

# SPRAYING APPARATUS

## BACKGROUND

### 1. Technical Field

5           The present disclosure relates to a two-fluid nozzle spraying apparatus which atomizes a liquid using a gas.

### 2. Description of the Related Art

          Nozzles for atomizing liquids are widely used in, for example, space/material cooling apparatuses, humidifying apparatuses, chemical  
10   solution dispensing apparatuses, combustion apparatuses, and dust control apparatuses. The atomization nozzles can be broadly divided into a single-fluid nozzle and a two-fluid nozzle. The single-fluid nozzle atomizes a liquid by spouting the liquid from a micro aperture. The two-fluid nozzle atomizes a liquid, using a gas such as an air, nitrogen,  
15   steam, etc. Comparing the single-fluid nozzle and the two-fluid nozzle, in general, the two-fluid nozzle is superior to the single-fluid nozzle in atomization performance because the two-fluid nozzle atomizes a liquid using energy of a gas.

          As an example of the two-fluid nozzle which atomizes a liquid, for  
20   example, Japanese Unexamined Patent Application Publication No. 2001-149822 (PTL 1) discloses a two-fluid nozzle. The two-fluid nozzle disclosed in PTL 1, as illustrated in FIG. 12, has a triple-barrel structure comprising inner barrel 40, middle barrel 41, and outer barrel 42. Inner

barrel 40 is formed of proximal barrel 43 and distal barrel 44 coupled with each other. A hollow portion of inner barrel 40 is referred to as center air passageway 45. An annular intermediate passageway between inner barrel 40 and middle barrel 41 is referred to as liquid passageway 46.

5 An annular outer passageway between middle barrel 41 and outer barrel 42 is referred to as outer air passageway 47. Proximal opening 47a of outer air passageway 47 and proximal opening 45a of center air passageway 45 are connected to an air supply main not shown. Thus, low pressure air is introduced from a pneumatic pressure source  
10 configured of an air compressor, not shown, into proximal opening 47a and proximal opening 45a via the air supply main. Proximal opening 46a of annular liquid passageway 46 is connected to a water supply main not shown. Pressurized water is introduced from a liquid reservoir, not shown, into proximal opening 46a via the water supply main and a pump.

15 Distal barrel 44 included in inner barrel 40, middle barrel 41, and outer barrel 42 include distal portions 40b, 41b, and 42b, respectively, at respective distal ends. Distal portions 40b, 41b, and 42b have openings 40a, 41a, 42a, respectively, which are positioned collinearly along axis L. Opening 41a of middle barrel 41 is positioned within opening 42a of outer  
20 barrel 42. Opening 42a is a spout. Opening 40a of inner barrel 40 is positioned within opening 41a of middle barrel 41.

In inner barrel 40, distal barrel 44 is screwed into and connected to proximal barrel 43. Inner barrel 40 has inner barrel opening 40a at

the tip, and small-diameter orifice 44a formed in the center of distal barrel 44 in the direction of axis L. Generally opposed two recessed grooves 44c are formed in distal surface 44b which defines the perimeter of opening 40a of inner barrel 40.

5           Distal portion 41b of middle barrel 41 has a conical external surface, and an internal surface having step 41c. Middle barrel 41 has, on the distal end side, a small-diameter hollow portion having a same diameter as and communicating with opening 40a of inner barrel 40. Middle barrel 41 has opening 41a at the tip. Opening 41a has a smaller  
10   diameter than the small-diameter hollow portion of middle barrel 41.

          Step 41c in middle barrel 41 abuts distal surface 44b of inner barrel 40 such that step 41c and grooves 44c form three liquid swirling communication passageways 48. Liquid swirling communication passageways 48 open to a distal hollow portion of inner barrel 40 and  
15   communicating between the distal hollow portion of inner barrel 40 and a distal hollow portion of middle barrel 41. A distal hollow portion formed and communicating between inner barrel 40 and middle barrel 41 is referred to as first mixing chamber 49.

          Distal portion 42b of outer barrel 42 is positioned widely spaced  
20   from distal portion 41b of middle barrel 41. Second mixing chamber 50 is formed between distal portion 41b of middle barrel 41 and distal portion 42b of outer barrel 42. Second mixing chamber 50 communicates with annular outer air passageway 47. Opening 42a, which is the spout,

is located in the tip center of outer barrel 42.

In the nozzle as configured above, initially, water that enters liquid passageway 46 is swirled as it passes through liquid swirling communication passageways 48 and the swirl flow enters first mixing  
5 chamber 49. Thus, the water has been put through primary atomization by being swirled. The water that entered first mixing chamber 49 in a form of the swirl flow impinges and mixes with an air from an air compressor which has passed and spouted from orifice 44a of center air passageway 45. Thus, the water has been put through secondary  
10 atomization by impinging and mixing with the air, and a gas-liquid mixed fluid spouts from opening 41a of middle barrel 41 into second mixing chamber 50.

The gas-liquid mixed fluid resulted from the secondary atomization impinges and mixes, in second mixing chamber 50, with an  
15 air from an air compressor that enters through outer air passageway 47. A gas-liquid mixed mist resulted from the tertiary atomization in this manner in second mixing chamber 50 is sprayed through opening 42a, which is the spout, of outer barrel 42. In particular, owing to second mixing chamber 50 being a large space, the air that enters second mixing  
20 chamber 50 through outer air passageway 47 uniformly impinges and mixes with the gas-liquid mixed fluid that enters through opening 41a and the gas-liquid mixed fluid is also swirled, thereby uniformly atomizing water droplets (see PTL 1).

