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Spray Angle Expansion Method of a Twin-Fluid Atomizer for the Application to CO_2absorption

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ABSTRACT :*This paper presents the results of an experimental study for a new type twin-fluid atomizer, which is based on a multi fluids mixer patented by Sadatomi & Kawahara (2012). This atomizer has a simple structure and can suck water by itself without a pump by introducing pressurized air alone into an internal mixing chamber with less energy consumption. The present study focuses on the improved design of the atomizer for spray angle expansion and its application to* CO_2 *absorption. Experiments relating to two angle expansion methods (Coanda effect and propellers) were conducted, also six sizes of PET (Polyethylene Terephthalate) propellers were tested. We found that, the atomizer with a PET propeller of 4 blades and 25 mm in diameter showed the best spray angle expansion effect and presented a good spray quality, especially reduced the Sauter mean diameter* (d_{32}) *significantly. Finally, the mist sprayed by the optimized atomizer was applied to* CO_2 *absorption, and experimental results showed that the mist sprayed by the optimized atomizer can significantly decrease the* CO_2 *concentration in a closed room.*

Keywords -*Atomizer, spray-angle, Coanda effect, propeller,* CO_2*absorption*

I. INTRODUCTION

Liquid atomizer has been applied extensively in our daily life, such as fire suppression, paint spraying, humidity control, etc. In this context, several types of atomizers have been developed by Lal et al. [1], and some makers such as HYPRO EU Ltd. [2]. Till now, all forms of pressure nozzles accomplish this by discharging the liquid at high velocity into quiescent or relatively slow-moving air. Rotary atomizers employ a similar principle, the liquid being ejected at high velocity from the rim of a rotating cup or disc. An alternative method of achieving a high relative velocity between liquid and air is to expose slow-moving liquid into a high-velocity stream of air. Devices based on this approach are usually termed air-assist, air-blast or, more generally, twin-fluid atomizers.

There are also plenty of experimental and numerical researches that address the atomization methods of the twin-fluid atomizers. Some employ the pressure principle, where the liquid is supplied from a pressurized source; others use the gravity principle, where the liquid supply is located above the nozzle, invoking gravity for the liquid flow; the siphon principle is also used in some twin-fluid atomizers, where the liquid source is self-aspirating. Applications for this family of atomizers includes humidification, dust control, gas cooling, precision coating and spray drying.

The purpose of the present study is to expand the spray angle of Sadatomi & Kawahara’s new type twin-fluid atomizer [3], which had the characteristic of less energy consumption and simple structure but narrow spray angle. In order to expand the spray angel, two methods (Coanda effect and propellers with different material, different blade number and diameter) are tested, and the best specifications are determined.

In addition, Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. In 2011, CO_2 accounted for about 84% of all U.S. greenhouse gas emissions from human activities. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle—both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution. In consequence, the growing awareness on the risks associated with the green-house effect caused by CO_2 motivates the researchers to develop various methods for eliminating CO_2 since 1989 [4]. So, we tried to utilize Sadatomi & Kawahara's atomizer for the absorption of CO_2.

II. EXPERIMENTS AND METHODS

2.1 Principle of Sadatomi & Kawahara's atomizer

The proto type of the atomizer is shown in Fig. 1, in which pressurized air is supplied into a pipe with an orifice in the core. From the conservation equations of mass and energy, (1) and (2).

$$\frac{P_1}{\rho g} + \frac{v_{G1}^2}{2g} = \frac{P_2}{\rho g} + \frac{v_{G2}^2}{2g} \quad (1)$$

$$P_2 - P_1 = P_1 - \frac{\rho}{2}(v_{G2}^2 - v_{G1}^2) \quad (2)$$

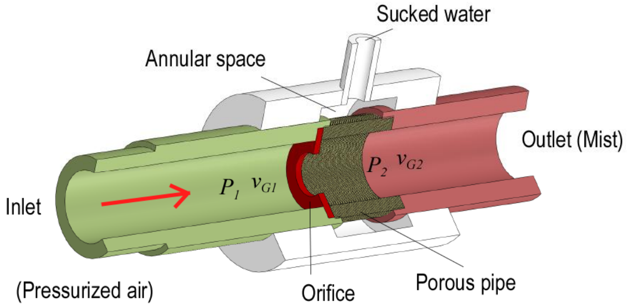

Fig. 1 Principle of new-type twin-fluid atomizer patented by Sadatomi & Kawahara (2012).

