

Figs. 11a and 11b show the pictures of mist room just after the stop of spray in the CO₂ adsorption test respectively for the single-fluid swirl type and the twin-fluid S type. Q_L for the twin-fluid S type was 0.10 L/min, while that for the single-fluid swirl type was 0.09 L/min, being the same as those in the test of Fig. 10. The picture for the single-fluid type is clearer than that for the twin-fluid S type because larger droplets than 80 μm cannot suspend in air because of higher fall velocity. In the twin-fluid type, however, droplets smaller than 40 μm are about 85%, and can float for a while if they were not evaporated, so the room becomes foggy as seen in Fig. 11b.

Fig. 12 shows time variations in CO₂ concentration in air at the bottom of the mist room for the following four cases: three mists filled cases with the single-fluid swirl type, the twin-fluid MMA100 type and the twin-fluid S type, and no mist spray case. Shortly after the flow down of CO₂ into the mist room, CO₂ concentration detection was started at the bottom of the mist room. The CO₂ concentration in air at 25 s from the start is the same as that outside of the room, i.e., about 470 ppm, because CO₂ could not reach to the detectors. The concentration after 25 s rapidly increased with time, and took a maximum value at 150 s or after. The concentration in no mist spray case after the peak decreased gradually because of some leakage of CO₂ to the outside.

The mass of CO₂ adsorbed by the mists is known from the concentration difference between the mists filled case and the no mist spray case. The CO₂ concentration difference from the no mist spray case for the twin-fluid S type is about 25% higher than that for the twin-fluid MMA100 type, and 50% higher than that for the single-fluid swirl type. This means that the droplets of 20 to 40 μm in diameter are very effective to adsorb CO₂.

From the CO₂ concentration difference between 470 ppm at 25 s and the respective values at 525 s, we can confirm that about 70% of CO₂ in the mist room was

(a) Single-fluid swirl type (b) Twin-fluid S type
Fig. 11 Pictures of mist room just after the stop of spray by the single-fluid type and the twin-fluid S type.

Fig. 12 Time variation in CO₂ concentration in air at the bottom of mist room—Effects of mist generation method.

adsorbed by the mists in the twin-fluid S type case while about 55% in the twin-fluid MMA type. Thus, the twin-fluid S type is superior to the commercial two atomizers in the CO₂ adsorption by the mists under the above operation conditions.

5. Conclusions

Firstly, a twin-fluid water suction type atomizer invented by Sadatomi and Kawahara [2] was introduced together with its practical applications to date. Secondly, the performance of the twin-fluid atomizer with best performance, i.e., S type, was compared with those of the commercial twin-fluid MMA100 type and the single-fluid swirl type. From the comparison, the followings were clarified:

The ratio of the spray rate to the power required, Q_L/L_L or Q_L/L_G , was much higher in the single-fluid type than the two kinds of twin-fluid types. Thus, the single-fluid type is superior in energy saving point of

view. However, the droplets for the single-fluid type were bigger than those for the two twin-fluid types, and could not suspend in air.

The most droplets of the twin-fluid MMA100 type were smaller than 20 μm , and disappeared due to evaporation. 20 to 40 μm droplets were 40% for the twin-fluid S type, and could suspend in air. The CO_2 adsorption by mists was 70% in the twin-fluid S type while 55% in the twin-fluid MMA100 type. Thus, the twin-fluid S type is the best in the adsorption performance of harmful gases such as CO_2 .

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