## SUMMARY

However, a problem with the configuration of the conventional two-fluid nozzle disclosed in PTL 1 is that, despite of the complex nozzle structure, the liquid to be sprayed is not sufficiently atomized, ending up spraying a liquid having a large particle size. Specifically, the liquid sprayed through the two-fluid nozzle disclosed in PTL 1 has a particle size of 50  $\mu\text{m}$  or greater. The liquid sprayed having a large particle size as such requires time to vaporize. In other words, an object sprayed with the liquid gets dripping wet due to late vaporization.

The present disclosure solves the conventional problem stated above and has an object to provide a spraying apparatus which sprays liquid which has a small particle size and vaporize so quickly that an object sprayed with the liquid does not get dripping wet. More specifically, an object of the present disclosure is to provide a two-fluid nozzle spraying apparatus which sprays a liquid which has a small particle size such as 10  $\mu\text{m}$  or less and vaporizes so quickly that an object sprayed with the liquid do not get dripping wet.

In order to achieve the above object, according to one aspect of the present disclosure, a spraying apparatus is provided which includes: a spraying apparatus main body having a liquid passageway and a gas passageway; an inner lid which includes an inner lid plate, the inner lid being disposed on a distal end of the spraying apparatus main body and covering an opening of the liquid passageway, the inner lid plate being

flat; an outer lid which includes an outer lid plate which is flat and faces the inner lid plate of the inner lid, the outer lid being disposed on the distal end of the spraying apparatus main body and covering the inner lid and an opening of the gas passageway; an annular member which is  
5 disposed between the inner lid and the outer lid and forms a gas-liquid mixing section which is a space and has a disc-shaped profile; a flow guide plate disposed between the gas-liquid mixing section and the outer lid and having a through hole communicating with the gas-liquid mixing section; a liquid inlet for introducing the liquid through the liquid  
10 passageway into the gas-liquid mixing section, the liquid inlet passing through the inner lid plate of the inner lid in an edge portion of the inner lid plate and communicating with the gas-liquid mixing section; a gas inlet for introducing the gas through the gas passageway into the gas-liquid mixing section to the liquid that entered the gas-liquid mixing  
15 section through the liquid inlet, the gas inlet communicating with the gas-liquid mixing section; and a spouting portion for spouting a liquid atomized by the gas and the liquid being mixed in the gas-liquid mixing section, the spouting portion communicating with the gas-liquid mixing section and the through hole in the flow guide plate and passing through  
20 the outer lid plate of the outer lid.

As such, according to the spraying apparatus of the above aspect of the present disclosure, the spraying apparatus is provided which sprays a liquid which has a small particle size and vaporizes so quickly

that an object sprayed with the liquid does not get dripping wet. More specifically, the two-fluid nozzle spraying apparatus can be provided which sprays a liquid which has a small particle size such as 10  $\mu\text{m}$  or less and vaporizes so quickly that an object sprayed with the liquid do not get  
5 dripping wet.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a cross-sectional end view of spraying apparatus 10 according to Embodiment 1 of the present disclosure;

FIG. 1B is a cross-sectional view of spraying apparatus 10  
10 according to Embodiment 1, taken along a line 1B-1B in FIG. 1A;

FIG. 1C is a cross-sectional view of spraying apparatus 10 according to Embodiment 1, taken along a line 1C-1C in FIG. 1A;

FIG. 2 is a cross-sectional end view of spraying apparatus 10B according to Embodiment 2 of the present disclosure;

15 FIG. 3 is a diagram illustrating a flow guide plate having a through hole whose edge is serrated with six teeth according to Embodiment 3 of the present disclosure;

FIG. 4 is a diagram illustrating a flow guide plate having a through hole whose edge is serrated with twelve teeth according to  
20 Embodiment 3;

FIG. 5 is a cross-sectional end view of spraying apparatus 10C according to Embodiment 3;

FIG. 6 is a table showing a relationship of the diameter of a

tubular passageway according to Embodiment 3 with the number of teeth forming the serrated edge of the through hole in the flow guide plate, the diameter of a tip circle, the diameter of a root circle, and noise value;

FIG. 7A is a diagram illustrating a flow guide plate having a through hole which has a serrated edge according to Embodiment 4 of the present disclosure;

FIG. 7B is a side view of the flow guide plate having a through hole which has a serrated edge according to Embodiment 4;

FIG. 7C is a close-up perspective view of the through hole having the serrated edge in the flow guide plate according to Embodiment 4;

FIG. 7D is a diagram for illustrating a dihedral angle between a tooth and the flow guide plate according to Embodiment 4;

FIG. 8 is a cross-sectional end view of spraying apparatus according to Embodiment 4;

FIG. 9 is a table showing a relationship of the dihedral angle with noise value according to Embodiment 4;

FIG. 10 is a table showing a relationship of the number of teeth with noise value according to Embodiment 4 when the dihedral angle is 150 degrees;

FIG. 11A is a diagram illustrating a flow guide plate having continued three teeth according to a variation of Embodiment 4m when the dihedral angle is 150 degrees;

FIG. 11B is a diagram illustrating a flow guide plate having

discontinued three teeth according to a variation of Embodiment 4 when the dihedral angle is 150 degrees; and

FIG. 12 is a cross-sectional view showing a schematic illustration of a conventional spraying apparatus.