The velocity of the air after passing through the orifice, v_{G2}, becomes much higher than before v_{G1}, so, $v_{G2}>v_{G1}$, and the pressure there becomes much lower, $P_2<P_1$. If the pressure becomes negative, then the water can be automatically sucked into air stream through a porous pipe. Since the air flow there is highly-turbulent and shear flow, air and water interact each other in the internal mixing chamber of the atomizer, and a huge number of tiny water droplet, i.e. mist is formed and discharged through the outlet port.

Based on previous studies in this series [5, 6], we can conclude the main special advantages of Sadatomi & Kawahara's atomizer as follows: (a) lower energy consumption. The energy is supplied only by a compressor or blower although it is a twin-fluid atomizer, and the gas pressure needed is less than 70 kPa., quite lower than those for other atomizers [7, 8]; (b) simple structure, which means easy to manufacture. The mixing chamber and the orifice are easy to manufacture, and the porous pipe is a kind of common fiber material which can be readily available; (c) mist diameters are quite small, 90% of them are less than 30 µm. That means the atomizer can jet fine mists, which is qualified to be applied to air cooling, CO_2 absorption, smoke absorption, etc.

However, the spray angle of Sadatomi & Kawahara's atomizer is limited by the inherent structure of the atomizer and is not wide enough for many applications, this disadvantagewill be solved in the present study.

2.2Experimental Apparatus

The experimental apparatus for studying the sprayangle expansion is revealed in Fig. 2. In the experiment, the volume flow rate of air and water are Q_G = 300 l/min, Q_L = 0.2 l/min. At 500 mm downward from the atomizer nozzle, 22 test tubes each 13 mm apart in center to center distance were set in line in four radial directions, so as to collect mist and get the radial distribution of the mist. Meanwhile, to eliminate the introduction of water due to level difference, the water in the tank and the water suction part of the atomizer should be on the same level. The output signals from the flow rate and pressure sensors were acquired by computer via an A/D converter.

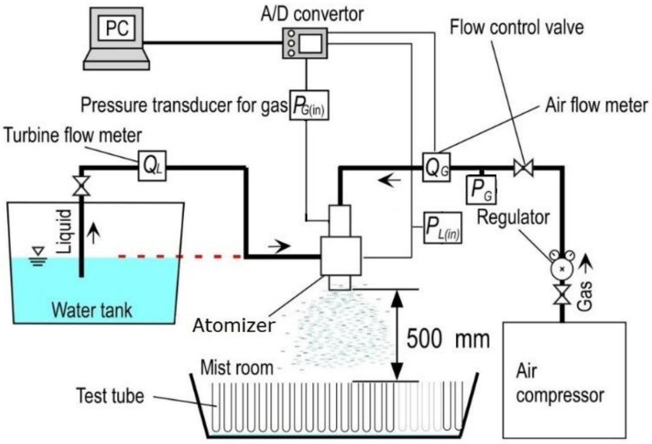

Fig. 2 Experimental apparatus for the test of spray performance of twin-fluid atomizer.

For the droplet measurement, a digital camera (in Fig. 3) with a microscope is used, and more than a thousand droplet diameters are tested with an image processing system. Fig. 4 shows a typical picture of water droplets in an oil pond, which are about unity in sphericity, even in the largest 150 µm droplet [9].