## 5 DETAILED DESCRIPTION

Hereinafter, embodiments according to the present disclosure are described with reference to the accompanying drawings.

The embodiments pertain to a spraying apparatus which atomizes and sprays a liquid using a gas. Examples of the gas include an air,  
10 nitrogen, oxygen, and inert gas. The gas for use may be selected appropriately, according to an intended use of the spraying apparatus. Examples of the liquid include water, ozonated water, chemical solutions having bactericiding and disinfecting capabilities, paints, and fuel oils. The liquid for use may be selected appropriately, according to an intended  
15 use of the spraying apparatus.

## EMBODIMENT 1

FIG. 1A is a cross-sectional end view of spraying apparatus 10 according to Embodiment 1 of the present disclosure. In the following, a configuration of spraying apparatus 10 is described with reference to FIG.  
20 1A.

Spraying apparatus 10 includes, at least, spraying apparatus main body 10a, inner lid 13, and outer lid 14. Inner lid 13, annular member 24, flow guide plate 30, and outer lid 14 form gas-liquid mixing

section 15. Spraying apparatus 10 further includes spraying apparatus lid securing part 17.

Spraying apparatus main body 10a is a cylindrical member and has first liquid passageway 11 and gas passageway 12. First liquid  
5 passageway 11 is formed along the direction of central axis 27. Gas passageway 12 is in a cylindrical shape and formed spaced from and around first liquid passageway 11 along the direction of central axis 27. First liquid passageway 11 and gas passageway 12 are partitioned by cylinder 10b which is a portion of spraying apparatus main body 10a and  
10 located in the middle. Only the distal end portion of first liquid passageway 11 is shown. A liquid supply port not shown is provided at the proximal end portion of first liquid passageway 11, and is, for example, connected via a liquid supply conduit to a pump connected to a liquid reservoir. Only the distal end side of gas passageway 12 is shown. A  
15 gas supply port not shown is provided at the proximal end of gas passageway 12, and is, for example, connected via a gas supply conduit to a pneumatic pressure source configured of an air compressor.

The tip of cylinder 10b projects to the distal end side of spraying apparatus 10 slightly more than the portion of spraying apparatus main  
20 body 10a not including cylinder 10b. Inner lid 13 is secured to the tip of cylinder 10b.

Inner lid 13 covers the opening of first liquid passageway 11. Inner lid 13 includes flat inner lid plate 13a and has a generally C-shaped

cross section in the direction of central axis 27. Second liquid passageway 22 in a disc shape is formed between an end face of cylinder 10b and the internal surface of inner lid plate 13a of inner lid 13. Liquid inlet 18 is formed in an edge portion of inner lid plate 13a, liquid inlet 18  
5 passing through inner lid plate 13a of inner lid 13 along the direction of central axis 27. To be more specific, liquid inlet 18 passes through inner lid 13 in an edge portion of inner lid 13. For example, liquid inlet 18 is located proximate the internal surface of annular projection 24, and communicating between first liquid passageway 11 and gas-liquid mixing  
10 section 15 to introduce liquid through first liquid passageway 11 into gas-liquid mixing section 15.

Outer lid 14 is disposed on the tip of spraying apparatus main body 10a, covering inner lid 13 and the opening of gas passageway 12. Outer lid 14 has a generally  $\Omega$ -shaped cross section in the direction of  
15 central axis 27, and includes flat outer lid plate 14a facing inner lid plate 13a of inner lid 13. Outer lid 14 covers inner lid 13 such that second space 23 in a cylindrical profile is formed uniform between outer lid 14 and inner lid 13.

Thin, disc-shaped flow guide plate 30 which has through hole 31 in  
20 the center is matingly engaged with the internal surface of outer lid 14, the internal surface being on the distal end side of spraying apparatus 10. Through hole 31 has the same diameter as the inner diameter of tubular passageway 16b described below.

Annular member 24 is fixed between inner lid 13 and flow guide plate 30 on outer lid 14. Specifically, annular member 24 is fixed between the external surface of inner lid plate 13a of inner lid 13 and flow guide plate 30. Annular member 24 has a C-shaped plane in a cross section taken along the line 1B-1B, and has hole 24a having a greater diameter than the diameter of through hole 31. Annular member 24 and flow guide plate 30 form gas-liquid mixing section 15 in a disc-shaped profile. Annular member 24 has a notch or an opening forming gas inlet 19.

FIG. 1B is a cross-sectional view of spraying apparatus 10, taken along the line 1B-1B in FIG. 1A. As illustrated in FIGS. 1A and 1B, gas inlet 19 is located 180 degrees from liquid inlet 18 about the center (central axis 27) of spraying apparatus main body 10a. Stated differently, gas inlet 19 and liquid inlet 18 are located on opposite sides relative to the center (central axis 27) of spraying apparatus main body 10a. Thus, outer lid 14 is securely sandwiched between an end face of spraying apparatus main body 10a and spraying apparatus lid securing part 17, covering inner lid 13, annular member 24, and flow guide plate 30. It should be noted that spraying apparatus lid securing part 17 may be omitted, and outer lid 14 may instead be secured directly to the end face of spraying apparatus main body 10a.