Fig. 3 Drop size testing facility

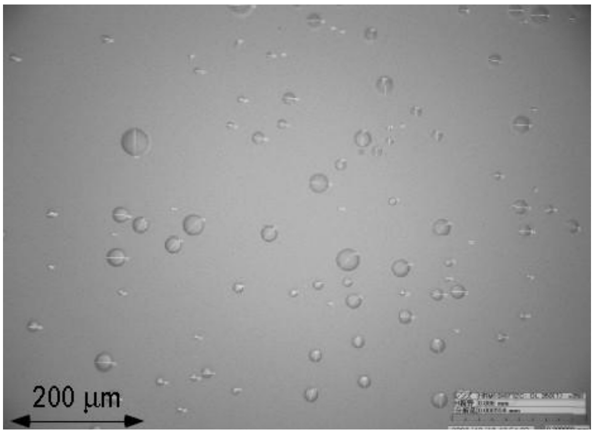

Fig. 4 A typical picture of water droplets.

Drop-size distributions are often described by characteristic diameters (3) [10]:

$$d_{ab} = \left[\frac{\sum_i n_i d_i^{\,a}}{\sum_i n_i d_i^{\,b}} \right]^{\frac{1}{a-b}} \quad (3)$$

Here,*i* denotes the number of droplet size range, n_i is the number of droplets in the size range*i*, and $d_i$is the diameter of the size range *i*. Thus, for example, d_{10} is the arithmeticmeandiameter of all the drops in the spray; and d_{32}, Sauter mean diameter, is the diameter of the droplet whose ratio of volume to surface area is the same as that of the entire spray, which is often of use in applications where the active surface or surface area is important (e.g. air cooling, gas absorption) [11]. In the present experiments, d_{10} and d_{32} are used to identify the spray effect of droplets.

2.3Spray-Angle Expansion Methods

Spray angle (injection angle) is an apex angle of the spray, which characteristics the shape of the drop jet. In many cases it is necessary to predict the spray shape because it guarantees proper utilization of the jet [12]. It is important mostly in cases in which atomizers are applied in gas absorption (e.g. CO_2 capture in this study). For Sadatomi & Kawahara's atomizer, it is an atomizer with internal mixing chamber and a cylindroid outlet, so spray angle is too narrow, and need to be expanded as large as possible.We developed two methods to expand the spray angle: Coanda effect and propeller.

The Coanda effect states that a fluid or gas stream will hug a convex contour when directed at a tangent to that surface. This was discovered in the 1930s by a Romanian named Henri-Marie Coanda [13]. What is unusual about the Coanda effect is the fact that the fluid or gas flow is pulled so strongly by a curved surface. A concave curve will naturally push the flow, but the fact that a convex one would react so strongly to fluid or gas is unusual. This property is particularly relevant to aircraft design. This paper designed an outlet for the atomizer described in Fig. 5.

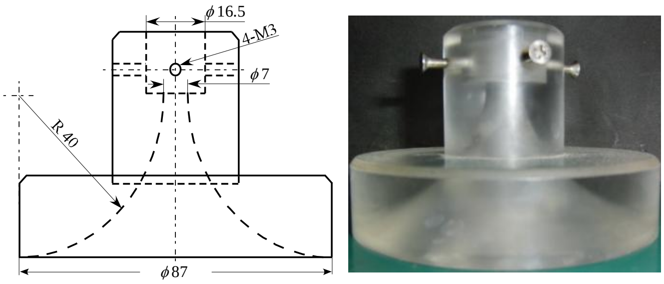

Fig. 5 Coanda effects of spreader utilizing.

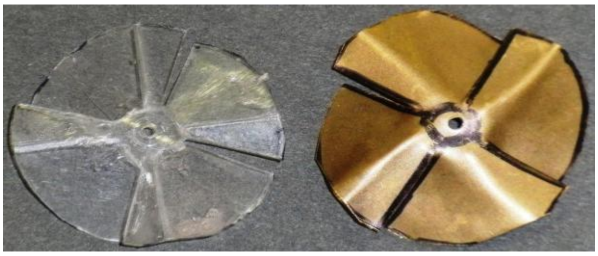

Fig. 6 Propellers with different materials.