In order to securely form gas-liquid mixing section 15 in the disc-shaped profile and uniform between outer lid 14 and inner lid 13 as

such, annular member 24 and flow guide plate 30 are provided so that gas-liquid mixing section 15, which is the space, is formed in hole 24a of annular member 24 and between an internal surface of flow guide plate 30 and inner lid plate 13a of inner lid 13.

5           FIG. 1C is a cross-sectional view of spraying apparatus 10 taken along a line 1C-1C in FIG. 1A. As illustrated in FIGS. 1A and 1C, through hole 31 in flow guide plate 30 has a circular edge. Gas-liquid mixing section 15 thus configured is for mixing gas that enters through gas passageway 12 and liquid that enters through first liquid passageway  
10   11.

As illustrated in FIG. 1A, gas inlet 19 is communicating with gas-liquid mixing section 15 between inner lid 13 and outer lid 14, and introduces the gas through gas passageway 12 into gas-liquid mixing section 15 to the liquid that entered gas-liquid mixing section 15 through  
15   liquid inlet 18. For example, gas inlet 19 is located 180 degrees from liquid inlet 18 about the center (central axis 27) of spraying apparatus main body 10a. Stated differently, gas inlet 19 and liquid inlet 18 are located on opposite sides relative to the center (central axis 27) of spraying apparatus main body 10a. Further, spouting portion 16 in a  
20   cylindrical shape is formed projecting from and secured to the center of the external surface of outer lid plate 14a of outer lid 14. Spouting portion 16 has tubular passageway 16b, gas-liquid mixed fluid inlet 16c, and spout 16a which passes through spouting portion 16 and outer lid

plate 14a along the direction of central axis 27. Stated differently, spouting portion 16 passes through lid plate 14a of outer lid 14 and communicates with gas-liquid mixing section 15 and through hole 31 in flow guide plate 30. Liquid atomized by the gas and the liquid being  
5 mixed in the gas-liquid mixing section is rectified by through hole 31 in flow guide plate 30, and spouted out from spouting portion 16. Spout 16a, tubular passageway 16b, gas-liquid mixed fluid inlet 16c, and through hole 31 having the circular edge in flow guide plate 30 are arranged along central axis 27 along which first liquid passageway 11 is  
10 formed. Liquid inlet 18, on the other hand, is located offset from central axis 27.

Thus, gas-liquid mixing section 15 is defined by annular member 24, inner lid 13, and flow guide plate 30, and communicates between: liquid inlet 18 passing through inner lid 13 along the direction of central  
15 axis 27; gas inlet 19 formed in annular member 24 and extends along the direction (e.g., radial direction) intersecting with the direction of central axis 27; through hole 31 having the circular edge in flow guide plate 30; and spout 16a passing through outer lid 14 along the direction of central axis 27.

20 In such a configuration, liquid supplied to spraying apparatus 10 enters spraying apparatus main body 10a through the liquid supply port not shown, transforms into a liquid flow as it flows through first liquid passageway 11 toward the distal end of spraying apparatus 10, and the

liquid flow passes through second liquid passageway 22 and liquid inlet 18 and is supplied into gas-liquid mixing section 15. Gas supplied to spraying apparatus 10 enters spraying apparatus main body 10a through the gas supply port not shown, transforms into a gas flow as it flows through gas passageway 12 toward the distal end of spraying apparatus 10, and the gas flow passes through space 23 and gas inlet 19 and is supplied into gas-liquid mixing section 15.

The gas and liquid supplied in gas-liquid mixing section 15 are mixed together, thereby atomizing the liquid into a gas-liquid mixed mist.

The atomized liquid is thereafter rectified as it passes through hole 31 having the circular edge in flow guide plate 30, and then the gas-liquid mixed mist passes through gas-liquid mixed fluid inlet 16c and tubular passageway 16b of spouting portion 16 on outer lid 14 and spouts from spout 16a.

In the following, the mechanism for atomizing the liquid in gas-liquid mixing section 15 is described with reference to FIGS. 1A and 1B. The liquid through first liquid passageway 11 passes through second liquid passageway 22 and passes through liquid inlet 18 formed in inner lid 13, enters gas-liquid mixing section 15 along the internal surface of hole 24a of annular member 24 toward spouting portion 16.

Meanwhile, the gas passes through gas inlet 19 facing liquid inlet 18 across central axis 27, and is supplied in gas-liquid mixing section 15. The gas impinges, in gas-liquid mixing section 15, with the liquid

supplied from liquid inlet 18. The liquid impinged with the gas as such spreads out to the inner surface (internal surface) of hole 24a of annular member 24 and transforms into a thin film. The thin film of liquid further flows in a circumferential direction along the internal surface of hole 24a of annular member 24, and thereby further transforms from the thin film to fine water droplets. Still further, a gas-liquid mixed fluid comprising the water droplets is aggregated in gas-liquid mixing section 15. As a result, the water droplets can further be atomized, allowing a liquid having a small particle size to be sprayed from spout 16a.

Specifically, spraying apparatus 10 includes: gas-liquid mixing section 15 having an inner diameter of 6.0 mm and a height of 2.0 mm; flow guide plate 30 having a thickness of 0.5 mm and circular edged through hole 31 having a diameter of 1.0 mm; spouting portion 16 including spout 16a and gas-liquid mixed fluid inlet 16c each having a diameter of 1.0 mm; tubular passageway 16b having a diameter of 1.0 mm and a length of 3.0 mm; liquid inlet 18 having a diameter of 0.7 mm; and rectangular gas inlet 19 having a width of 1.0 mm and a height of 1.0 mm.