Table 1 Specifications of PET propellers.

PET Propeller	Blade No.	Outer Dia.	Mass
	-	***mm***	***g***
b3d15	3	15	0.113
b4d15	4		0.112
b3d25	3	25	0.321
b4d25	4		0.320
b3d35	3	35	0.636
b4d35	4		0.634

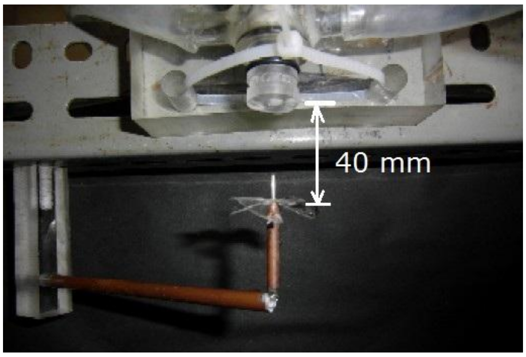

Fig. 7 Installed position of the propeller is 40 mm downward from the exit of the atomizer nozzle

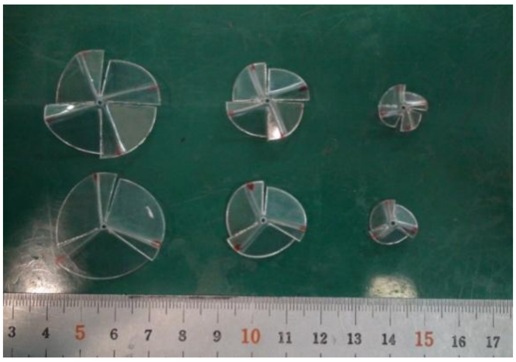

Fig. 8 Six sizes of PET propellers with different outer diameters.

For another method, two kinds of propellers were developed like Fig. 6, which is made of PET and brass with outer diameter of 25 mm.

Furthermore, propellers made of PET with different specifications are listed in in Table I, the name of propeller such as b3d15 for example, stands for a PET propeller with 3 blades, and 15 mm in outer diameter. These propellers could rotate automatically by an action of the air stream with mist.

The position of the propeller was about 40 mm downward from the exit of the atomizer nozzle as shown in Fig. 7. Six types of PET propellers were tested as listed in Table 1 and shown in Fig. 8.

2.4CO_2 absorption

As for the application of CO_2 absorption, we developed a facility like a vinyl greenhouse as shown in Fig. 9. Inside the house (2000mm high ×1200mm wide ×1200mm deep), the atomizer was set at 1800 mm in height in the middle of the house. In the bottom space, the carbon dioxide concentration meter and a balloon filled with CO_2 gas were placed near the side walls.

In the experiment, at first, the house was filled with mist at Q_G = 300 l/min, Q_L = 0.2 l/min, and with the propeller of PP-b4d25. After breaking the balloon with a needle, we collected the data of CO_2 concentration every 4 seconds, for 150 times.

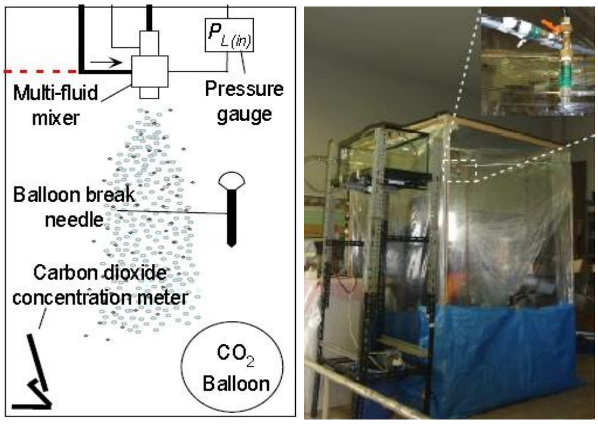

Fig. 9 CO_2 absorption method and facility.