Spraying apparatus 10 was supplied with a compressed air, which is an example of the gas, pressurized by 0.3 MPa (gauge pressure) and a water, which is an example of the liquid, pressurized by 0.26 MPa (gauge pressure). A Sauter mean diameter of the water atomized under the above conditions was evaluated by a laser diffraction technique. A measurement according to the laser diffraction technique was carried out

on atomized water 300 mm away from the tip of spraying apparatus 10, and Sauter mean diameter evaluated was 10.0  $\mu\text{m}$ . Moreover, noise at a location 1000 mm away from the tip of spraying apparatus 10 under the above conditions was measured, indicating a noise value of 80 dB.

5           According to spraying apparatus 10 of Embodiment 1, gas-liquid mixing section 15 that is in the disc-shaped profile and uniform between outer lid 14 and inner lid 13 is securely formed by providing annular member 24 and flow guide plate 30 between inner lid 13 and outer lid 14. Thus, in gas-liquid mixing section 15, gas through gas inlet 19 impinges  
10 in a vertically downward direction with liquid through liquid inlet 18 and spreads out on the internal surface of hole 24a of annular member 24, by which the liquid is circulated and aggregated along the internal surface and atomized, thereby allowing the atomized liquid to be rectified by through hole 31 in flow guide plate 30 and spout from spouting portion 16.  
15 As a result, spraying apparatus 10 is provided which sprays a liquid which has a small particle size and vaporizes so quickly that an object sprayed with the liquid does not get dripping wet. More specifically, two-fluid nozzle spraying apparatus 10 is provided which sprays a liquid which has a small particle size such as 10  $\mu\text{m}$  or less and vaporizes so  
20 quickly that an object sprayed with the liquid does not get dripping wet.

Gas inlet 19 according to Embodiment 1 is disposed at a position facing liquid inlet 18 across central axis 27 of spraying apparatus main body 10a. However, the arrangement of gas inlet 19 is not limited

thereto. For example, gas inlet 19 may be located proximate liquid inlet 18 in a manner that a flow of the liquid out of liquid inlet 18 and a flow of the gas out of gas inlet 19 intersect. Further, a plurality of gas inlets 19 and a plurality of liquid inlets 18 may be arranged.

5           Moreover, disc-shaped projection may be formed on inner lid plate 13a of inner lid 13 so as to be located proximate liquid inlet 18 and have a width in a direction perpendicular to the line 1B-1B less than a width of gas-liquid mixing section 15 in the direction.

## EMBODIMENT 2

10           FIG. 2 is a cross-sectional end view of spraying apparatus 10B according to Embodiment 2, which includes frustoconical gas-liquid mixed fluid inlet 16Bc. As illustrated in FIG. 2, gas-liquid mixed fluid inlet 16Bc has opening 16Bd having a greater diameter than through hole 31B, and is in a frustoconical shape defined by sloped conical surface 16Be that  
15   decreases in diameter from opening 16Bd toward spout 16a. The purpose of frustoconical gas-liquid mixed fluid inlet 16Bc is to further atomize the liquid. As the gas and the liquid are supplied into gas-liquid mixing section 15, they are mixed together in gas-liquid mixing section 15 so that the liquid is atomized, after which the liquid is rectified as it  
20   passes through through hole 31B formed in flow guide plate 30B, through hole 31B having a circular edge. Then, the mixed, atomized liquid passes through gas-liquid mixed fluid inlet 16Bc and tubular passageway 16b in spouting portion 16B formed on outer lid 14B and spouts out

through spout 16a. Owing to gas-liquid mixed fluid inlet 16Bc being frustoconical, the gas-liquid mixed fluid flowing toward spout 16a is rectified as it passes through hole 31B, which has the circular edge and formed in flow guide plate 30B, and spreads out in opening 16Bd having  
5 the greater diameter than the diameter of through hole 31B, and the flow rate decreases. The flow of gas-liquid mixed fluid is then gradually constricted along conical surface 16Be, thereby causing the atomized water droplets less likely to gather before reaching spout 16a. As a result, the water droplets in the gas-liquid mixed fluid can be sprayed  
10 through spout 16a, while being kept atomized. Preferably, a maximum diameter of the entrance side of frustoconical gas-liquid mixed fluid inlet 16Bc is less than or equal to the diameter of hole 24a in annular member 24, and is twice the diameter of tubular passageway 16b or greater. More preferably, the maximum diameter of the entrance side of  
15 frustoconical gas-liquid mixed fluid inlet 16Bc is twice to four times the diameter of tubular passageway 16b.

As a specific example, frustoconical gas-liquid mixed fluid inlet 16Bc has an entrance side whose maximum diameter is 3.0 mm, and tubular passageway 16b has a diameter of 1.0 mm and a length of 2.0 mm.

20 Spraying apparatus 10B was measured under the same conditions as Embodiment 1, indicating a Sauter mean diameter of 9.0  $\mu\text{m}$  and a noise value of 80 dB.