III. RESULTS AND DISCUSSION

3.1Results of Spray-Angle Expansion

Fig. 10 shows the spay angle expansion effect with different methods, the abscissa gives out the radial distance from the center of spray area, and the ordinate describes the mist flow rate sprayed by the atomizer. For all cases, the flow rate decreased from center to rim, but only for the method with PET propeller, we can get a relative uniform flow rate comparing other methods. This effect comes from the less momentum of the PET propeller than that of brass propeller.

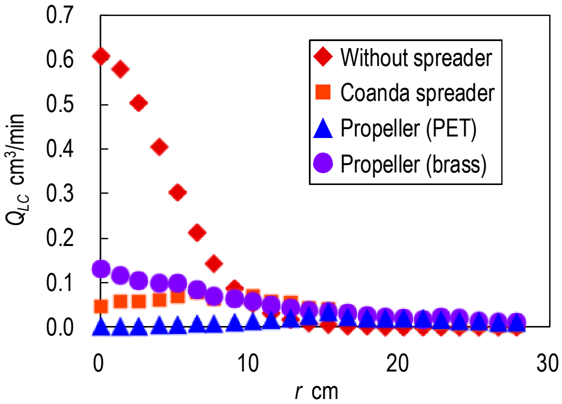

Fig. 10 Radial mist flow rate distribution with different spay angle expansion methods.

Fig. 11 demonstrates the experimental results of the atomizer's spray angle expansion with six sizes of PET propellers, and the condition without a propeller. Abscissa and ordinate directions stand for the radial distance from the center and the flow rate of the mist, respectively. We can notice that, under different conditions, the flow rate also decreased from center to rim. When we used 15 mm diameter propeller or without a propeller, most of the mists were distributed around the center, so the effect of expansion was not visible. For the 25 mm and 35 mm diameter propeller, the flow rate around the center can be reduced under 0.1 cm^3/min, and displayed good expansion effect.

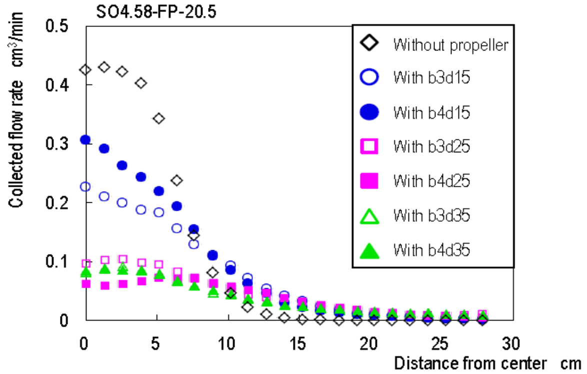

Fig. 11 Results of spray-angle expansion

Fig. 12 shows mist size distribution classified into 11 diameter ranges for different propellers and no propeller. We find that the atomizer with b4d25 propeller shows the best atomization performance, and about 95% of the mist diameter is smaller than 30 µm.

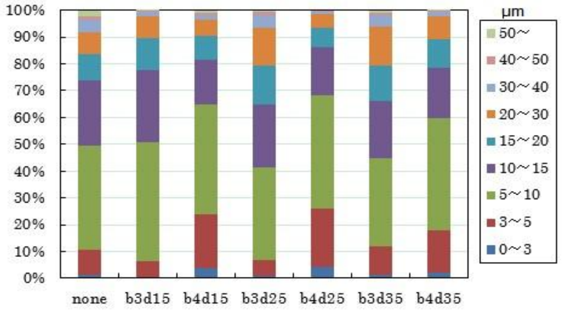

Fig. 12 Mist diameter distribution for the atomizer with six propellers and no propeller.