### EMBODIMENT 3

FIGS. 3 and 4 are diagrams illustrating flow guide plate 30C having through hole 31C whose edge is serrated according to Embodiment 3. Here, FIG. 3 shows flow guide plate 30C having through hole 31C whose edge is serrated with six teeth. FIG. 4 shows flow guide plate 30C having through hole 31C whose edge is serrated with twelve teeth.

The purpose of the serrated edge of through hole 31C in flow guide plate 30C is to reduce noise that is generated when gas-liquid mixed fluid comprising atomized liquid spouts out through spraying apparatus 10 (see FIG. 1), 10B (see FIG. 2) according to the above embodiments. A gas-liquid mixed fluid jet spouting at a high velocity through spraying apparatus 10, 10B causes friction with ambient air and turbulence is formed between the gas-liquid mixed fluid jet and ambient air, thereby generating the noise. The flow rate at which the gas-liquid mixed fluid comprising atomized water spouts from spout 16a is not relatively uniform in a vicinity of spout 16a. Through hole 31C having a serrated edge, formed in flow guide plate 30C, causes varying spout velocities in the vicinity of spout 16a, thereby reducing the turbulence formed between the gas-liquid mixed fluid jet and ambient air. This allows a reduction of noise.

FIG. 5 is a cross-sectional end view of spraying apparatus 10C according to Embodiment 3. Spraying apparatus 10C is the same as spraying apparatus 10B (see FIG. 2) according to Embodiment 2, except that spraying apparatus 10C includes flow guide plate 30C (see FIG. 3),

in place of flow guide plate 30. Specifically, flow guide plate 30C has a thickness of 0.5 mm, the edge of through hole 31C in flow guide plate 30C is serrated with six teeth, the tip circle has a diameter of 1.0 mm, and the root circle has a diameter of 1.7 mm.

5           Spraying apparatus 10C illustrated in FIG. 5 was measured under the same conditions as Embodiment 1, indicating a Sauter mean diameter of 9.0  $\mu\text{m}$  and a noise value of 75 dB.

          The relationship of the diameter of tubular passageway 16b with the number and size of the teeth with which the edge of through hole 31C is serrated in flow guide plate 30C, and the noise value is shown in FIG. 6.

          Specifically, noise values were measured for tip circle 32 in different diameters and root circle 33 in different diameters in spraying apparatus 10C illustrated in FIG. 5, provided that the diameter of tubular passageway 16b is 1.0 mm and 1.5 mm and flow guide plate 30C having a thickness of 0.5 mm has through hole 31C whose edge is serrated with six teeth (see FIG. 3) and with twelve teeth (see FIG. 4).

          The noise value was small when tip circle 32 and tubular passageway 16b were close in diameter. As the diameter of tip circle 32 was increased, the noise value increased. The noise value remained substantially at a constant value when the diameter of tip circle 32 exceeded half the diameter (6.0 mm) of gas-liquid mixing section 15 in the disc-shaped profile. Tip circle 32 smaller in diameter than tubular

passageway 16b is not preferable because it resists the flow of the gas-liquid mixed fluid, thereby reducing the flow of the gas-liquid mixed fluid and increasing the Sauter mean diameter. Comparing the cases where through hole 31C has the edge serrated with six teeth and with  
5 twelve teeth, the relationship of the diameter of tip circle 32 with the noise value changed in a similar way.

Moreover, similar to what was obtained when the diameter of tubular passageway 16b was 1.0 mm, the noise value when the diameter of tubular passageway 16b was 1.5 mm was small when tip circle 32 and  
10 tubular passageway 16b were close in diameter, and the noise value was increased with an increase of the diameter of tip circle 32.

Thus, the noise value can be reduced if the diameter of tip circle 32 is greater than or equal to the diameter of tubular passageway 16b and the diameter of root circle 33 is less than or equal to half the diameter of  
15 gas-liquid mixing section 15 in the disc-shaped profile.

The noise value can further be reduced when the diameter of tip circle 32 is greater than or equal to the diameter of tubular passageway 16b and the diameter of root circle 33 is 1/3 the diameter of gas-liquid mixing section 15 in the disc-shaped profile. It should be noted that flow  
20 guide plate 30C according to Embodiment 3 may be used, in place of flow guide plate 30 in spraying apparatus 10 according to Embodiment 1. Such a spraying apparatus was measured under the same conditions as Embodiment 1, provided that flow guide plate 30C has a thickness of 0.5

mm, flow guide plate 30C has through hole 31C whose edge is serrated with six teeth, the tip circle has a diameter of 1.0 mm, and the root circle has a diameter of 1.7 mm. The measurement indicated a Sauter mean diameter of 10.0  $\mu\text{m}$  and a noise value of 75 dB.

5           As such according to the spraying apparatus of Embodiments 1 through 3, in gas-liquid mixing section 15 formed between inner lid 13 and flow guide plate 30, 30B, or 30C, liquid through liquid inlet 18 impinges with gas through gas inlet 19, and the liquid spreads out to the inner surface (internal surface) of hole 24a of annular member 24 and  
10 transforms into a thin film. The thin film of liquid flows along the internal surface in the circumferential direction of annular member 24, and thereby further transforms from the thin film to fine water droplets. Still further, a gas-liquid mixed fluid comprising the water droplets is aggregated in gas-liquid mixing section 15. As a result, the liquid is  
15 atomized, allowing the atomized water to be spouted from spouting portion 16B.

Moreover, according to the spraying apparatus of Embodiments 2 and 3, owing to gas-liquid mixed fluid inlet 16Bc being frustoconical, the atomized water droplets are caused less likely to gather before reaching  
20 spout 16a, thereby allowing further atomized water droplets to be spouted from spouting portion 16B.

Further, according to the spraying apparatus of Embodiment 3, gas-liquid mixed fluid comprising atomized liquid is passed through

through hole 31C having the serrated edge in flow guide plate 30C, thereby reducing turbulence formed between a gas-liquid mixed fluid jet and ambient air and allowing the atomized liquid to be spouted from spouting portion 16B at reduced noise.

5           As a result, the spraying apparatus is provided which sprays a liquid which has a small particle size and vaporizes so quickly that an object sprayed with the liquid does not get dripping wet. More specifically, the two-fluid nozzle spraying apparatus can be provided which sprays, with a reduced noise, a liquid which has a small particle  
10   size such as 10  $\mu\text{m}$  or less and vaporizes so quickly that an object sprayed with the liquid does not get dripping wet.

#### EMBODIMENT 4

A spraying apparatus according to Embodiment 4 includes flow guide plate 30D having a configuration different from flow guide plate 30  
15   according to the above embodiments. Through hole 31D has an edge serrated with triangular teeth 34 which are angled relative to gas-liquid mixing section side surface 30Da that is demarcated between root circle 33 and perimeter 35 of flow guide plate 30D.

FIG. 7A is a diagram illustrating flow guide plate 30D according to  
20   Embodiment 4. FIG. 7B is a side view of flow guide plate 30D. FIG. 7C is a close-up perspective view of through hole 31D which has the serrated edge and formed in flow guide plate 30D. FIG. 7D is a diagram illustrating dihedral angle 36 formed between gas-liquid mixing section

side surface 30Da and one of teeth 34, for illustrating dihedral angle 36 between tooth 34 and flow guide plate 30D.

In flow guide plate 30D, an angle between: gas-liquid mixing section side surface 34a of one of teeth 34 with which the edge of through hole 31D is serrated; and gas-liquid mixing section side surface 30Da demarcated by root circle 33 and perimeter 35 of flow guide plate 30D, is defined as dihedral angle 36 (see FIGS. 7C and 7D). To be more specific, dihedral angle 36 is formed between adjacent two surfaces 34a and 30Da. Herein, as an example, dihedral angle 36 is less than or equal to 180 degrees.

The purpose of angled teeth 34 of flow guide plate 30D is to further reduce the noise that is generated when the gas-liquid mixed fluid comprising the atomized liquid spouts out through the spraying apparatus according to the above embodiments. Teeth 34 being angled allows the flow of the gas-liquid mixed fluid to strike to surfaces 34a of teeth 34 at approximately perpendicular angles as the flow is constricted from gas-liquid mixing section 15 toward spout 16a, thereby further reducing turbulence formed between the gas-liquid mixed fluid jet and ambient air. This allows further reduction of noise.

FIG. 8 is a cross-sectional end view of spraying apparatus 10D according to Embodiment 4. Spraying apparatus 10D is the same as spraying apparatus 10B (see FIG. 2) according to Embodiment 2, except that spraying apparatus 10D includes flow guide plate 30D (see FIG. 7A),

in place of flow guide plate 30. Specifically, flow guide plate 30D has a thickness of 0.5 mm, the edge of through hole 31D in flow guide plate 30D is serrated with six teeth, the tip circle has a diameter of 1.6 mm, the root circle has a diameter of 2.6 mm, and dihedral angle 36 is 150 degrees.

5           Spraying apparatus 10D illustrated in FIG. 8 was measured under the same conditions as Embodiment 1, indicating a Sauter mean diameter of 9.0  $\mu\text{m}$  and a noise value of 72 dB.

          The relationship between dihedral angle 36 and the noise value is shown in FIG. 9. As dihedral angle 36 was decreased from 180 degrees,  
10   the noise value decreased, indicating that the noise value is minimum when dihedral angle 36 is in a range from 150 degrees to 120 degrees. As dihedral angle 36 was decreased from 120 degrees to 90 degrees, the noise value increased, indicating that the noise value when dihedral angle 36 was 90 degrees was the same as when dihedral angle 36 was 180  
15   degrees. When dihedral angle 36 was less than 90 degrees, the noise value increased greater than when dihedral angle 36 was 180 degrees. The noise value is small and preferable when dihedral angle 36 is greater than or equal to 90 degrees and less than or equal to 180 degrees. The noise value is minimum and more preferable when dihedral angle 36 is  
20   greater than or equal to 120 degrees and less than or equal to 150 degrees.

          FIG. 10 shows the relationship of the number of teeth with the noise value when dihedral angle 36 is 150 degrees. As the number of

teeth was increased when dihedral angle 36 was 150 degrees, the noise value decreased. There was no difference in noise value between three continued teeth and three discontinued teeth when dihedral angle 36 was 150 degrees.

5           FIG. 11A illustrates a variation of Embodiment 4 in which flow guide plate 30D has three continued teeth each having dihedral angle 36 of 150 degrees. FIG. 11B illustrates flow guide plate 30D having three discontinued teeth spaced apart and each having dihedral angle 36 of 150 degrees. Configuring at least one or more of teeth 34 to have dihedral  
10   angle 36 of 150 degrees yields the effects of reducing the noise.