Fig. 13 illustrates the Sauter mean diameter (d_{32}) of mist for different propellers. The abscissa is the cutting frequency (cutting times for the mist flow per second), f_c, by the propeller blades determined from the number of blades, the blade diameter and the number of rotation. Of these propellers, b4d25 propeller shows the highest cutting frequency and the lowest d_{32} of about 18 µm.

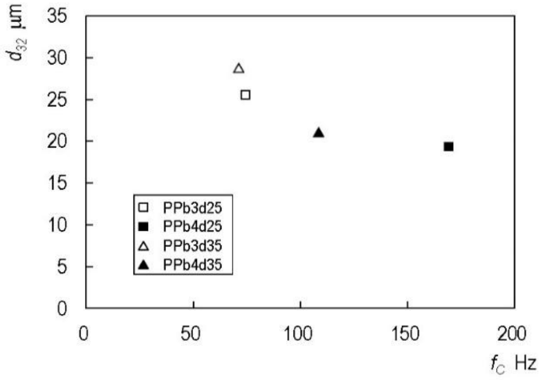

Fig. 13 Comparison of Sauter mean diameter for the atomizer with different propellers.

It is worthwhile to note that, comparing to other types of propellers, b4d25 propeller can provide the lowest flow rate as 0.08 cm^3/min within 5 mm radius, and sustained this value until about 15 cm away from the center. That is to say, b4d25 propeller showed the best expansion effect and good spray quality.

3.2CO_2 absorption effect

The experimental results of CO_2 absorption effect are denoted in Fig. 14 under three conditions: air with mist (condition 1), air with mist using b4d25 propeller (condition 2), and air alone (condition 3). X direction expresses the time after the rupture of CO_2 balloon, while Y direction is the concentration of CO_2.

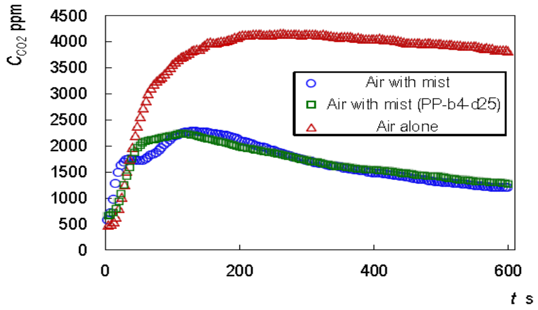

Fig. 14 CO_2 absorption effect.

It can be concluded that, the mist at conditions 1 and 2 can control the CO_2 concentration under 2400 ppm, much lower than 4200 ppm of condition 3. Though the absorption effect was similar between conditions 2 and 1, condition 2 can spray mist with much larger angle, this is an important advantage for absorbing CO_2 if the house is wide.

IV. CONCLUSIONS

In the present study we could expand the spray-angle withtwo methods, by using Coanda effect or inserting a propeller into the air flow with mist discharged from a new type twin-fluid atomizer invented by Sadatomi & Kawahara. The experimental results are concluded as follows:

(1) Compared with Coanda effect, an atomizer with a propeller can jet a spray with much larger angle.
(2) Propellers made of PET material possess lower momentum, so they can expand a much larger spray angle than that of brass.
(3) Among six PET propellers with different outer diameter, the propeller with 4 blades and 25 mm in outer diameter (b4d25) can providesthe largest spray angle and the most uniform mist flow rate from spray center to rim, and also, 95% of the mist diametersare smaller than 30 µm, Sauter mean diameter is only 18µm. That means high quality of spray is generated by the atomizer with b4d25 propeller of PET material.
(4) A new application in CO_2 absorption was developed. The mist sprayed by the optimizedatomizer with a large spray angle can effectively absorb the CO_2 in a closed room and reduce the CO_2 concentration significantly.

V. Acknowledgements

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