While six teeth 34 are illustrated by way of example in Embodiment 4, the number of teeth 34 is not limited thereto.

According to the spraying apparatus of Embodiment 4, teeth 34 of flow guide plate 30D are angled so that dihedral angle 36 between flow  
15   guide plate 30D and each of teeth 34 is greater than or equal to 90 degrees and less than or equal to 180 degrees. Thus, noise that is generated when the gas-liquid mixed fluid comprising atomized liquid spouts out of the spraying apparatus can further be reduced. It should be noted that flow guide plate 30D according to Embodiment 4 may be  
20   used, in place of flow guide plate 30 in spraying apparatus 10 according to Embodiment 1. Such a spraying apparatus was measured under the same conditions as Embodiment 1, provided that flow guide plate 30D has a thickness of 0.5 mm, flow guide plate 30D has through hole 31D whose

edge is serrated with six teeth, the tip circle has a diameter of 1.6 mm, the root circle has a diameter of 2.6 mm, and dihedral angle 36 is 150 degrees. The measurement indicated a Sauter mean diameter of 10.0  $\mu\text{m}$  and a noise value of 72 dB.

5           Among the various embodiments described above, any embodiments may be combined as appropriate to yield the advantageous effects of the respective embodiments. In addition to combining any embodiments, features of the different embodiments may be combined.

10           The spraying apparatus according to the above aspect of the present disclosure is a spraying apparatus which sprays a liquid having a small particle size such as about 10  $\mu\text{m}$  or less. The spraying apparatus according to the above aspect of the present disclosure is widely applicable, for example, to cooling a space or material, humidifying, dispensing a chemical solution, combustion, or dust control.

15

What is claimed is:

1. A spraying apparatus comprising:

a spraying apparatus main body having a liquid passageway and a gas passageway;

an inner lid which includes an inner lid plate, the inner lid being disposed on a distal end of the spraying apparatus main body and covering an opening of the liquid passageway, the inner lid plate being flat;

an outer lid which includes an outer lid plate which is flat and faces the inner lid plate of the inner lid, the outer lid being disposed on the distal end of the spraying apparatus main body and covering the inner lid and an opening of the gas passageway;

an annular member which is disposed between the inner lid and the outer lid and forms a gas-liquid mixing section which is a space and has a disc-shaped profile;

a flow guide plate disposed between the gas-liquid mixing section and the outer lid and having a through hole communicating with the gas-liquid mixing section;

a liquid inlet for introducing the liquid through the liquid passageway into the gas-liquid mixing section, the liquid inlet passing through the inner lid plate of the inner lid in an edge portion of the inner lid plate and communicating with the gas-liquid mixing section;

a gas inlet for introducing the gas through the gas passageway into the gas-liquid mixing section to the liquid that entered the gas-liquid mixing section through the liquid inlet, the gas inlet communicating with the gas-liquid mixing section; and

a spouting portion for spouting a liquid atomized by the gas and the liquid being mixed in the gas-liquid mixing section, the spouting portion communicating with the gas-liquid mixing section and the through hole in the flow guide plate and passing through the outer lid plate of the outer lid.

2. The spraying apparatus according to claim 1, wherein the spouting portion is a frustoconical gas-liquid mixed fluid inlet communicating with the outer lid plate of the outer lid.

3. The spraying apparatus according to claim 1, wherein the through hole in the flow guide plate has a serrated edge.

4. The spraying apparatus according to claim 3, wherein a tip circle of the serrated edge of the through hole in the flow guide plate has a diameter greater than or equal to a diameter of a tubular passageway in the spouting portion, and a root circle of the serrated edge of the through hole has a diameter less than or equal to half a diameter of the gas-liquid mixing section.

5. The spraying apparatus according to claim 2, wherein the through hole in the flow guide plate has a serrated edge.

6. The spraying apparatus according to claim 5, wherein a tip circle of the serrated edge of the through hole in the flow guide plate has a diameter greater than or equal to a diameter of a tubular passageway in the spouting portion, and a root circle of

the serrated edge of the through hole has a diameter less than or equal to half a diameter of the gas-liquid mixing section.

7. The spraying apparatus according to claim 3, wherein a surface of at least one tooth included in the serrated edge of the flow guide plate in the through hole and a surface of the flow guide plate form a dihedral angle greater than or equal to 90 degrees and less than or equal to 180 degrees, the surface of the at least one tooth being on a gas-liquid mixing section side, the surface of the flow guide plate being on the gas-liquid mixing section side and demarcated by a root circle and a perimeter of the flow guide plate.

8. The spraying apparatus according to claim 7, wherein the dihedral angle is greater than or equal to 120 degrees and less than or equal to 150 degrees.

9. The spraying apparatus according to claim 5, wherein a surface of at least one tooth included in the serrated edge of the flow guide plate in the through hole and a surface of the flow guide plate form a dihedral angle greater than or equal to 90 degrees and less than or equal to 180 degrees, the surface of the at least one tooth being on a gas-liquid mixing section side, the surface of the flow guide plate being on the gas-liquid mixing section side and demarcated by a root circle and a perimeter of the flow guide plate.

10. The spraying apparatus according to claim 9, wherein the dihedral angle is greater than or equal to 120 degrees and less than or equal to 150 degrees.